

I-5 Freight Zero Emissions Route Operations (ZERO) Pilot Study

Final Report

Prepared for:

San Joaquin Valley Regional Planning Agencies

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Executive Summary

This report outlines current and future conditions, issues and challenges, and exploratory analyses of solutions to freight operation problems in the San Joaquin Valley (SJV). The SJV is a key trade and transportation gateway, vital for the local economy, and accompanied by sustainability concerns relating to the movement of goods. Transportation and goods movement have many harmful externalities, which will be exacerbated by the significant growth expected to take place in coming years. This work addresses these concerns in planning through small scale and long-term large-scale conceptual pilot studies. Paired with an analysis of different technological solutions, these pilot studies serve as the next step in proposing problem-specific technology and other solutions that will help improve sustainability in the SJV.

In creating these pilot studies, the current conditions and problems in the SJV were identified, characterized, and used as guides. Namely, the six primary problems in goods movement in the region are (1) safety and collisions, (2) congestion, (3) environmental and air quality, (4) pavement deterioration, (5) illegal parking, and (6) low rail usage. The challenges identified may be addressed as partners endeavor to accomplish the regional goals to build a tech hub, where alternative fuel vehicles and high-tech solutions are not only feasible, but widely used.

The SJV has over 2,700 miles of designated truck routes (over 80% being Surface Transportation Assistance Act National Truck Routes). In the region, truck movements use I-5 and SR 99 for north-south movements and SR 58, SR 108, SR 120, SR 180, I-580 to 205, SR 152, SR 46, and SR 198 for east-west movements. The SJV is expected to experience significant growth in the form of goods movement (intraregional movements, outbound tonnage) and residents. The primary mode of goods transport is currently and is projected to be trucks, traveling along these same primary corridors (I-5, SR 99, SR 58, and I-580 to 205).

Given the existing concerns and their projected growth, this study outlines two separate but complementary pilot studies. The first is a vehicle data collection effort which can help inform analyses to evaluate the economic feasibility of different technologies. The second is a long-term large-scale pilot study concept that describes solution components to address the major problems in the region, which can be pieced together depending on budget, regional goals, and other relevant factors.

A review of various data sources reveals different freight patterns in the SJV. For example, vehicle classes are characterized according to their typical trip lengths, showing that over 90% of Class 3 – Class 7 vehicles travel less than 150 miles per day, while for Class 8 vehicles, less than 60% travel less than 150 miles per day, and about 20% travel more than 500 miles per day. The secondary data, as well as the efforts to conduct a small-scale data collection pilot finds that diesel and compressed natural gas (CNG) vehicles are the only vehicles ready to serve the needs of SJV fleets today. Today, battery electric vehicles (BEVs) can be cost-competitive with the help of financial incentives, however, electrification is currently difficult for larger vehicles and/or longer-range trips. With over 40% of Class 8 vehicles making trips that are 150 miles or more (and 20% traveling more than 500 miles per day), the necessary batteries could exceed 6,000 pounds—resulting in an additional hurdle for adoption.

This issue was evidenced during the planning of the small-scale pilot, as there were no zero-emission battery electric or hydrogen fuel cell vehicles available to complete the 187 mile stretch between Buttonwillow and Wesley rest areas along I-5. The team inquired with fleets, OEMs, and other agencies to find suitable vehicle technologies. At the end, the team collaborated with Cox Petroleum and Western Milling companies to collect data by instrumenting diesel and CNG vehicles. The data collection included two cases, one refers to the travel between the previously mentioned rest areas (northbound and southbound) with payload and empty; and the other data collection was under regular vehicle operations

in their fleets. The team analyzed the data, estimated trip statistics, and used them to validate assumptions for the total cost of ownership (TCO) analyses.

The analyses showed that there are some freight vehicles that are more well-suited and prepared to take on soon-to-be-available technologies. These include, for example, vocations or commodities with shorter tour distances or low payloads, and yard trucks, which can be updated to zero-emission and/or automated vehicles. Among the most important conclusions is that incentives and funding are critical for this transition to a smart and clean corridor. This includes incentives and funding for research and purchase, investments in charging and fueling infrastructure, and low-cost access to financing for new business models, such as owner-operators or small fleets.

There is certainly a need for smart and clean transportation corridors. Private industry in the San Joaquin Valley (SJV) is interested in the deployment of charging infrastructure. This will require working with utility companies and other service providers, streamlining the permitting process, and otherwise improving accessibility.

For the long-term pilot, the first stage of analysis focused on zero and near-zero emission vehicles, including an analysis of the Total Cost of Ownership (TCO) for different vehicle types. From this analysis, the results show that for short- and long-haul single unit and combination trucks, diesel vehicles have the highest TCO. The lowest TCO is seen for BEVs and natural gas vehicles (including compressed natural gas or CNG and liquefied natural gas or LNG). The emissions externalities are higher for natural gas vehicles (near zero emission) than for BEVs (zero emission), although renewable natural gas could help bridge this gap. Even so, natural gas vehicles still have significantly lower emissions externality costs than diesel vehicles. Comparing the fueling infrastructure of each fuel type vehicle, California and the SJV have higher portions of CNG than propane fueling stations. Natural gas and propane vehicles have the benefit of quick refueling times, which is not necessarily true for charging stations. This analysis suggests that for long-haul trips (single unit or combination truck), CNG and LNG vehicles have the lowest TCO. Otherwise, for smaller vehicles (single unit) and/or shorter trips, BEVs are preferred.

The second stage of analysis identifies several long-term pilot study components, intended to be “pieces” of a comprehensive long-term pilot study. The idea is that there is a great deal of uncertainty about precise future conditions, meaning extensive planning efforts are required. These pieces can be combined to form a comprehensive plan, which considers regional goals, budgets, and addresses regional problems, while introducing a high and essential amount of flexibility for Metropolitan Planning Organizations (MPOs). The solution components described in this study are:

- Zero-Emission Technology/Infrastructure
- Connected Technology/Infrastructure
- Automation
- Signal Coordination
- Dynamic Parking Systems
- Increase in Truck Parking
- Increased Capacity
- Connectivity
- Pavement Improvement
- Intermodal/Transfer Facility
- Intermodal/Transfer Application
- Signage
- Information
- Enforcement
- Incentives/Funding

These solutions have a high level of interdependency and some tradeoff of costs, effort, and anticipated benefits. Using these components and considerations, two sample comprehensive long-term pilot studies (low cost and high tech) are outlined in this report which are intended to highlight the intention of this format (presenting solution components) and the flexibility of doing so.

This study is intended to guide planning efforts and help the planning agencies in the SJV move toward their goal of becoming a tech hub for goods movement, while considering the needs of all goods movement operations and problems in the region.

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I-5 Freight Zero Emissions Route Operations (ZERO) Pilot Study

1 Introduction

The freight transportation system in the San Joaquin Valley (SJV) is vital for the economy; unfortunately, the vehicles that move the cargoes from origins to destinations generate several externalities such as congestion, pollution, and safety impacts. The SJV has some of the worst air quality in the nation, failing to meet federal health standards for particulates and ozone.

In addition to the strategic importance of its freight system and corridors, because of the role as a major international trade gateway, the SJV is particularly important to the nation as it produces a sizable portion of all the fruits, vegetables and nuts consumed. According to the forecasts, the SJV is expected to almost double the truck traffic along its major corridors (e.g., I-5, SR 99, SR 58, SR 46, and SR 152) during the next couple of decades, which could exacerbate the existing issues. Figure 1 shows that the current freight volumes in the SJV are already very high and will continue to get higher in the future. Therefore, developing strategies to mitigate the various issues (e.g., GHGs, criteria pollutants) brought by the system, and improve its efficiency, it is critical for the sustainability of the system and the communities in the area. Public and private interventions and strategies are required. These strategies include planning, strategic, and operational improvement approaches. Of particular importance to this project, and in line with state regulations, is the analysis of strategies that target vehicle technologies and clean operations. Specifically, the use of zero-emission technologies.



Figure 1. Current (left) and future (right; 2035) truck volumes. Source: FHWA Office of Operations – Department of Transportation.

Considering the current and projected freight volume and movement conditions in the SJV, the main objective of this project was the study of strategies, technologies, and interventions for potential implementation along the I-5 corridor in the Valley. Specifically, this project i) reviews the freight patterns along the corridor (and other important corridors, e.g., SR 99); ii) synthesizes different technologies such as zero emission vehicles, autonomous and connected vehicles, and truck cargo utilization based on recent guidelines and plans; iii) develops a pilot study concept for large-scale implementation of such technologies; iv) conducts a small-scale data collection pilot with available¹ zero-emission vehicle technologies; v) uses the empirical data to validate the assumptions taken in the quantification of benefits

¹ Technology availability includes both the market readiness of the technology and the willingness of technology providers to participate in the demonstration efforts. As it is discussed later in this report, zero-emission vehicles capable of operating along the specified distance along the I5 were not available during the timeframe of this study.

and costs of the technologies; and vi) considering the overall analyses and results, provides insights for the development of a plan that considers the implementation of the pilot study concept from iii).

This report first summarizes the freight patterns in the SJV, including the current and future conditions, and major freight problems. This is followed by an analysis of solutions to freight operations in the SJV, including a vehicle and freight technology assessment, then a description of the small-scale pilot study concept, data collection and analysis, and results. The remaining sections describe the longer term proposed solutions in the form of pilot study concept components, and how they could form long-term plans tailored to desired goals or constraints in the region, such as cost. The pilot studies outlined in this report identify reasonable solutions for emissions reductions and improved safety and efficiency for freight operations.

This report's structure follows the project tasks, including:

- Task 2 – Review of freight patterns in the SJV
- Task 3 – Assessment of vehicle & freight efficiency technologies
- Task 4 – Development of pilot study concept
- Task 5 – Small-scale pilot data collection
- Task 6 – Data analysis
- Task 7 – Updates to pilot study concept

Task 2. Review of Freight Patterns in the San Joaquin Valley

2 The San Joaquin Valley

The SJV includes eight counties in California: San Joaquin, Kings, Stanislaus, Merced, Fresno, Madera, Tulare, and Kern. Several planning agencies work together to try to solve the transportation and air quality issues and address the needs of the region. These include the Council of Fresno County Governments, Kern Council of Governments, Kings County Association of Governments, Madera County Transportation Commission, Merced County Association of Governments, San Joaquin Council of Governments, Stanislaus Council of Governments, Tulare County Association of Governments, and more broadly, the California Air Resources Board (CARB), the California Department of Transportation (Caltrans), and the San Joaquin Valley Air Pollution Control District, among others.

The SJV is especially important for California and the nation. The SJV economy lead sectors consist of agriculture, food production, energy, and construction. Over 407 million tons of goods were moved to, from and within the valley in 2007, and it is estimated to exceed 500 million tons by 2040. The volume of current and future goods moving through this region have prompted several goods movement studies [1] [2] [3] [4]. The California Department of Food and Agriculture stated that the SJV holds over one-half the value of the state's agricultural commodities. As of 2010, there were 1.2 million people employed in the SJV. 44% (564,000) of these jobs are in industries dependent on goods movement—187,000 in agriculture, 170,000 in wholesale and retail trade, 102,000 in manufacturing, 48,000 in transportation/warehousing and utilities. This dependence on the goods movement industry is greater here than it is in any other state region.

In the SJV, the gross domestic product (GDP) of the previously listed industries was \$56 billion. The contributions of each industry are wholesale and retail trade: \$14 billion (26% of total GDP); agriculture: \$13 billion (24% of total GDP); and manufacturing: \$12 billion (21% of total GDP). It is also worth noting that 80% to 90% of SJV businesses have less than 20 employees, which can affect the warehousing and consolidation needs of the region. By 2040, industries dependent on goods movement are expected to increase by 45%, with the wholesale and retail trade being the largest industries.

In the SJV there are over 2,700 miles of designated truck routes with over 80% being Surface Transportation Assistance Act (STAA) National Truck Routes. In the SJV, truck movements use I-5 and SR 99 for north-south movements and SR 58, SR 108, SR 120, SR 180, I-580 to 205, SR 152, SR 46, and SR 198 for east-west movements. It is worth noting that SR 99 holds most of the SJV urban centers while I-5 is used for trucks traveling through the SJV region. The truck stops in the region are clustered along I-5 and SR 99.

In this task, the research team reviewed and synthesized planning reports commissioned by the agencies in the region. This synthesis concentrates on the key factors related to the freight patterns in the SJV and provide background for the consideration of issues and the identification of potential improvement strategies. Appendix A includes an extensive inventory and discussion of existing transportation and freight infrastructure.

2.1 Existing Traffic Conditions [1]

The San Joaquin Valley I-5/SR 99 Goods Movement Corridor Study [1] used several data sources containing information ranging from 2009 to 2015, including GPS data, trip distributions, weigh-in-motion, Performance Measurement System (PeMS) data and other database and monitoring systems to analyze the existing traffic conditions in the SJV. The analyses divided the SJV road network into 152 segments [1].

PeMS database was the only source that provided continuous information about speed and volume through the year at each location. PeMS detectors are radars and loops that do not differentiate vehicle type; therefore, other sources such as local counts, GPS and WIM were required in [1] to provide a good indicator of the overall traffic and truck traffic flows in the area. In 2015 there were 912 PeMS stations located on state highways and freeway mainlines. There were 382 stations on SR 99, 151 stations on I-5, 71 on other North-South highways, and 273 East-West truck routes. [1] excluded high-density urban areas in the analyses. Additionally, [1] calculated three ratios to measure seasonal variation in traffic volume monthly:

- (1) *maximum/minimum*
- (2) *maximum/average*
- (3) *minimum/average*

In addition to PeMS, the study used the National Performance Management Research Data Set (speed data) to identify the congested speed. From data collected in 2015, the average speed data was aggregated to 15-minute periods, and the lowest 15-minute average speed was compared with the posted speed and considered as congested speed. Figure 2 shows the results for AM and PM periods.

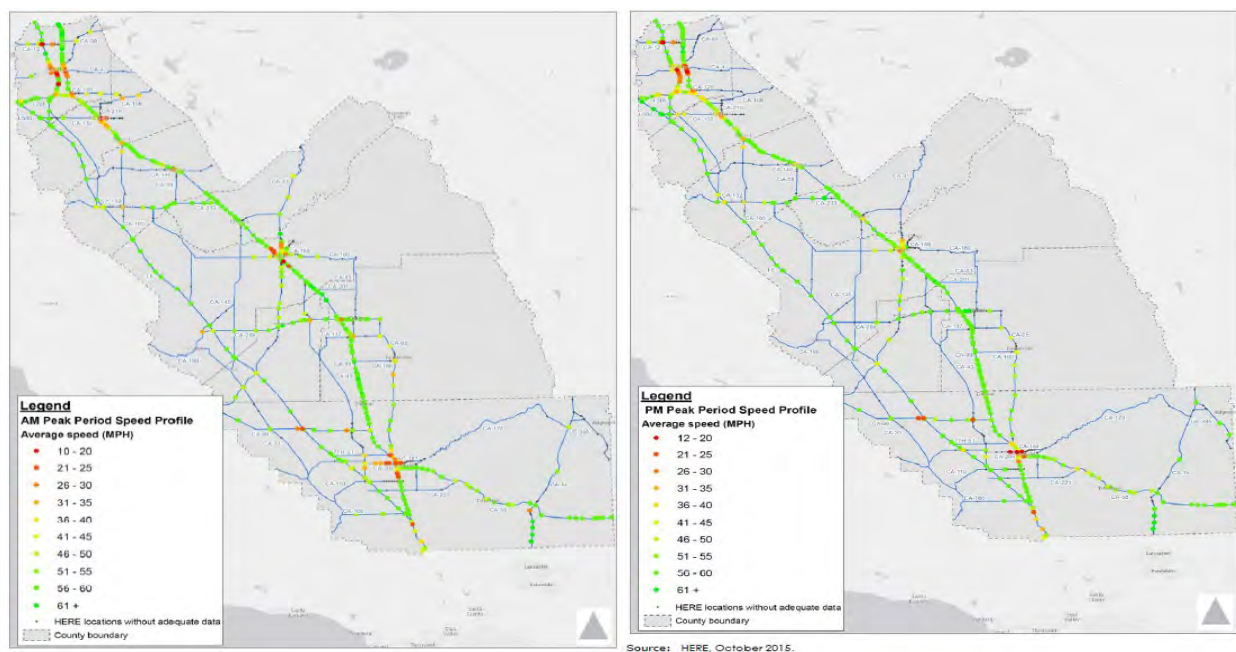


Figure 2. Congested Speed during AM and PM peak obtained from [1]

Some of the most notable results include:

- **Monthly Traffic Patterns:** In general, the highest seasonality effects for both corridors are in San Joaquin and Merced counties. Additionally, the highest traffic months are April to July, and the lowest are December to February.
- **Day of Week:** Merced and San Joaquin counties have the highest daily fluctuation. Thursday and Friday are the busiest days on all the corridors; the lowest traffic days on SR 99 and other highways are Saturday and Monday, and Saturday or Tuesday on I-5.

- **Traffic Operation Performance Measures:** The analysis shows that the congested speed on some segments of I-5 and SR 99 are 10% to 60% lower than posted speed, but it does not necessarily indicate bottlenecks exist. Because sensors are outside the urban area, and PeMS does not have coverage on interchanges and ramps where most users usually experience delay. In fact, the volume-to-capacity (V/C) ratio during peak periods outside urban dense areas is 0.65, and the average V/C along I-5 and SR 99 is 0.25 and 0.51, respectively.

PeMS allows the estimation and mapping of bottlenecks by using the algorithm discussed in [5]. Such algorithm identifies a bottleneck based on the following conditions: i) if the drop in the speed is at least 20mph; ii) the speed at the current detector is less than 40mph; iii) the detectors are less than three miles apart; and iv) the decline in speed lasts at least five to seven contiguous 5-minutes data points [6]. If such conditions occur at a specific location, PeMS identifies it as a bottleneck [6]. Figure 3 shows an overview of the bottlenecks on the SJV for all months in 2019 by using the online PeMS tool [7]. The colors and sizes on Figure 3 represent the duration, distance upstream, and the total delay of the bottleneck. Note that this bottleneck analysis was not performed on [1]; but it provides an updated version of the traffic behavior and congestion (bottleneck) on the SJV. Using the PeMS tool to identify the bottleneck for the months prior to 2019 (2009 to 2015), shows that the bottleneck problem has been increasing over time, more along the SR99 than over I-5.

2.2 Truck Traffic Patterns & Characteristics

To analyze seasonal and daily patterns, [1] used WIM data from 2014, except for April. Table 1 shows a description of the 13 WIM Stations that Caltrans (by District) has in the SJV. Notice that four of them are along I-5 (1, 7, 27, and 73 from Table 1), three along SR 99 (10, 74, 75) and six along other state highways (113, 44, 99, 115, 114, 36). The WIM data source provides truck classifications including heavy-heavy duty trucks (classes 11-13), medium-heavy duty trucks (classes 8-10), and light-heavy duty trucks (classes 5-7).

Table 1. Description WIM station in SJV

WIM	District	County	Route	Postmile	Location
10	6	FRE	99	25	Fresno
73	6	KER	5	48.7	Stockdale
74	6	KER	99	20.2	Bakersfield
114	6	KER	58	R64.9	Arvin
115	6	TUL	65	R23.4	Porterville
1	10	SJ	5	43.7	Lodi
7	10	MER	5	20.2	Santa Nella
27	10	SJ	5	7.4	Tracy
36	10	MER	152	23	Los Baños
44	10	SJ	205	R9.5	Banta
75	10	STA	99	R8.4	Keyes
99	10	TUO	20	6.4	Tulloch
113	10	SJ	580	8.2	Carbona

Monthly truck pattern: WIM data analysis in [1] shows that there is a clear difference in the seasonality between truck classes. For instance, Figure 4 shows that the peak season for heavy-heavy duty trucks is between July and October for both I-5 and SR 99. Medium-heavy duty trucks and light-heavy duty trucks do not show any pattern. The share of heavy-heavy, medium-heavy, and light-heavy duty trucks on I-5 and SR 99 is summarized as in Table 2.

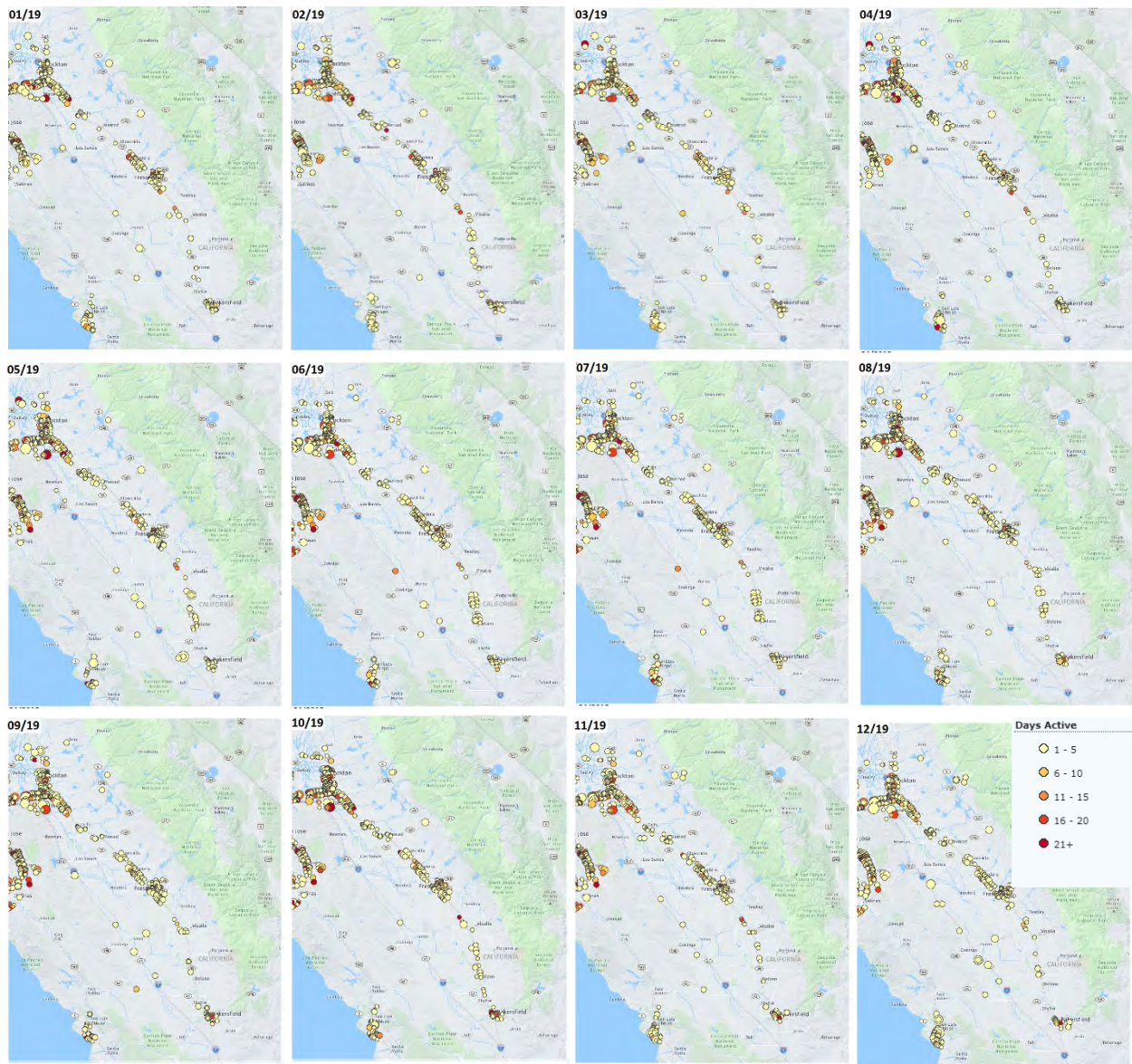


Figure 3. Bottlenecks on SR 99 2019 obtained using the PeMS tool [7]

Table 2. Average of share of traffic for heavy-, medium-, light-heavy duty trucks on I-5 and SR 99 monthly [1]

Vehicle class	I-5	SR 99
Heavy-heavy duty trucks	11%	9%
Medium-heavy duty trucks	75%	70%
Light-heavy duty trucks	1%-21%	11%-24%

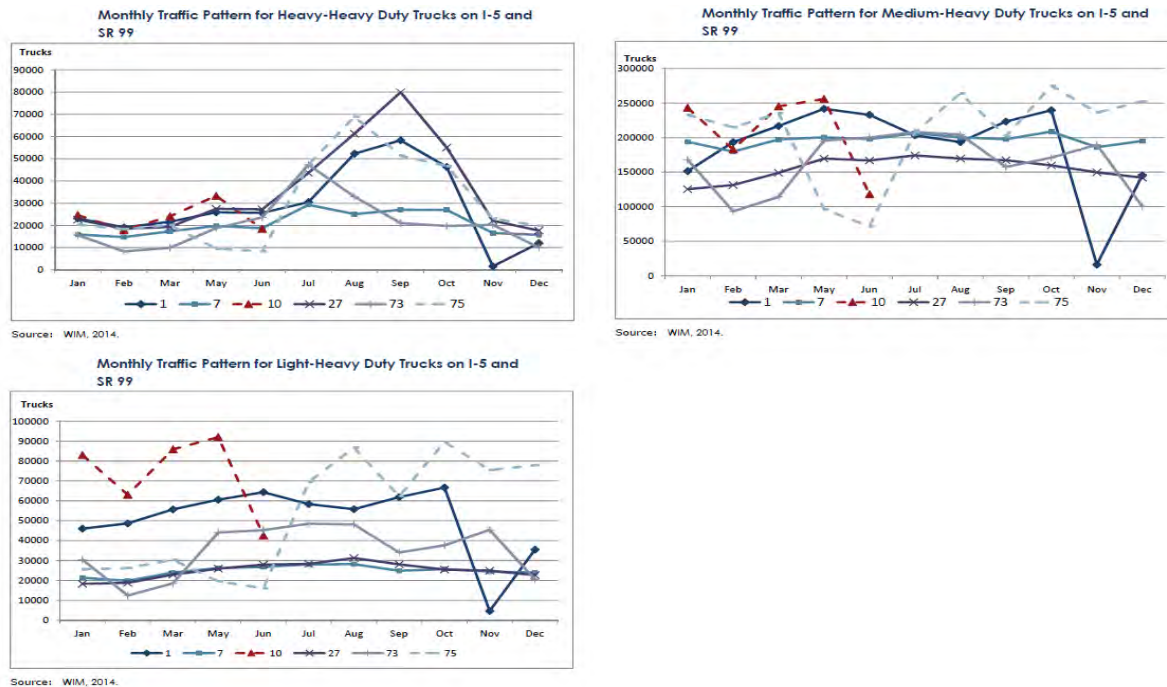


Figure 4. Monthly traffic pattern for heavy-, medium-, light-heavy duty trucks [1]

Truck traffic pattern by day of week: Based on Figure 5, Monday through Thursday are steady and higher than Fridays and Sunday, and Saturday is the lowest day. The percent of average daily traffic in I-5 and SR 99 is summarized in Table 3.

Table 3. Percent of average daily traffic for heavy-, medium-, light-heavy duty trucks on I-5 and SR 99 [1]

Vehicle class	I-5		SR 99	
	Friday	Sunday	Friday	Sunday
Heavy-heavy duty trucks	60%-75%	60%-75%	50%-60%	50%-60%
Medium-heavy duty trucks	50%-60%	88%	40%-45%	90%
Light-heavy duty trucks	68%-78%	68%-78%	51%	5%

Truck traffic patterns by year: In this report, the research team updated the analyses from [1] to analyze the other changes through time in the truck traffic flows. In doing so, the team analyzed the WIM data between 2003 and 2015 and estimated the updated shares by vehicle type and route.

Figure 6 shows that average yearly traffic volumes between 2003 through 2015 at the various WIM stations. Overall, the analyses did not uncover significant changes. Of importance, there seems to be a slight change in patterns after 2008, which is consistent with the trends observed in southern California, which could be attributed to the impacts of the financial crisis. Among the stations over I-5, there are mixed results with half of the stations increasing in flows over time, while the remaining reduce. Most notable changes are observed in the flows of the light-heavy duty vehicles, which are between 100,000 and 200,000, with some locations experiencing a significant increase over time. Additionally, the average

percent of yearly traffic in I-5 and SR 99 is summarized in Table 4. The results of Table 4 are consistent with the monthly shares mentioned above in Table 2.



Figure 5. Day of week traffic pattern for heavy-, medium-, and light-heavy duty trucks on I-5 and SR 99 [1]

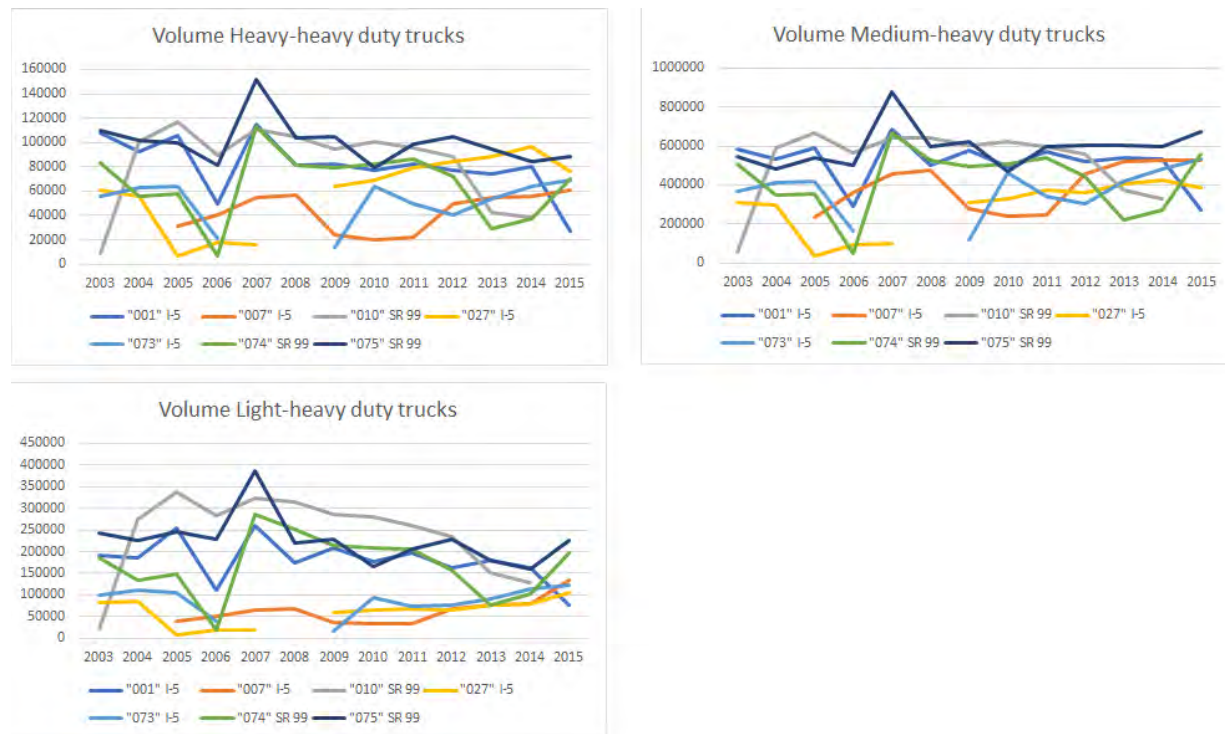


Figure 6. Yearly pattern for heavy-, medium-, and light-heavy duty trucks on I-5 and SR 99 (sample of approximately 23% of the year)

Table 4. Average of share of traffic for Heavy-, Medium-, Light-heavy duty trucks on I-5 and SR 99 yearly

Vehicle class	I-5	SR 99
Heavy-heavy duty trucks	11%	10%
Medium-heavy duty trucks	72%	64%
Light-heavy duty trucks	17%	26%

Figure 7 and Figure 8 show the weekly and monthly traffic patterns of heavy-, medium-, and light-heavy duty truck in 2019, respectively.

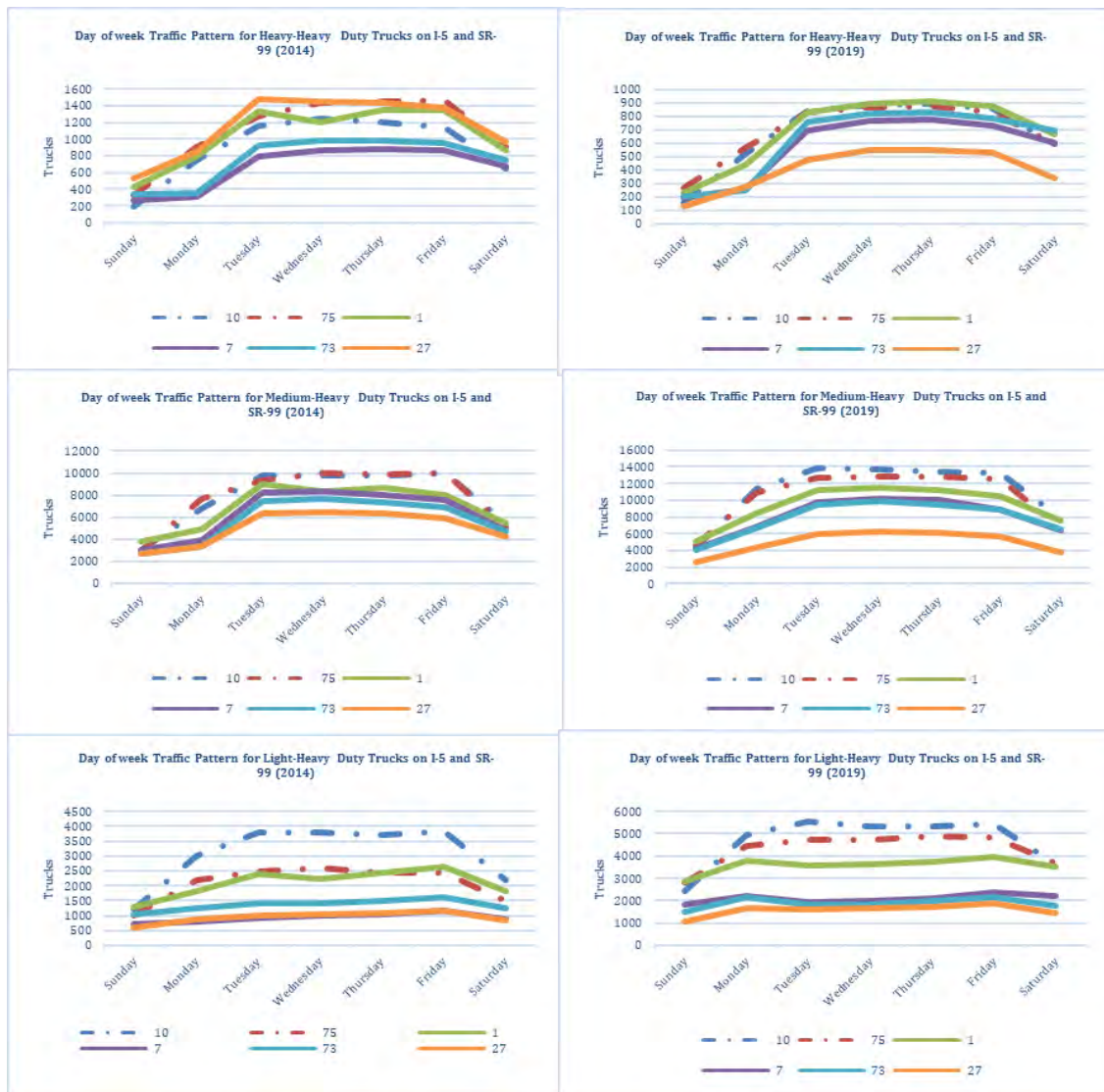


Figure 7. Weekly pattern for Heavy-, Medium-, and Light-Heavy Duty Trucks on I-5 and SR 99 (2014 Left, 2019 Right)

Notice in Figure 7 that the behavior is almost the same compared with the analysis of 2014 (Figure 7 left), and that performed by [1]. In Figure 7 and Figure 5, the traffic of trucks usually decreased during weekends. In Figure 8 the team did not use data from February and June due to lack of reliability. Additionally notice that for heavy-heavy duty trucks there is a peak around July and October, and no pattern for medium- and light-heavy duty trucks, as well as in Figure 4.



Figure 8. Monthly pattern for heavy-, medium-, and light-heavy duty trucks on I-5 and SR 99 in 2019

2.3 Truck Fleet Characteristics: The California Vehicle Inventory and Use Survey (CA-VIUS) [8]

The CA-VIUS obtained data from 11,118 fleets and 14,790 trucks, between June 2016 and January 2018 [8]. The survey is divided by registration, geography, vehicle type, and vehicle age. To account for truck movements in California, the survey considered two sets of trucks: registered in California from the Department of Motor Vehicles (DMV), and out of state trucks from the Interregional Registration Plan (IRP). The factors analyzed include:

- Fleet size: 1-5 trucks, +6 trucks
- Fleet location:
 - IRP: adjacent states, all other states
 - DMV: Central Coast/Valley, LA/Inland/San Diego, Sacramento/ Bay Area, rest of State.
- Age of vehicle: (only IRP) earlier than 2010 vs later
- Type of vehicle: Tractor vs other
- GVW: Less than 26000 lb. or more and equal

Table 5 shows the strata of 14,790 completed surveys, 12,889 DMV and 1,901 IRP trucks. This table demonstrates that the final target was surpassed in all strata.

Table 5. Survey completion by Sampling plan strata [8]

Source	Fleet size	Region	Gross vehicle weight (lb)	Vehicle type	Vehicle model	Final target	Completed surveys	Completed surveys by target	Percent complete
California Department of Motor Vehicle (DMV)	Small fleets (1-5 trucks)	Central Coast/Valley	<26,000			980	1,301	1,301	133%
			≥ 26,000			918	781	781	85%
		LA/Inland/Empire/SD	<26,000			3,000	3,917	3,917	131%
			≥ 26,000			1,700	1,499	1,499	88%
		Sacramento/Bay Area	<26,000			1,400	1,771	1,771	127%
			≥ 26,000			526	628	628	119%
	Rest of state	<26,000			355	453	453	128%	
		≥ 26,000			180	226	226	127%	
	Subtotal small fleets (DMV)					9,059	10,576	10,576	117%
	Large fleets (6 + trucks)	Central Coast/Valley	<26,000			377	238	238	63%
			≥ 26,000			200	291	291	146%
		LA/Inland/Empire/SD	<26,000			708	609	609	86%
			≥ 26,000			230	457	457	199%
		Sacramento/Bay Area	<26,000			380	328	328	86%
			≥ 26,000			74	241	241	326%
	Rest of state	<26,000			200	51	51	26%	
		≥ 26,000			20	98	98	490%	
	Subtotal large fleets (DMV)					2,189	2,313	2,313	106%
	Total DMV					11,248	12,889	12,889	115%
	International Registration Plan (IRP)	Small (1-5 trucks)	Adjacent states		Tractor	2010 and later	55	36	60
				Other			4		
Large (6 + trucks)				Tractor		18			
				Other		2			
Small (1-5 trucks)				Tractor	Earlier than 2010	50	32	45	90%
				Other			7		
Large (6 + trucks)				Tractor		6			
				Other		0			
Subtotal adjacent states (IRP)					105	105	105	100%	
Small (1-5 trucks)		Other states (including Canadian provinces)		Tractor	2010 and later	600	606	646	108%
				Other			40		
Large (6 + trucks)				Tractor		350	518	518	148%
				Other		30	37	37	123%
Small (1-5 trucks)				Tractor	Earlier than 2010	400	406	430	106%
			Other			24			
Large (6 + trucks)			Tractor		220	141	141	64%	
			Other		35	24	24	69%	
Subtotal other states (IRP)					1,635	1,796	1,796	110%	
Total IRP					1,740	1,901	1,901	109%	
Grand total (DMV & IRP)						12,988	14,790	14,790	114%

The percentage of completed surveys in comparison with the initial target in the central coast/ valley is as follows: 1) for small fleets (1-5 trucks), 133% of trucks with GVW lower than 26,000 and 85% for trucks with a GVW greater and equal to 26,000, 2) For large fleets (6+ trucks), 63% of trucks with GVW lower than 26,000, while 146% of trucks with GVW greater and equal than 26,000. Additionally, Table 6 shows that the expansion weight in central valley for small fleets are between 10.8 and 16.8, and for large fleets are between 101 and 147. This means that one truck observation in large fleets represents more than 100 trucks in the area.

Based on [8], the types of fuel mainly used by trucks in California are diesel (91%), and gasoline (8%); small trucks have almost an equal split between diesel and gasoline (see Table 7). As gross vehicle weight (GVW) increases, the proportion of gasoline decreases with only 0.1% for Class 8. Alternative fuels are used by a very small fraction of trucks overall. Additionally, [8] summarizes the total average annual vehicles miles traveled (VMT) per truck by class and vehicle age. Based on [8] DMV trucks travel less than half the miles of the IRP trucks in California (31,856 miles versus 88,461 miles). Trucks travel more as the GVW increases, implying the heavier trucks travel longer distances; after 10 years of usage, mileage decreases, implying the older vehicles are used for more local movements as compared with newer vehicles.

Table 6. DMV Trucks Expansion Factors by Strata

Region	Fleet size	Gross vehicle weight (lb)	January 2018 truck database	January 2018 adjusted truck database	Trucks surveyed	Expansion weight
LA/Inland Empire/San Diego	Small (1-5)	<26,000	61,874	46,238	3,917	11.8
		≥ 26,000	37,892	29,334	1,499	19.6
	Large (6 +)	<26,000	92,897	79,586	609	130.7
		≥ 26,000	103,641	95,113	457	208.1
Central Coast/Valley	Small (1-5)	<26,000	18,185	13,987	1,301	10.8
		≥ 26,000	16,067	13,111	781	16.8
	Large (6 +)	<26,000	27,126	24,027	238	101.0
		≥ 26,000	46,461	42,777	291	147.0
Sacramento/Bay Area	Small (1-5)	<26,000	26,797	20,677	1,771	11.7
		≥ 26,000	11,617	9,579	628	15.3
	Large (6 +)	<26,000	47,741	42,876	328	130.7
		≥ 26,000	42,070	39,911	241	165.6
Rest of state	Small (1-5)	<26,000	4,720	3,741	453	8.3
		≥ 26,000	2,844	2,529	226	11.2
	Large (6 +)	<26,000	4,584	4,180	51	82.0
		≥ 26,000	6,075	4,765	98	48.6
Total			550,591	472,431	12,889	

Table 7. Number of Trucks by Fuel Type and GVW Trucks Class

Fuel type	Truck class						Total
	3	4	5	6	7	8	
Diesel (including biodiesel)	38,445	34,706	44,192	78,554	61,712	433,364	690,974
Gasoline (including gasohol)	36,383	13,556	5,345	4,933	910	273	61,401
Other fuel (alcohol fuels, electric, natural gas, etc.)	24	1,410	2,032	327	907	2,624	7,323
Total	74,852	49,672	51,569	83,814	63,530	436,261	759,698

In the Central Coast/Central Valley, the fuel usage are diesel and gasoline. Table 8 shows that the split between diesel and gasoline changes as GVW increases, for example, 40% of Class 3 trucks use gasoline, while no Class 8 trucks use it. Notice that other fuels like electric vehicles (EVs), and natural gas vehicles are not counted in the survey in this area.

Table 8. Number of trucks by Fuel Type and GVW Trucks class in Central Coast/Central Valley

Fuel type	Truck class						Total
	3	4	5	6	7	8	
Diesel (including biodiesel)	7524	4879	6970	10836	9693	45701	85603
	60%	79%	88%	96%	95%	100%	91%
Gasoline (including gasohol)	5012	1328	702	473	335	0	339
	40%	21%	9%	4%	3%	0%	8%
<i>Hybrid Diesel-Electric</i>			267				267
<i>Propane (liquefied petroleum gas)</i>				11	159		170
<i>Alcohol Fuels (ethanol or methanol)</i>				11			11
Total	12536	6207	7939	11331	10187	45701	93902

Additionally, Figure 9 illustrates that trucks in the Central Valley have the same behavior as the entire survey. For instance, smaller fleets are more-or-less uniformly distributed between ages 1 through 24 years, while large fleets are more concentrated toward newer vehicles peaking around an age of 2 to 3 years old [9]. The long tails on both fleets suggest that a very small fraction of trucks is kept in use even

though they are more than 25 years old, and these vehicles are maintained and used to carry goods over short distances.

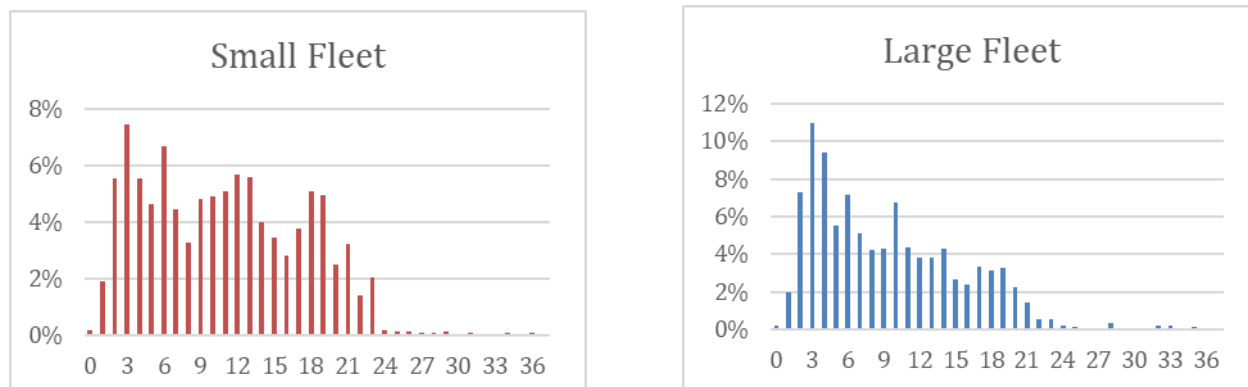


Figure 9. Distribution of Percentage of trucks by age (Small fleet and Large fleet) in Central Coast/ Central Valley

In California, the CA-VIUS identified that at least 27% of DMV trucks travel in California deadheading empty or bobtailing (not carrying any trailer), and 15% for IRP trucks (Figure 10).

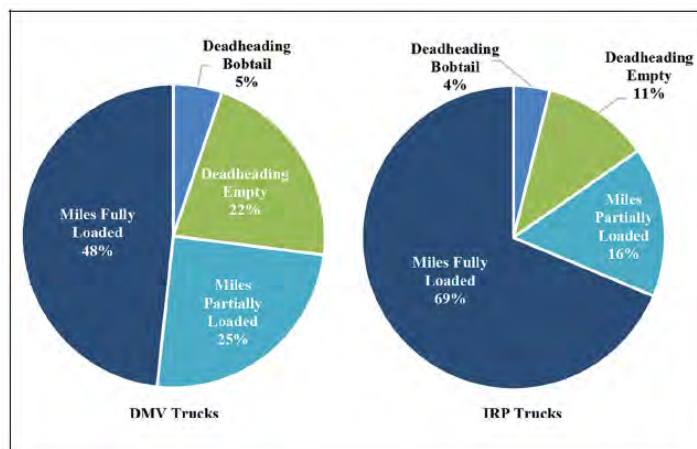


Figure 10. Loading percentage of California vehicle miles traveled [8]

In summary, [8] states that the average payload in California is about 26,000 pounds, this payload increases gradually with truck class, going from 2,000 pounds for Class 3 trucks to about 36,000 pounds for Class 8 trucks. Table 9 shows that the highest payload is for food, beverage, and tobacco products at 33,000 pounds, followed by agriculture 32,000 pounds. The highest average payload of DMV trucks operating in California is for crude petroleum at 34,333 pounds, while for IRP trucks the highest average is gravel/sand and non-metallic minerals at 41,000 pounds.

In the case of the Central Coast and Central Valley, the average payload is about 26,800 pounds, this payload increases gradually with truck class, going from 2,400 pounds for Class 3 trucks to about 38,500 pounds for Class 8 trucks. Table 10 shows that the highest payload is for crude petroleum at 47,500 pounds, followed by non-metal mineral products 37,500 pounds, and agriculture, food, beverage, tobacco products, and gravel are around 31,000 pounds. The highest average payload of Class 8 trucks operating in the Central Valley and Central Coast in California is for crude petroleum at 48,000. Based on [5], it is important to be cautious about the results of the commodity, because the design of the survey and the

difficulty of responders to choose between a set of 15 commodities. Nevertheless, this provides some insights into the payload by commodity of trucks (See Table 9 and Table 10).

Table 9. Average payload by Truck Class and by Commodity

Attribute		Dataset		Combined average
		DMV	IRP	
Truck class (GVW)	Class 3	1,835	3,833	1,969
	Class 4	2,368	5,194	2,512
	Class 5	3,721	8,444	4,492
	Class 6	5,266	6,008	5,361
	Class 7	11,081	13,932	12,162
	Class 8	34,682	37,066	36,069
Commodity	Agriculture products	26,145	38,747	31,941
	Chemical/pharmaceutical products	25,066	24,002	24,615
	Coal/metallic minerals	22,420	34,850	29,488
	Crude petroleum	34,333	1,646	28,541
	Electronics	14,153	24,707	19,013
	Food, beverage, tobacco products	26,580	37,493	32,904
	Fuel and oil products	21,511	39,569	24,335
	Gravel/sand and nonmetallic minerals	26,933	40,869	28,853
	Logs	21,873	38,319	24,682
	Manufactured products	16,307	29,230	22,608
	Metal manufactured products	14,897	35,710	25,545
	Nonmetal mineral products	20,232	36,598	30,084
	Transportation equipment	16,574	33,976	24,177
	Waste material	16,593	30,062	18,393
	Wood, printed products	20,053	36,764	27,190
Combined average payload (lb)		20,162	34,001	26,361

Note: DMV = California Department of Motor Vehicles; IRP = International Registration Plan; GVW = gross vehicle weight.

Table 10. Average payload by Truck Class and by Commodity in Central Coast and Central Valley

Commodity	Truck class						Combined average
	3	4	5	6	7	8	
Agriculture products	5,988	2,947	4,887	6,523	17,368	41,205	31,518
Chemical / Pharmaceutical products	2,028	1,130	5,309	4,612	17,594	38,351	21,762
Coal / Metallic minerals	-	5,000	-	9,500	-	21,443	18,553
Crude petroleum	-	-	400	-	-	48,544	47,509
Electronics	777	1,249	1,998	211	4,916	21,228	15,242
Food, beverage, tobacco products	2,331	2,833	4,257	7,192	8,305	37,935	31,216
Fuel and oil products	1,164	300	2,397	1,768	12,337	37,043	22,809
Gravel / Sand and nonmetallic minerals	1,716	4,117	1,617	5,043	10,834	40,424	31,113
Logs	1,000	-	5,000	-	6,000	40,151	27,079
Manufactured products	1,679	1,483	3,640	4,699	5,315	34,476	20,596
Metal manufactured products	1,449	1,414	2,747	3,506	7,980	34,751	16,829
Nonmetal mineral products	1,547	1,250	6,212	3,000	-	47,143	37,483
Transportation equipment	2,203	3,259	4,363	4,556	4,998	37,004	20,038
Waste material	1,233	1,092	3,393	6,051	10,411	39,773	26,523
Wood, printed products	1,257	1,859	5,033	5,064	12,385	39,513	30,582
Combined average payload (lb)	2,399	2,106	3,920	5,079	13,411	38,492	26,840

Figure 11 shows the percentage of trips made in the last 12 months where each vehicle class traveled between 0-50 miles, 50-99 miles, 100-149 miles, 150-499 miles, and more than 500 miles. Notice that the distribution of the percentages is similar for Class 3 to Class 7 vehicles, where the highest percentage is between 0-50 miles away from the home base. On the other hand, Class 8 vehicles show a more uniform distribution between the mileage classifications, and as expected, this vehicle class has the higher share for more than 500 miles of travel. As shown, about 60% of Class 8 trucks travel less than 150 miles per

day, a distance that is feasible with the battery electric trucks coming into the market in the short-term. From the remaining 40% that travel more than 150 miles, half travel more than 500 miles per day, which is a significant barrier for the penetration and use of battery electric vehicles, at least in the short- and medium-term when these vehicles will have a limited range capacity (considering the weight of the batteries and the charging infrastructure constraints).

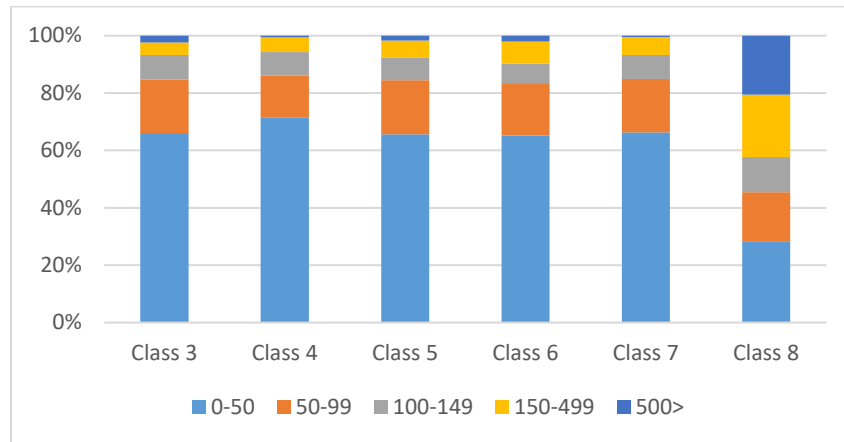


Figure 11. Percentage of miles for trips made from the home base in the last 12 months

2.4 Future Conditions

The SJV region is expected to have the following future conditions based on [2]:

- Increase goods movement 72% over the next 25 years,
- House 6 million people (it was 4 million in 2013) and handle over 800 million tons of freight (a 60% increase from 2007) by 2040,
- The intraregional movements will continue to make up over half (400 million tons) of the total tonnage,
- Increase outbound tonnage by about 90% between 2007 and 2040 while inbound tonnage is expected to increase about 60%, and
- To carry most of the tonnage (93% – 750 million tons) by trucks, followed by rail (7% – 60 million tons), and air and water modes will continue to carry less than 1% of the tonnage [2].

Additionally, it is expected that the main trucking corridors will continue to be I-5, SR 99, SR 58, and I-580 to 205. Truck volume on I-5 will nearly double (total of over 15,000 trucks per day), SR 99 will also have some segments that carry over 15,000 trucks per day (over 50% increase), and some of the lower volume corridors are also expected to double their overall volumes from 2007 to 2040. In fact, most segments on SR 58 will carry about 5,000 trucks per day by 2040 [2].

Cambridge Systematics used the California Statewide Freight Model (CSFM) to estimate the overall truck traffic pattern along I-5, SR 99 and major highways and selected a sample of forty segments for the analyses. The selected segments are close to county lines to understand the intraregional flow between counties and internal versus through trips. Although the CSFM was the best available tool to estimate 2040 truck traffic, the land use forecast in the version of the model used for year 2040 was prepared in 2008 and is not consistent with recent Metropolitan Planning Organizations (MPOs) land use forecasts. For this, it is recommended to conduct similar analyses with the newer version of the CSFM. Further discussion of shortcomings of the previous version are provided in [3].

2.5 Regional Freight Problems

This section describes the current condition of the main freight problems in the SJV, with an overview provided in Figure 12.

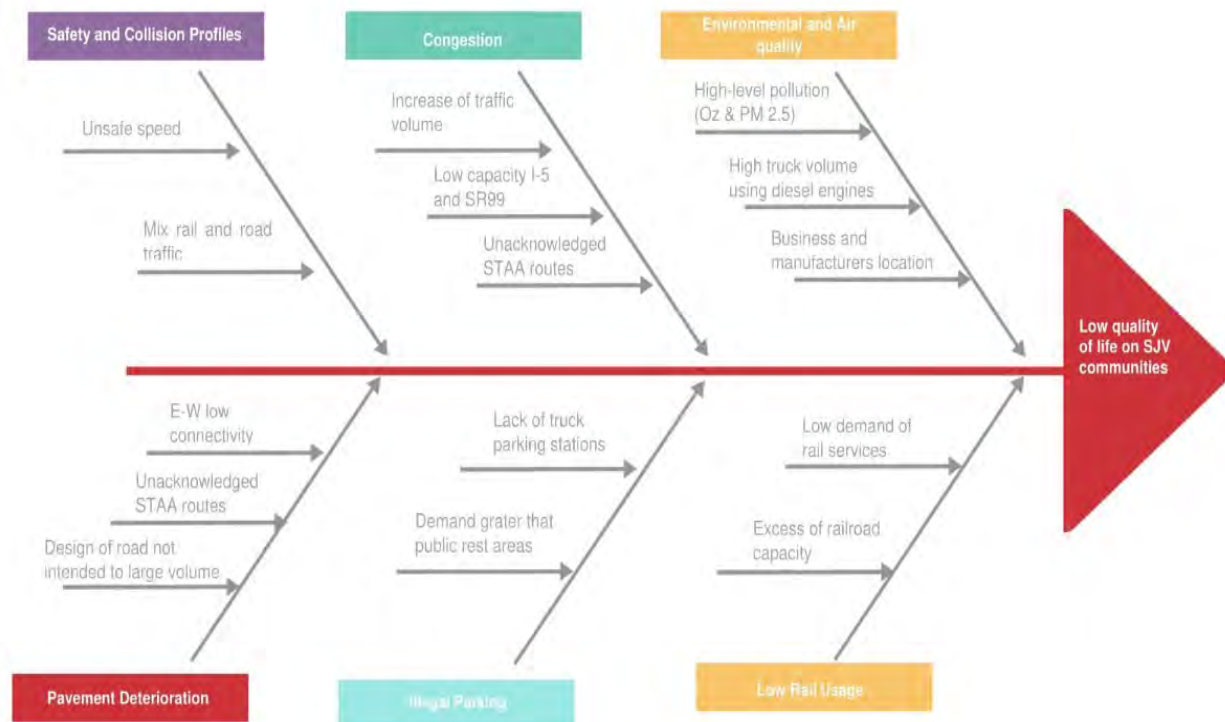


Figure 12. Overview of SJV Primary Problems and Causes

2.5.1 Safety

Between 2009 and 2013, 10.6% of all crashes in the SJV involved a truck [1]. In identifying crash hotspots in the region, [1] finds that I-5 has more fatal outcomes than SR 99, but SR 99 has a higher number of collisions than I-5. One probable reason is that on I-5, speeds are higher, and I-5 has fewer potential points of conflict. Additionally, minor collisions in SR 99 are most common near Bakersfield and Stockton, while severe truck collisions are spatially dispersed along I-5.

Additional safety concerns include illegal truck parking (which can impact visibility and driver safety), high speeds, mixed traffic conditions [2], and various others such as affecting the right of way of impacted communities along these corridors and or near freight facilities.

2.5.2 Congestion

The most important corridors in the SJV are I-5 and SR 99. The congestion on both corridors is influenced by the economic activity of the region. For instance, the SJV region has around seventeen clusters that include intermodal facilities, major distribution centers and large manufacturing [1]. Thirteen of these have access to SR 99, while only nine have access to I-5. The main consequence of this is that SR 99 has higher truck traffic flow than I-5. In fact, the speed in several segments on SR 99 are slower than 35 mph during the daily peak hours [1]. In contrast, I-5 usually has a free flow speed and is less congested than SR 99. Medium-heavy duty trucks have the highest share of vehicles on both corridors; while the share of light-heavy duty trucks is higher on SR 99 than I-5.

2.5.3 Environmental & Air Quality

The SJV air basin has one of the highest levels of pollution in California [10]. The SJV competes with southern California for the highest number of days above national and state standards of ozone concentration, and it leads in the estimated number of days in the year above the particulate matter 2.5 microns (PM_{2.5}) national standard. These high concentrations of PM_{2.5} and ozone in the SJV, relative to the remainder of the state, is evidenced by the CalEnviroScreen measurements in Figure 13. Additionally, Fresno and Bakersfield have among the highest concentrations of diesel PM per day (Figure 13) [11].

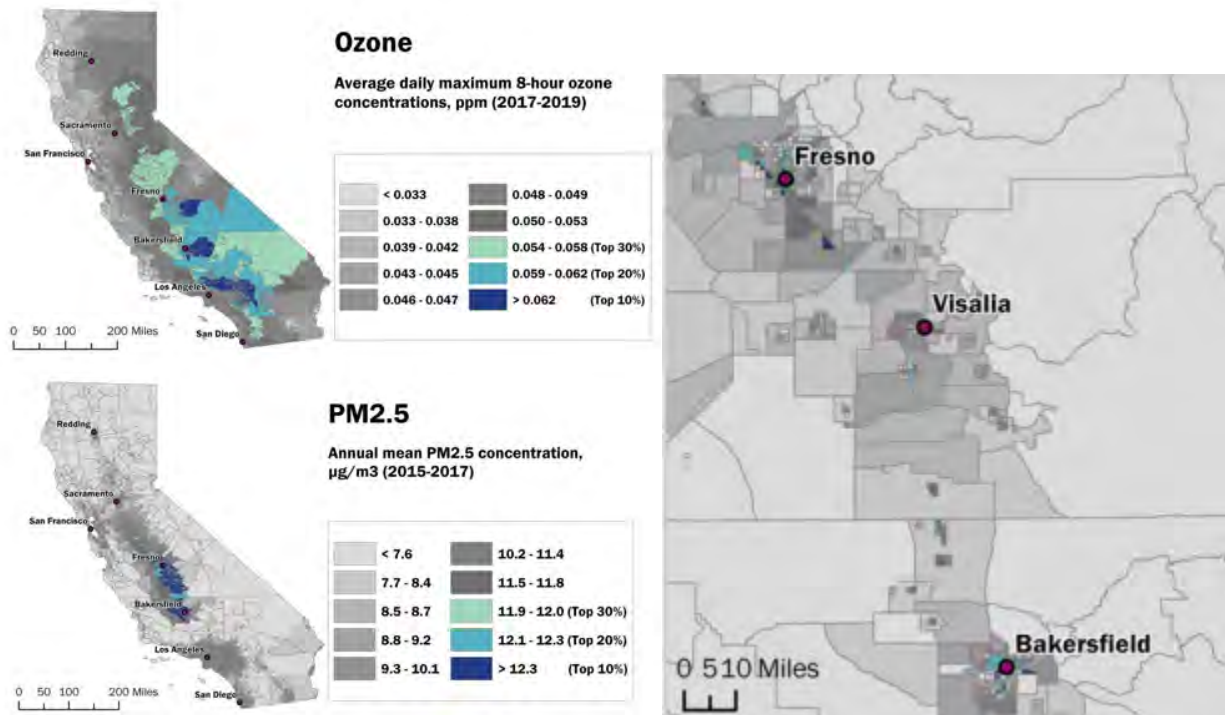


Figure 13. Ozone and PM_{2.5} concentrations in California [11] (left) and diesel PM in the SJV obtained from CalEnviroScreen 4.0 (right)

Overall, the SJV and the South Coast Air Basins exhibit the largest numbers of days in each year that the maximum 8-hour average ozone concentration is greater than 0.070 parts per million and the number of days in each year that the maximum 1-hour ozone concentration was greater than 0.09 parts per million. Furthermore, the SJV leads the estimated number of days in the year that the national 24-hour PM_{2.5} standard (35 micrograms per cubic meter) would have been exceeded.

Looking specifically at freight activities and fuel consumption in the SJV, there are considerable environmental impacts to communities, contributing to the region's air pollution problems, as well as the associated impacts to public health and the environment. According to the SJV Air Pollution Control District (SJVAPCD), the projected emissions in 2019 estimate that on-road vehicles contributed about 7% of daily PM_{2.5} emissions and about 50% of daily NO_x [12]. Trains and aircraft accounted for 3% and 10% of daily PM_{2.5} and NO_x projections, respectively [12].

Using the CARB Emission Factors (EMFAC) 2017 model [13] and the California Statewide Transportation Demand Model (CSTDm) truck VMT in the region, the research team estimated the emissions for diesel trucks in 2018, 2020, 2025, 2030, and 2040 running inside the SJV as shown in Table 11. The data includes

CARB's model estimates for daily vehicles across trucks of different fuel types, along with emissions per mile for CO₂ and other pollutants.

Table 11. Estimated Running exhaust emission from Diesel trucks based on EMFAC rates and CSTDM truck VMT for the project scope

LDV	2010			2015			2020			2035			2040		
	NO _x	CO ₂	PM _{2.5}	NO _x	CO ₂	PM _{2.5}	NO _x	CO ₂	PM _{2.5}	NO _x	CO ₂	PM _{2.5}	NO _x	CO ₂	PM _{2.5}
Fresno	478,085	560,670,013	2,525	397,520	561,521,670	1,901	330,136	1,803.88	1,804	119,529	851,762,251	2,019	69,814	911,891,059	2,213
Kern	329,838	408,968,950	1,731	311,146	410,874,727	1,301	283,500	603,562,744	1,564	97,268	739,854,783	1,748	59,957	820,522,934	1,991
Merced	118,072	131,324,593	642	100,030	131,606,709	496	76,891	141,120,532	428	26,967	172,104,308	415	15,826	193,038,423	470
S. Joaquin	343,227	413,465,399	1,856	291,227	414,260,447	1,454	223,903	442,583,515	1,274	78,912	559,890,126	1,354	47,819	620,681,228	1,520
Stanislaus	239,493	281,529,636	1,326	213,516	281,945,956	1,038	179,865	332,400,390	994	72,115	430,482,640	1,038	39,936	58,582,712	1,116
Tulare	275,158	295,197,315	1,482	263,246	295,570,666	1,131	223,927	403,470,722	1,227	84,938	558,573,574	1,347	46,721	595,531,096	1,453

(a) Light-heavy duty vehicles

MDV	2010			2015			2020			2035			2040		
	NO _x	CO ₂	PM _{2.5}	NO _x	CO ₂	PM _{2.5}	NO _x	CO ₂	PM _{2.5}	NO _x	CO ₂	PM _{2.5}	NO _x	CO ₂	PM _{2.5}
Fresno	1,785,049	815,639,604	4,042	1,357,390	1,012,786,253	2,476	645,523	1,255	1,255	114,260	1,248,298,843	1,325	108,326	1,354,585,339	1,456
Kern	1,698,662	815,735,356	3,224	1,283,173	1,100,630,136	1,963	664,112	1,258,920,472	1,302	135,221	1,515,869,776	1,604	148,191	1,859,821,294	1,998
Merced	505,251	227,085,782	1,271	404,468	280,381,922	782	187,854	273,105,370	343	29,882	314,491,210	333	28,719	354,320,507	381
S. Joaquin	1,987,100	912,732,259	4,203	1,283,572	997,031,402	2,082	566,815	990,317,985	1,070	106,003	1,162,327,333	1,231	106,567	1,330,422,104	1,430
Stanislaus	811,624	417,890,683	2,089	628,907	461,192,532	1,213	290,212	460,658,649	538	50,170	538,133,477	570	50,264	622,731,014	669
Tulare	1,115,379	461,723,187	2,975	867,733	613,586,860	1,798	411,011	694,181,904	847	79,217	890,590,581	946	75,505	952,455,048	1,025

(b) Medium-heavy duty vehicles

HDV	2010			2015			2020			2035			2040		
	NO _x	CO ₂	PM _{2.5}	NO _x	CO ₂	PM _{2.5}	NO _x	CO ₂	PM _{2.5}	NO _x	CO ₂	PM _{2.5}	NO _x	CO ₂	PM _{2.5}
Fresno	8,687,772	3,326,691,168	4,468	9,530,372	3,832,585,951	3,079	7,840,423	1,501	1,501	9,174,112	4,870,612,890	3,166	10,130,329	5,294,267,709	3,506
Kern	14,474,440	4,743,455,314	7,549.47	11,369,133	5,682,608,895	2,647	11,576,332	6,403,074,339	1,770	14,760,467	7,824,284,482	4,977	16,441,143	8,599,783,460	5,668
Merced	6,527,674	1,447,071,550	5,287	4,187,214	1,653,830,631	1,900	3,462,921	1,780,990,171	581	4,083,207	2,154,647,172	1,345	4,490,398	2,346,701,748	1,541
S. Joaquin	7,127,906	2,351,169,563	3,838	5,812,465	2,536,270,378	1,549	4,711,232	2,545,926,190	948	5,585,493	2,964,161,293	1,926	6,257,820	3,270,992,475	2,165
Stanislaus	5,485,096	1,396,867,971	4,509	3,717,699	1,543,714,840	1,267	3,060,453	1,605,319,958	617	3,780,853	2,001,258,010	1,289	4,150,607	2,165,766,372	1,432
Tulare	4,349,489	1,304,664,123	3,104	3,221,704	1,615,773,682	1,021	3,304,677	1,829,191,526	405	4,312,831	2,279,424,277	1,407	4,552,499	2,384,498,207	1,563

(c) Heavy-heavy duty vehicle

2.5.4 Pavement deterioration

Freight movement in the SJV results in pavement deterioration, which is related to vehicle weight. Table 12 shows the average payload in California and specifically in the Central Coast and Central Valley [9]. It is important to be cautious in interpreting this dataset because of the design of the survey and the difficulty of responders to choose between a set of fifteen commodities. Nevertheless, this data provides some insights into the payload by commodity of trucks in California and the SJV.

Table 12. Relationship between payload and vehicle and load characteristics

Average payload	California (pounds)		Central coast and central valley (pounds)	
all~	26000		26800	
Class 3 Truck	2000		2400	
Class 8 Truck	36000		38500	
	Commodity	Average payload (pounds)	Commodity	Average payload (pounds)
DMV CA	food, beverage, and tobacco	33000	Crude petroleum	47500 (48000)
	agriculture	34333	non-metal mineral	31000
Outside California registered truck	gravel/sand and non-metallic minerals	41000		

Notice in Table 12 that the average payload weights in SJV exceed the average payload weights in California. This excessive weight can significantly deteriorate the roadway surfaces in this area, because in the SJV there are many smaller connector facilities that are not designed for heavy trucks but are heavily utilized by them. In fact, Kings and Madera counties both consider pavement deterioration as one of their most relevant challenges [3].

2.5.5 Illegal parking

Lack of official truck parking results in illegal truck parking. Oftentimes these illegal spots include residential streets or locations near goods movement facilities. In California, demand exceeds capacity at all public rest areas and 88% of private rest areas on the state's highest volume corridors (this includes I-5). In the SJV, there are approximately 4,900 parking stations between I-5 and SR 99, and around 8% of them are public parking, while the rest are private. In general, there is a parking deficiency of around 10% of the current availability. Additionally, there is no widely available information about the operational characteristics, sensors, and technologies of the parking stations in the SJV. Appendix B includes a more in-depth evaluation of the truck parking situation in the region.

2.5.6 Low rail usage

In the SJV trucking is the dominant mode of goods movement; rail is critical for long-haul movement of SJV agricultural products and supplies [2]. The network of short line tracks in the region presents unique connectivity opportunities, currently being underutilized. Some of the potential opportunities listed in the *SJV Goods Movement Plan* include short-haul intermodal or shuttle services, connectors to inland ports, and truck-to-load trans-load operations which will feed into larger Class 1 rail lines. Class 1 rail lines are reportedly not expected to experience capacity constraints in the region, aside from the Union Pacific line over the Tehachapi Mountains between Kern Junction and Mojave [2]. It is worth noting that this was reported in 2013, meaning that with time, considering COVID-19, the rail capacity situation may now be

different. This is especially true considering the anticipated growth of freight movements in California [14], necessitating additional investments in Class 1 rail lines, to bolster the use and usefulness of short line rail. Nonetheless, if managed intentionally, the rail network might experience an expansion and provide an alternative option that helps reduce the congestion on roadways. The study and analysis of the rail capacity, and mode shift was outside of the scope of this project and there may be other ongoing projects analyzing some opportunities for truck to rail shifts in the region. For example, the Kern-Area Regional Goods Movement Operations (KARGO) project commissioned by Kern COG is addressing some of these opportunities [15].

Task 3. Assessment of Vehicle & Freight Efficiency Technologies

3 Vehicle and Freight Technology Assessment

This section discusses currently available technologies for freight movement across the interstates and provides a description, existing or expected technical specifications and the general assumptions used in the assessment.

3.1 Intelligent Transportation Solutions (ITS) for Parking Availability and Information

Information and communications technology infrastructure can be used to disseminate real-time information needed for developing apps to improve parking facilities. Developed apps combined with ITS show information for nearby interchanges with parking and number of available parking spaces. These can be combined with other types of information about amenities, including public/private locations and rest rooms.

3.1.1 Advanced Intelligent Transportation [16] [17]

ITS is the umbrella name for technologies that improve transportation safety and mobility either through the transportation infrastructure and vehicles [16]. Some of these technologies include:

- Electronic toll collection (allows drivers to pay their tolls via an automated system) [16]
- Ramp metering (ramp meters control the flow of vehicles entering a highway or freeway that is nearing congestion levels) [16]
- Red light camera (for ticketing drivers who enter the intersection after the signal turns red) [16]
- Traffic signal coordination [16]
- Transit signal priority (prioritize approaching transit vehicles to improve operational efficiency) [16]
- Traveler information system (the use of apps, websites, hotline, TV, or radio to allow travelers to make informed decisions about their trip times, routes, and mode) [16]
- Intelligent traffic signals (this includes adaptive signals and freeway meters; the signal timing is adjusted based on data from sensors) [18]
- Multimodal intelligent traffic signal systems (use dedicated short range communications to communicate with all travelers utilizing the intersection including pedestrians, vehicles, transit, emergency vehicles, freight; improves efficiency and safety) [18]. Freight prioritization at signals can help reduce emissions generated from stop-and-go traffic.
- Freight lockers (lockers at multimodal stations for food and package deliveries) [18]
- Wireless charging (stationary wireless inductive charging devices so that drivers will recharge their electric vehicles while driving over a charging coil) [18]
- Mobility marketplace (allow residents to pay for a variety of transportation options, such as bikeshare, carshare, transit, and rideshare all in one place) [18]
- Accessibility apps (provide routing information for differently abled people, such as routes with the best ramp access, audible traffic signals; this will also help cities for future planning) [18]

3.2 Parking Availability

Appendix B discusses truck parking in the SJV. Parking space and rest facilities availability are critical across truck routes. According to the previous findings, California ranks among the worst states in terms of parking facilities for truckers, with having an average of 53.7 parking space per 100 thousand miles. This even gets worse during peak seasons (July-October). These establish the motivation to improve parking facilities in this area using ITS-based developed technologies.

Table 13 summarizes the parking supply along I-5 and SR-99 corridors in. Furthermore, Table 14 shows demand information on the same area segmented by three sections along the corridor

Table 13. Summary of Parking Supply on I-5 and SR-99

Ownership Type	I-5	SR-99	Total
Public	288	128	416
Private	2,475	2,011	4,486
Total	2,763	2,139	4,902

Table 14. Truck Parking Demand Estimation on I-5 and SR 99

Type of truck Parking	I-5			SR-99		
	(1)	(2)	(3)	(1)	(2)	(3)
Total parking demand for truck	993	728	809	1027	567	845
Available parking space	1585	192	691	586	970	477
Parking deficiency	592	-536	-118	-441	403	-368
Sum of the Corridor	-61			-406		

A sample of available parking spaces (or the location of rest areas) is illustrated below in Figure 14, separated by their types (public, private). In addition to these, there are several fuel stations with available parking spaces which are not considered as supply in Table 13. In the SJV some of the private parking spaces are open 24 hours and have amenities such as showers for truck drivers and are equipped with reservation systems, but only one provides dynamic information for parking spaces which is private and located alongside I-5.

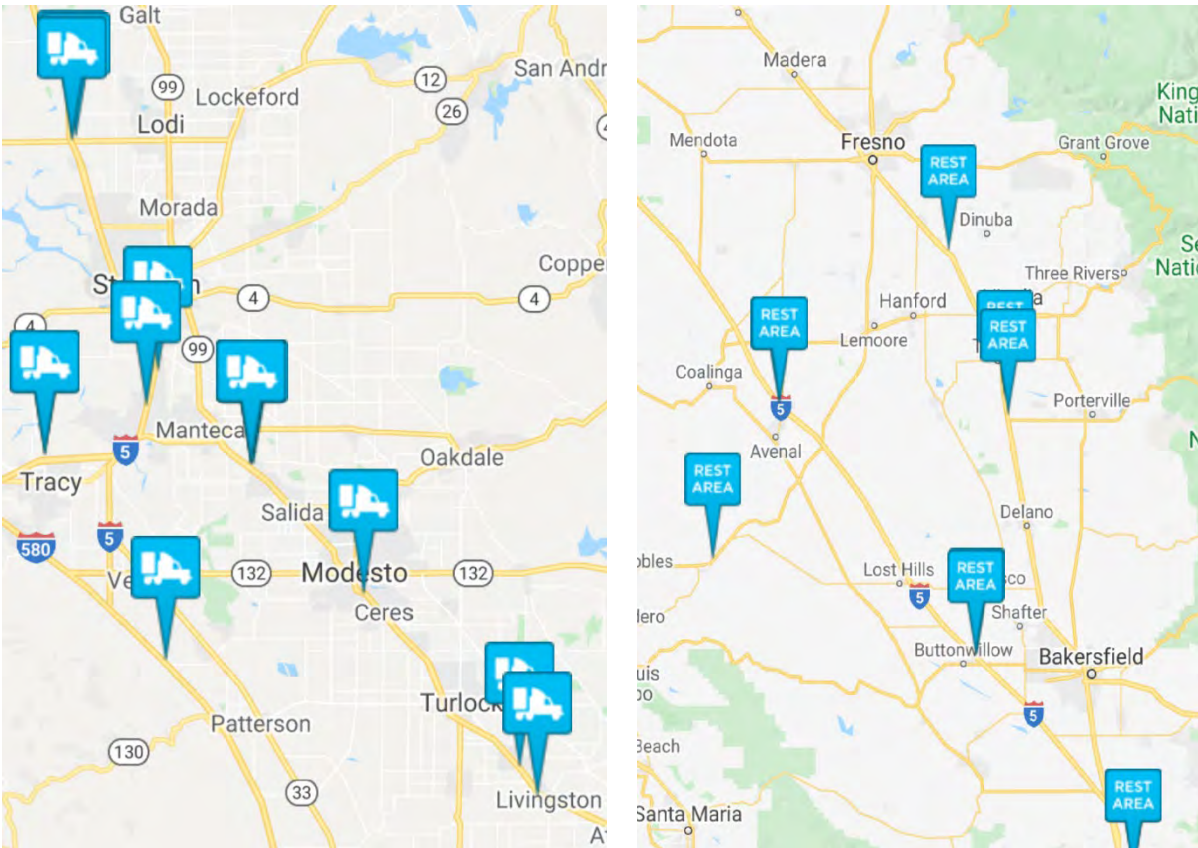


Figure 14. Parking supplies private (left) and public (right) alongside corridors

3.2.1 Dynamic Parking [19]

Dynamic parking can be used to influence travel demand via trip timing, mode choice, and parking facility choice. Dynamic parking might entail providing real-time parking information to avoid circling around parking facilities. There are several dynamic parking strategies:

- **Dynamic Parking Reservation:** allows users to use an online platform to reserve a parking space at their destination. Parking facilities would be continuously monitored.
- **Dynamic Wayfinding:** includes providing real-time information about parking availability and location so that routing information can be given specifically for a parking spot.
- **Dynamically Priced Parking:** varies parking costs to account for demand and availability. This practice has the potential to influence when people choose to make trips, where they park, and reduce traffic impacts.

3.3 Truck Toll Lanes [20]

The purpose of having truck-only lanes is to encourage the use of greener technology while also separating heavy commercial vehicles from passenger vehicles. Truck Only Toll Lanes (TOT) allow heavy weight trucks (exceeding the 80,000 pound as current maximum) to pass by and reduce toll rates for zero and near-zero emission trucks. Since this pilot encourages near-zero and zero emission trucks, proper fueling infrastructure is needed along the routes.

Electronic toll collection requires two important components: vehicle recognition and account identification. In the former, vehicle classification is detected by in-road and overhead sensors, cameras,

vehicle-to-roadside communication, or combinations of these. The latter is accomplished by matching the vehicle ID to a user account in a database.

Sensor systems may be subsurface, roadside or overhead. Different sensors have different functionalities. For example, inductive sensors determine the presence of a vehicle, light-curtain laser profilers record the shape of the passing vehicle, and traffic reporting and control (TRAC) can perform classifications in less than a second.

The use of overhead cameras for vehicle license plate identification in tolling is referred to as video tolling. The picture taken from the vehicle license plate is then checked against a database to find the owner associated with the vehicle.

Despite the wide use, the picture quality by video tolling might be poor and blurry and subject to weather conditions and possible obstacles. They usually work in conjunction with both Global Positioning Systems (GPS) and Dedicated Short Range Communication (DSRC). Typical DSRC field components include:

- DSRC radio
- DSRC poles and mounting structures
- DSRC cabinet and equipment
- Communications, power conduit, and cabling
- Splice vaults and pull boxes

DSRC roadside installation sites would need to be implemented at regular intervals. Installation may also need to occur on connecting arterials to provide the degree of coverage necessary for some connected vehicle (CV) applications.

Transponders are other means to collect vehicle information that works based on radio-frequency identification (RFID). The RFID is embedded in a tag which is located near the front window and as the vehicle passes through a transmitter, it responds to radio signals. Two types of tags exist, passive (no connection to power) and active (connected to vehicle power source).

In addition, there are other emerging technologies for tolling such as odometer tolling, cell phone tolling, GPS tolling and satellite tolling that are in development.

Costs associated with this service are construction costs (structure, electronic toll collection, violation enforcement service, vehicle detection, lane processing equipment, signs, pavements, communication, power), design and engineering costs and operation costs (e.g., software, network equipment, workstations, installation, and configuration cost).

Due to the urban centers located along SR 99 and the rural nature of much of I-5 in the valley, I-5 has more capacity to provide safe and efficient freight moves as compared to SR-99. To reduce congestion and encourage regional truck traffic to travel on I-5 in lieu of SR 99, some of the East/West corridors between I-5 and SR 99 might be considered for tolling programs. TOT lanes on I-5 between I-5 and I-205 junction in San Joaquin County and I-5 and SR 99 junction in Kern County were proposed in 2016 for substantial mobility, safety, and air emission reduction benefits to freight transportation system users, however, the trucking industry in various parts of the U.S. are opposed to tolling and it would also have a high opportunity cost.

California has two truck-only lanes and others under consideration:

1. Northbound and southbound I-5 in Los Angeles County at the State Route 14 split. Looking in the northern direction, the truck lanes begin as two roads: NB at LA County postmile C043.925 and SB at C043.899. The NB and SB roads join at postmile C044.924 and continue together up to postmile C046.351. The total lengths are 2.426 miles (NB) and 2.452 miles (SB). The purpose of these truck lanes is to separate slower moving trucks from the faster general traffic on the grade. After constructing the new I-5 alignment, the original alignment was used for the truck-only lanes. This truck-only facility has been in place for about 30 years.
2. Southbound I-5 in Kern County at the State Route 99 junction near the Grapevine. This truck lane begins on Route 99 at Kern County postmile L000.629 (the equivalent of I-5 postmile R015.838) and ends on I-5 at postmile R015.492. The total length is 0.346 miles. The purpose of this design is to place truck merges further downstream of the automobile traffic merge of I-5 & SR 99.







There are two types of tolls: fixed and variable tolls. The fixed tolls are predetermined based on the distance covered, axle amount, and/or weight per axle of the vehicle, and do not change during the day. The variable tolls are dependent on features, but also change throughout the day either in response to current conditions or according to a predetermined schedule. California currently has no interstate system tolls that are dependent on the weight per axle of the vehicle. Such a system of tolling would be an ideal method for mitigating the damage caused by heavy trucks traveling on I-5 and SR-99.

3.4 Automation

3.4.1 Overview [17]

Automated vehicles (AVs) have some control functions that do not require direct driver input. There are six levels of automation currently recognized (see Table 15).

Table 15. Six levels of vehicle automation [17]

SOCIETY OF AUTOMOTIVE ENGINEERS (SAE) AUTOMATION LEVELS					
Full Automation					
					
0	1	2	3	4	5
No Automation	Driver Assistance	Partial Automation	Conditional Automation	High Automation	Full Automation
Zero autonomy; the driver performs all driving tasks.	Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.	Vehicle has combined automated functions, like acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at all times.	Driver is a necessity, but is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times with notice.	The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.	The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle.

Although AVs are still largely in the experimental and development phase, there are many anticipated benefits. These include:

- Improved safety due to removing human error
 - Human error is the cause of 94% of serious crashes
- Economic and societal benefits due to the improved safety and lower costs of loss of life

- Efficiency and convenience will improve because of more smooth and efficient travel which will reduce congestion, save travel costs, and save time. Even more, travelers will be able to choose other activities to participate in during their travel rather than driving.
- Mobility is thought to be a benefit of autonomous vehicles that will provide independent transportation for the elderly and disabled, given that employment and independent living require access to convenient and reliable transportation.

3.4.2 Efficiency [21]

Automation may reduce the energy intensity of vehicle travel, by enabling more efficient operations, facilitating a shift away from the owner-driver model of personal mobility, and altering the size, weight, and efficiency of vehicles.

Vehicle automation may reduce the energy wasted by congestion, by improving traffic flow and reducing accident frequency (both are sources of congestion). Automation may facilitate the broad implementation of so-called “eco-driving,” a set of practices that tend to decrease in use fuel consumption without changing vehicle design. One way to reduce energy consumption is to drive so that the engine can spend as much time as possible at its most efficient operating points, which typically means high load and moderate speed. Another is to minimize repeated braking-acceleration cycles since braking represents wasted energy. Platooning is another way to reduce fuel consumption through tight, smooth driving and increasing roadway capacity, which is discussed before. Automation may lead to increased highway travel speeds if human attention and reaction times are no longer limiting factors in determining safe speeds. Since aerodynamic losses increase with speed, this could increase the energy intensity of vehicle travel. Automation can dramatically lower crash rates and render crashworthiness of the vehicles much less important in the future. In this situation, vehicles could become smaller and potentially shed safety equipment. This would decrease fuel consumption and emission as well. In a study by [21], four scenarios of automation in both LDV and HDV were simulated:

1. “Optimistic” scenario, where all the energy intensity benefits develop, and travel demand increases only slightly.
2. “Stuck in the middle” scenario, where energy intensity benefits are partially offset by higher travel demand.
3. “Strong responses,” all the envisioned mechanisms deliver maximum effects, yet these cancel out to due to high demand.
4. “Pessimistic case” in which no energy intensity improvements materialize, but travel time costs fall, travel demand increases significantly, and highway speeds increase energy intensity.

Figure 15 shows the results for the four scenarios, illustrating a broad range of plausible outcomes. The variability of the scenarios is instructive, emphasizing both the opportunity for significant energy and transportation benefits, and the need for more careful analysis to identify net effects, and guard against adverse outcomes, especially for level 4 automation.

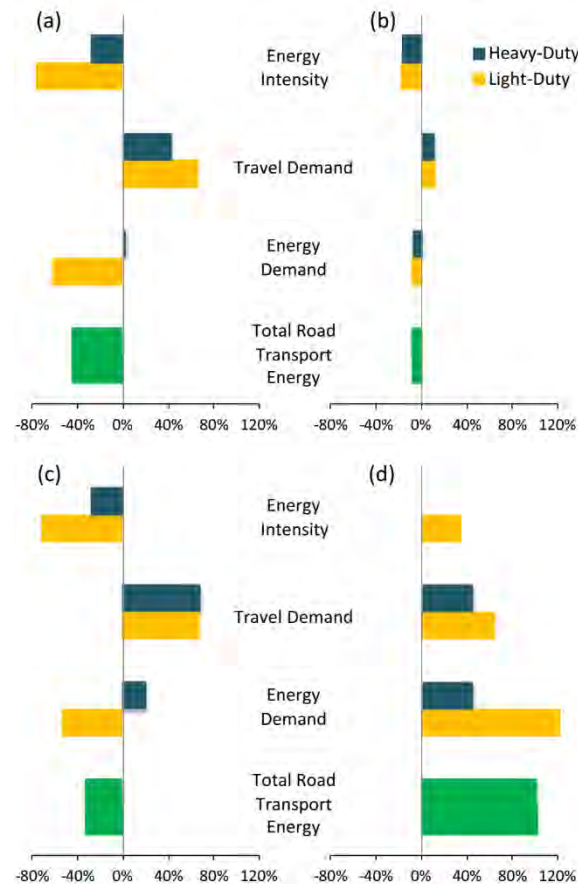


Figure 15. Changes in energy intensity per kilometer, travel demand, and total road transport energy consumption for light-duty (LDV) and heavy-duty vehicles (HDV) under varying four automation scenarios: (1) “Optimistic” (2) “Stuck in the middle at Level 2” (3) “Strong responses” (4) “Pessimistic” [21]

3.4.3 Automated Trucks

The introduction of AVs to the freight industry has many potential impacts and a variety of applications. The potential impacts of AVs on the freight industry include savings in shipping costs, solution to the driver shortage, changes to the locations and amount of distribution centers, and ability to create platoon-based truck fleets.

3.4.3.1 Economic Impacts

Autonomous trucks have the potential to decrease operating costs by about 45% and save the for-hire trucking industry anywhere from \$85 billion to \$125 billion in the US [22]. However, companies must also consider the high capital costs and the uncertainty associated with AVs entering the secondary market (i.e., reselling aged vehicles) [22]. Currently, a major question mark in the field of autonomous freight is the impact on jobs. There are many estimates for the number of jobs lost, although the great amount of uncertainty makes these numbers unreliable.

According to the Harvard Business Review Industrial and Labor Relations Review, there are three main reasons why losses may not be so high [23]. First, beyond driving, truck drivers are responsible for checking vehicles, securing cargo, maintaining logs, and providing customer service [23]. Next, full automation of trucks (particularly level-5 automation) is currently not even in the testing phase and will not be seen for many years [23]. Finally, there are fewer jobs in long-haul heavy duty and tractor-trailer

truck driving than estimated [23]. In fact, it makes up about 0.3% of the U.S. workforce (about 456,000 jobs), which although significant, is not as high as some reports suggest [23].

McKinsey similarly predicts that companies will need to fill more technical jobs to help maintain the vehicles, and driver spots to navigate the trucks to and from highways or freeways [22]. They also predict that the first trucking jobs to transition to AVs will be long-haul trips. Long-haul trips tend to be the least popular among commercial drivers and represents most of the driver shortage [22], even though the UC Berkeley labor center states that these jobs are among the best paying jobs in the industry [24]. They clarify that many, if not more jobs than were lost, might be created in local and last-mile delivery. Those jobs have poorer pay and poorer working conditions [24]. Drivers for less-than-truckload companies who deliver many parcels to many different customers, tend to have higher wages, better benefits, and stability in their career due to high unionization rates [24]. On the other hand, companies that deliver a truckload to one customer have lower wages, tend to have high rates of workers who are new to the industry, and misclassify those workers as independent contractors where unionization rates are low [24].

A spokesperson for the Owner-Operator Independent Drivers Association claims that there are many situations that AVs are not well equipped to handle without a driver [25]. This includes emergencies, cargo issues, law enforcement, and others [25]. The press secretary for the Teamsters also claims that AVs may result in consequences to human drivers [25]. This includes extended hours and limited breaks.

Importantly, although AVs can perform driving tasks on their own, they currently still operate with a driver on board [26]. This could be for several reasons including legalities, insurance purposes, lack of ability to maneuver certain hubs or ports, or undesirable road or weather conditions [26]. This is important to consider when discussing potential job losses in the freight industry or operational cost savings for companies, at least soon [26].

In their forthcoming work, [27] find that adoption of automated driving systems for long-haul and last-mile operations is anticipated to be slow and in the more distant future. They anticipate that this adoption will *change* the responsibilities of truck drivers, at least at lower levels of automation, but might supplant drivers at higher levels of automation. Adoption at these high levels of automation is far from certain, especially at a high level of penetration, and they anticipate that the adoption will be slow and gradual enough that the labor market will be able to adjust in some ways (creation of and training for other transportation and logistics jobs).

3.4.3.2 Social Impacts

An additional consideration is the social pushback that might be experienced from these large, now driverless vehicles [26]. This could include these trucks making other drivers feel unsafe or certain shippers or customers being unwilling to use AV services [26].

3.4.3.3 Operational Impacts

For warehouses, automated trucks have the potential to speed up e-commerce fulfillment (picking and shipping will be possible 24/7), and they will be able to inventory more quickly which will reduce per-unit costs of warehousing [22]. Importantly, warehouses will need to invest in compatible infrastructure and autonomous warehouse vehicles that can seamlessly connect with autonomous trucks [22].

On a broader scale, as autonomous trucks become more widespread warehouses can relocate to more desirable but remote locations [22]. Figure 16 shows the four main stages that the McKinsey Center for Future Mobility estimates autonomous trucks will go through to get to full autonomy [22].

Autonomous trucks will likely roll out in four waves.

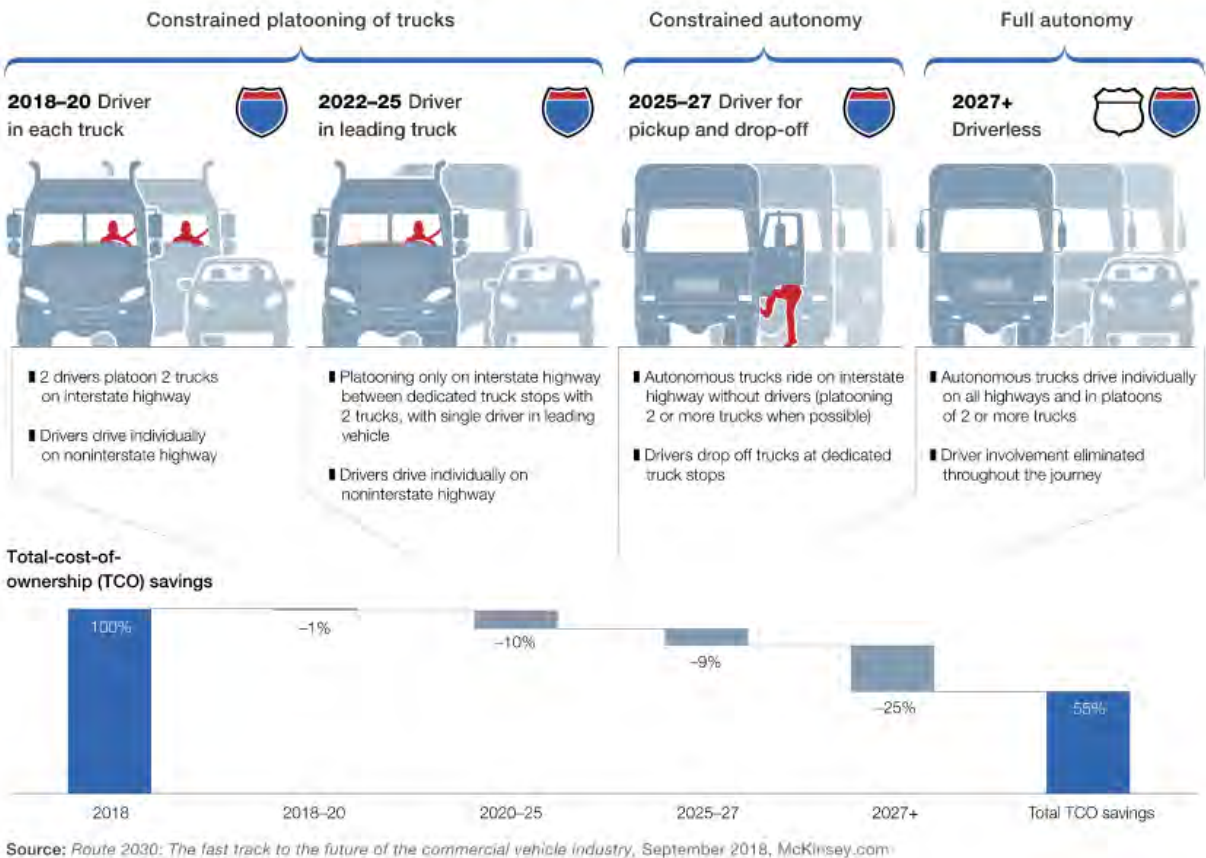


Figure 16. Possible autonomous truck roll-out phases alongside TCO savings [22]

The public policies regarding AVs have the potential to impact whether the replacement jobs are good jobs, whether they improve safety and congestion, and how efficient they are [24]. Specifically, policies should actively regulate this modern technology to ensure that the social, economic, and environmental outcomes are positive [24].

3.4.4 Panel of Automated Technology Providers on the Potential Impacts of Automation for the SJV region

On December 10th, 2021, the research team organized an online seminar with technology providers to discuss “How the San Joaquin Valley can Implement Freight Automation Technologies to Improve Quality of Life.” The online seminar was organized with the help of the Association for Unmanned Vehicle Systems International (AUVSI). See online seminar invite (Figure 17) for a description of the objective of the online seminar and the key topics discussed. The invited companies included:

- Embark (autonomous long-haul truck)
- Locomotion (autonomous long-haul truck)
- SmartPoint (data)
- Perrone Robotics (autonomous yard truck)
- Boston Dynamics (loading/handling robots)



How the San Joaquin Valley can implement freight automation technologies to improve quality of life.

Friday, December 10, 2021

10:00 a.m. - 11:30 a.m. PST

Virtual - Zoom Webinar

Register Here

This webinar brings various stakeholders together to discuss the potential for freight automation in the San Joaquin Valley. The industry will share the latest in automated technologies that could benefit the freight system and the region, and the agencies and academia will discuss the role of these technologies. After the presentations, the discussion will center around the following questions:

How can technologies be implemented to help communities operate more efficiently in the San Joaquin Valley?

What are the benefits to the region and local communities?

What are common misconceptions about these solutions?

What are the expected downstream effects of these technologies?

What policies or regulations are needed to foster the adoption and use of these technologies?

Figure 17. Automation Webinar Invite

The reader is referred to <https://youtu.be/Zc3LtcRo52U> to watch the recording of the online seminar.

3.5 Connected Vehicles (CVs) and Platooning

3.5.1 Connected Vehicles

CVs communicate with varying infrastructural components via wireless communications, computer processing, vehicle sensors, GPS, and smart infrastructure. Connected vehicle technologies have the potential to improve safety and efficiency. There are many distinctions of connectedness, depending on what the vehicle is communicating with. This includes vehicle to vehicle (V2V), vehicles to infrastructure (V2I), and vehicles to mobile devices (V2D).

3.5.2 Platooning

Platooning uses CV technology so the lead vehicle can communicate and coordinate with other trucks, enabling them to travel in proximity. Using radar, cameras and reflective light scanning, tractor-trailers

can travel at a following distance of 30 to 50 feet, which reduces wind resistance and that would result in fuel savings as well as safety benefits by reducing rear-end crashes through automated braking. It also increases the number of trucks that can fit on the road at high speeds, thereby increasing roadway capacity. Several technologies work together to support this type of interaction: Adaptive Cruise Control (ACC), Cooperative Adaptive Cruise Control (CACC), and truck automation.

3.5.2.1 Adaptive Cruise Control (ACC)

ACC supports truck platooning but is not considered a truck platooning system. ACC systems permit the driver to choose a set speed, activate automated brake systems, and throttle systems to maintain safe following distances. The driver is still responsible for steering the vehicle and maintaining an awareness of road conditions to minimize headways and maximize performance.

3.5.2.2 Cooperative Adaptive Cruise Control (CACC)

CACC was developed to address coordination shortfalls between ACC-equipped vehicles and safely minimize following gaps. CACC extends an ACC system by including V2V communication to provide important speed and location information from the vehicle in front of the platoon and supplement in-vehicle sensors (including radar, LiDAR, cameras, ultrasonic sensors). This additional information allows the following vehicle(s) to adjust speed quickly enabling shorter following gaps, and consequently, smoother acceleration and deceleration profiles to reduce aerodynamic drag and improve fuel economy and emissions for vehicles in the platoon.

ACC and CACC are examples of Level 1 automation, but global coordination strategies that support fleet operations will be required for higher levels of automation to develop global, local, or ad hoc/coordination strategies to form platoons. Researchers at the California Partners for Advanced Transportation Technology (PATH) describe four primary stages of truck platooning:

1. **Forming** – During the first stage of truck platooning, trucks must identify potential platoon partners based on a range of characteristics, including their current location, destination, the number of stops, type of truck, and other variables. This information may be difficult to ascertain if other drivers work for competing firms.
2. **Steady-State Cruising** - The cruising stage occupies the largest period while the platooning system is activated. Once a platoon is formed, the drivers will operate the vehicle based on the level of automation in the vehicle. Steady-state cruising would be modified as trucks join or drop out of the platoon or when an equipped vehicle cuts in. Most truck platooning benefits accrue during the cruising stage.
3. **Departing or Splitting** - Trucks may depart from the platoon when needed to complete their trips or make a trip deviation. Once the departing truck has left, the trucks that were following it rejoin the original platoon and close the gap left by the departing vehicle.
4. **Abnormal Conditions** - This last stage accounts for other situations that are not addressed in the previous three stages. This stage can include potential errors in the system or abnormal operating conditions. Any truck platooning system will need to be able to identify and resolve these unexpected abnormalities.

Truck platooning technology typically includes the following:

- **Sensors** - A combination of both short- and long-range sensors (such as LIDAR (light detection and ranging), radar, and cameras) are used by vehicle to track not only other vehicles in the platoon but all other objects in the road, including pedestrians and cyclists. Sensors all work in conjunction to provide a complete image of the surroundings.

- **Localization services** - Global positioning systems (GPS) and inertial navigation systems (INS) are used to accurately determine the location of the vehicle. These systems provide the necessary information to the vehicle to establish the spacing between the platoon vehicles. As with sensors, the system needs to be redundant so if the GPS temporarily fails (as in low coverage areas or tunnels) the INS can use motion sensors and rotation sensors to determine the vehicle orientation until the GPS reestablishes its connection.
- **V2V communication** - DSRC is utilized for low latency exchange of vehicle performance parameters between vehicles. An extension of Wi-Fi technology, DSRC communicates passing speed and locational information, which allows the CACC system to quickly adjust to changing speeds and positions, facilitating an effective platoon.
- **Software** - These algorithms are the core of the CACC systems as they are required to process the information, predict the movement and speed of the vehicle in front to set the new speed of the following vehicle.
- **Hardware** - There is a broad range of hardware components distributed throughout the vehicle that connects critical systems and controls the vehicle speed and braking.
- **Human interface** - The Human Machine Interface informs the user about changes in the CACC stages.

Regarding the associated cost with truck platooning, the payback on investment period is not clear now. Surveys across freight operators resulted in an estimate of 10-18 months. In addition to the technology adoption, there are other costs associated with equipment acquisition, driver training, logistics and coordination, testing, and insurance costs.

3.5.2.3 *Current Conditions for Platooning*

As for the I-5 facility, truck platooning would work well on the 298-mile segment of interstate from Kern County to San Joaquin County. This long segment of I-5 provides two travel lanes, but it provides three to four travel lanes in the northern segment and three in the southern segments near I-580 and SR 99, respectively. I-5 through the SJV follows the back side of the Sierra Nevada Mountain range, which provides a relatively flat and straight stretch of highway. On average, approximately 11% of the traffic on I-5 consists of heavy-duty trucks, albeit the volumes increase near I-580 in the northern part of the SJV and near the merge with SR 99 in the southern part of the SJV. Nearly half of the heavy-duty trucks (approximately 6,000 daily) using I-5 through the region have origins or destinations beyond the SJV, such as southern California, the Bay Area, and Sacramento. Heavy-duty trucks traveling long distances have the greatest incentive for becoming part of a two- or three-truck platoon because they receive the greatest benefits from platooning, most notably, fuel savings.

3.6 Digital Freight Matching [28] [29] [30] [31]

Digital freight matching involves the use of apps and digital platforms to replace the third-party logistics companies and brokers [28]. These platforms will provide a direct connection between drivers and shippers [28]. The advantages of digital freight matching in terms of cash-flow, affordability, and turnaround time are outlined in Table 16.

In addition, these platforms could assist in filling what would typically be empty miles by allowing drivers more control over their schedules [28]. This is especially important given the electric logging device mandates (see Appendix B and Appendix D). Digital freight matching will help drivers ensure that they efficiently utilize their limited work hours [28]. These platforms also have the potential to result in a better use of cargo space, less waiting, more efficient fleets, reduced traffic, paperless operations, transparent pricing, and stronger safety standards [29].

Table 16. Advantages of digital freight matching [28]

Cash-flow	Affordability	Turnaround time
Shipping invoices can often take weeks to be fulfilled, leaving a large gap for truckers.	High fees that traditional brokers offer can often amount to almost forty-five percent of the delivery cost per load.	Traditional brokers rely on phone calls, emails, and faxes to secure a scheduled load which can take hours to confirm.
Digital freight matching can offer 'quick-pay' options and fuel advances.	Digital freight matching platforms open up competition in the market for lower rates of commission.	Freight matching platforms can display loads within twenty-four hours where drivers can claim them just as quickly.

Digital freight matching is set up so that drivers can input their preferences, vehicle specifications, and certifications as their profile [30]. Then, shippers or brokers will create a post about their freight load (i.e., including load details, weight, rate, distance, locations) and the app will alert drivers about loads that they qualify for. Drivers will then be able to decide whether they accept the load [30].

These platforms should also be designed to simplify the matching process [30]. This includes allowing digital messaging and paperwork completion, connecting partners, provide insights for profits and growth, quick-pay options, offer predictive matching, automatically match capacity to load for brokers, and integrate the app into a transportation management system or a mobile device [30]. Even more, shippers could track their delivery so they always know the status of their goods, and truckers will eventually be able to determine if they can carry additional freight (based on space and weight) [31]. The authors also specify that no companies are currently producing an app that does all these things [30].

3.7 Radio-Frequency Identification (RFID) [32] [33]

RFID uses radio waves to gather information from a tagged item. The tag is a small computer chip that utilizes a range of radio frequencies. It does not need to be in the line-of-sight to be read, and data can be transmitted quickly [32] making it an effective choice in the transportation field.

They can help maximize efficient use of assets or equipment, reduce operating costs while also improving customer satisfaction. RFID can help with monitoring (battery, fluid, status, location), granting access, safety/security, reporting key performance indicators, vehicle, and package tracking [33]. RFID gives supply chains a high level of automation and control [32].

The data collected using RFID can help interested parties understand bottlenecks in their service, automate some portions of their workflow [33], vehicle identification for entry to a site or confirmation of a load, identify if vehicles have gone to the correct loading bay or station, ensure tractors and trailers are correctly matched, load identification measures (for curtain-sided vehicles or bin identification), and payment of tolls or other road pricing measures [32].

3.8 Video [34]

Video surveillance in transportation can be used from a stationary location or from inside the vehicle.

Video surveillance at a stationary location or outside the vehicle is particularly useful when the transportation issue is occurring in one area of interest. Video feeds might be used at locations with high crash volumes, poor pedestrian safety, or other safety concerns that transportation engineers need more information about. Video surveillance is also especially useful for collecting data that is tedious or unreasonable to collect in person. For example, collecting data on the number of trucks that pass through a specific corridor or intersection during a given day is tedious work that is much more easily recorded and counted later (e.g., with freeze-frame, rewind, change playback speed).

On-board cameras can include internal cameras, dash cameras, rearview cameras, or side panel coverage. Even more, recordings can be continuous or event-based [34]. Event-based recordings occur when a crash or a hard-braking occurs, and it records 15-30 seconds before the braking event and 30-60 seconds after the event [34]. On-board cameras can be installed for driver monitoring, passenger monitoring, and vehicle safety (including enhanced collision review and analysis) [34].

3.9 Other Strategies

3.9.1 Eco-driving [35]

Eco-driving is a driving style intended to reduce fuel consumption and vehicle efficiency. Eco-driving reduces exhaust emissions while driving. Eco-driving includes the following practices:

- Accelerate and decelerate smoothly
- Avoid excess idling in non-traffic situations (e.g., drive-through)
- Travel at the posted speed limit
- Maintain proper tire pressure
- Maintain steady speed
- Selective use of air conditioning
- Remove excess weight (e.g., items that stay in the trunk)
- Make fewer trips (plan carefully and consolidate)
- Carpool
- Do not “top-off” (i.e., do not overfill the gas tank)
- Newer model vehicles do not need to be warmed up in the winter

3.9.2 Geo-fencing [36]

Geo-fencing refers to perimeter (or geo-fence) around a specified location, such that an app on the user’s phone will push a notification or message once the user’s phone crosses the perimeter. Google provides the example of airline passengers receiving notifications to access their boarding pass once they enter the airport (distinguished by a geo-fence). In freight applications, geo-fencing could be utilized for many purposes, such as clear communication to truckers about parking access near them.

3.10 Zero- and Near-Zero Emissions Truck Technology

Zero emission truck technologies are a promising alternative to reduce the emission impacts from trucks by shifting trucks away from petroleum-based fuels to bring tremendous emission benefits for the transportation sector. However, by the writing of this report, for long-haul heavy duty there are still current barriers including limited technology availability, limited economies of scale, limited fuel/energy autonomy, payload mass and volume constraints, and a lack of refueling and recharging infrastructure. Several state policies recently developed and some under consideration could help accelerate the technology development to mitigate some of these challenges. For example, for short-haul movements and last-mile deliveries, there are several commercially available battery electric vehicles and new ones coming to market with the capabilities to meet the operational requirements of fleets. For long-haul,

there are promising alternatives, but it has been challenging. Overall, there are a few zero- and near-zero emission truck technologies that have been or are still under various levels of technology readiness. These are briefly described below.

3.10.1 Hybrid Electric

There are several important variations of hybrid electric vehicles include dual mode, plug-in hybrid electric vehicles, range-extended electric vehicles with integrated engines, and range-extended electric vehicles with integrated fuel cells. There have been some pilots of heavy-duty electric vehicles at the ports of Los Angeles and Long Beach, and there are other vehicles in operations by fleets. Several types of hybrid electric trucks include dual mode, plug-in hybrid electrics (PHEVs) and range-extended electric vehicles (REEVs) with integrated engines or fuel cells. Dual mode are hybrid electric technologies that works in parallel or in series with a combustion engine as the main energy source. The effectiveness of dual mode hybrid electric vehicles can vary depending on speed and load of the vehicle, because these factors also dictate which mode the vehicle is operating in. These vehicles tend to have a small battery which only accounts for a limited range of zero emission miles, though it can be beneficial to mitigate local impacts if those miles are driven in and around vulnerable populations. PHEVs utilize electric and combustion engine powertrains, the batteries can be charged using a charging equipment, and can benefit by reducing emissions relative to vehicles with only combustion engine powertrains. This technology has larger batteries and is charged over the grid that leads to a higher range of operation compared to HEVs. Some PHEVs have range extenders (REEVs) with integrated engines which can operate by either diesel or compressed natural gas (CNG) with electricity as the primary source of energy. The battery size determines the range of operation which impacts truck type and cost in return. Range extenders serve as on-board power generators that recharge the vehicle's battery while driving when the vehicle's battery is nearing depletion. This technology is still under development and is expected to see major improvements (in range and emissions reductions) in coming years. Alternatively, there are REEVs with integrated fuel cells, which rely on a fuel cell when the vehicle battery is depleted. The fuel cells depend on hydrogen refueling stations for recharging; thus, they are a practical solution only in areas where such refueling stations exist. This technology requires reasonable space to be placed, thus it can be accommodated by a standard diesel truck. Currently, there may be differences in the price point of these technologies compared to other technologies, though the developments in fuel cell vehicles can help bring the costs down and improve accessibility to fueling infrastructure. Overall, these technologies can offer long useful lifespans and small maintenance costs. Because these vehicles are capable of operating in true zero-emissions mode, it is easy to obtain regulatory certification for them.

3.10.2 Propane or Liquefied Petroleum Gas (LPG) Vehicles [37]

LPG vehicles are fueled by propane autogas. Some LPG trucks are currently available on the market and vehicle conversions kits are also viable and relatively affordable for gas and diesel trucks. Availability and attractiveness of these options can vary depending on truck size and vocation, which limits their applicability for heavy-duty operations. Propane autogas pricing per gallon is currently comparable to the cost of gas or diesel. LPGs emit low levels of NOx, particulate matter, and air toxins; and, if renewable propane is used, GHG emissions could be lower than gas-powered vehicles. Although renewable propane is produced in the same process as renewable diesel from vegetable oils and animal fats, it has added cost and complexity. Moreover, additional infrastructure investments would be needed for fueling [38], service and support within the SJV, compared to other vehicle technologies (excluding hydrogen fuel). Looking beyond the SJV, in California and the US, LPG stations have similar frequencies, although LNG stations are sparse [38].

3.10.3 Natural Gas

The primary natural gases used as transportation fuel include compressed natural gas (CNG), and liquified natural gas (LNG). Recently, some natural gas technologies have shown significant improvements in NOx emissions and have been classified as ultra-low NOx engines certified to levels that are 90% cleaner than U.S. EPA standards for nitrogen oxides. Depending on the source of the renewable natural gas (RNG), it can be cleaner than some electricity and hydrogen powered vehicles. In the SJV, there are several fleets that have invested in RNG technologies, and the vehicles are currently in operation moving heavy volumes across long distances; however, access to RNG is still limited and vehicles are mostly using CNG.

3.10.4 Hydrogen Fuel Cell Electric Vehicles (FCEVs) [37]

FCEVs have the potential to be a zero-emission option while also accomplishing longer range and faster refueling. FCEVs has received increased interest from the industry and researchers in the last few years, as there are developments in hydrogen production, handling, and storage, as well as changes in the overall energy sector that can help overcome the limitations this technology faced before. FCEVs are proposed as a solution to long-haul heavy duty as they may not experience range limitations as other zero-emission technologies such as battery electric trucks, and costs have come down significantly in the last few years. For example, although hydrogen fuel costs are currently about double that of gasoline, they have been cut in half over the past decade and industry parties are working to halve them again in the next decade. However, these vehicles are still in the demonstration and re-commercialization phase for medium-and heavy-duty applications. And, issues faced by the industry with a recent failed attempt to commercialize a fuel cell vehicle model and incorrect advertisement from a prominent company may have added some uncertainties to their short-term availability. Nevertheless, there are several ongoing efforts by different agencies and the private sector to move FCEVs to market and serve the heavy-duty segment. These efforts include vehicle and technology development, as well as fueling infrastructure.

3.10.5 Battery Electric Vehicles (BEVs)

BEVs seem to have reached a level of market readiness for some vocations (e.g., transit, short-haul, and last mile deliveries), which have prompted to an increased (though still slow) adoption of these vehicles by fleets. Battery prices and vehicle prices have also come down, and for some specific applications, cost parity with diesel can be reached. There are still some limitations and challenges associated with BEVs such as the weight of the battery required for longer ranges, the time to charge those batteries and accessibility to charging facilities. But as mentioned, there are ongoing efforts to mitigate those, thus BEVs are thought to be the most mature zero-emission vehicle technologies. Further supporting their adoption is that BEVs tend to be eligible for the highest government incentives for clean vehicles. There are ongoing efforts by the private sector to develop the required charging infrastructure, and it has already started in the SJV. There have been some demonstration projects in the state, and in 2022 several companies will demonstrate Class 8 BEV trailers in California. In addition, utilities throughout the nation have committed over \$1 billion to support EV infrastructure by 2025. Today, BEVs can be cost-competitive with the help of financial incentives; although, electrification is currently difficult for larger vehicles and/or longer-range trips.

In general, there are various alternative fuel vehicles currently available or in development. These zero and near-zero emission vehicles come with the general benefit of emissions reductions, and some also boast improved driver and mechanic satisfaction, including cleaner working environments and reduced operational and maintenance costs. However, today, they also come with major hindrances in terms of capital costs, fueling and charging station availability and fueling/charging times, fuel costs, range, load limits, and difficulty finding support/mechanics. The next section discusses some analyses conducted related to the cost of ownership for some of these technologies, including various financial incentives and support offered for alternative fuel trucks in the SJV. Additionally, there are programs such as Low Carbon

Fuel Standards (LCFS) that provide benefits for cleaner fuels improving the financial feasibility of some of these technologies. Moreover, many of these challenges exist today, but industry parties are actively working to reduce and or eliminate these challenges, meaning these issues are current and not all are expected to be long-term issues.

Task 5 – Small Scale Pilot Demonstration and Data Collection & Task 6 – Data Analysis

4 Small Scale Data Collection Pilot

This section outlines the methods and results of the small-scale data collection pilot. A discussion of comparable and relevant studies is outlined in Appendix C. Even more, the policies that motivate or influence work in freight and sustainability are discussed in Appendix D.

4.1 Motivation and Overview

The small-scale data collection was initially intended to collect data from zero and near-zero emission freight technologies traveling in the SJV to validate assumptions in the estimation of costs (e.g., total cost of ownership – TCO) used for the comparative assessment of the various technologies. In doing so, the data collection was a two-pronged approach: i) collecting data over the I-5 corridor in a control environment setting; and ii) collecting data for regular transport operations inside the fleets. Combined, they would help evaluate the feasibility of these vehicles in the region and to generate or update TCO estimates for these alternative fuel vehicles.

The small-scale data collection pilot entailed the organization of a data collection plan, recruitment of participating companies or service providers, identification of technologies to evaluate, acquiring data collection equipment, and obtaining approvals and permits.

The initial plan was to conduct the data collection in the second half of 2020 or the first half of 2021, but there were significant challenges in various fronts. First, and especially important, in March 2020 the state and the nation implemented mitigation measures for the COVID-19 pandemic. The pandemic and the measures limited the ability of the research team to conduct in-person activities, and agencies and other partners were also affected by the pandemic. This significantly delayed the pilot (additional details in the next subsections). Furthermore, the pandemic also affected the development and production of ZEVs, and their entry to market. Second, and following the last point, at the time of this study, there were no ZEV technologies in operation in SJV fleets to operate long-distance travel, and there was no supporting infrastructure (e.g., charging). And third, it was challenging to garner fleet interest and participation. Some of these issues are further discussed next.

4.2 Key Limitations

4.2.1 Impact of COVID-19

By mid-April, 2021 conditions had improved (compared with 2020), with most of the population in California qualifying to receive the Covid vaccine; however, there were still uncertainties about the impacts of the pandemic towards the development of the small-scale pilot. Throughout this time, the team identified measures to mitigate potential hazards to the team, agency officials, pilot participants, and any other individual involved with the small data collection effort. But the pandemic exhibit waves with tightened and relaxed measures. Even in September and October, when the team conducted the pilot, conditions were fluid considering that at the end of December and early January 2022, the Omicron variant was infecting individuals in record numbers. Certainly, the pandemic negatively affected the progress of the project, especially the data collection effort. Nevertheless, this was not the only issue.

4.2.2 Availability of ZEV Technologies from OEMs for Data Collection

In 2019, when the proposal was finalized, there were expectations from OEMs that by 2021 there would be more availability of fuel, infrastructure, and ZEV vehicle technologies in the market, and especially in

and around the central valley. The research team was in constant communications with OEMs and contacts in the private sector to get additional information on when to expect new vehicle technologies. At the writing of this report, there are still uncertainties about the delivery of ZEVs to fleets, although they have started in small numbers. Just a handful of Class 8 BEV trucks are operating in the state, and mostly for short haul. These vehicles have a mid-range of about 150-250 miles, which may limit the full set of applications of vocations, especially those in the long-haul markets. There were also additional concerns about specific vehicle technologies (i.e., battery electric and fuel cell) over the availability of charging/fueling infrastructure during the pilot, especially considering that a 150-200-mile distance between the preliminary end points of the corridor (selected for the pilot) are at the limit of pilot vehicles. Lacking recharging or refueling infrastructure at these locations was a major concern.

Additionally, there were other vehicles technologies (e.g., Low-NOx) that may also enter the market, fostered by the Low-NOx Omnibus Rule considered by the Air Resources Board. However, there are no offerings in the market that comply with these requirements. Overall, the only vehicles technologies that could fit the pilot requirements included diesel and natural gas trucks. With respect to other technologies, the California Air Resources Board's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP)² website provides information about expected commercial offerings and includes information on battery capacity and other characteristics. Considering that it takes approximately 2kWh to traverse a mile, the expected battery electric trucks have a potential range between 110 to 235 miles in the medium-term, and up 370 miles in the longer term.

4.3 Scheduling and Coordinating the Pilot

As mentioned, the study employed two types of data collection, 1) data from travel along the I-5 corridor between the Wesley and Buttonwillow truck stop (as seen in Figure 18), and 2) data from regular truck operations.

² <https://californiahvip.org/>

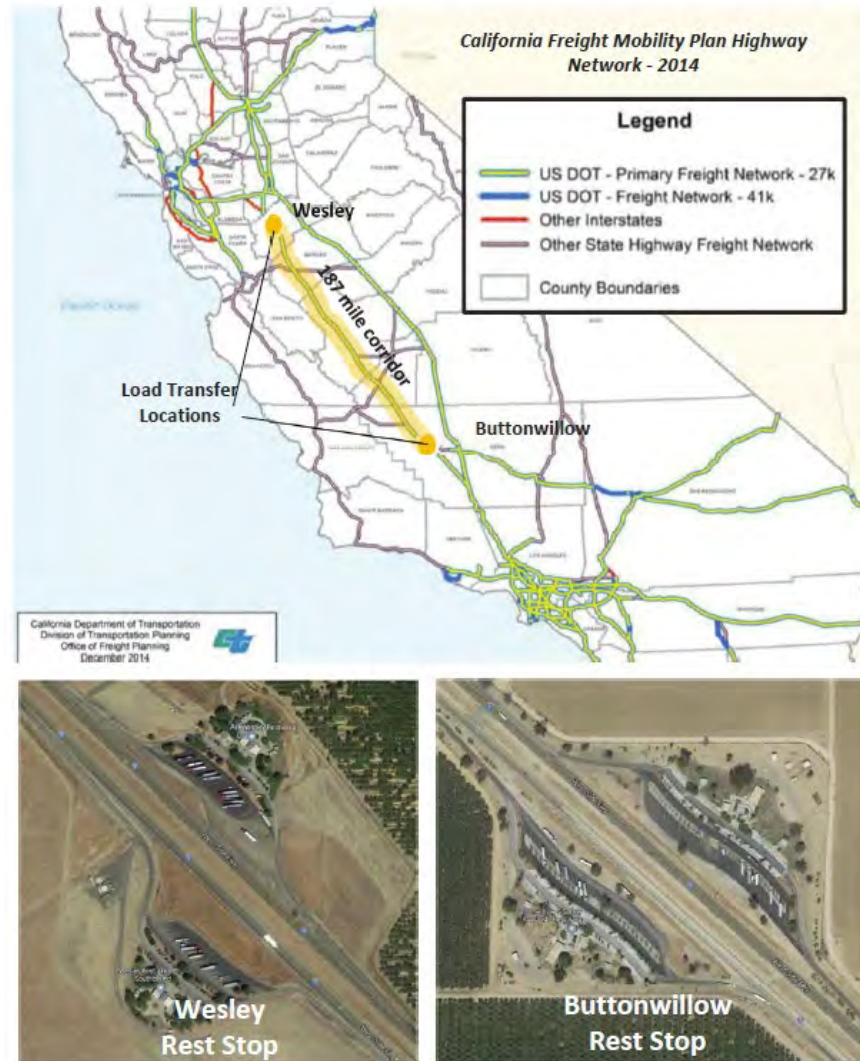


Figure 18. Small scale pilot study conceptual diagram

The corridor between the two rest stops has about 185 miles for a total of 370 miles with an additional 20 miles to reach their depots. Which is still at the limit of the longer-term BEV offering. Using secondary data, the team analyzed existing corridor conditions to identify alternatives to conduct the data collection considering the potential vehicle technology limitations of pre-market vehicle options. Specifically, the team considered Firebaugh and Huron rest stops as potential replacements for Wesley. In addition to providing a shorter distance between locations, the team also considered the availability of other services at or near these locations. Moreover, a preliminary analysis of the data, indicated that there is reduced variability in travel conditions therefore, the data could be collected for shorter distances.

Additionally, the team continued conversations with OEMs, and private operators to identify, which types of vehicles technologies were currently in pilot phases, which could be suitable for the data collection as part of this project. One OEM already indicated that their demonstration vehicles would not be available for data collection, but the team continued conversations to have the vehicles displayed during the planned showcase event.

During the first half of 2021 (including the summer months) the team also engaged with potential partners for the data collection such as Cox Petroleum Transport, B&N Trucking, Convoy Solutions LLC, Western

Milling, and WattEV Inc. The team developed advertisement material to entice fleet to participate and disseminated through multiple channels (see Figure 19 for an example). Unfortunately, there was limited interest in participating in the pilot. Specifically, the team was interested in:

- Class 8 trucks
- Zero & near-zero emission vehicle technologies
- Clean fuels (e.g., Low NOx fuels/engines, ultra clean diesel)



Figure 19. Example of section of advertisement material.

In coordination with Kern COG, the team scheduled the pilot for the end of September (29th) and the early October. Cox Petroleum and Western Milling agreed to participate in the data collection event, and the team coordinated with the companies for the number of trucks involved. Additionally, they would provide operational data as the trucks would be instrumented. The team also worked with B&N Trucking (and Dynamic Renewable Solutions) to participate in the pilot and help coordinate the planned showcase event (which was scheduled for November 2021, and then postponed to February 2022, but finally cancelled). Unfortunately, COVID affected B&N trucking, a small family-owned company, and they could not continue helping.

At the same time, the team contracted with OneStopGPS company to secure the OBDII data loggers to instrument the vehicles and arranged with the participating fleets for shipping of the devices.

The small-scale data collection pilot started on September 29th, with two trucks from Cox Petroleum (see Figure 20). That day, Western Milling had to cancel because of logistics issues (driver availability), but instrumented the vehicles, and the team collected information from regular operations (Figure 21). For the next 4 days, various trucks from Cox Petroleum (using regular and clean diesel) travelled between the Wesley and Buttonwillow as follows:



Figure 20. Cox Petroleum trucks on September 29th at the Buttonwillow Rest Stop



Figure 21. Stock picture of Western Milling trucks at their renewable CNG fueling station

- First day: 2 Volvo VNR trucks with total weight ~ 74,000 pounds), trip between Buttonwillow and Westley rest areas and back, using regular diesel and renewable clean diesel
- Second day: 2 Volvo VNR trucks (total weight ~ 74,000 pounds), trip between Buttonwillow and Westley rest areas and back, using regular diesel and renewable clean diesel.
- Third day: 2 Volvo VNR trucks (empty haul), trip between Buttonwillow and Westley rest areas and back, using regular diesel and renewable clean diesel.
- Fourth day: 2 MACK trucks (full load), trip between Buttonwillow and Westley rest areas and

back, using regular diesel and renewable clean diesel.

As mentioned, the four trucks remained instrumented, and the team collected data on their regular operations. Although one of the trucks went offline shortly after. Western Milling instrumented three vehicles, and the team collected operational data.

Overall, despite the various and persistent efforts, it was not possible to collect data from zero emission vehicles (e.g., battery electric, fuel cell). These vehicles are not commercially available, and those used in other pilots and demonstration projects were not able to be secured for participation in the small-scale pilot. Additionally, those demonstration vehicles do not have the capabilities (e.g., range) to complete the travel between the selected Buttonwillow and Westley rest areas, and there is no available public charging infrastructure over the corridor for the vehicles to complete the travel over trip segments. It also became evident to the team that efforts to improve the efficiency of the freight system, (especially for the testing and development of vehicle technologies consistent with the Valley's needs) require the level of funding provided by agencies and the private sector to other jurisdictions. One clear example is the Volvo Lights Project in inland Southern California, which received an award of \$44.8 million from the Air Resources Board for a total budget of \$90 million and was able to evaluate several technologies.

4.4 Data Collection & Empirical Results

The team collected vehicle telematics data including trip distances (miles), idling (minutes), fuel level, GPS tracks, and other information. Figure 22 shows an example of travel for a Class 8 diesel truck with depot in Bakersfield, CA. With the data, the team estimated aggregate and disaggregate statistics at the vehicle delivery trip and tour level.

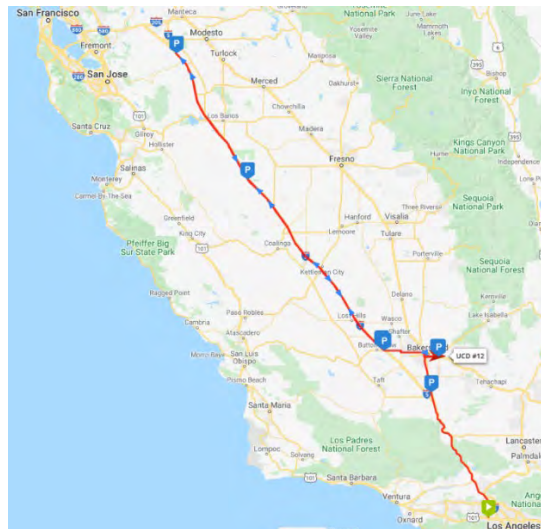


Figure 22. Class 8 diesel trucks tours from Bakersfield, CA

For example, Figure 23 shows examples of eight travel days for a truck. Specifically, the figure shows the various tours (departing and returning to the depot) performed by the vehicle (tour #1 corresponds to the travel depicted in Figure 22) from the vehicle in Figure 1. Figure 23 displays instantaneous speed (blue), instantaneous fuel consumptions (orange), and altitude (green) for a sample of tours. It is important to mention that the first four tours correspond to travel within the I-5 pilot study section, while the rest of the tours are for regular operations. There are different driving cycles performed by these vehicles. Considering that the data was collected during the pandemic, there may be changes in the flow patterns along the corridor and the network. However, the companies indicated that the conditions were like pre-

pandemic, and as identified, over the corridor the vehicles were moving at speed limits. Thus, the team believes that the impact on the data is minimal.

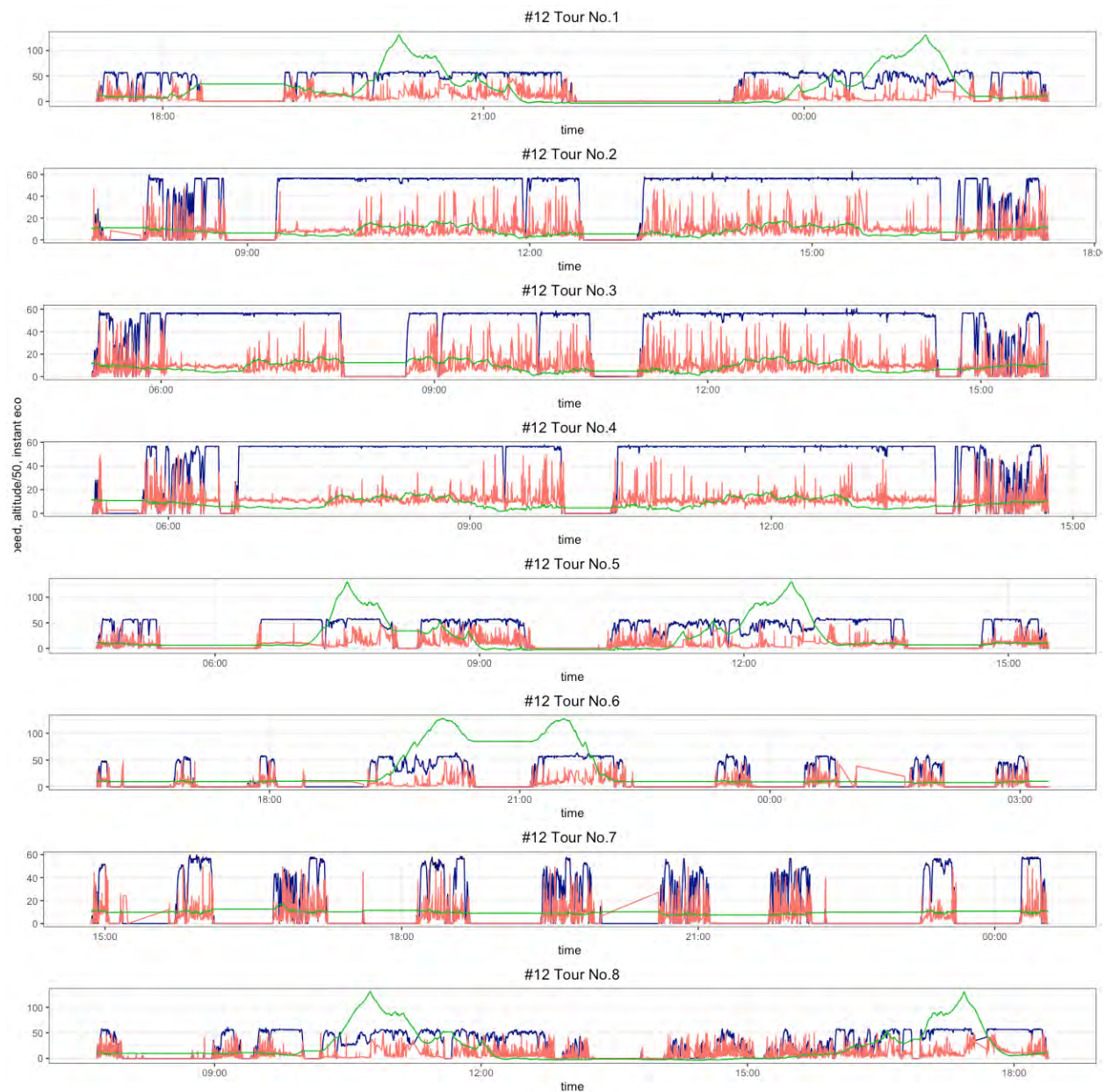


Figure 23. Tour examples from diesel truck showing speed (blue), fuel consumption or instant eco (orange) and altitude (green)

Figure 24 shows an example of the driving cycle for a vehicle on September 29th making the north and southbound trajectory along the study area.

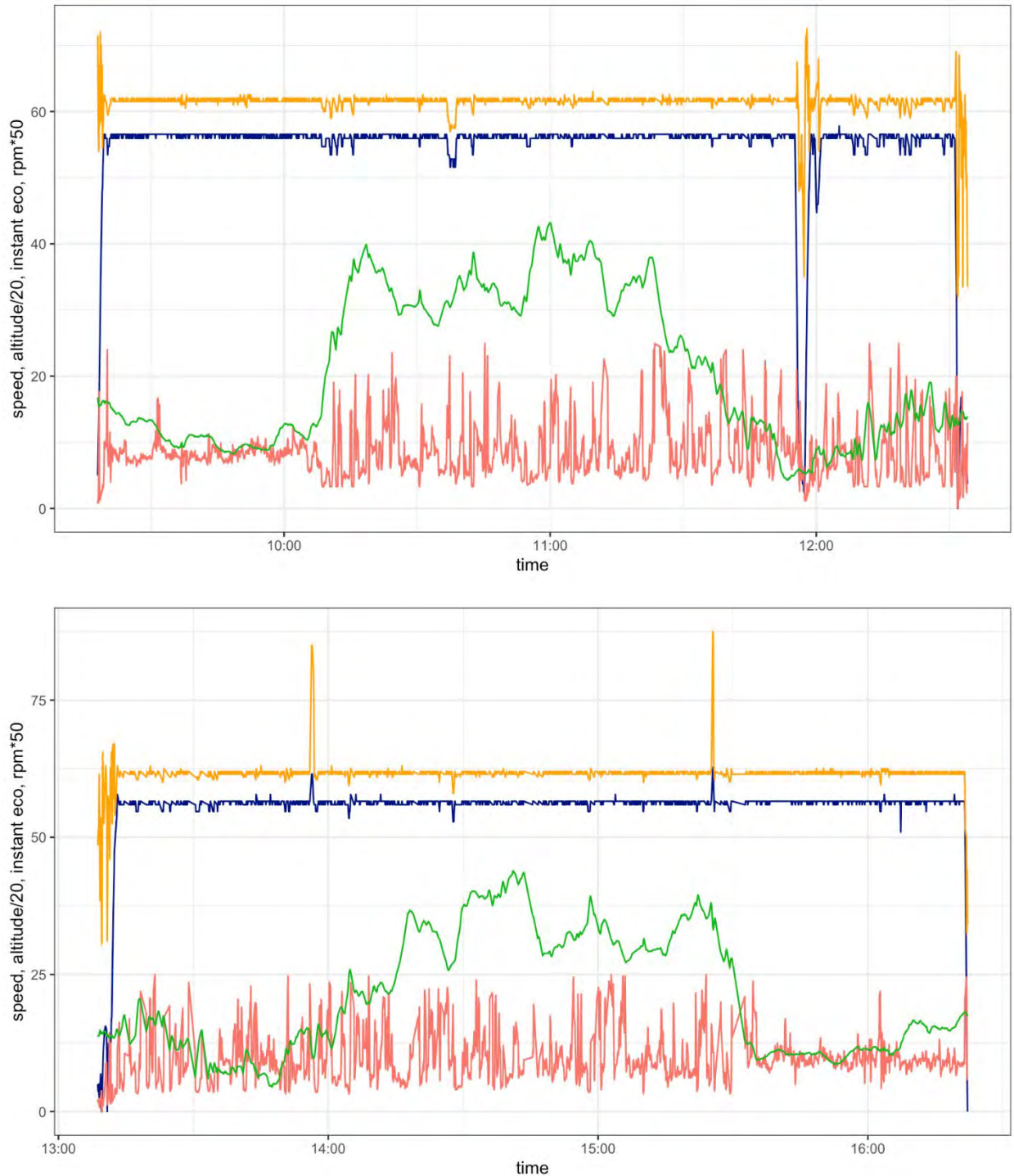


Figure 24. Example of driving cycle for vehicle traveling north from Buttonwillow to Wesley (top) and traveling south from Wesley to Buttonwillow (bottom). Speed in blue, instantaneous fuel economy in orange, altitude in green, and engine revolutions per minute in orange

Additionally, Figure 25 shows the change in fuel percentage as the vehicle travel north- and southbound the I-5 corridor on September 29th and October 1st. As shown, the trucks have approximately 50% of the tank, which indicates that they could travel more than 700 miles with a full tank. It is important to mention

that although the trucks could have been able to operate over the corridor with higher frequency in a day, the hours of service and operations would have limited them. For some trips, the fuel percentage keeps constant for some time before starting to decrease. For the southbound trips on 9-29 and 10-1, the fuel percentage dropped from 99.6% to 44% and from 84% to 58.8% respectively.

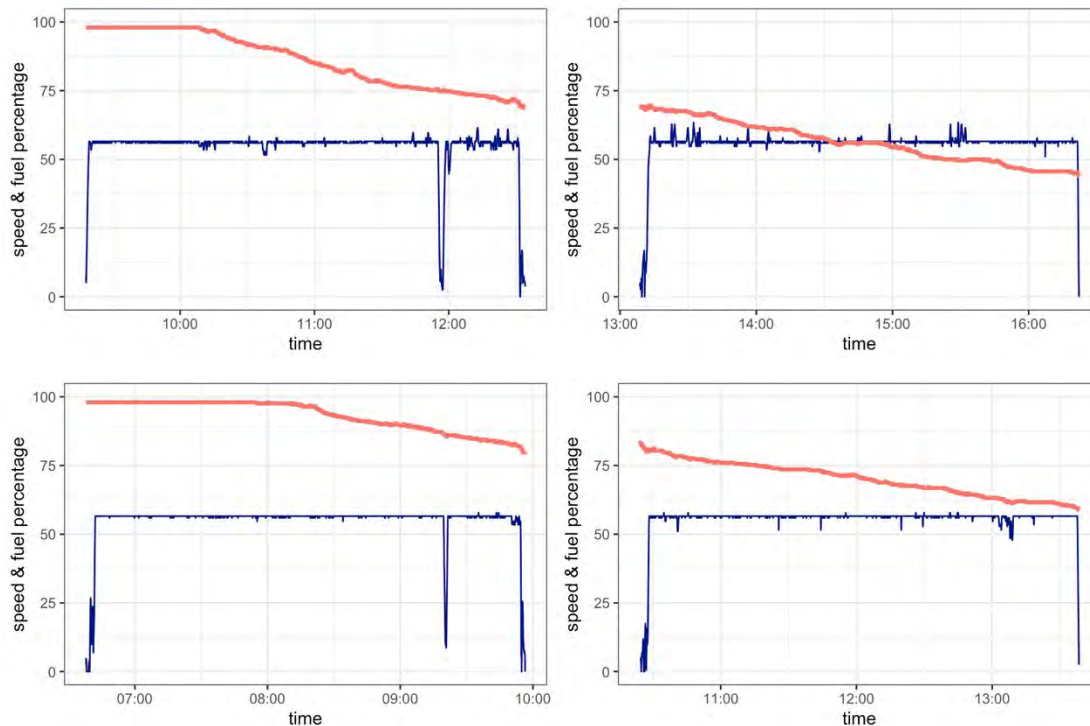


Figure 25. Speed (blue) and fuel tank level (red) for travel northbound (left) and southbound (right) for truck on September 29th (top) and October 1st (bottom)

4.4.1 Estimating Emissions

The data collection did not include Portable Emissions Measurement Sampling (PEMS), therefore the team used emission rates from the Emission FACtor (EMFAC) model from the Air Resources Board, considering the region and the vehicles used, as well as the speed collected by the data loggers. Figure 26 shows examples of different emission rates for various pollutants as a function of vehicle speed. Moreover, considering the forecasted fleet and activity, EMFAC also provides future emissions rates until 2050. As shown, it is expected that vehicles will be significantly cleaner for the species shown in Figure 27.

Using these emission rates, the team estimated the emissions for the tours traveled by the vehicles in the pilot. Figure 28 compares a trip northbound I5 between Buttonwillow and Wesley and a trip from Taft to Los Angeles. The green curve represents NO_x emissions as rate*2000 in grams/sec, while the red curve is the cumulative NO_x emissions in grams. For the trip between Taft and LA, the speed is less constant, thus the emissions also vary, and the cumulative emission is less linear. But overall, it is still close to linear.

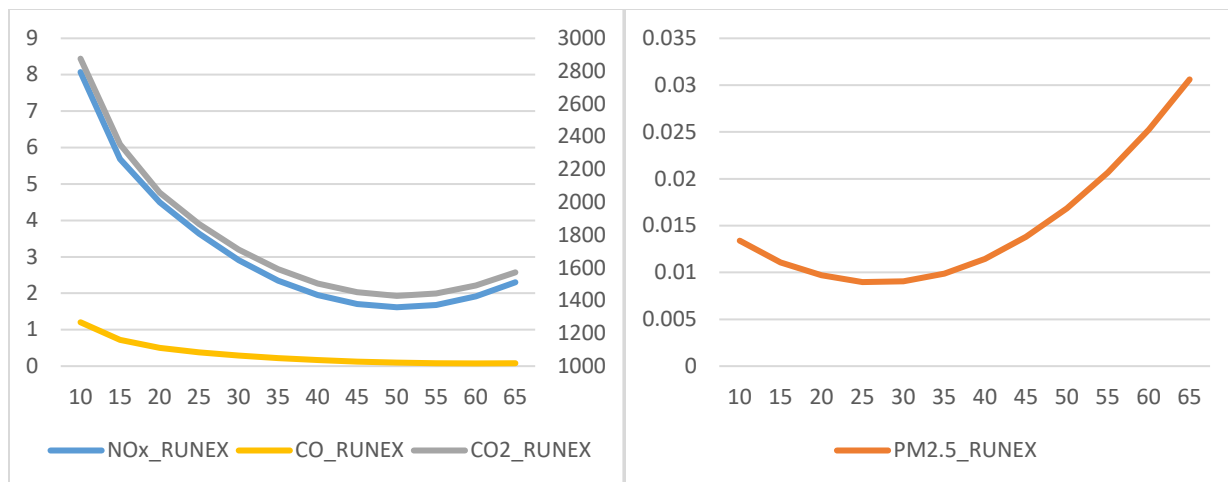


Figure 26. Emission rates in grams/mile

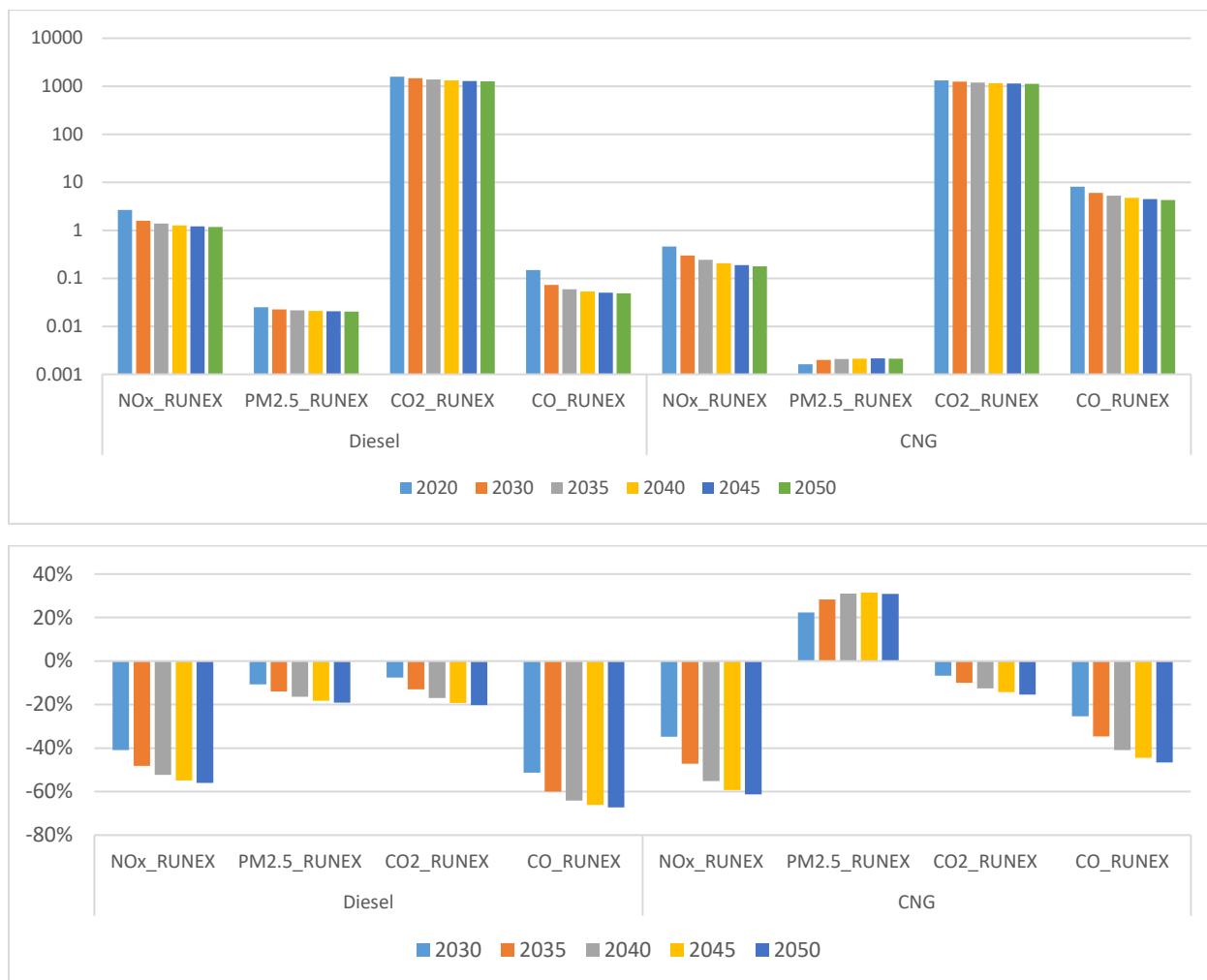


Figure 27. Emission rates in grams/mile (top) and Changes in emission rates in percentages (bottom) for diesel and CNG trucks

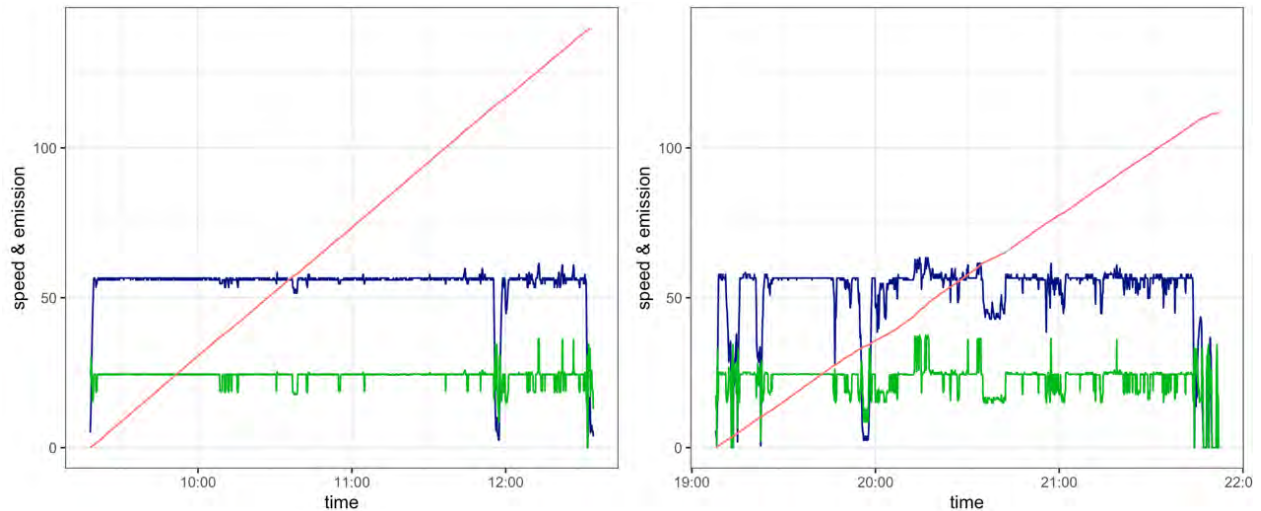


Figure 28. Real time emission rate in 2000 grams per second (green) and cumulative emissions (red) for NO_x for the northbound leg of tour on September 29th (left) and a trip between Taft and Los Angeles (right)

Similarly, Figure 29 shows the estimated aggregate emissions by day, exemplifying the level of emissions generated by trucks.

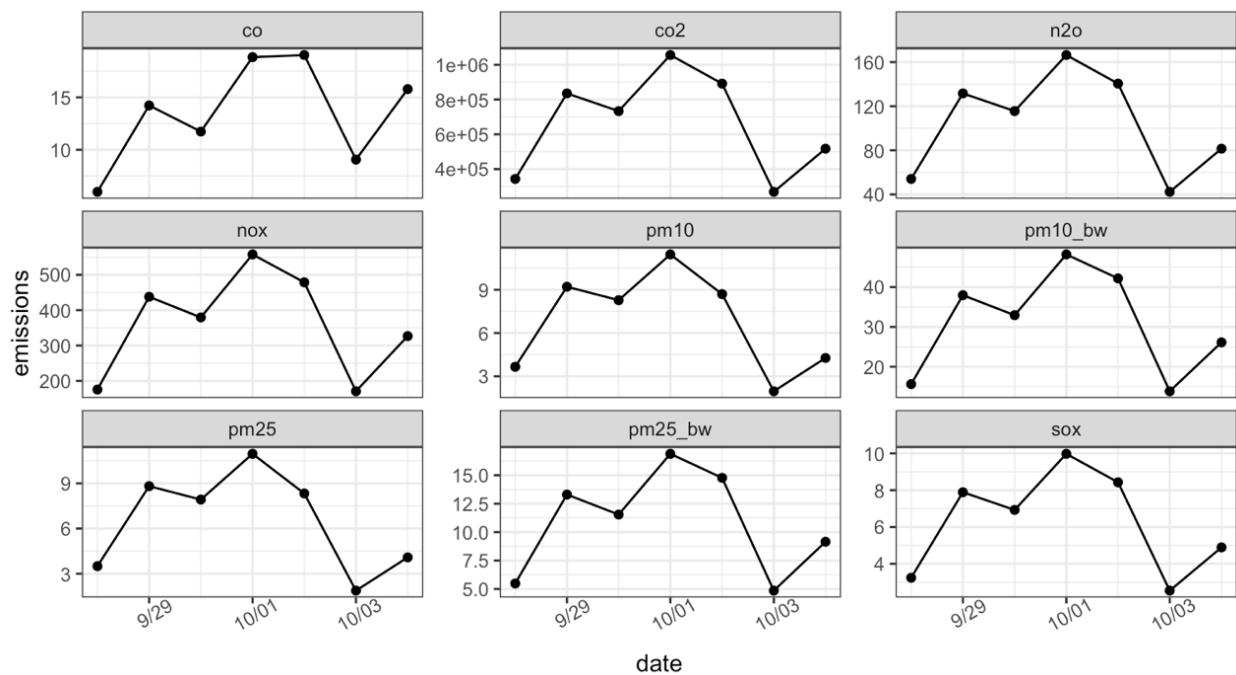


Figure 29. Emissions in grams per day for different species

4.4.2 Summary Statistics

Despite having a small sample, the research team estimated summary statistics of the tours performed by the vehicles. At least for the Cox Petroleum trucks, there are just slight differences between the travel under regular operations, and the travel in the controlled environment or selected stretch of I-5. As shown in Figure 30, the average distance of the tours is around 430 miles, making between 4 and 5 stops, in the

controlled environment. In regular operations this distance is about 25% shorter. For example, the trucks start from their depot in Bakersfield, travel to the weight station (stop 1), then travel northbound on I5 until they reach Wesley Rest Area (stop 2), head back to Buttonwillow (stop 3), travel to fuel (stop 4), and back to depot. Or some variant of these tour. The other statistics that shows some significant differences is the average speed, with travel along the regular operations roads. This difference can be more than 20%. Interestingly, the estimated emissions are, for the most part, larger when conducting regular operations, though this could be expected as we follow the emission patterns from Figure 26.

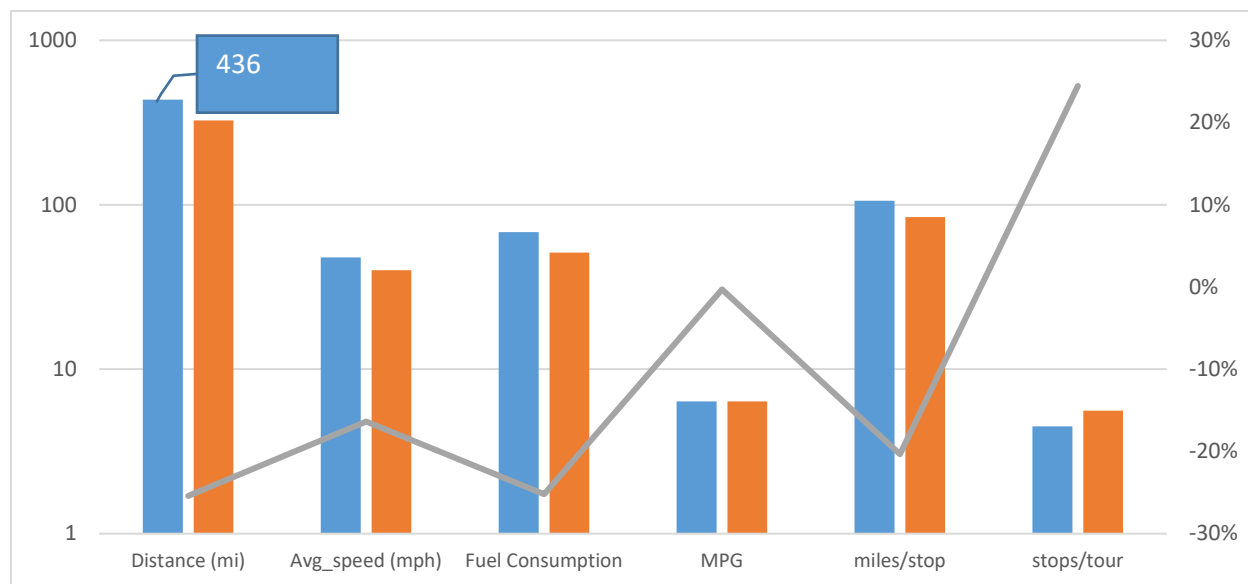


Figure 30. Tour statistics for the sample & comparison (grey) between controlled segment (blue) and other segments (orange)

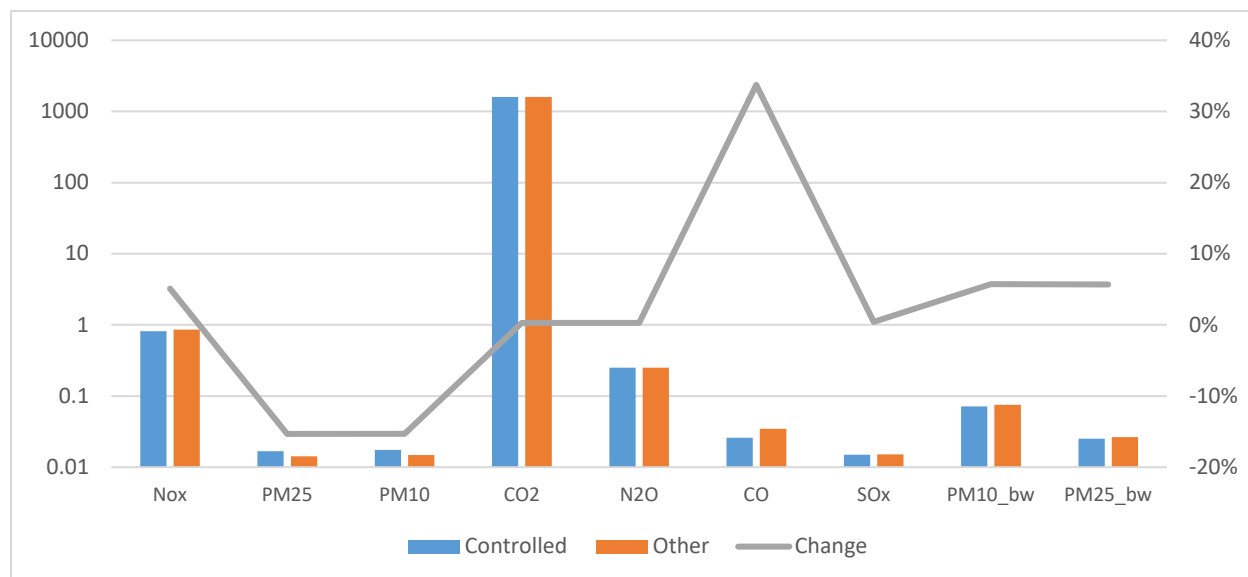


Figure 31. Comparison of emissions between controlled (blue) and other areas (orange) & percent difference (grey)

4.5 Cost of Ownership

As mentioned before, one of the main objectives of the data collection was to gather some insights about the truck activity for different vehicle technologies to validate assumptions for the estimation of costs, especially the TCO. The team conducted a comprehensive review of other empirical results from a few studies, to collect adequate data to conduct the analyses. Preliminary results from [39] show that zero-emission vehicles will be competitive with diesel vehicles in the 150-mile range, especially city delivery. Long haul trucks are in a competitive disadvantage in terms of cost in the 300 and 500-mile range. Short-haul truck costs are close to the diesel cost, but still higher by 2030, in terms of purchase cost.

BEVs have equal or better cost advantage over diesel and FCEVs around 2030 according to TCO estimates during a 5-year period with a discount rate of 2%. On the other hand, during a 15-year period, the TCO is still lower for BEVs than diesel fueled vehicles. Additionally, FCEVs are slightly preferred for long haul trucks with 300-500-mile range. Note that the 5-year period is more common on trucks than 15-year period.

The payback period is lower for BEVs in 2030 than in 2025, for most of the vehicle categories, the payback period in 2030 is reduced in more than half the time of payback for vehicles purchased in 2025. In 2030, the maximum payback period is for long haul 500-mile trucks and is less than 5 years, while in 2025 it is more than 10 years. In the case of FCEV trucks, the expected behavior is not as optimistic as BEVs, for instance long-haul trucks are not expected to achieve their payback.

The authors conducted TCO analyses using the Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) [40]. This is a complex, Excel based model which can estimate various environmental and economic aspects of vehicle purchases for various vehicle types, broadly categorized as light duty and heavy duty. For this analysis, the team primarily focused on single unit short and long-haul vehicles, and combination short and long-haul vehicles. The tool also produces detailed payback period estimates, TCO, idle reductions, and footprint (energy use and emissions). For the purposes of this study, the team primarily focused on the TCOs with and without externalities.

The tool also comes with all relevant data populated so that the user needs to select the location and vehicle type. However, this study is limited in scope to the previously stated vehicle types in the state of California, and this narrow scope allowed updating various inputs accordingly. Specifically, fuel prices were updated by time and geography (most representing California values), and purchase prices were updated to reflect market prices of vehicles matching fuel type and size and including purchase incentives offered to fleets operating in the SJV. The updated fuel prices are provided in Table 17, updated depreciation percentages by vehicle age are in Table 18, while incentives and purchase prices are presented in Table 19 and Table 20, respectively. Note that these are general estimates and that the incentives each have different eligibility, rules, and requirements. Finally, other key AFLEET inputs are provided in Table 21.

These and other inputs are used to generate TCO estimates for each vehicle size and fuel type. These AFLEET TCO estimates are presented in Figure 32 and Figure 33. It is worth noting that the interpretation of depreciation can be flexible in terms of TCO. For example, the default setting of AFLEET is that depreciation is a cost to the owner, thus it increases TCO. However, CARB acknowledges that depreciation is a loss of value, although this loss of value is claimed as an expense and lead to tax deductions. The values in Table 18 represent the Internal Revenue Service depreciation schedules. Given that this loss of value is recovered through tax deductions, CARB refers to depreciation as a cost-savings. Thus, special considerations should be made when interpreting how depreciation contributes to the TCO.

Table 17. Fuel costs used to update AFLEET

Fuel	Fuel Unit	Public Station (\$/fuel unit)	Fuel Price Source
Gasoline	gasoline gallon	4.57	[41]
Diesel	diesel gallon	4.83	[41]
Electricity	kWh	0.18	[42]
G.H2	GGE	8.50*	[39]
B20	B20 gallon	4.13	[43]
B100	B100 gallon	4.62	[43]
RD20	RD20 gallon	4.15	[43]
RD100	RD100 gallon		
E85	E85 gallon	3.39	[44]
Propane	LPG gallon	3.425	[45] [46]
CNG	CNG GGE	2.63	[47]
LNG	DGE	3.19	[43]

* Hydrogen fuel costs are currently high and are anticipated to decrease significantly with time. This estimate represents the projected cost per GGE (where 1 kg = 1 GGE for hydrogen [48]) for 2025.

Table 18. Depreciation values used to update AFLEET [49]

Age	0	1	2	3	4	5	6+
Truck	20.00%	32.00%	19.20%	11.52%	11.52%	5.76%	0%
Tractor	33.33%	44.45%	14.81%	7.41%	0%	0%	0%

Table 19. Maximum incentives available in California [50] [51]

	Single Unit Short Haul (\$/veh)	Single Unit Long Haul (\$/veh)	Combination Short or Long Haul (\$/veh)
Gasoline	-	-	-
Diesel	-	-	-
Electricity	60,000	120,000	200,000
G.H2	35,000	45,000	120,000
Diesel HEV	-	-	80,000
Diesel HHV	-	-	-
B20	20,000	30,000	50,000
B100	20,000	30,000	50,000
RD20	20,000	30,000	50,000
RD100	20,000	30,000	50,000
E85	-	-	-
Propane	40,000	50,000	-
CNG	40,000	50,000	100,000
LNG	40,000	50,000	100,000

Table 20. AFLEET vehicle purchase prices [40]

	Single Unit Short Haul	Single Unit Long Haul	Combination Short Haul	Combination Long Haul
	(\$/veh)	(\$/veh)	(\$/veh)	(\$/veh)
Gasoline	-	-	-	-
Diesel	70,000	75,000	130,000	150,000
Electricity	150,000	185,000	242,000*	509,000*
G.H2	-	-	201,000*	255,000*
Diesel HEV	85,000	90,000	145,000	165,000
Diesel HHV	-	-	-	-
B20	70,000	75,000	130,000	150,000
B100	70,000	75,000	130,000	150,000
RD20	70,000	75,000	130,000	150,000
RD100	70,000	75,000	130,000	150,000
E85	-	-	-	-
Propane	78,000	89,000	-	-
CNG	110,000	115,000	170,000	215,000
LNG	100,000	105,000	160,000	200,000

* Updated from the base AFLEET inputs, from [39]

Table 21. Other AFLEET key inputs [40]

	Single Unit Short Haul		Single Unit Long Haul		Combination Short Haul		Combination Long Haul	
	Fuel Econ	M & R	Fuel Econ	M & R	Fuel Econ	M & R	Fuel Econ	M & R
	MPDGE	\$/mi	MPDGE	\$/mi	MPDGE	\$/mi	MPDGE	\$/mi
Gasoline	6.03	0.13	5.35	0.13	5.21	0.00	5.65	0.00
Diesel	7.24	0.20	6.42	0.20	6.25	0.18	6.78	0.18
Electricity	25.42	0.13	22.55	0.16	10.25	0.15	9.91	0.15
G.H2	15.86	0.13	14.07	0.16	6.50	0.15	6.92	0.15
Diesel HEV	8.76	0.15	7.77	0.18	6.50	0.16	6.92	0.16
Diesel HHV	8.76	0.15	7.77	0.18	6.25	0.16	6.78	0.16
B20	7.24	0.20	6.42	0.20	6.25	0.18	6.78	0.18
B100	7.24	0.20	6.42	0.20	6.25	0.18	6.78	0.18
RD20	7.24	0.20	6.42	0.20	6.25	0.18	6.78	0.18
RD100	7.24	0.20	6.42	0.20	6.25	0.18	6.78	0.18
E85	6.03	0.13	5.35	0.13	5.21	0.00	5.65	0.00
Propane	6.03	0.13	5.35	0.13	5.21	0.00	5.65	0.00
CNG	6.15	0.21	5.78	0.22	5.63	0.19	6.10	0.19
LNG	6.15	0.21	5.78	0.22	5.63	0.19	6.10	0.19
Assumed Annual VMT	16,500		23,000		65,000		170,000	

Note: M & R = maintenance and repair

In this case, depreciation is included in Figure 32 and Figure 33 for the sake of being comprehensive, although it can be interpreted as savings (similarly to purchase incentives represented by the dotted lines) or as costs (in which case it would replace purchase price, as to not count purchase prices and owner costs twice). For these figures, the externalities include air pollutants, greenhouse gas emissions, and petroleum use.

Figure 32 shows that single unit diesel trucks have the highest relative TCO, followed by LPG, then biodiesel and renewable diesel trucks. Even more, the lowest TCO is seen for BEVs for short and long haul, then natural gas vehicles (CNG and LNG) for long haul trucks. The fuel costs (light green color) tend to be the largest cost contributing to the TCO for all vehicle types aside from BEVs.

Focusing more specifically on the externalities, a key component when considering sustainability, BEVs have the lowest externality cost, followed by renewable diesel (RD100) and biodiesel (B100) for both short and long-haul trucks. Unsurprisingly, diesel trucks and diesel HEVs have the highest externality costs. It is also worth noting that natural gas vehicles have approximately mid-level externality costs for both short and long-haul trucks. Meaning, they lead to a clear reduction in externalities relative to diesel trucks, but they do not accomplish the same level of reduced externalities as BEVs.

In comparison, Figure 33 reflects the considerably high cost of hydrogen fuel. The cost of hydrogen fuel is expected to decrease dramatically over time. The currently estimated high-cost leads to a comparatively high TCO for gaseous hydrogen FCEVs (G.H2.FCV).

Looking at other fuel types, similarly to single-unit trucks, diesel combination trucks have the highest TCO and the highest externality cost, followed by diesel HEVs. For short haul combination trucks, BEVs, CNG and LNG vehicles have comparatively low TCOs while for long haul trucks, the TCO for BEV is slightly higher. However, the CNG and LNG vehicle TCO remains low.

All these results evidence that for smaller vehicles (single unit) and/or shorter trips, BEVs are a desirable option with relatively low TCO. However, for combination long haul trucks, the TCO of BEVs increases, and yields the natural gas vehicles as the front-runners with the lowest comparative TCO. Even though the natural gas vehicles have relatively low TCOs for other vehicle types as well, the higher externality costs make the alternative (i.e., BEVs) more attractive. In the long-haul truck scenario for both single unit and combination trucks, the higher cost of externalities is balanced by the significantly improved TCO and complemented by the fact that the externalities remain much smaller compared to the base case scenario, which is to continue operations using diesel fuel vehicles.

The results in this section are compiled into a sample pamphlet for fleets to understand the details of switching to ZEVs and ZEV fleets. This pamphlet is included in Appendix E – Summary Pamphlet for Fleets.

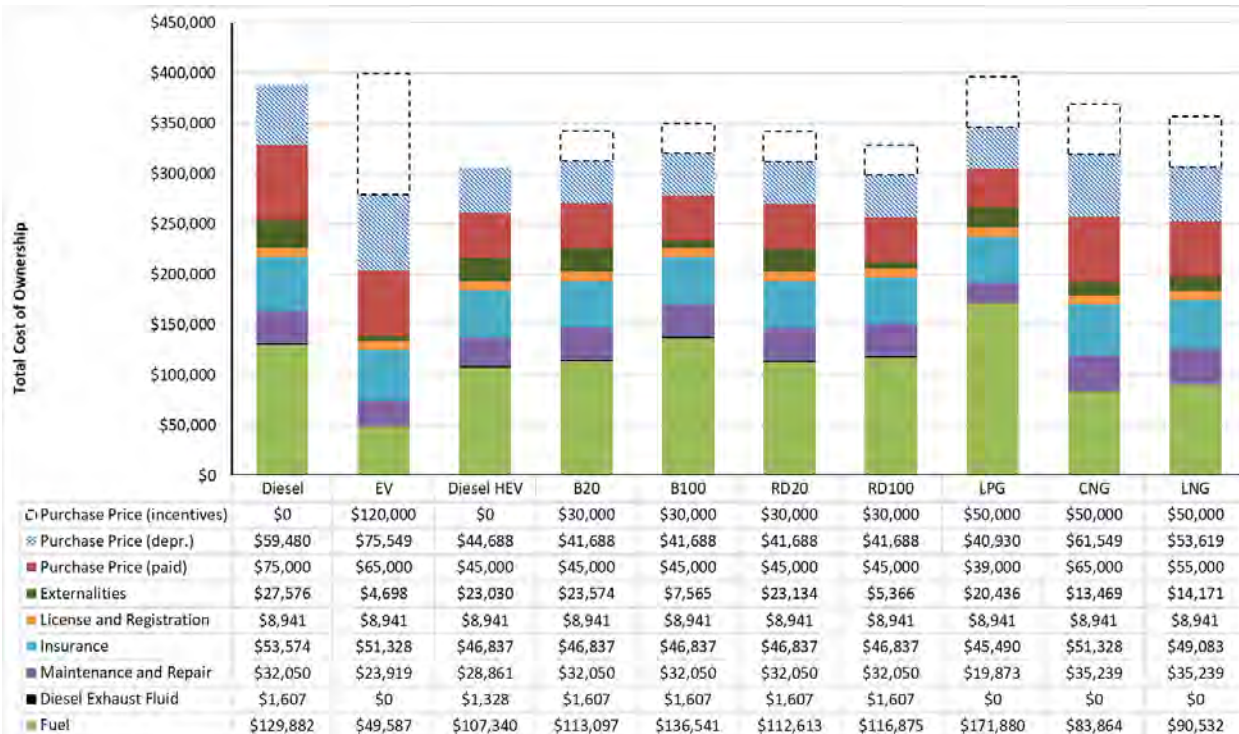
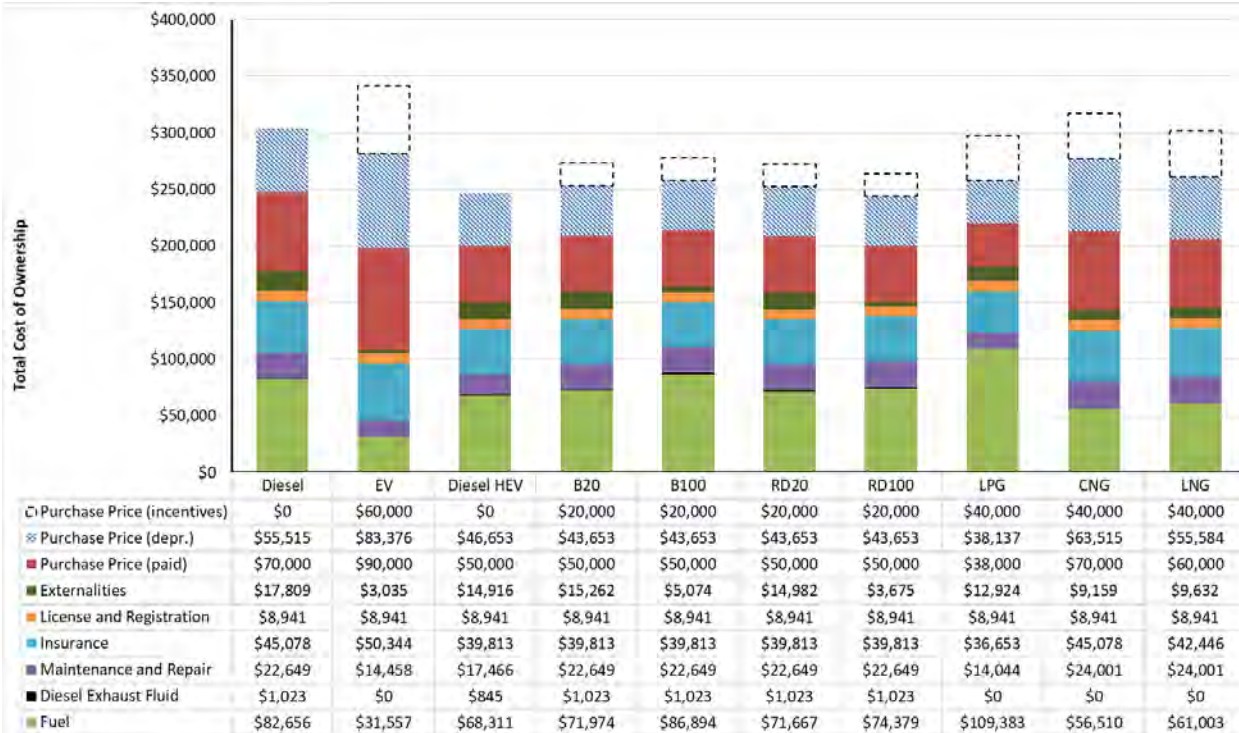


Figure 32. TCO in dollars for single-unit short-haul (top) and long-haul trucks (bottom) [40]

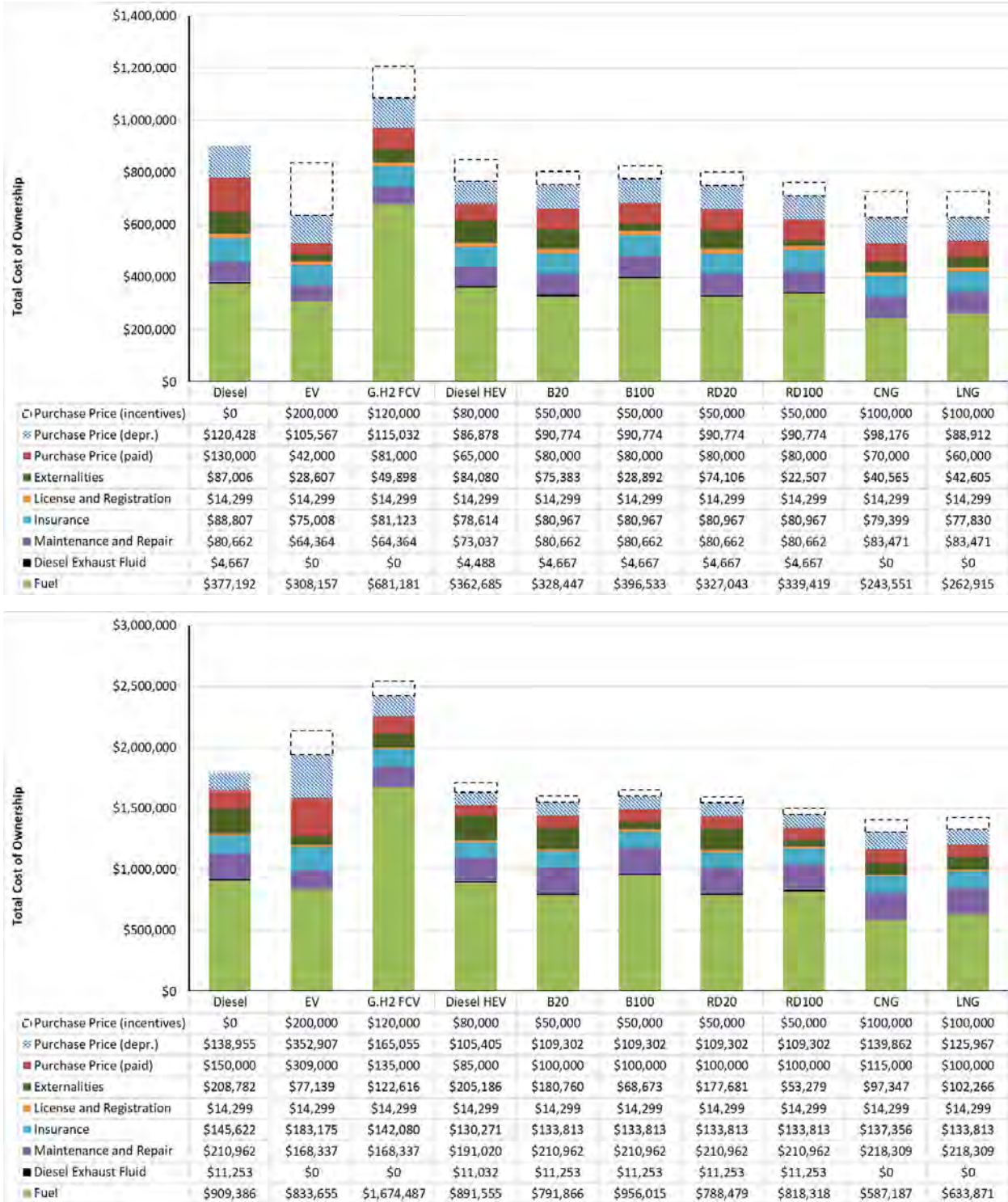


Figure 33. TCO in dollars for combination short-haul (top) and long-haul trucks (bottom) [40]

4.6 Key Findings from Pilot

Overall, considering the preliminary analysis of the data about the freight patterns in the SJV, together with the process to design and implement the small-scale pilot, and the TCO estimates, the team have the following set of key findings:

- Other than Diesel and CNG, there are no other available technologies today to serve fleets in the SJV
- Battery electric trucks can be cost competitive with diesel with the help of the purchase incentives and other incentives to reduce costs (e.g., \$/kWh)
- There are some commodity/vocations that can take advantage of soon to be available trucks (shorter tour distances, low payloads)
- Yard truck technologies (zero emission and automated) seem to be ready, though incentives are needed
- Incentives and funding for research and purchases is necessary
- Need for heavy investments in charging and fueling infrastructure
- There is a need for smart and clean corridors
 - The private sector is interested in the deployment of charging infrastructure
 - Working with utility companies and other service providers
 - Permitting and accessibility
- Urgent need for low-cost access to financing or new business models for ZEVs
 - Small fleets, owner operators

Task 4 – Development of Pilot Study Concept & Task 7 – Updates to Pilot Study Concept

5 Long-Term Pilot

5.1 Introduction

In addition to the small-scale pilot study, this study also outlines some components of a large-scale pilot, developed to address the primary problems identified in the region. This section describes long-term pilot study components that can be pieced together according to desired budgetary constraints, most urgent problems to be addressed, or various other factors. The components are separated into color-coded tables (Table 22 – Table 36) which include the description, relevant details, the regional problems addressed via this solution, cost category and who the costs are borne to, the advantages and disadvantages. These long-term components fall into four major categories: **technology**, **infrastructure**, **funding and incentives**, and **communication**.

Technology components include changes or additions to vehicles, infrastructure, or introducing technology-based information sharing in the region. **Infrastructure** changes include updating and expanding current infrastructure. There are also several intangible potential solutions which suggest specific, **funding and incentive** programs as well as methods for better **communication** to truck drivers in the region. The solutions are more generally categorized in Figure 34 below, and each of these solutions are described in detail in the following section, color-coded by the *primary* category they fall into.

5.2 Proposed Solutions

The previously described proposed solutions serve as potential components of a proposed pilot study (discussed in the following section). Even though each section serves as an independent component, there is a certain level of interdependency between most of the solutions. This is true in the sense that some solutions will be more effective if paired with others, and the solutions should be used to create a system with these components, rather than imposing these solutions into the existing system. These interdependencies are visually represented in Figure 35, and elaborated in this section.

In Figure 35, the solutions discussed in this chapter are grouped by category (as defined in Figure 34), with arrows linking proposed solutions that are interconnected.

- **Connected Technology/Infrastructure & Automation:** The implementation of connected technology/infrastructure and automation will improve the efficiency of dynamic truck parking. It will also allow smoother traffic flow through signal coordination, in which signals and vehicles are communicating. Connected and autonomous vehicles also have the potential to improve the efficiency and performance of intermodal transfer facilities. This might bolster the attractiveness of such facilities and make them staples of freight movement in the SJV. Finally, the use of such technologies comes with added costs which can be significantly higher depending on the level of connectedness/automation. With this, if the use of these technologies is desired within the SJV, it is important to provide incentives and funding that will allow many truckers and trucking companies to acquire these technologies.

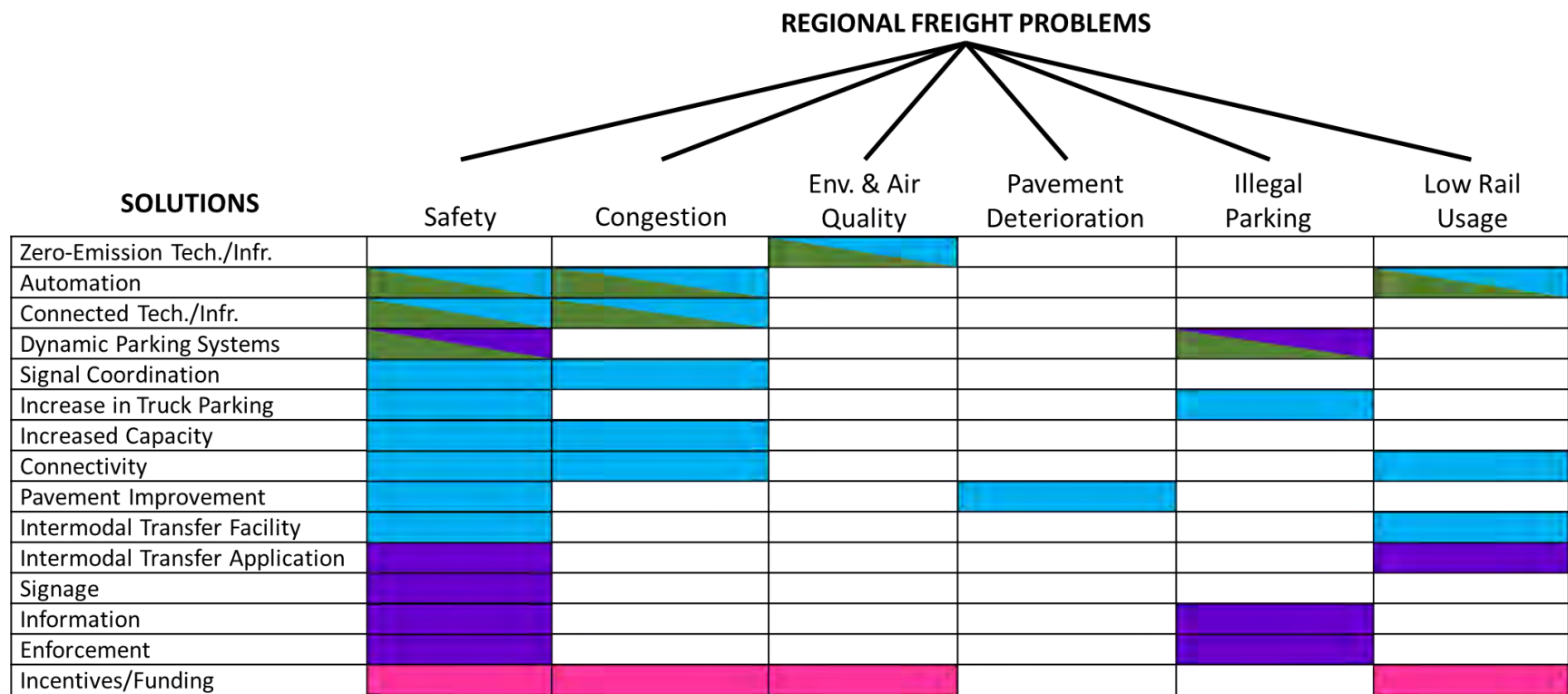


Figure 34. Categorization of solutions by regional freight problem

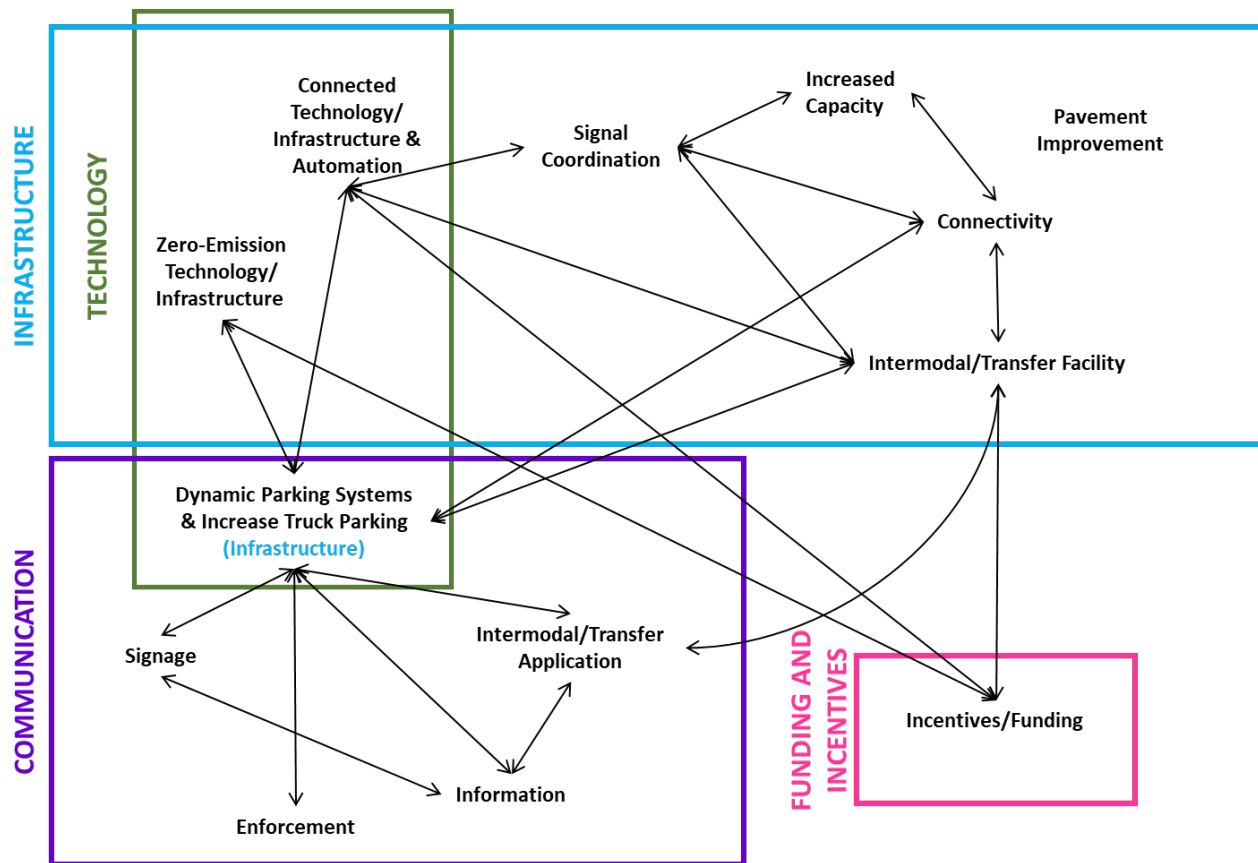


Figure 35. Interdependencies of proposed solutions

- Zero-Emission Technology/Infrastructure:** The promotion of zero-emission technology and infrastructure will similarly be accompanied by increased costs to purchasers, and thus requires incentives and funding opportunities. It will also require some consideration in terms of truck parking or truck stops, some accommodations should also be considered which allow for fueling or charging vehicles with various fuel types.
- Dynamic Parking Systems & Increase Truck Parking:** Improving parking conditions in the SJV will benefit from improved connectivity (easier access to parking) and has the potential to improve the experience of truckers and the efficiency of goods flow through the region. This is in the sense that truck parking and truck stops for ZEVs can improve the number of vehicles in the region that *can* adopt these technologies. Dynamic parking systems can be integrated with connected (or autonomous) vehicles, improving the driver experience and safety (as they do not have to find parking on such short notice or park in non-designated spaces). Improved parking will also need to be a consideration in planning intermodal transfer facilities and intermodal reservations. This is because intermodal facilities need to be on active rail lines, and the location may not have accessible parking infrastructure and services nearby. Finally, parking can be problematic for truckers in the region, given that truckers do not always understand where they can park, or the implications of their parking location (if not in a designated area). This also relates to enforcement, in that truckers are subjected to many rules and restrictions, and do not always have time or information to find their preferred parking. Thus, enforcement of truck parking should be adjusted to help truckers find safe parking nearby, versus ticketing or otherwise penalizing them

for parking in other areas. The improvement of signage and information will hopefully alleviate the penalization of truckers in that they will be able to find more information about where they can park, or where they can check the restrictions relating to them in the region.

- **Signal Coordination:** Signal coordination can be used strategically with increased capacity and connectivity in the region to improve traffic flow, particularly freight traffic flow. Similarly, the intermodal transfer facility will experience a high volume of truck traffic, and thus, signal coordination should be used to move truck platoons smoothly, or in a way that minimizes the impact on local communities. Signal coordination and connected technology/infrastructure can also help each other, so-to-speak, in that communication between vehicles and infrastructure can improve traffic flow, especially in the form of moving truck platoons smoothly through the more congested corridors.
- **Increased Capacity:** In conjunction with signal coordination and connectivity, increased capacity can be used to improve traffic flow in the region and avoid overly congested corridors.
- **Connectivity:** In addition to the previous bullet point for increased capacity, improved connectivity can also increase the access to and therefore usefulness of intermodal transfer facilities.
- **Intermodal Transfer Facility:** In addition to the interdependencies previously discussed, an intermodal transfer facility should also be accompanied by an intermodal application, to ensure that the usefulness of such a facility is maximized. Even more, incentives and funding are required to entice businesses to build and/or participate in intermodal transfers. This type of facility is anticipated to be highly beneficial in reducing the traffic burden and associated externalities related to freight in the region. As the costs can be high, innovative solutions such as creating partnerships, or encouraging private investments so that facility operators may take advantage of incentives or funding may help in initiating an intermodal facility.
- **Incentives/Funding:** Each of the interdependencies related to incentives and funding have been previously discussed. Incentives and funding for private entities will be critical in getting the region and its freight entities to adopt the desired technologies and practices.
- **Intermodal Transfer App:** In addition to the previously mentioned relationships, this mobile application would also play a critical role in sharing information with relevant parties in the region. In the other direction, it is also important to share information with local companies and truckers about the existence and use of this app (and services) in the SJV.
- **Signage, Enforcement, and Information:** Finally, signage, enforcement, and information have been discussed under the truck parking bullet point above. In addition, signage should be used to share information that is immediately necessary (such as parking information), and to share where truckers can obtain more detailed information about the relevant regional operations, services available, and the rules and regulations that apply to them.

Finally, the approximated effort (or planning) to cost tradeoff is presented in Figure 36. As expected, the **communication** solutions are both low cost and low effort. These solutions will require a small amount of labor which will constitute most of the anticipated costs. The **infrastructure** solutions are among the highest effort with variable costs, while the **technology** solutions are comparable, although slightly lower, in effort, with higher costs. The infrastructure solutions will require a substantial amount of planning and budget, given that they entail major changes to existing infrastructure and will lead to years-long efforts and construction. Alternatively, the technology solutions also depend on a substantial planning effort (consider technology availability, design, planning, implementation) and although they are high in cost, they are expected to be comparatively lower than the vast infrastructure changes that are expected.

The placement of **incentives/funding** reflects the anticipated high cost of providing financial support, however, the amount of effort is less clear, given that discretionary funds might be readily available. Alternatively, offering strong incentives and funding programs might also require a substantial fundraising or lobbying effort.

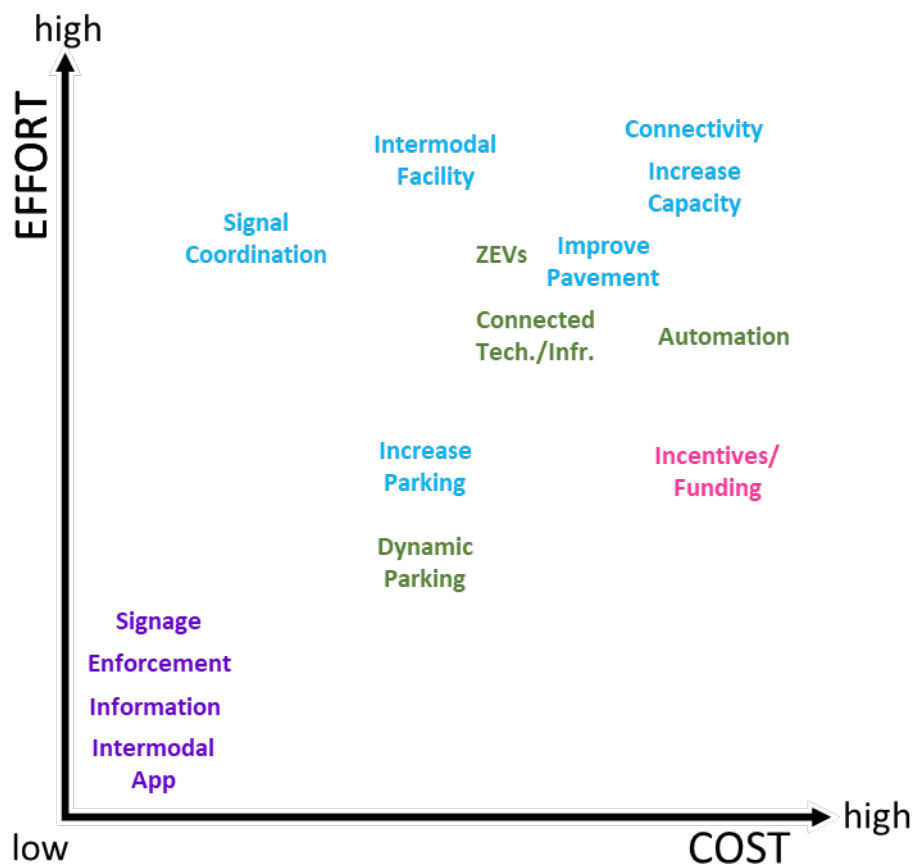


Figure 36. Effort and cost tradeoff of proposed solution components

5.3 Overview of Different Solutions

Each solution is summarized in a table, describing the solution, which problems it addresses (as outlined in Figure 12), the costs and who is expected to take on these costs, and advantages and disadvantages. Importantly, for several of the proposed solutions the estimated costs are *highly* variable and depend on the outcomes of additional analyses (which also have added expenses). Thus, where possible, estimated costs are reported. These estimated costs can then be used as a frame of reference for the other solutions, which are more generally categorized as “low,” “medium,” or “high” cost solutions. Further, these are cost *estimations* based on available information (from several years ago, other states, etc.), and do not necessarily reflect the actual cost, but provide context or magnitude of the anticipated cost.

Table 22. Solution Overview: Zero-Emission Technology & Infrastructure

ZERO-EMISSION TECHNOLOGY & INFRASTRUCTURE	
<p>Description: Zero and near-zero emission vehicles are fueled by more sustainable (zero or near-zero emission) fuels. These fuels are considered alternative fuels (relative to diesel or gasoline) and these vehicles are still emerging within the passenger vehicle and freight market.</p> <p>To establish a baseline to compare the zero and near-zero emission technologies to, especially in terms of cost, it is critical to include diesel-powered engine medium and heavy-duty vehicles. When looking to apply zero and near-zero emission technologies to the freight industry, there are many key considerations. This includes limited availability of the technology, limited economies of scale, long-distance travel requirements, payload mass and volume constraints, and a lack of refueling/recharging stations or infrastructure.</p> <p>In terms of infrastructure, we recommend conducting an inventory analysis of charging/refueling infrastructure in the region to ensure that people traveling north-south and east-west have adequate access to spaced charging/refueling stations. In this context, “adequate” refers to the need for each vehicle to have access to enough fueling stations on this corridor to ensure that the least efficient vehicle or conditions, can still travel in SJV region.</p>	
<p>Details/Elements: Hybrid Electric Vehicles (HEVs), Propane/Liquefied Petroleum Gas (LPG) Vehicles, Hydrogen Fuel-Cell Electric Vehicles (FCEVs), Battery-Electric Vehicles (BEVs), Compressed and Renewable Natural Gas (CNG/RNG) Vehicles</p>	
<p>Problems Addressed: Environmental & Air Quality</p>	
<p>Cost: <i>Middle - High</i> Variable across alternatives & time (see Appendix F)</p>	
<p>Who takes on the cost: Private companies, fleet owners</p>	
<p style="text-align: center;">TCO by Vehicle Fuel Type</p> <p style="text-align: center;"><i>Note: Derived from data provided in Appendix F</i></p>	
<p>Advantages:</p> <ul style="list-style-type: none"> • Clean technology (reduced emissions) • Cleaner work environments • Steadily improving (for longer travel distances and reduced costs) 	<p>Disadvantages:</p> <ul style="list-style-type: none"> • Requires fueling and charging infrastructure on site and throughout the state • Some technologies are still emerging and developing • Not all alternative fuel trucks can travel long distances

Table 23. Solution Overview: Automation

AUTOMATION	
<p>Description: Vehicle automation is seen when the vehicle controls some or all driving functions without driver input. Vehicle automation is closely related to connected vehicles and infrastructure, in which case they will help each other's effectiveness and improve the likelihood of experiencing the described advantages.</p>	
<p>Details: Automation can include partially autonomous capabilities, such as adaptive cruise control or lane correction, or fully autonomous capabilities in which the vehicle performs all driving functions on its own. Importantly, each of these scenarios (and the many scenarios in between) have different impacts on safety, efficiency, the economy, planning, and others.</p> <p>In addition to be closely related to connected vehicles and infrastructure, automation can also have major impacts on multimodal freight movements and the efficiency of intermodal facilities. This includes autonomous vehicles undertaking major operations <i>at</i> the intermodal facilities, as well as autonomous vehicles transferring goods <i>to</i> the intermodal facilities in the last mile.</p>	
<p>Problems Addressed: Safety, Congestion, Low Rail Usage</p>	
<p>Cost: High over \$250,000 [52], additional \$30,000 - \$100,000 compared to non-automated trucks [53]</p>	
<p><i>Comparison of driverless (DL) and manually driven (MD) truck costs per 1,000 ton-kilometers [54]</i></p> <p>Note: This figure represents what the author's defined as the "base scenario," in which case DL trucks have level 4 automation and no driver's cabin.</p>	
<p>Who takes on the cost: Private companies</p>	
<p>Advantages:</p> <ul style="list-style-type: none"> • Have the potential to drastically improve safety and efficiency • Generally, improves mobility, might eliminate barriers to employment in the freight/trucking industry • Alleviate driver shortages • Decreased operating costs 	<p>Disadvantages:</p> <ul style="list-style-type: none"> • Extensive and costly updates or retrofits or replacements required • Higher benefits realized with more connected vehicles and technology • Social, shipper, or industry pushback • Potential negative impacts on employment opportunities/work conditions

Table 24. Solution Overview: Connected Technology & Infrastructure

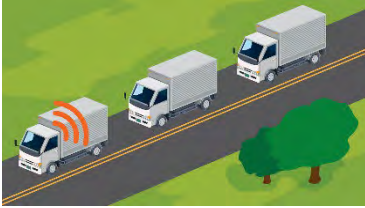
CONNECTED TECHNOLOGY & INFRASTRUCTURE	
<p>Description: Connected technologies, such as those that allow V2I and V2V communication should be implemented throughout the corridor. Specifically, signals should be equipped with the technology to accommodate trucks and truck platoons. Trucks should be equipped with the proper technology to communicate with one another (for platooning), and traffic signals. Platooning trucks reduce the overall wind resistance experienced by all the trucks in the platoon. This results in fuel savings, safety improvements, increased capacity, and reductions in emissions. As an added benefit, platooning improves the technological integration of vehicles on this corridor and can be a segue to connectedness (V2X) on the corridor. Even more, as the connectedness of the corridor improves (including vehicles, infrastructure, and devices), the corridor's readiness for autonomous technology will also improve.</p>	
 <p>https://www.eng.auburn.edu/news/2018/09/truck-platooning-study.html</p>	
<p>Details: To create a technological environment that can sustain platooning, sensors, localization services (i.e., GPS), V2V communication, software, hardware, and human interface are required. The operational impact of platooning is seen when full (or near full) market penetration is achieved. Longer platoons are possible and 45 to 60% of drag can be reduced, however, the platoon may block or pause freeway ramp traffic, which could result in increased congestion, emissions, and energy consumption.</p> <p>To create a technological environment that can sustain platooning, sensors, localization services (i.e., GPS), V2V communication, software, hardware, and human interface are required.</p> <p>The payback on investment period for cooperative adaptive cruise control (required for platooning) is estimated to be approximately 10-18 months. This is estimated from surveys across freight operators. Beyond the cost of the technology required to implement platooning capabilities, there are also costs associated with equipment acquisition, driver training, logistics and coordination, testing, and insurance.</p>	
<p>Problems Addressed: Safety, Congestion</p>	
<p>Cost: High</p> <p><u>Vehicle (2020)</u> [55]: Approximately \$449-\$1,029 per vehicle (depends on the quantities, equipment and installation needed, etc.)</p> <p><u>Infrastructure (2017)</u> [56]: \$3,000-\$40,000 to upgrade the state back office, private operator, or traffic management center; \$7,450 per site to upgrade roadside equipment (\$3,000 for each roadside unit); 2-5% of the hardware and labor costs are needed for recurring maintenance; \$1-\$6 (average \$3.14) per vehicle for the security credentials management system</p>	
<p>Who takes on the cost: Public agencies and private companies</p>	
<p>Advantages:</p> <ul style="list-style-type: none"> • Have the potential to drastically improve safety and efficiency 	<p>Disadvantages:</p> <ul style="list-style-type: none"> • Extensive and costly updates or retrofits required • Higher benefits realized with more connected vehicles and technology

Table 25. Solution Overview: Dynamic Parking Systems

DYNAMIC PARKING SYSTEMS	
<p>Description: Truck parking is cited as a major problem on this corridor. Research at the American Transportation Research Institute (ATRI) shows that the average truck driver is spending 56 minutes per day looking for parking, which Dan Murray (the ATRI vice president of research) relates to an average of \$4,600 in lost compensation [57]. Given this, the topic of parking is approached from several angles, including the addition of dynamic parking systems, increased parking spots, and better communication with drivers about available parking. Through these, the number of parking spots and access to parking spots will be improved.</p> <p>Many drivers on this corridor have trouble finding designated truck parking spots or sites within a reasonable range of their desired location. There should be a precise and dynamic virtual system available to allow drivers to reserve a parking spot, continuously monitor parking availability and associated costs, and have the capability to provide routing information to get to a site with available parking. This is important for reducing drivers circling parking lots looking for spots, traveling to multiple stops to find an empty spot, and illegal parking. This includes the use of sensors and monitoring systems, and online reservations/up-to-date information available to drivers.</p> <p>These authors also recommend that Kern COG implement an improved strategy to communicate parking availability. There are already several apps on the market for truckers to communicate with one another or to determine what their stop will look like (including fuel prices, available parking, shower access and availability). However, each app provides different information for different companies from various sources. Even more, some apps are more widely used and better rated than others. In terms of parking apps, this group recommends that Kern COG forms a relationship with one of the apps, including advertising this app as the regionally selected app and ensuring that truck stops and fuel stations update their information in this app as frequently as possible. See Table 40 in Appendix B.</p>	
<p>Details: Some truck stops do not have showers, reservation systems, or do not operate 24 hours per day. These are crucial factors for truckers, especially considering that drivers have hours of service limitations and may work during hours that are considered atypical.</p>	
<p>Problems Addressed: Safety, Illegal Truck Parking</p>	
<p>Cost: <i>Middle</i></p> <p>Parking spaces: see “Increase Truck Parking” cost</p> <p>Parking detection/sensors: highly variable depending on the preferred configuration (overhead or in-pavement sensors for each space, entrance and exit vehicle counters)</p> <p>Examples of implementations are provided in:</p> <p>https://static.tti.tamu.edu/tti.tamu.edu/documents/0-5002-1.pdf</p> <p>https://www.saratoga-springs.org/DocumentCenter/View/7186/Team-7-Street-Parking-FullReport#:~:text=These%20cups%20are%20installed%20in,only%20sense%20one%20parking%20spot</p> <p>https://www.itskrs.its.dot.gov/node/209110</p> <p>App [58]: \$100,000 - \$500,000 for a new app, but has the potential to be significantly less to partner with an existing app.</p>	
<p>Who takes on the cost: Private companies and public agencies</p>	
<p>Advantages:</p> <ul style="list-style-type: none"> • Improve driver experience in the region • Address illegal truck parking, and thus safety, in the region 	<p>Disadvantages:</p> <ul style="list-style-type: none"> • Additional measures required to be inclusive of drivers uncomfortable with technology

Table 26. Solution Overview: Signal Coordination

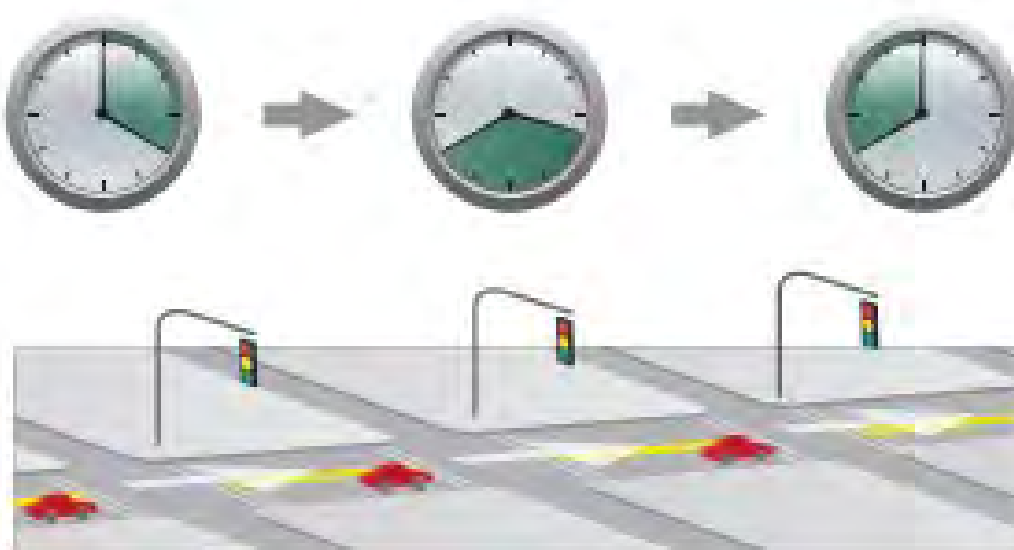
SIGNAL COORDINATION	
<p>Description: Traffic signal coordination is a strategy for moving platoons of vehicles through a corridor. Specifically, the traffic signal green times are coordinated to allow a platoon of vehicles to move through the corridor mostly uninterrupted.</p>  <p>https://udot.utah.gov/connect/public/signal-education/</p>	
<p>Details: High traffic urban truck routes should be appropriately coordinated to allow truck platoons to move quickly through the corridor. These corridors should be selected based on local traffic patterns and need (i.e., not in regions that operate efficiently in their current state). Traffic signal coordination will require a public agency planning effort. First, some areas might already have signal coordination, and thus an evaluation of this coordination is worthwhile to understand if the coordination is beneficial (in terms of congestion and emissions) and if it can/should be updated. Second, the corridors that will most benefit from signal coordination should be selected. Again, these corridors should have a priority on signal coordination that moves trucks through the area efficiently. Finally, the signal retiming will require some analysis of other signal cycles and other coordinated corridors in the network. This planning aspect of signal coordination can be non-negligible in congested or high-volume networks.</p>	
<p>Problems Addressed: Safety, Congestion</p>	
<p>Cost: <i>Low</i> \$1,500 - \$3,700 per intersection to retime signals [59, 60, 61, 62] and an average of 26-person hours [61]</p>	
<p>Who takes on the cost: Public agencies</p>	
<p>Advantages:</p> <ul style="list-style-type: none"> • Easy to implement • Improved truck efficiency on corridor • Improve safety on the corridor 	<p>Disadvantages:</p> <ul style="list-style-type: none"> • Extensive traffic analysis required to avoid traffic delay consequences elsewhere in the local network

Table 27. Solution Overview: Increase Truck Parking

INCREASE TRUCK PARKING	
<p>Description: The authors recommend increasing the number of parking spots in the region. This could be through incentives for private truck stops, increasing capacity at existing truck stops, or permitting truck parking at locations that are currently used by truckers illegally.</p>	
	
<p>Details: There are parking and rest area issues in the region. For example, Table 13 shows that the I-5 corridor has a deficit of sixty-one truck parking spots and SR-99 is deficient by over 400 spots.</p> <p>It is also important to address that where some illegal parking (example below) locations are not burdensome to community members or other drivers, some are. In these cases, it might be beneficial to provide signage and alternative options in the region for truckers to park and rest, or to otherwise improve the circumstances for truck drivers and residents.</p>	
	
<p>https://www.silive.com/news/2022/02/rampant-illegal-parking-of-tractor-trailers-on-exit-ramp-a-serious-concern-for-staten-island-motorists.html</p>	
Problems Addressed: Safety, Illegal Truck Parking	
<p>Cost: <i>Middle</i> \$10,000 per spot per year [63]</p>	
Who takes on the cost: Private companies and/or public agencies	
<p>Advantages:</p> <ul style="list-style-type: none"> • Easy to implement • Alleviate widely cited concern 	<p>Disadvantages:</p> <ul style="list-style-type: none"> • Potential inefficiencies (increase in empty parking spots)

Table 28. Solution Overview: Increased Capacity

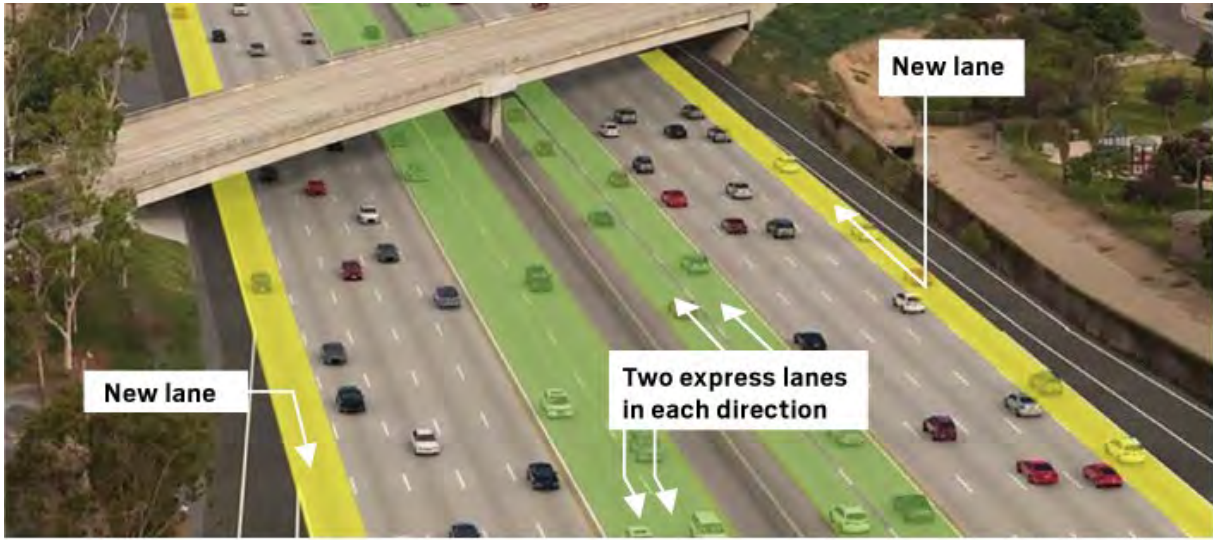
INCREASED CAPACITY	
<p>Description: The authors suggest adding corridor capacity in specified locations. This is generally in the form of lane additions.</p>	
	
<p>Details: Locations should be selected according to a need specified in other truck movement reports based in the SJV. Increasing capacity is also cited as creating induced demand, however, the SJV is cited as lacking east/west connectivity. With this, some of the routes utilized might not have been designed to manage the traffic, and especially the truck traffic, that they currently carry. Given this, adding capacity in selected areas might be warranted and highly beneficial. Even more, Senate Bill (SB) 743 guides planning efforts to use VMT rather than level of service (the historically used metric) which offers some protection against projects that will induce demand [64]. The needs of the region combined with the analytical planning guidance outlined by SB 743 will help balance the corridors which should and should not have capacity added.</p>	
<p>Problems Addressed: Congestion, Safety</p>	
<p>Cost: High <u>Rural (2012) [65] [66]:</u> \$1.4 million - \$10 million per lane-mile* <u>Urban (2012) [65] [66]:</u> \$2 million - \$50 million per lane-mile* * These large ranges are the result of these costs ranging because of the type of road (interstate, major collector, minor arterial, or other principal arterial) and the type of terrain (flat, rolling, mountainous). Refer to [66] for the disaggregated costs per lane-mile.</p>	
<p>Who takes on the cost: Public agencies</p>	
<p>Advantages:</p> <ul style="list-style-type: none"> • Alleviate unsafe and/or inefficient traffic conditions • Allows for strategic planning for how to route vehicles in the region 	<p>Disadvantages:</p> <ul style="list-style-type: none"> • Costly • Potential to induce additional demand

Table 29. Solution Overview: Connectivity


CONNECTIVITY	
<p>Description: Another important and useful change is to improve connectivity to and around intermodal facilities. This aligns with the goal of improving access to active rail lines and increasing the usage of rail. Once locations have been specified for new intermodal facilities, an analysis of the surrounding network will be conducted to evaluate where connectivity issues or opportunities may exist. Specifically, this analysis will focus on moving trucks to and from the intermodal facility, minimizing interaction with non-freight transportation or local communities.</p> <p>Improve the East/West connectivity and connectivity to intermodal facilities (discussed later) in the region. The connectors should be resurfaced and redesigned (new signage and safety implementations) to properly accommodate heavy vehicle traffic including high truck volumes. A travel demand model should be used to identify the East/West connectors that have the highest potential to improve current and future congestion issues and environmental impacts. This will allow project dollars to be spent efficiently and effectively.</p>	
<p>Details: This will allow vehicles, including trucks, to take alternative routes to their destination rather than relying on I-5 or SR 99 to carry them most of the way to their destination. Especially with vehicle volumes projected to increase significantly in the next 20 years, congestion on these two major corridors should be addressed and minimized as soon as possible.</p>	
 <p>Source: SJV Truck Model.</p> <p>Note: Highway network is constrained 2030 model network.</p>	
<p>Problems Addressed: Safety, Congestion, Low Rail Usage</p>	
<p>Cost: High</p> <p>Rural (2012) [65],[66]: \$1.4 million - \$10 million per lane-mile*</p> <p>Urban (2012) [65],[66]: \$2 million - \$50 million per lane-mile*</p> <p>* See "Cost" in Table 28</p>	
<p>Who takes on the cost: Public agencies</p>	
<p>Advantages:</p> <ul style="list-style-type: none"> • Improve safety and congestion in the region • Connect truck corridors to rail services and/or intermodal facilities 	<p>Disadvantages:</p> <ul style="list-style-type: none"> • Costly

Table 30. Solution Overview: Pavement Improvement




PAVEMENT IMPROVEMENT	
<p>Description: There are several sites within the geographic scope of this study that report poor pavement conditions. The pavement on each of these segments should be more thoroughly evaluated and subsequently improved via the method deemed most appropriate.</p> <p> https://www.nps.gov/orgs/1548/management-systems.htm https://www.pavemanpro.com/article/identifying_asphalt_pavement_defects/ </p> <div>   </div> <div>  </div> <p> https://www.clarkcountytoday.com/news/city-of-vancouver-boosts-summer-street-pavement-management-program/ </p>	
<p>Details: Specifically, the segment of SR 198 between Kings and Fresno county and SR 165 (an STAA route) have reported significant issues with pavement quality.</p>	
<p>Problems Addressed: Safety, Pavement Deterioration</p>	
<p>Cost: <i>Middle - High</i></p> <p><u>Rural (2012)</u> [66]: \$700,000 - \$2.2 million per lane-mile* to reconstruct an existing lane or \$250,000 - \$550,000 per lane-mile* to resurface an existing lane</p> <p><u>Urban (2012)</u> [66]: \$1.1 million - \$5.6 million per lane-mile* to reconstruct an existing lane or \$250,000 - \$1.1 million per lane-mile* to resurface an existing lane</p> <p>* See "Cost" in Table 28</p>	
<p>Who takes on the cost: Public agencies</p>	
<p>Advantages:</p> <ul style="list-style-type: none"> • Improve safety • Improve driving experience • Prevent worsened pavement conditions 	<p>Disadvantages:</p> <ul style="list-style-type: none"> • Potential costs are highly variable, dependent on pavement analysis

Table 31. Solution Overview: Intermodal Transfer Facility


INTERMODAL TRANSFER FACILITY	
<p>Description: It would be useful to develop an intermodal or transfer facility for mode shifts from trucks to rail. The location should be selected considering distance, customer interest, volume, and cost. It should be located on a portion of rail line that is as close to I-5 and SR 99 as possible to minimize travel distances and times for trucks. It is also important to consider the customer interest in utilizing the intermodal facility to ensure that the selected location is useful to customers interested in using rail. More clearly, it is not useful to locate an intermodal facility in a cluster of businesses who are not interested in or able to utilize rail, this has the potential to make this facility inconvenient or undesirable for those who are interested. The volume of goods is also important to ensure that the facility is operationally more efficient than truck transport. Finally, the cost of the facility and necessary updates to the system will be considered, alongside the cost to users.</p>	
	
<p><small>https://www.dot.ny.gov/portal/page/portal/regional-offices/region10/repository/intermodal/background.html</small></p> <p>Details: To implement the rail intermodal facility several steps are required to understand the local freight climate. This includes, but is not limited to, conducting customer surveys, and generating a list of potential locations. Customer surveys can help establish who is likely to use an intermodal facility, what they would ship, and where they are located. A location list can then be generated based on location of companies likely to use such a facility, vacant property on a rail line, and ease of access for trucks, considering that autonomous trucks might be well-suited for last-mile operations.</p>	
<p>Problems Addressed: Safety, Low Rail Usage</p>	
<p>Cost: <i>Middle - High</i> Approximately \$4 million (for a very small facility) to \$156 million (large facility) [67] (converted to dollars from euros using 2017 average conversion rate, includes total infrastructure, groundbreaking, pavement) An Intermodal Transfer Facility feasibility study in Oregon estimates a cost of \$9 - \$120 per container (2016 dollars), or capital costs excluding land in the \$7 million - \$8 million range + annual operating costs from \$235,000 - \$510,000 <i>for their site</i> [68]</p>	
<p>Who takes on the cost: Private companies</p>	
<p>Advantages:</p> <ul style="list-style-type: none"> • Improve intermodal operations • Improve safety 	<p>Disadvantages:</p> <ul style="list-style-type: none"> • Requires a substantial planning effort and investment

Table 32. Solution Overview: Intermodal Transfer Application

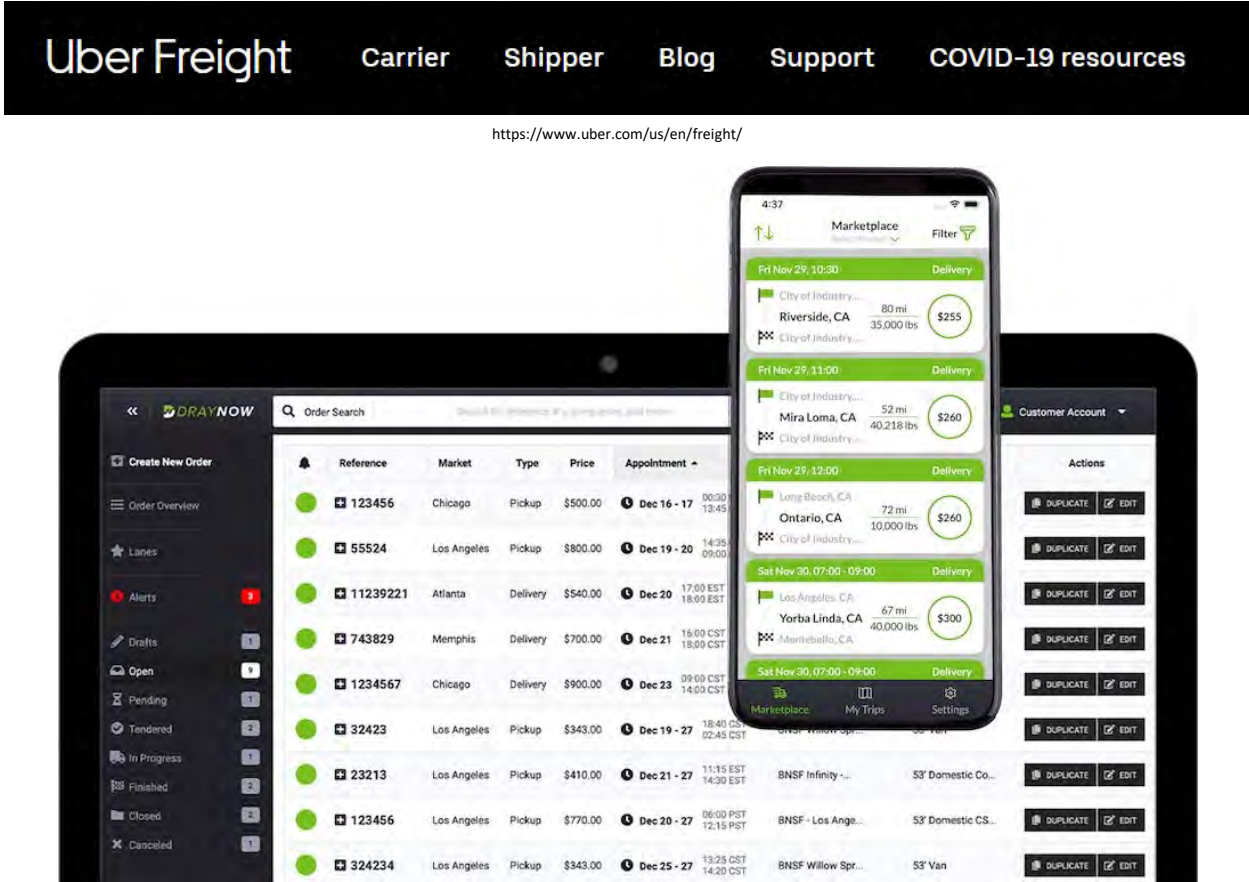
INTERMODAL TRANSFER APPLICATION	
<p>Description: Similarly to the truck parking applications, Kern COG should develop a relationship with an intermodal application or choose a primary app to promote within the region. This technology-based communication service (e.g., mobile app such as Uber Freight or DrayNow) should help rail services connect with customers to implement customer-specific initiatives.</p>	
 <p>https://www.uber.com/us/en/freight/</p> <p>https://draynow.com/</p>	
<p>Details: Shippers can use this platform to reserve cargo space in advance or on short notice while the cargo carrier can share up-to-date information about their available space, shipping times, and shipping costs.</p>	
<p>Problems Addressed: Safety, Low Rail Usage</p>	
<p>Cost: Low \$100,000 - \$500,000 [58] for a new app in 2016, but has the potential to be significantly less to partner with an existing app.</p>	
<p>Who takes on the cost: Private companies</p>	
<p>Advantages:</p> <ul style="list-style-type: none"> • Low cost implementation • Improve safety • Potential to increase rail usage • Improve freight efficiency 	<p>Disadvantages:</p> <p>Additional measures required to be inclusive of shippers or carriers uncomfortable with technology</p>

Table 33. Solution Overview: Signage

SIGNAGE	
Description: This pilot should include a detailed analysis of the current signage on this corridor and recommend improvements.	
Details: These improvements should specifically focus on communicating to and about trucks and their route and parking options.	
https://www.myparkingsign.com/MPS2/no-semi-truck-parking-sign/sku-k2-0769	https://www.truckingtruth.com/trucking_blogs/Article-3869/dont-miss-that-sign
	
	
Problems Addressed: Safety	
Cost: Low \$0.75-\$3.50 per square foot, life cycle (25 years) net present cost of \$485,576-\$1,508,980 for 1,000 signs (\$485.58 - \$1,508.98 each) [69]* * costs are estimated by adding the sign sheeting costs to total installation costs, which include labor, hardware, administrative expenses, and other costs	
Who takes on the cost: Public agencies	
Advantages: <ul style="list-style-type: none"> • Low cost • Potential for high reward • Improve safety 	Disadvantages: <ul style="list-style-type: none"> • May require non-standard signage (more extensive planning effort)

Table 34. Solution Overview: Disseminating Information

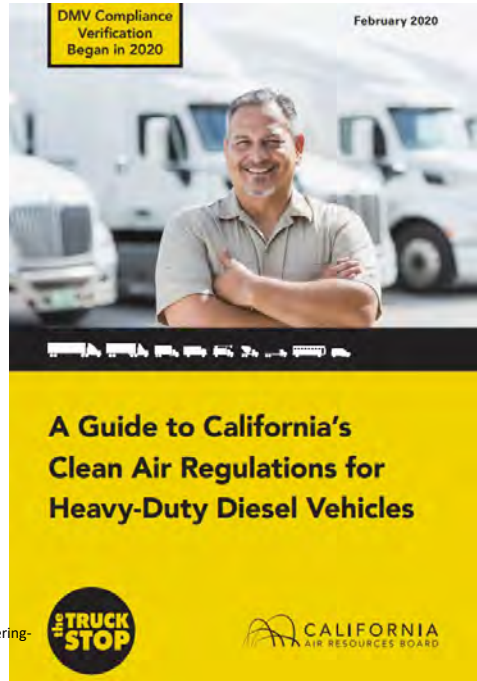
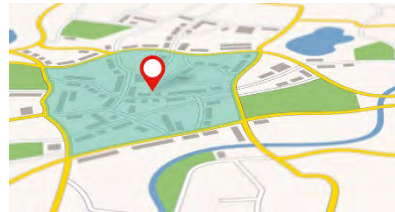
DISSEMINATING INFORMATION	
<p>Description: The authors recommend developing a system for trucks to have better access to information that pertains to them. We propose enhancing or developing a website (which would be heavily shared and advertised in the region) in which drivers can get access to information such as: rules and regulations that apply to them within the region, parking information (perhaps linking them to the previously discussed app), services available, fueling/charging stations in the region, funding opportunities, and any other relevant information.</p> <p>This information could be similar in nature to the CARB guidance on clean air regulations. However, the information should be broader in scope, as previously described, and state/area-specific. This might look like an SJV-specific website, or a California site with links to region-specific information.</p> <p>https://www.aqmd.gov/docs/default-source/ab-617-ab-134/steering-committees/wilmington/handouts-may9-2019.pdf?sfvrsn=8</p>	
<p>Details: The chosen media of information dissemination should be shared with fleets operating on this corridor. This could be done by utilizing geofencing capabilities to notify truck drivers on the corridor, or drivers at truck stops or fueling stations in the region.</p> <p>Even more, billboard advertisements or other advertising forms (fliers at truck fuel pumps, inside refueling stations, etc.) should be used to ensure widespread communication and access to information. Even more, this information source should be integrated with others in the state to allow truckers moving through California to easily access statewide and region-specific information (for each region) in one place.</p>	 <p>https://www.actsoft.com/2020/02/04/what-geofences-can-do-for-a-business-security-levels/</p>
Problems Addressed: Safety, Illegal Truck Parking	
Cost: Low	
Who takes on the cost: Public agencies	
<p>Advantages:</p> <ul style="list-style-type: none"> • Low cost • Improve trucker experience • Improve safety • Improve parking conditions 	<p>Disadvantages:</p> <ul style="list-style-type: none"> • Additional measures required to be inclusive of drivers uncomfortable with technology

Table 35. Solution Overview: Enforcement

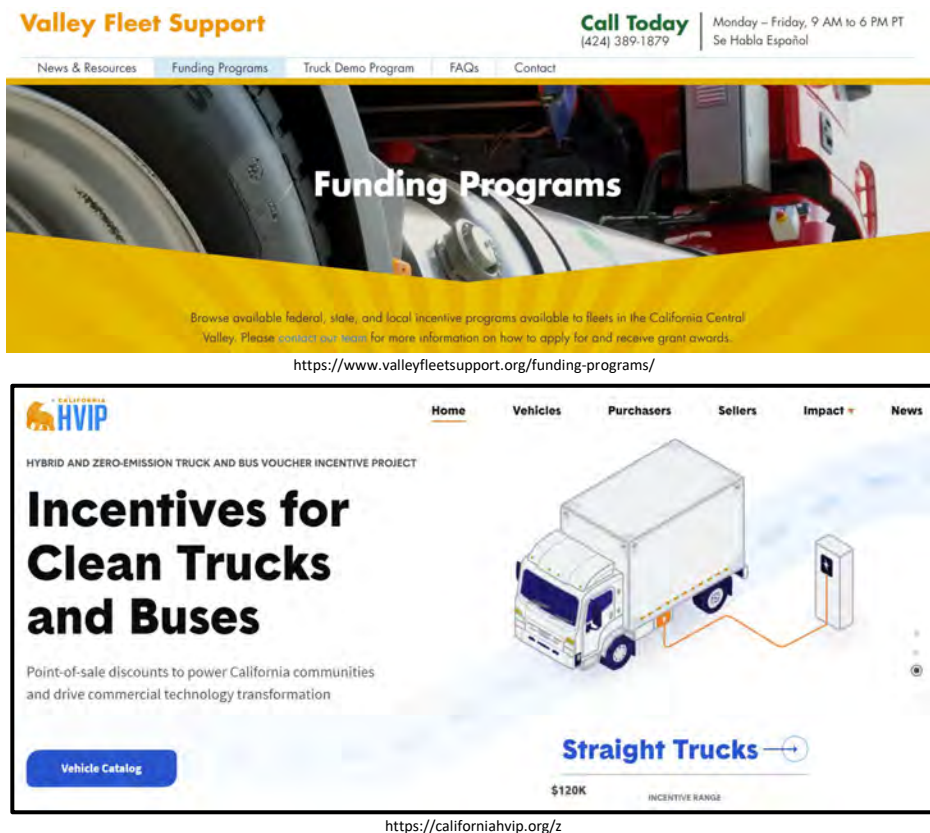
ENFORCEMENT	
<p>Description: Regional law enforcement officers should standardize the treatment of illegal or unsafe truck parking within the region. Specifically, trucks should be directed to relocate (and assisted in finding parking locations), rather than ticketed or otherwise penalized.</p>	
<p>https://en.wikipedia.org/wiki/Parking_violation</p> 	<p>https://cdllife.com/2019/truckers-parked-in-a-walmart-lot-wake-up-to-boots-a-500-fine-and-a-1-hour-time-limit-to-pay-up/</p> 
 <p>https://www.dnainfo.com/chicago/20170227/north-park/illegal-truck-semi-tractor-parking-north-park-sawyer-bldg</p>	
<p>Details: Truck drivers are limited by their work hour restrictions, pickup and delivery times, unpredictable traffic conditions, and limited or unknown parking availability/locations. This combination of variables can lead drivers to park on short notice, in an unknown location, which may not be designated as truck parking. This can lead to unintentional, disruptive, and sometimes unsafe community conditions. However, given that drivers are constrained by many factors, some beyond their control, law enforcement intervention should be focused on improving public safety and helping drivers find access to safer parking in the area. This requires information about local truck parking (designated or not) to be widely accessible to law enforcement officers, and to be communicated to truck drivers as needed.</p>	
<p>Problems Addressed: Safety, Illegal Truck Parking</p>	
<p>Cost: Low</p>	
<p>Who takes on the cost: Not applicable</p>	
<p>Advantages:</p> <ul style="list-style-type: none"> Creates consistent, non-punitive parking enforcement Improves safety 	<p>Disadvantages:</p> <ul style="list-style-type: none"> Requires coordination and consistency between several agencies/departments

Table 36. Solution Overview: Funding & Incentives

FUNDING & INCENTIVES

Description: First, the authors recommend increasing vehicle technology and vehicle (i.e., zero and near-zero emission vehicles) funding opportunities. Even more, regional efforts should focus on incentivizing shippers and receivers to locate on active rail lines.

Details: Funding could be offered in a manner similar to, or as a part of, the *Valley Fleet Support* Programs [70] or California's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) [51].



Incentives should be financial in nature, in the form of tax benefits, stipends, or grants. This would allow better connectivity between trucks and rail in the region, allowing for more reliance on rail, relieving the amount of trucks required to transport goods in and through the region.

Problems Addressed: Safety, Congestion, Environment & Air Quality, Low Rail Usage

Cost: *Variable*

Who takes on the cost: MPO, public agency, other

Advantages:

- Take all/some of the funding burden off private industry parties
- Expedite vehicle and freight change in the region

Disadvantages:

- Substantial fundraising and planning effort

5.4 Example of Comprehensive Plan

Figure 12 summarizes the primary issues relating to freight movement in the SJV. This section outlines several proposed solutions to these problems. Given that these solutions are overlapping, redundant,

and/or interconnected, this section outlines comprehensive plans, which combine the solutions proposed in the previous section. The two plans proposed in this section highlight the different how regional goals and project motivation can lead the planning effort.

5.4.1 Low-Cost Plan

This section proposes a comparatively low capital cost plan, using the previously described proposed solutions, to address each of the six major problems identified in the region (safety, congestion, environmental and air quality, pavement deterioration, illegal parking, low rail usage).

This plan is outlined in Table 37 below, with the columns representing one of the primary freight related issues in the region and the rows each containing one of the pilot study components from this section.

Table 37. Low Cost Pilot Study Plan Overview

		PROBLEMS					
		Safety	Congestion	Environmental & Air Quality	Pavement Deterioration	Illegal Parking	Low Rail Usage
SOLUTIONS	ZEVs						
	Signal Coordination						
	Increased Parking						
	Pavement Improvements						
	Signage						
	Information (parking apps) & enforcement						
	Small intermodal facility & existing intermodal app						

Here there are **technology**, **infrastructure**, and **communication** solutions representing (missing only the fourth category of **funding and incentives**). Using this subset of solutions, all six major problems in the region are addressed. Even more, these solutions are selected based on their comparatively low-cost relative to solutions that accomplish similar goals (e.g., improve the parking situation).

This section presents a *relatively* low-cost pilot, but there are many planning and regional cost topics that dictate the actual cost of implementation. Thus, this pilot study is even more flexible in that planning efforts can be used to adjust where dollars are spent in implementation. For example, the planning phase might identify several locations that require pavement improvement ranging from urgent need to eventual need. Depending on the MPO budget, only the most urgent locations can be addressed, or all locations of concern can be addressed. Similar logic can be followed for other solutions, which can even further be categorized as highest to lowest priority (pavement improvements might take priority over signage).

5.4.2 High Tech Plan

Alternatively, this section presents the components of a pilot study plan which focuses on technology solutions (Table 38).

Table 38. High Tech Pilot Study Plan Overview

		PROBLEMS					
		Safety	Congestion	Environmental & Air Quality	Pavement Deterioration	Illegal Parking	Low Rail Usage
SOLUTIONS	ZEVs						
	Connected Technology/Infrastructure						
	Automation used in certain areas/corridors and at intermodal facilities						
	Signal coordination which prioritizes moving trucks (and truck platoons) more efficiently						
	Dynamic parking						
	Pavement improvements						
	Intermodal facility & app						
	Signage						
	Information						
	Enforcement						
	Incentives/Funding						

This section prioritizes technology solutions to address each of the six primary problems in the region. This pilot study also uses all four solution categories (technology, infrastructure, communication, funding, and incentives).

Given that public projects are constrained by budgets, a similar logic to the low-cost pilot study can be followed. Namely, some categories, solutions, or locations can be prioritized over others to accomplish the goals of implementing technology solutions, improving regional operations, and minimizing costs.

Given that the high-tech pilot study entails many vehicle technologies and add-ons, it is critical to provide substantial incentives and funding. As shown in Figure 35, the technology solutions are largely and critically interdependent with funding availability. Without access to financial assistance, it is possible that the region and MPO will employ substantial resources to create a freight tech hub, and users will not have the financial means to fully utilize these improvements.

Even more, although this pilot is the high-tech option, it is also necessary to include adequate signage, information, and enforcement (mostly non-tech) to ensure smooth and safe operations. High tech corridors exist across the nation, however, most truck miles traveled take place on more traditional (low/no tech) corridor and network designs. Given the newness of not only a high-tech corridor, but a high-tech region, these communication solutions will need to be high priority in the planning and implementation process.

6 Conclusions

The SJV is a key trade and transportation gateway, vital for the local economy, and accompanied by sustainability concerns in the space of goods movement. These sustainability concerns are the result of

many transportation and freight externalities in the region, which are further exacerbated in the planning efforts by the significant growth expected to take place in coming years. This work addresses these concerns in planning through two pilot studies, small scale and long-term.

In creating these pilot studies, the current conditions and problems in the SJV were characterized and identified. Namely, the six primary problems in goods movement in the region are safety and collisions, congestion, environmental and air quality, pavement deterioration, illegal parking, and low rail usage. Even more, the regional goals are to build a tech hub, where alternative fuel vehicles and high-tech solutions are not only feasible, but widely used.

The assessment of various freight and transportation technologies is comprehensive, representing those currently available, although the most viable and well-suited for the region are reflected in the long-term pilot proposed solutions. This includes, zero-emission technology/infrastructure, connected technology/infrastructure, automation, dynamic parking systems, and the use and promotion of certain mobile apps. This assessment is also reflected in the small-scale pilot, in which the most viable (based on the technology review and regional availability), inform the small-scale pilot design.

The small-scale pilot study shows that the feasibility of many zero-emission vehicle types is currently hindered by regional accessibility, or other vehicle characteristics. For example, over 90% of Class 3 – Class 7 trucks in the SJV travel less than 150 miles per day, while for Class 8 vehicles, less than 60% travel less than 150 miles per day, and about 20% travel more than 500 miles per day. BEVs can be cost-competitive with the available financial incentives, however, electrification as it stands now, is very difficult for larger vehicles and/or longer-range trips. With over 40% of Class 8 vehicles making trips that are 500 miles or more, the necessary batteries could exceed 6,000 pounds – hampering the performance and usefulness of BEVs for these types of trips. The small-scale pilot shows that the only vehicles that are ready to serve the SJV heavy load long-haul movements *today* are diesel and CNG. Additionally, it is important that these vehicles are fueled by clean and renewable fuels such as RNG, and clean diesel to reduce their emissions and impacts. Moreover, if these technologies are currently available and the other zero emission technologies might take years to develop and mature for the required applications, it is important to use the clean and low-NOx technologies promoted by the agencies. Now, there are some vehicles that are well-suited to use upcoming automation and current zero-emission technologies, such as yard trucks and vocations/commodities with shorter tour distances and low payloads.

There is a need for smart and clean corridors, and the SJV private industry expressed interest in the deployment of charging infrastructure. This will require working with utility companies and other service providers, streamlining the permitting process, and otherwise improving accessibility. Importantly, accessibility and the adoption of any/all these technologies requires extensive incentive/funding programs, investment in charging/fueling infrastructure, and low-cost financing for new and small business models.

For the long-term pilot, the first stage of analysis focuses on evaluating TCO for different vehicle types. In doing so, for short and long-haul single unit and combination trucks, diesel vehicles have the highest TCO. The lowest TCO is seen for BEVs and natural gas vehicles (CNG and LNG). The externality costs for natural gas vehicles tends to be higher for all vehicle types than it is for BEVs. Even so, this analysis suggests that for long-haul trips (single unit or combination truck), CNG and LNG vehicles have the lowest TCO. It is also worth clarifying that although the externality costs are higher for natural gas vehicles relative to BEVs and some other alternative fuel vehicles, the externality cost is still lower than that of diesel fueled vehicles. These results seem to suggest that for smaller vehicles (single unit) and/or shorter trips, BEVs are preferred, although for combination long haul trucks, natural gas vehicles are preferred.

The second stage entails identifying several long-term pilot study components, which can be pieced together according to regional goals and budgets to address the problems identified in the region. These solution components include:

- Zero-Emission Technology/Infrastructure
- Connected Technology/Infrastructure
- Automation
- Signal Coordination
- Dynamic Parking Systems
- Increase in Truck Parking
- Increased Capacity
- Connectivity
- Pavement Improvement
- Intermodal Transfer Facility
- Intermodal Transfer Application
- Signage
- Information
- Enforcement
- Incentives/Funding

There is a high level of interdependency between these solution components, and each comes with some tradeoff of cost, effort, and anticipated benefit. There is also some limitation to the formation of a comprehensive pilot study proposal here, in that this will depend on the budgetary preferences of the MPO and substantial and/or uncertain exploratory planning efforts required to understand the full extent of need. Even so, two sample pilot studies are outlined in this report which are intended to highlight the intention of this format (presenting solution components) and the flexibility of doing so.

6.1 Future Work

Depending on the pilot study components selected for implementation, there are several options that require additional analyses (such as increased capacity and pavement improvements). Future work on this topic should expand on the solution options available in the region, as this will surely change with time and innovation, and focus on the proposed solutions of interest. Specifically, this pilot study is a generalized plan with emphasis on technology solutions, and consideration for other solutions that complement the regional problems and the technological solutions. Thus, depending on the decisions of the local decision-makers this study can be refined in the future to match narrowed preferences or expanding availability of solutions.

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Appendix A – Existing Infrastructure

SJV's Freight and Transportation Infrastructure [2]

Figure 37 displays the freight transportation facilities within the SJV. Each category of facility (highways, railroads, ports, airports) is described in detail in the following sections. Approximately half (49% – 225,046,285 tons) of the goods movements within the SJV are intraregional (i.e., internal SJV location to internal SJV location) movements via trucks. Inbound commodities account for 29% (136,408,919 tons) of non-through flows and outbound commodities account for 22% (101,742,937 tons). These commodities are primarily agricultural/food products for trucking and rail (over one-third of the inbound and outbound commodities by these modes). The through trips make up about 30% of the total truck tonnage. These flows tend to utilize I-5 and SR 58 [2].

The truck tonnage is largely (53%) made up of raw agricultural products (animal feed, cereal grains) and mining materials (stone, sand). Notably, the tonnage associated with agricultural products may be increased because they require at least two movements (farm to processor/packer, processor/packer to market). Ten percent of the truck tonnage from the SJV are destined for the Bay Area while Southern California is the origin of 10% of the inbound tonnage (more than any other region).



Source: National Transportation Atlas Database, Caltrans.

Figure 37. Freight transportation facilities [2]

Highways [2]

Trucking makes up most of the freight transportation in the SJV in terms of mode. There are over 2,700 miles of designated truck routes with over 80% being STAA National Truck Routes. Given this, the highway system is critical to analyze and maintain to ensure safe and efficient movement of goods. Truck movements generally utilize I-5 and SR 99 for north-south movements and SR 58, SR 108, SR 120, SR 180, I-580 to 205, SR 152, SR 46, and SR 198 for the east-west movements. It is worth noting that SR 99 holds most of the SJV urban centers while I-5 is used for trucks traveling through the SJV region. The truck stops in the region are clustered along I-5 and SR 99. A mapped summary of trucking volumes is provided in Figure 38.



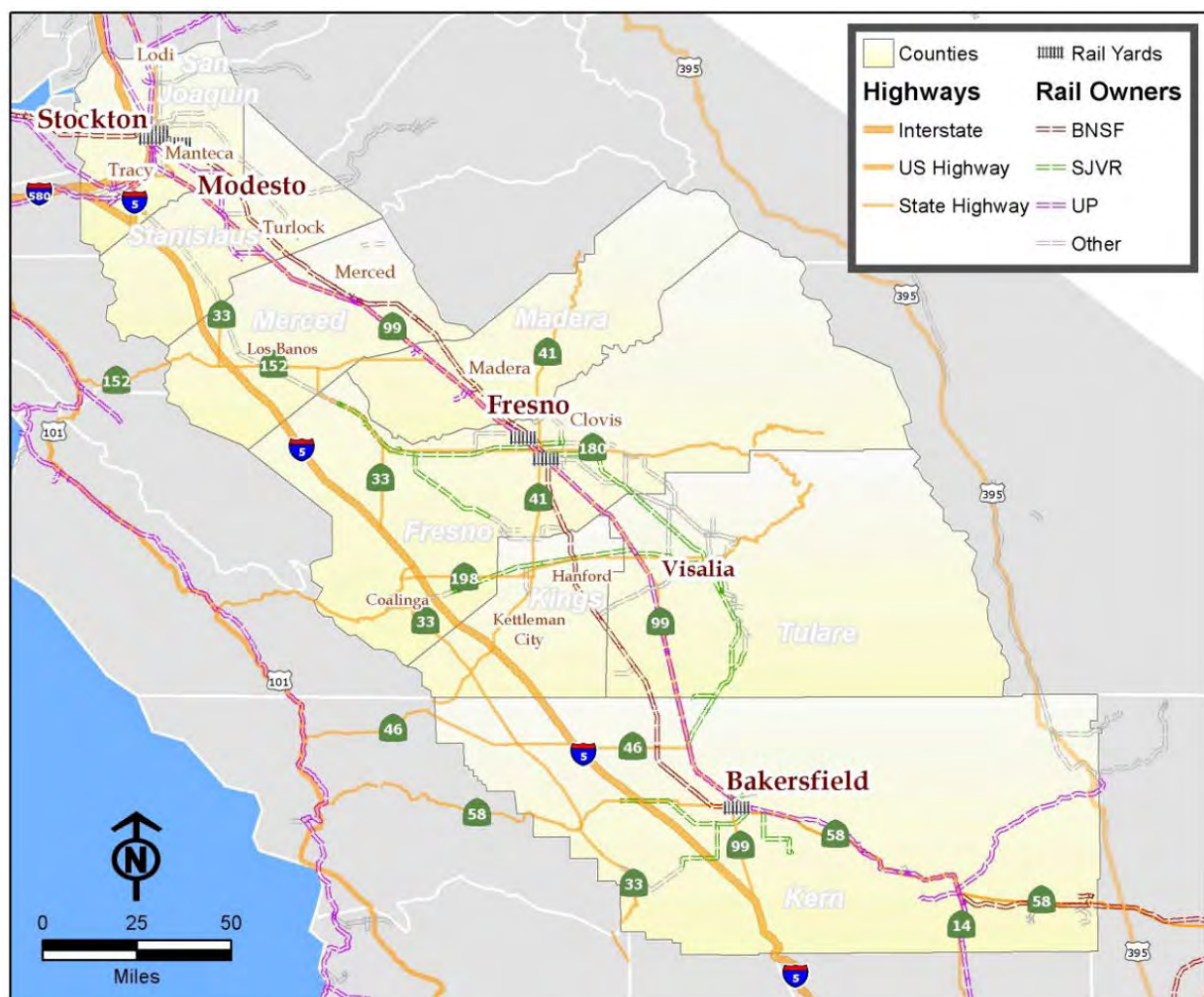
Source: SJV Truck Model

Figure 38. Mapped trucking volumes (2007) [2]

Trucks carry 92% (425 million tons) of the regional tonnage. Of these 425 million tons, 53% (225 million tons) are intraregional movements, 21% (90 million tons) originate in the region but are shipped outside the region, and 26% (110 million tons) are shipped into the region from outside the SJV.

Railroads [2]

Although trucking is the dominant mode of goods movement in the SJV, rail is critical for long-haul movement of SJV agricultural products and supplies. There are two Class I railroads in the SJV region: Burlington Northern Santa Fe Corp (BNSF) and Union Pacific (UP). Class I railroads are the largest rail operations, according to the Surface Transportation Board, they generate over \$399 million in annual operating revenues. The SJV also homes several short line and regional railroads as well: Sierra Northern Railway, California Northern Railroad, Stockton Terminal & Eastern, Central California Traction, Modesto & Empire Traction Company, San Joaquin Valley Railroad (SJVR) Company, West Isle Line. The rail network is displayed in Figure 39. BNSF and UP both carry carload and intermodal traffic. The carload goods include traditional rail commodities (assembled motor vehicles), bulk commodities (e.g., grain, coal, plastic pellets, general merchandise such as lumber and bagged cement). The intermodal traffic includes consumer products, general freight, and specialty products.



Source: National Transportation Atlas Database.

Figure 39. Key rail facilities [2]

The network of short line tracks in the region presents unique connectivity opportunities. Some of the potential opportunities listed in the SJV Goods Movement Plan include short-haul intermodal or shuttle services, connectors to inland ports, and truck-to-load transload operations. If managed intentionally, the

rail network might experience an expansion and provide an alternative option that helps reduce the congestion on roadways.

Rail carries 8% (50 million tons) of the regional tonnage. Most of the rail traffic moves to or from other states. The descriptions of these movements are provided in Table 39. About 75% of carload rail tonnage is inbound. This is because the region requires many agricultural inputs (grain, animal feed, fertilizers, farming chemicals), heavy bulky materials (coal, petroleum products, wood products), and semi-finished goods. All intraregional traffic is carload.

Table 39. Goods movement via rail transport [2]

Region	Outbound	Share	Inbound	Share	Total	Share
Other States	9,503,024	87%	24,193,548	96%	33,696,572	92%
San Jose-San Francisco-Oakland	221,556	2%	370,076	1%	602,312	2%
San Diego	74,976	1%	39,360	0%	114,336	0%
Sacramento	10,160	0%	22,520	0%	32,680	0%
Remainder of California	52,760	0%	39,360	0%	52,760	0%
Los Angeles-Long Beach	1,083,848	10%	603,312	2%	1,686,160	6%
Total	10,957,004	100%	25,227,816	100%	36,494,492	100%

Source: California State Rail Plan – Freight Rail Market Assessment.

Ports [2]

The SJV utilizes all the California seaports, however, the only port within the SJV is the Port of Stockton. The other ports are linked to the SJV via trucks. The Port of Stockton mainly handles bulk commodities and is one of the three ports connected by the California Marine Trade Corridor. The Port of Stockton also has access to extensive rail track operated by Central California Traction. This rail track also has connections to UP and BNSF tracks.

The California Marine Trade Corridor began operation in 2013 and is intended to provide container-on-barge shipments between the Ports of Oakland, West Sacramento, and Stockton. If fully utilized, up to 2,000 trucks per week might be eliminated from the I-580 corridors. This project cost about \$70 million and was paid from multiple sources, including \$30 million from TIGER grant funds (2009).

The Port of West Sacramento serves many agricultural shippers in the SJV with bulk and break-bulk cargoes. The Port of Oakland handles imports and exports to the SJV. Although there have been some efforts to develop intermodal rail between the SJV and the Port of Oakland (California Interregional Intermodal System, Shatter Intermodal Rail Facility, Crows Landing), most of the movement of goods occurs by trucking. The Ports of Los Angeles and Long Beach are the closest to the southern part of the SJV and tend to be the preferred ports for imports to the SJV because they are the first to receive vessels from Asia and Europe.

The Port of Stockton is the only port within the SJV and handles less than 1% of the freight tonnage. The Port of Stockton receives mainly bulk commodities, however, the agricultural imports (anhydrous ammonia, liquid and dry fertilizers, molasses, nitrates, urea) mainly affect the SJV goods movement flows. Overseas imports from the Port of Oakland mainly include consumer or semi-finished goods. The Ports of Los Angeles and Long Beach are preferred for receiving imports. The SJV region mainly exports food and agricultural products.

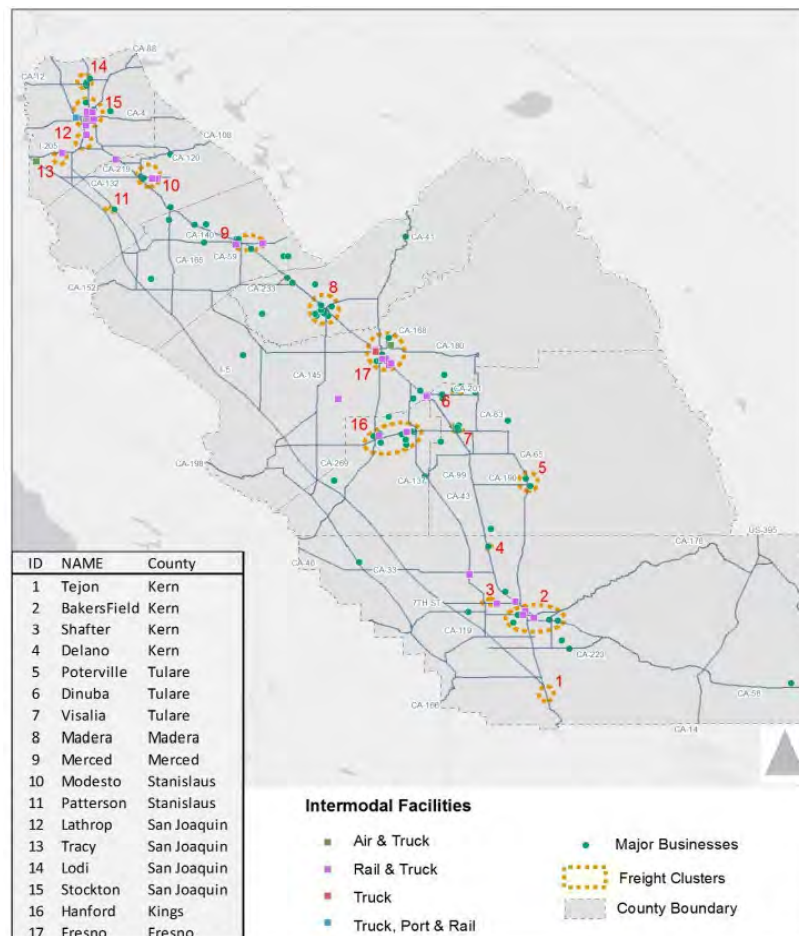
Airports [2]

There are seven airports in the SJV: (1) Fresno-Yosemite International, (2) Inyokern, (3) Meadows Field (Bakersfield), (4) Merced Regional, (5) Modesto Municipal, (6) Stockton Metropolitan, and (7) Visalia Municipal. Aside from Stockton Metropolitan, all airports are served by all-cargo aircraft (varying in size) by FedEx, UPS, or contract carriers (Westair, Ameriflight, Redding Aero Enterprises).

The freight movement via air occurs primarily through the Fresno-Yosemite airport. Air transport also accounts for less than 1% of freight tonnage in the region. As a state, California shipped over \$1 billion in agricultural exports by air in 2011, however, there are no direct flights from the SJV to overseas markets meaning that many of the goods from the SJV are shipped by truck to LAX or SFO, then flown overseas.

Multimodal Facilities and Warehouse/Distribution Centers [1]

There are seventeen clusters that include a combination of intermodal facilities, major distribution centers, and large manufacturing firms. Figure 40 depicts the location of freight clusters in the valley. In the last few years, the SJV has received increased attention for its strategic logistics opportunities. In Kern County, there are about 50 million recent and planned square foot of warehouses and distribution center facilities.



Source: California EDD.

Figure 40. Clusters on San Joaquin Valley obtained from [1]

Appendix B—Truck Parking [3] [4]

Federal laws limit the number of hours a driver can legally operate their truck, meaning parking along truck routes is critical to ensure drivers can rest or take breaks as long as is necessary. This is a matter of safety for the driver and other road users. However, lack of adequate truck parking can result in unfavorable parking behaviors from truck drivers. For example, if parking facilities are unavailable, at capacity, or poorly located, truck drivers may opt to stop where they are rather than risk continuing their search. In addition, when truck drivers are in a hurry, their delivery time or hours of service limit may not permit them to search for parking too far beyond the road they are already on. Parking costs are not always covered by shippers or employers meaning drivers will prefer the free alternative (even if that means not parking at a truck stop, but on the side of the road). Although it is sometimes possible to plan for parking needs in advance (locate a site, reserve a spot) this is not always possible, and drivers must make their decision on short notice with little information available about their options (if they are in an unfamiliar area). This uncertainty can be further exacerbated by the fact that travel times can be highly unpredictable, and a driver may hit their limit of hours of service out of range of a designated truck or rest stop [3].

Truck Parking Recommendations [4]

Truck Stop Electrification [4]

The National Renewable Energy Laboratory collects data for the Truck Stop Electrification Site Locator. The tool was developed as an effort between the Federal Highway Administration and the U.S. Department of Energy. The tool can help drivers locate public truck stops with idle reduction facilities for trucks. There are seven electrified sites in California, three of which are in the SJV.

Jason’s Law Truck Parking Survey Results and Comparative Analysis [4]

With 53.7 parking spaces per one hundred thousand miles, California is ranked as the second worst state for parking spaces per 100 thousand miles. In California, 36% of truck drivers and 42% of logistics professionals reported regularly occurring difficulty finding safe and legal parking when they wanted to rest (at night it is 50%). There is no single government or private entity in charge of truck parking facilities, making it difficult to address the shortage. Truck-stop operators reported difficulty with environmental and zoning laws and resistance from local communities. California is one of the most difficult states to acquire permits for new or expanded parking. This is due to high construction and maintenance costs and limited funding.

Planning and Funding [4]

The main recommendations can be summarized as follows:

- Improve data collection and analysis to better understand parking demand
- Involve, educate, and train law enforcement about improving the use of safe and available parking space
- Update plans and investment programs to include truck parking
- MPOs should incentivize land use decisions that attract private sector investment in expansion or development of parking facilities
- Convert surplus public properties to truck stops
- Utilize FAST funding to construct or expand truck parking facilities and develop tools for commercial drivers to find safe and available spaces

Demand Control [4]

The main recommendations can be summarized as follows:

- Recommend policies that incentivize off-peak deliveries to reduce the demand for long-term parking spaces
- Improve older parking facilities that might lack space for truck circulation of larger trucks
- Establish flexibility in the rule that shippers and receivers often demand drivers leave the facility immediately after delivery. For example: encourage industries to allow drivers to use their parking facility to rest if needed.

Technology [4]

The main recommendations can be summarized as follows:

- Develop phone applications (apps) that let drivers find parking information for interchanges
- TA Petro's TruckSmart app provides parking information across the network
- Caltrans can develop or sponsor an app that shows public and private parking locations, amenities, occupancy, reservation options.
- More apps like the Caltrans real time parking solutions on segments of I-5 (results show increase in parking occupancy)

Emission Reduction Policies [4]

The main recommendations can be summarized as follows:

EPA SmartWay carrier partners use Truck Stop Electrification when possible, trucking associations can encourage fleet owners to pay drivers to use designated parking areas and Caltrans can help promote it.

Establishing new open-access truck parking facilities can be unattractive because they "count" in the EPA's inventory of sources of mobile sources air emissions (MOVES). If outfitted with idle reduction equipment, they might qualify as a lower impact facility.

Truck Parking Solutions – Mobile App

These authors recommend the adoption/advertising of one of the more comprehensive apps. Here, "comprehensive" refers to the app with the most capabilities, covering the most rest stops and fuel stations, and the most widely used. Based on these criteria, these authors recommend the *Trucker Path* app or the *TruckMap* app.

Table 40. Currently available truck parking apps and their descriptions

App Name	App Description	User Ratings (as of 1/6/2021)
Love's Connect	"Find your favorite Love's Travel Stops, check your My Love Rewards account, secure the next shower with Mobile Shower Check In, activate commercial fuel pumps with Love's Mobile Pay, view transaction and loyalty receipts, map your route, view real-time fuel prices, request Truck Tire Care roadside assistance and connect with our customer service team using the Love's Connect mobile app." https://apps.apple.com/us/app/loves-connect/id421276073	G: 4.2/5.0 (25,922 reviews) A: 3.9/5.0 (2,043 reviews)
Pilot Flying J	Trip planner (tracks fuel, supplies, amenities), filter locations (by amenities, parking availability, food & restaurants), track rewards, pay for fuel, reserve showers, monitor parking availability https://play.google.com/store/apps/details?id=com.pilottravelcenters.mypilot&hl=en_US&gl=US	G: 4.3/5.0 (33,484 reviews) A: 4.7/5.0 (27,600 reviews)

TruckSmart	Interactive map (displaying TA, TA Express, and Petro sites), complete list of amenities, location list within a specified radius, current fuel prices, redeem points, activate fuel pump, call roadside assistance & share coordinates, real-time shower and parking availability, work order requests https://apps.apple.com/us/app/trucksmart/id420579235	G: 2.8/5.0 (4,736 reviews) A: 2.2/5.0 (13 reviews)
TruckPark	"TruckPark helps you to reserve spots in real-time along your routes. When you book your parking spot in advance, you can save time and money when searching for parking. TruckPark gives you access to secure and private parking locations across several US states. Whether you are picking up a load or parking your trailer, we have a parking spot near you. Use the TruckPark parking app to reserve parking across major US transportation hubs." https://play.google.com/store/apps/details?id=com.truckpark.mobile&hl=en_US&gl=US	G: 3.7/5.0 (9 reviews) A: 3.9/5.0 (18 reviews)
Trucker Path	"We have Pilot Flying J, Love's Travel Center, Petro TA, Blue Beacon, Roady's, KwikTrip, Weigh Stations, CAT Scales, Diesel Fuel Prices, Rest Area, Truck Parking, Truck GPS, Truck Navigation, all in our Truck Maps." Reports weather and live road traffic conditions, can plan multi-day trips with trucking GPS, see which weigh stations are open/closed, trucker map with real-time updates, parking updates (full, some, empty) from other truckers https://play.google.com/store/apps/details?id=com.sixdays.truckerpath&hl=en_US&gl=US	G: 3.7/5.0 (50,165 reviews) A: 4.7/5.0 (59,913 reviews)
DAT One	Find truck stops (Pilot, Flying J, Love's, TA Petro, including showers, amenities, and diesel fuel prices), parking information (from TruckPark, MAASTO Regional TPIMS and Find Truck Services), reserve a spot, find CAT scales, truck maps for clearance and cargo, hotels for truckers, find truck services, rest areas, find truck loads nearby https://play.google.com/store/apps/details?id=com.dat.unified&hl=en_US&gl=US	G: 3.6/5.0 (94 reviews) A: 4.1/5.0 (17 reviews)
Road Hunter	"Customize truck height, weight, and avoid toll roads with voice directions powered by best navigation routes provider. Truck stops: Flying J Travel Plazas, Loves Travel Stops, TA Travel Center, Pilot, Petro, AM Best, Sapp Brothers, Independent truck stops Diesel Stations: Shell, Mobil, Exxon, Valero and many other Always updated diesel prices" https://apps.apple.com/us/app/truck-navigation-road-hunter/id1069171213	G: 4.4/5.0 (2,023 reviews) A: 4.2/5.0 (79 reviews)
TruckMap	"TruckMap is the best free mobile app built for Truck Drivers. The only app with truck optimized GPS routes, diesel fuel, weigh stations, overnight parking, Walmart, and Rest Areas." Truck optimized GPS routes: routes and directions for trucks, plan for truck weight, clearance, and HAZMAT, customize truck height/weight, avoid tolls, filter locations on the way Locations: Walmart, Pilot/Flying J, Petro, Love's Roady's, AM Best, TA TravelerCenters of America Identify truck stops with laundry, showers, and truck washes, weight stations, DOT inspection sites, and rest areas "Filter Locations With: Parking (Daytime, Overnight, HAZMAT), Truck Washes, Convenience and Grocery Stores, Diesel Fuel, Biodiesel, Propane, DEF Lines, CAT Scales, Air Hoses, ATM, Restrooms, Showers, Laundry, Wi-Fi, RV Dump Stations, and Open 24/7 Truck Services: Truck Washes, Oil Changes, Tire Service, Truck Mechanics, Truck Dealers, Roadside Assistance, Towing."	G: 4.3/5.0 (2,258 reviews) A: 4.6/5.0 (24,584 reviews)
Park My Truck	"Park My Truck helps professional drivers identify available parking no matter where they are in the United States and allows any parking provider to share their parking availability for free through the app. ...	G: 2.4/5.0 (43 reviews) A: 1.0/5.0

	<p>Parking availability in the app is reported every two hours by participating parking providers. If the parking availability has not been reported for more than two hours, the available parking will be noted as N/A.</p> <p>Park My Truck was developed by the Truck Parking Leadership Initiative, comprised of the NATSO Foundation, NATSO, the American Trucking Associations and the American Transportation Research Institute (ATRI), based on feedback from professional drivers and trucking companies who describe truck parking availability as a critical need.”</p>	(2 reviews)
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G: Google Play
A: Apple

Based on the “Zero or Near-Zero Emissions Technology” section of this report, it is also apparent that the adoption of some modern technologies is highly reliant on the presence (and frequency) of different fuel types along the corridor(s) of interest. Given this, it is also highly recommended that the Kern COG establishes some method for helping drivers of these alternative fuel trucks appropriately plan their trips. These authors suggest a collaboration with one of the previously mentioned mobile apps. Specifically, Kern COG should provide detailed and continuously updated information about the publicly available fueling/charging options and recommend that the app developers allow drivers to see stations and nearby rest stops based on the vehicle fuel type. This would allow drivers of alternative fuel trucks to find refueling/charging stations and convenient rest areas based on the location of these stations.

The primary infrastructure changes recommended are added parking lots and spots, located throughout the region. There are many factors that contribute to when and where truckers park, including cost, convenience, location, amenities, length of stay, and availability of spots. It is also important to consider that some drivers plan their stops in advance (highlighting the usefulness of a truck parking app), but some must make their decisions on short notice. Especially considering the hours of service laws, sometimes drivers may have to stop on short notice in a location they did not expect to be.

In addition to added parking, it is also important to improve communication to truckers in the form of new and increased signage on freeways and off-ramps.

Appendix C – Similar Projects and Work

This section describes similar or related studies to this pilot study. These projects informed the development of the small-scale data collection pilot study, and the design and outcomes of these studies can be used to help stakeholders select piece-wise components for the long-term pilot.

In the US

Volvo LIGHTS [71]

Volvo LIGHTS (Low Impact Green Heavy Transport Solutions) is a project based in the greater Los Angeles area and is intended to demonstrate the capabilities of battery-powered electric freight trucks. Even more, the project includes elements that will help prepare the region for widespread use of battery electric trucks. The California Air Resources Board has invested \$45 million in California Climate investments grant money, contributing to the total project cost of \$90 million. The grant was awarded to the South Coast Air Quality Management District, Volvo Trucks, and fourteen other organizations.

The project started in 2019 and is scheduled to end in 2021. It includes twenty-three electric trucks, 29 pieces of electric freight-moving warehouse equipment, 58 public and private chargers, two electric truck after-market service centers, and 1.8 million kilo-watt hours in solar energy generation. They also plan to install solar panels at local warehouses to provide some renewable power for the vehicles. In addition to infrastructure and vehicle elements, the program is also introducing training programs for electric truck maintenance at two local community colleges.

The vehicles are equipped with self-learning driveline control that help optimize energy usage and range, lithium-ion battery chemistries that increase energy density by more than 20%, and prevent premature degradation, and a variety of truck configurations (different ranges based on operations and powertrain). The related infrastructure includes a mix of public and private electric chargers (including a fast-charging truck station), network chargers with integrated vehicle telematics, use of onsite solar panels, and use of second-life batteries.

I-70 Truck Automation Corridor [72]

The I-70 Truck Automation Corridor Project, nicknamed the “Freight corridor of the future”, is located between Columbus, Ohio and Indianapolis, Indiana. This corridor has experienced and is experiencing substantial freight growth and it includes urban and rural traffic conditions, travels through big and small towns, and flat and hilly/mountainous terrain. The project is scheduled to take four years. The respective DOTs were awarded federal grants for the project upwards of \$4.4 million, matched by project partners, resulting in a total investment of \$8.9 million.

The project is primarily focused on truck automation, allowing freight companies and truck automation vendors deploy partially automated trucks on the corridor. The project will also include professional driver training, data and insights collection and sharing (regarding preparation of roadways for automated vehicles), identify infrastructure needs, and help shape federal policy.

33 Smart Mobility Corridor [73]

The 33 Smart Mobility Corridor project is located on a 35-mile stretch of US 33 in Ohio between Dublin and East Liberty. The project is developing the corridor to be a proving ground for autonomous and connected vehicle technology. As part of this project, the roadway is being equipped with fiber-optic cable and roadside sensors. These will be used to record and share data and communications vehicles and sensors on the roadway.

Texas Connected Freight Corridors [74]

The Texas Connected Freight Corridors project will deploy connected vehicle technology (V2V and V2I) to improve safety and congestion. The project is located on the “Texas Triangle” (865 miles), connecting I-35, I-45, and I-10. The project area links Austin, Dallas-Fort Worth, Houston, San Antonio, and an extension to also link Laredo. The Texas DOT and project partners have prioritized 11 V2I applications and one V2V application, including:

- Advance traveler information
- Eco-dynamic routing
- Queue warning
- Work zone warning
- Wrong way driving detection and warning
- Road weather warning
- Low bridge height warning
- Truck signal priority
- Pedestrian/animal warning
- Truck parking availability
- Border wait time notifications
- Emergency electronic brake light warning

The project will also focus some effort on adding to the intelligent transportation system technologies already in place. This project will utilize infrastructure condition monitoring technologies and freight-specific technologies, including freight parking system technologies and border crossing technologies.

Telecommunication is also a key component of this project. The I-35 segment is the most urban corridor which is why the proposed communication on the corridor is dedicated short-range communications. For the more rural corridors (I-45 and I-10), the project includes plans for other communication channels, such as cellular.

Connected Vehicle Safety Pilot [75]

The Connected Vehicle Safety Pilot is a research program to evaluate connected vehicle (CV) applications. The study will evaluate everyday drivers’ reactions (in a controlled environment and on actual roadways) to CVs.

- Controlled environment/safety pilot driver clinics: six different sites; one hundred drivers at each at each clinic; environment such as a racetrack
- Actual roadways/safety pilot model deployment: 3,000 vehicles equipped with wireless CV devices; designed to determine the effectiveness of CVs in reducing crashes; includes cars, trucks, and transit vehicles

The program will follow four research tracks:

1. Build vehicles & host driver clinics: driver clinics and performance testing in geographically diverse environments
2. Device development and certification: determine specifications for devices and safety systems (to work with all types of vehicles); will result in a qualified product list if they have met US DOT specifications and will be considered as potential devices for model deployment (including vehicle awareness devices, aftermarket safety devices, and roadside equipment)
3. Real-World Testing: gather exposure data through one-year model deployment, will test the effectiveness of V2V and V2I resulting in approximately 3,000 vehicles communicating; will also consider grade crossing warning, data utilization for transportation management and operations,

smart work zone merge management, warning system for pedestrian crosswalk at mid-block locations, emergency vehicle pre-emption

4. Independent Evaluation: analyze data from testing, provide assessments (performance, benefits, applications)

The designated project goals are:

- Obtain empirical data for user acceptance, system effectiveness, and technical readiness
- Demonstration
- Establish a real-world operating environment
- Archive data (for uses in government and industry)

The expected outcomes of the project are:

- Documentation & identification of potential benefits
- Evaluation of driver acceptance
- Identification of research gaps (and how to address them)

Finally, the safety applications of this project are primarily in the form of warnings. This includes warnings for blind spots, do not pass, emergency electronic brake lights, forward collision, intersection movement assist, lane change, red light, curve speed, pedestrian and turning transit vehicle crash, and right turn in front of transit vehicle crash warning.

[In the SJV \[76\]](#)

Several organizations and agencies have provided funding to both the South Coast Air Quality Management District and the SJV Air Pollution Control District to help spur early-stage, innovative technologies that need further testing and demonstration prior to massive deployment and commercialization. Below we discuss several important projects found relevant to truck emission reduction in the region with respect to their fuel consumption behavior. We divided the projects into three categories based on their status: finalized, under development, and under consideration for future approval.

[Kern-Area Regional Goods Movement Operations \(KARGO\)](#)

The KARGO project similarly addresses sustainable goods movement and options in Kern County [15]. This study proposes several sustainability strategies, broadly categorized into five groups [15]:

1. Targeted Logistics Transportation Fees
 - Logistics Mitigation Fees: a one-time facility-size-based fee imposed on new warehouse construction
 - Mobility Fee: a fee charged to all new development, based on the anticipated VMT that will be generated
2. Shift from Road to Rail
 - Freight Modal Shift Programs: provides incentives to shippers to use alternative modes (typically rail)
3. Utilize/Incentivize Clean Technologies
 - Technologies: zero-emission trucks (currently being incentivized and adopted in the SJV), autonomous trucks or automated driving systems (anticipated to be deployed in 2-3 years, posing an opportunity for Kern County, especially to connect industrial districts to intermodal facilities)

- Kern Safe Autonomous Freight Enhanced Testing Environmentally Clean (**SAFETEC**) logistics zone: include, among other things, autonomous trailer transfers to trucks with drivers or rail and autonomous truck routes (see Figure 41)
4. Revise Building Codes
 - Support Electric Infrastructure: commercial and industrial building codes could be updated to require EV supply equipment and supporting EV infrastructure
 5. Industrial Trade Port District
 - Cluster shippers around intermodal and trucking facilities (could be served by automated vehicles)
 - Rail Intermodal: facility where cargo can be loaded or removed from a train moving through the area
 - Truck Mobility Complex: location where automated trucks would shift to a human operator for last-mile deliveries

UPS Zero-Emission Electric Delivery Trucks (Finalized)

This project replaced 50 UPS diesel trucks located throughout the San Joaquin Valley with zero-emission medium-duty trucks. This project was funded, in part, by the California Air Resources Board's Hybrid Truck and Bus Voucher Program (HVIP), launched to help businesses replace fleets with low carbon emitting hybrid and electric vehicles.

Low Emissions Alternative to Open Burning for Paper Raisin Trays during Grape Harvest (Finalized)

This project tested a mobile prototype device that have the potential for broad applicability in the San Joaquin Valley and lead to significant emission reductions resulting from the burning of paper raisin trays used during the grape harvest. The technology has been shown to significantly reduce visible smoke and particulate matter emissions compared to open burning. One source of emission reduction was from eliminating the water truck fuel use. The watering of the feedstock used approximately 20 percent less water in the developed alternative compared to the traditional ways, which were watered by a 4,000-gallon watering truck with a sprayer on the back.

New Ultra-low Emissions Trucks (Ongoing)

Southern California Gas Co. (SoCalGas) officials from the San Joaquin Valley Air Pollution Control District and Western Milling, one of the largest and most diverse manufacturers and suppliers of nutrient solutions for plants, animals, and people in the U.S., unveiled the first of a planned thirty new ultra-low emissions trucks the company will deploy at its operation in Goshen, Calif. The near-zero emissions natural gas trucks will be fueled with renewable natural gas (RNG) that can virtually eliminate smog-forming pollutants and reduce greenhouse gas emissions linked to climate change by as much as 80 percent. These new trucks are powered by a 12-liter Cummins Westport engine, the first engine of its kind to meet the California Air Resources Board (CARB) optional low NOx standard. In addition, Western Milling revealed plans to open a new public fueling station supplying renewable natural gas in the city of Goshen later this year.

SoCalGas has worked with fleet owners to secure millions of dollars in incentive funding for the replacement of diesel trucks with cleaner, new near-zero emissions natural gas trucks. Since 2014, the utility has helped truckers and trucking companies replace more than 550 diesel trucks with clean natural gas trucks. That equates to taking about 30,000 cars off California's roads. Recently, SoCalGas supported a Los Angeles-Long Beach Port trucking company with their efforts to replace its entire 40 diesel truck fleet with near-zero emissions natural gas trucks.

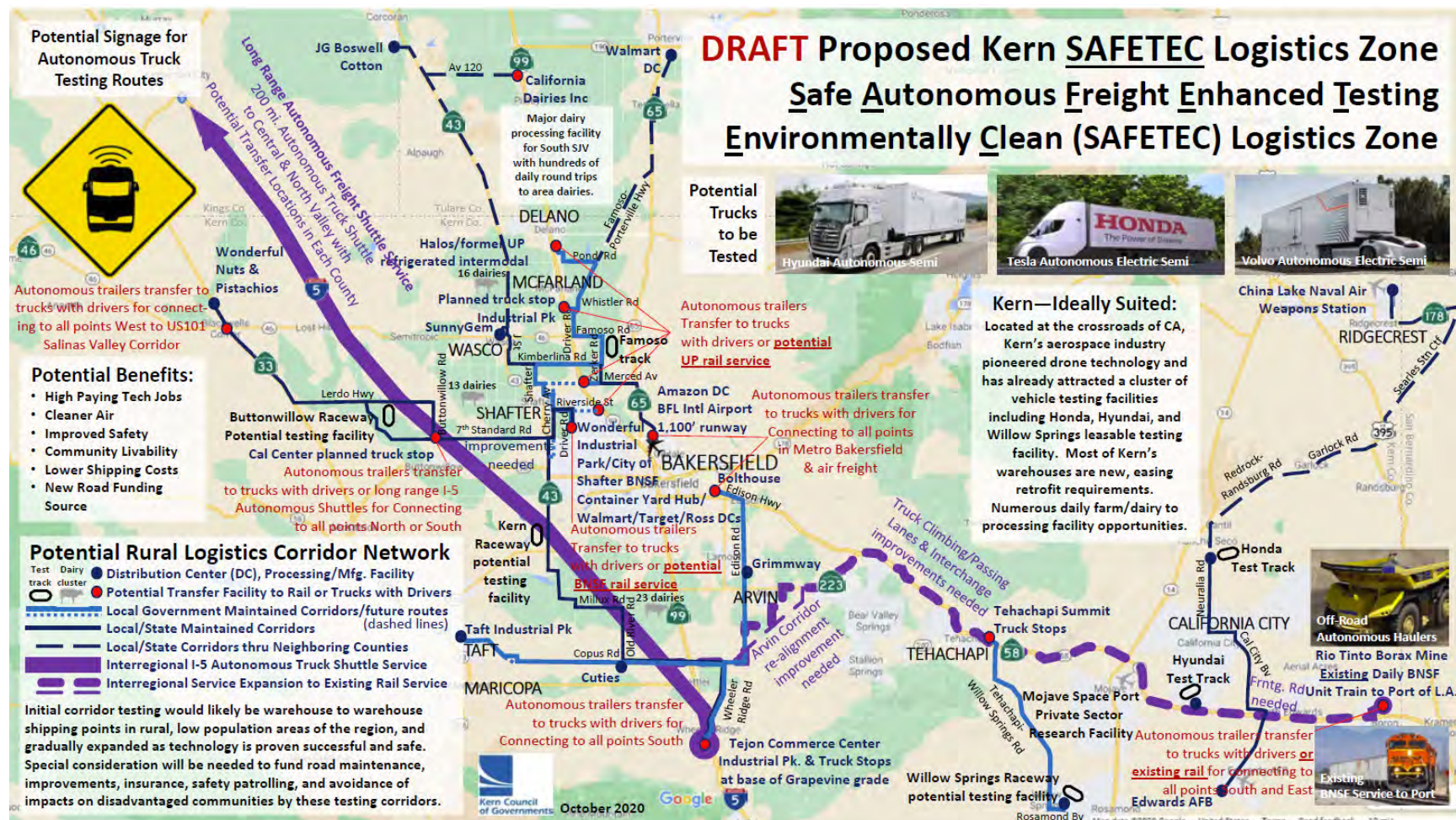


Figure 41. Overview of Proposed SAFETEC Logistics Zone (Source: [15])

San Joaquin Renewables (Ongoing)

San Joaquin Renewables was founded in 2018 as a project entity to build a plant that will convert orchard residues into renewable CNG to fuel trucks, buses, and other CNG vehicles. Vehicles running on renewable CNG can have lower emissions than electric vehicles, making it the obvious choice to reduce vehicle emissions. San Joaquin Renewables' facility will be located near McFarland, California. The facility is expected to begin operations in 2021.

Truck Replacement Project (Proposed)

San Joaquin Valley District is currently accepting applications to replace on-road diesel trucks with cleaner technology units or to expand fleets with the cleanest technology available with emphasize in low income and disadvantaged communities. The replacement occurs for old trucks having a 2009 or older model year diesel engine with newer truck having Zero Emission, Hybrid-Zero Emission Mile, Low-NOx (0.02g/bhp-hr NOx), or Hybrid technology.

Demonstration of an Electric Powered Yard Truck (Transpower/IKEA) (Proposed)

Transportation Power, Inc. demonstrated a zero-emission electric yard tractor which was placed into operation at IKEA to primarily move shipping containers and trailers around the facility at its main California Distribution Center in Lebec, CA. A diesel tractor was converted to battery-electric propulsion. The tractor accumulated a total of more than 12,500 miles of operation during the one-year demonstration phase of this project, producing a wealth of valuable data. This technology met or exceeded diesel yard tractor throughput while producing zero emissions at a higher rate of energy efficiency than the diesel counterparts. Operational costs for the electric tractor were lower, with an energy cost of 31 cents per mile, compared with \$1.12 per mile for an equivalent diesel yard tractor for an operational cost savings of \$5,000 to 6,000 per year. Other than replacement of a component due to a straightforward design flaw that was easily fixed, no significant maintenance or repairs were required during the full year that the tractors was demonstrated. This technology was proven successful and has the potential for widespread implementation.

Zero-Emission Electric Yard Tractor (Proposed)

This heavy-duty electric yard tractor would replace diesel rigs currently used to move trailers around a distribution facility in Lebec.

Hybrid CNG-Turbine Powered Range Extended Series Electric Truck (Proposed)

This project proposes to demonstrate a CNG-turbine powered range extended series electric truck in the Valley. The project seeks to demonstrate near-term commercialization and production capabilities in this class as well as illustrate the zero-tailpipe emission pathway represented by electric-traction truck architecture proposed in this project. This technology has the potential of demonstrating near zero emissions technology in the goods movement sector.

Plug-in Hybrid Wheel Loader at a Dairy (Proposed)

This project will convert a wheel loader to plug-in hybrid operation and identify fuel savings and emission reductions at a dairy. Hybrid electric technology, which has been available in the light-duty vehicle category in the past, is only recently being applied to off-road vehicles. This proposal will advance the transfer of this technology into this category and serve to verify and quantify the emission reductions associated with the system.

Plug-in Electric Hybrid Propane Utility Work Truck (Proposed)

This project will demonstrate a plug-in electric-hybrid propane utility truck using a Ford F-250 truck base at a farm. The demonstration and testing will identify NOx emission reductions, greenhouse gas reductions, and fuel savings. The outcome of this proposal has the potential to affect a large segment of

the on-road vehicle emissions inventory, considering the extensive use of utility truck in agriculture and other industries.

Advanced Series Hydraulic Hybrid Refuse Vehicle (Proposed)

This project will demonstrate two new refuse vehicles fitted with an advanced series hydraulic hybrid-drive technology to reduce diesel fuel consumption, and associated NOx and other emissions, by up to 45%. The City of Manteca will purchase the trucks, monitor the vehicles, and collect data from the hybrid truck and a conventional diesel truck, for comparison purposes.

Valley Fleet Support

[Funding Programs \[77\]](#)

The California Energy Commission Valley Fleet Support offers several funding programs summarized in Table 41.

Table 41. Valley Fleet Support funding program summary [77]

Program Name	Agency	Program Status	Due Date	Max Solicitation Funding
California Electric Vehicle Infrastructure Project (CALeVIP) San Joaquin Valley Incentive Project (SJVIP)	California Energy Commission (CEC)	Open; only funds for Level 2 chargers in San Joaquin County remaining	First-come, first-served	\$14,000,00
California VW Program for Combustion Freight and Marine 2021	California Air Resources Board (administered by SCAQMD)	Open	First-come, first-served, approximately \$19 Million in funding left	At least \$26,000,000 will be available.
Hybrid and Zero Emission Truck and Bus Voucher Incentive Project (HVIP) – Low NOx Incentives	California Air Resources Board		First-come, first-served	\$145 million
PG&E EV Fleet Program (MD/HD)	Pacific Gas & Electric (PG&E)	Open; Interested fleets must contact PG&E	Open; applications are taken on a rolling basis, as allowed by available funding	\$236,000,000
SJVAPCD Clean Vehicle Fueling Infrastructure Incentive Program 2022	San Joaquin Valley Air Pollution Control District	Under development to open in March 2022.	Under development. Previously open for 1.5 months.	\$15 million
SJVAPCD Clean Vehicle Fueling Infrastructure Program: Private Use	San Joaquin Valley Air Pollution Control District	Open on a first-come, first-served basis. As of 3/16/22 still accepting applications but will not say if funding has been exhausted by applications already received.	First-come, first-served	\$10 million
SJVAPCD Truck Replacement Program	San Joaquin Valley Air Pollution Control District	Open	First-come, first-served	No maximum established, but funding is added throughout the year
SJVAPCD VIP	San Joaquin Valley Air Pollution Control District (SJVAPCD)	Closed	First-come, first-served	\$1.2 million.
SJVAPCD Yard Truck Replacement Program	San Joaquin Valley Air Pollution Control District	Open on a first-come, first-served basis.	First-come, first-served	\$6 million

[Truck Demo Program \[78\]](#)

In October 2020, 30 alternative fuel or zero emission medium to heavy-duty vehicles will be demonstrated in the California Central Valley. The Central Valley has been selected as the focus of this demonstration

because of the large amount of goods movement and agricultural operation, and the resulting air quality issues.

The vehicles being demonstrated are powered by natural gas, propane gas, and the last is BEVs. Box trucks, tractors, cargo vans, cutaway cans, and others will be demonstrated. Aside from being the largest truck demo program of its kind in California, the program also allows interested parties to physically experience these trucks and technologies.

Appendix D – Relevant Policies

This section describes the current policies that might impact decision-making in goods-movement settings within the SJV.

Environmental Policies

Assembly Bill 32 (AB 32; California Global Warming Solutions Act) [79] [80]

AB 32 was passed by the California Air Resources Board (ARB) in 2006 with the purpose of reducing California global warming pollution. This bill imposes a cap-and-trade rule on the industries with the highest greenhouse gas (GHG) emissions. There is a limited “allowance” of tons of emissions available statewide and companies must accommodate this limited supply. Meaning, if their initial allowance is not sufficient to cover their emissions, they must obtain additional allowances from other industry parties who have an excess. Over time, the statewide availability of allowances (i.e., total amount of allowances, or cap) will decrease meaning that companies must plan for long-term decreases in their emissions. This incentive to decrease emissions quickly may lead to more industry interest in technological advancement in the form of emissions-limiting solutions, leading to advancements that could further contribute to the state economy.

Assembly Bill 170 (AB 170) [81]

AB 170 requires that each city and county within the SJV must amend their general development plans to include items related to improved air quality. This includes data and analysis, comprehensive goals, policies, and feasible implementation strategies. Specifically, these amended plans should integrate land use, transportation, and air quality plans, strategically consider land use decisions and local action that might support reduced congestion or vehicle trips and reduce emissions from sources within the local jurisdictions. In addition, they are recommended to support other initiatives from utilities. Guidance for the cities and counties in this task is provided through the [SJV Air Quality and Guidelines for General Plans](#).

Assembly Bill 617 (AB 617) [13] [82]

AB 617 requires the state board to develop a uniform system of reporting emissions of criteria air pollutants and contaminants from specific stationary sources (i.e., non-vehicular). Although prior to this bill the state board or the air district could require owners/operators to take reasonable measures to determine the amount of emissions from a given source. However, AB 617 requires the state board to monitor air pollutants and contaminants, and to identify the highest priority locations. The high priority locations will be fitted with a fence-line monitoring system for real-time, on-site monitoring that is reported to the air districts and the state board. In addition, the bill requires the state board to maintain and regularly update an emissions reductions strategy.

The SJV contains 20 of the 30 most disadvantaged communities in the state of California and is therefore expected to benefit from AB 617. The specific strategies for each selected community are outlined on the [SJV Air Pollution Control District website](#) [83]. In response to AB 617, the California Air Resources Board established the Community Air Protection Program, which is intended to reduce emissions exposure in the communities most strongly impacted.

Assembly Bill 1550 (AB 1550) [84] [85] [86]

AB 1550 modifies previous legislation which stated that 25% of all money collected by the state board as part of the market-based compliance mechanism must be deposited into the Greenhouse Gas Reduction Fund, must be used to fund projects that benefit disadvantaged communities, and 10% must be used for projects located within the disadvantaged communities. AB 1550 states that 25% of the available money should fund projects within disadvantaged communities, an additional 5% should benefit low-income households or be implemented in low-income communities, and an additional 5% should be allocated to

projects that benefit or are located within the boundaries of low-income households outside of disadvantage communities but within 0.5 mile of disadvantaged communities. A [map](#) of the previously described, disadvantaged, low-income, and bordering communities can be found on the CARB website.

[Tractor-Trailer Greenhouse Gas Regulation \(TTGHG\) \[87\] \[88\] \[89\]](#)

In 2008, the California ARB passed the Tractor-Trailer Greenhouse Gas Regulation, which is intended to reduce the GHG emissions from heavy-duty tractor-trailers. This regulation applies to 53-foot (or longer) box-type trailers (dry-van and refrigerated-van) and the heavy-duty tractors that pull them. In addition, this regulation does not apply to trucks that are 2014 model year or newer. Among the main requirements of this regulation is that tractors will need to be more aerodynamic, and trailers should be equipped with low rolling resistance tires. The trucks and trailers must use the U.S. Environment Protection Agency SmartWay certified tractors or trailers (or those retrofitted with SmartWay technologies). Vehicle owners, drivers, motor carriers, California-based brokers, and California-based shippers share responsibility for compliance.

[Senate Bill 350 \(SB 350; Clean Energy and Pollution Reduction Act\) \[90\]](#)

SB 350 sets goals for clean energy, clean air and GHG emissions reductions for 2030 and 2050, all in comparison to the 1990 levels. By 2030, the GHG levels should be 40% below what they were in 1990 and 80% below by 2050. In addition, by 2020, California's renewable electricity procurement goal is 33% and 50% by 2030. This is intended to increase the use of Renewables Portfolio Standards eligible resources (such as solar, wind, biomass, geothermal and others).

In addition, the state is required to double statewide energy efficiency savings (electricity and natural gas end uses) by 2030. As part of this, large utilities are responsible for producing a plan for meeting customer resource needs, reducing GHG emissions, and increasing the use of clean energy resources.

SB 350 also calls for several research studies, addressing barriers to and opportunities for bringing renewable energy and zero-emission (or near zero) to low-income or disadvantaged communities, providing contracting opportunities to local small businesses, and developing solar photovoltaic energy generation.

[Senate Bill 375 \(SB 375; Sustainable Communities Protection Act\) \[91\] \[92\]](#)

SB 375 designates a "bottom up" approach to accomplish the goals set out in AB 32. SB 375 ensures the inclusion of cities and counties in the regional planning process, and specifically the plans intended to reduce GHG emissions from cars and light trucks. Given the importance of local involvement to accomplish emission reduction goals, SB 375 also strengthens the requirements for public involvement in planning. It also establishes a collaborative process that includes regional and state agencies, while cities and counties maintain their existing authority. Metropolitan Planning Organizations (MPOs) will collaborate with ARB to develop regional targets, and each MPO must include a "Sustainable Communities Strategy" in the regional transportation plan. The Sustainable Communities Strategy will influence transportation funding allocation. SB 375 has three major components: (1) use the regional transportation plans to achieve reductions in GHGs, (2) offer CEQA incentives to encourage projects that reduce GHG emissions, and (3) coordinate regional housing needs allocation with transportation process, considering local authority over land use decisions.

[Senate Bill 535 \(SB 535; Disadvantaged Communities\) \[93\] \[85\] \[94\] \[95\]](#)

SB 535 builds upon the California Global Warming Solutions Act of 2006 which requires that CARB adopt regulations for reporting and verification of GHG emissions, monitor and enforce reporting and verification, and adopt a statewide GHG emissions limit (2020 should have no more than 1990 GHG emissions). The money collected by the state board from auction or sales of allowances of market-based

compliance mechanism must be deposited to the Greenhouse Gas Reduction Fund. SB 535 requires the California Environmental Protection Agency to identify disadvantaged communities. 25% of the Greenhouse Gas Reduction Fund must then be allocated to projects that benefit the previously identified disadvantaged communities, and 10% of the money must be used for projects within the disadvantaged communities.

[Senate Bill 617 \(SB 617\) \[96\]](#)

SB 617 expands upon CEQA requirements for an EIR or a negative declaration submission. SB 617 requires that the EIR or negative declaration, or the notice of determination must be filed with the Office of Planning and Research as well as the county clerk. This bill requires each of them to post the EIR or negative declaration for 30 days for public review. In addition, SB 617 requires the lead agency for a given project to additionally identify significant effects that could result from the location of the proposed project (i.e., is it near, or attracting people to, existing or foreseeable natural hazards or adverse environmental conditions?).

[Senate Bill 743 \(SB 743\) \[97\] \[98\]](#)

SB 743 addresses transportation impacts on the environment, and health and safety. This bill seeks to ensure that transportation projects include options that allow Californians to drive less. This includes considering infill development, promotion of active transportation and reduced GHG emissions in congestion management initiatives. Specifically, SB 743 requires the California Governor's Office of Planning and Research identify new metrics for identifying and mitigating transportation impacts.

[Advanced Clean Trucks \(ACT\) \[99\]](#)

On June 25, 2020, the Advanced Clean Trucks Regulation was passed, which begins the large-scale transition to electric zero-emission heavy trucks. Beginning in 2024, truck manufacturers will need to transition from diesel trucks and vans to electric zero-emission trucks. Then, by 2045 all new trucks sold in California will be zero-emission. In addition, this regulation should address the disproportionate burden placed on vulnerable communities by adjacent freight facilities and corridors. These communities are addressed via zero-emission short-haul drayage fleets in ports and railyards by 2035 and zero-emission last-mile vehicles by 2040. For land use projects this entails using vehicle miles traveled as a metric for transportation analysis. Lead agencies have more discretion to choose appropriate metrics for transportation projects.

[Advanced Clean Fleet Rule \(in development\) \[100\]](#)

This regulation from CARB will be aimed at achieving a zero-emission bus and truck fleet by 2045 in California, at least in the sectors that this is feasible, and earlier than 2045 for segments such as drayage and last-mile delivery. Their goal is to help the freight industry transition toward zero-emission medium and heavy-duty fleets.

[National Ambient Air Quality Standards \(NAAQS\) \[101\] \[102\]](#)

The U.S. Environmental Protection Agency has established a set of national health-based air quality standards, guided by the Clean Air Act. The NAAQS include identification of criteria air pollutants that are common in outdoor air, harmful to public health and the environment, and that come from variable sources. The criteria pollutants include carbon monoxide, ozone, lead, nitrogen dioxide, particulate matter, and sulfur dioxide. More scientific and technical information about each of these pollutants can be found on the [EPA website](#). The NAAQS are updated frequently and evolve with added information, goals, and accomplishments.

Within the SJV, the NAAQS has inspired several measures and rules to satisfy the requirements. This includes emissions inventories, identification of air pollutant sources, feasibility evaluations of potential

emission reduction opportunities, modeling to predict future circumstances, and strategy development to continue to decrease emissions.

[Intermodal Surface Transportation Efficiency Act of 1991 \(ISTEA\) \[103\]](#)

ISTEA was intended to develop a National Intermodal Transportation System to make the U.S. more competitive in the global economy. They also included the stipulations that the system should be economically efficient, environmentally sound and move people and goods in a way that was energy efficient. Some of the specificities of this act include that the National Highway System was established to ensure that Federal resources are allocated to projects that improve interstate connectivity and national defense, connect other modes of transportation, and those that might be important for international commerce. State and local governments were given more flexibility and guidance in evaluating transportation solutions, modern technologies were funded, and private sector funding was included as a potential for system improvements. Highway funds were made available for activities that improve the environmental impacts. In addition, highway safety was enhanced (safety belts and motorcycle helmets encouraged), and vehicle registration and fuel tax reporting were made more uniform to ease the recordkeeping and reporting burdens, thereby improving the productivity of truck and bus industries.

[Transportation Equity Act for the 21st Century \(TEA-21\) \[104\] \[105\]](#)

TEA-21 is the follow-up legislation to ISTEA. Some of the significant features are identified by the Federal Highway Administration as: (1) a guaranteed level of federal funds for surface transportation (at least through 2003), (2) extension of the disadvantaged business enterprise program to provide more opportunity for disadvantaged businesses to have access to highway and transit contracts, (3) strengthening safety programs across the Department of Transportation, (4) continuation and enhancement of ISTEA structures, such as flexible use of funds, emphasis on environmental improvements, and others, and (5) invest in research and application of the research to maximize transportation system performance.

Specifically, in terms of the environmental regulations, TEA-21 includes items such as ensuring active modes of transportation are considered in planning and facility design, safety and education activities for active modes are eligible for transportation enhancement funds and establishing monitoring capabilities of PM_{2.5} pollutants across the country.

[Clean Air Act \(CAA\) \[106\] \[107\] \[108\] \[109\]](#)

The CAA regulates the composition of transportation fuels as well as the emission-control components. For transportation purposes, the regulations limit the emissions of non-methane hydrocarbons (NMHC), carbon monoxide (CO), nitrogen oxides (NO_x), and particulate matter (PM; from diesel vehicles). The CAA requires states to adopt plans that will maintain air quality standards and have enforceable requirements.

[NEPA \[110\]](#)

NEPA was largely established to ensure, at a national level, that environmental impacts be a major consideration in all official (i.e. governmental, institutional, etc.) activities. NEPA states that entities should recognize the “...critical importance of restoring and maintaining environmental quality...” and “...use all practicable means and measures, including financial and technical assistance, in a manner calculated to foster and promote the general welfare, to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans.” Meaning, all measures should be taken to minimize environmental impacts while also meeting all the needs of communities.

NEPA also establishes the Council on Environmental Quality (CEQ) who are responsible for assisting and advising the U.S. president with: (1) the Environmental Quality Report (also a requirement established in

NEPA), (2) gather information about the environmental conditions within the U.S., (3) participate in current and potential programs/activities by the federal government that might help achieve improved environmental conditions, (4) develop and recommend relevant national policies, (5) conduct environmental investigations, studies, surveys, research, and analyses, (6) document and define environmental changes, (7) annually report the state of the environment to the president, and (8) utilize the work done in (5) to recommend legislative measures the president can or should undertake.

[CEQA \[111\]](#)

CEQA dictates that state and local governments are informed about the environmental impacts that projects could potentially induce and minimize those impacts to the best of their abilities. If projects have the potential to result in negative environmental impacts, a detailed report (an EIR) of those impacts must be produced, including the measures that can be taken to reduce or avoid those impacts or alternative projects. If the project will not result in negative environmental impacts, a Negative Declaration is issued. Importantly, CEQA ensures that the public can review and respond to the EIR or the Negative Declaration.

[Clean Air Action Plan \(CAAP\) \[112\] \[113\] \[114\]](#)

The Clean Air Action Plan is an aggressive clean air strategy focused on reducing emissions from the Port of Long Beach and the Port of Los Angeles container port complexes. Specifically, the CAAP is intended to bring these ports closer to a zero-emission future while maintaining their economic competitiveness on the global scale [112].

The strategies utilized covered ships, trucks, trains, cargo-handling equipment, harbor craft, and energy. For this report, trucks are the main area of interest. Under CAAP, the ports banned trucks from before 1989 in 2008 as well as a ban on all trucks that did not meet 2007 emission standards by the year 2012 [113].

Another component of interest is the Technology Advancement Program. This program identifies funding priorities for clean technologies and required infrastructure. Zero- and near-zero emissions cargo handling equipment and heavy-duty on-road trucks, and harbor craft, ship, and locomotive technologies [114].

[Electronic Logging Devices Mandate \[115\]](#)

As part of the Moving Ahead for Progress in the 21st Century Act, the use of Electronic Logging Devices (ELDs) are mandated to create safer work environments for drivers. This mandate was also intended to allow easier, faster, and more accurate tracking, management, sharing of records of duty status data. These devices connect to the vehicle engine to record driving time and hours of service.

[Vehicle Size](#)

[Length \[116\]](#)

Any single unit may not exceed 40 feet. This does not include:

- Auxiliary parts
- Fender and mudguard parts
- An articulated bus or trolley coach not exceeding 60 feet or with a 3-foot folding device for bike transport
- A semitrailer (with two axles not to exceed 40 feet, with one axle not to exceed 38 feet)
- 1-foot front or rear safety bumper on buses or house cars
- 10-inch crossing arm for school buses
- 18-inch wheelchair lift on buses
- 10-foot bus bike rack (as long as the total length does not exceed 50 feet)

- 36-inch bike rack on a 40-foot transit bus (45-foot bus on approved routes)
- 45-foot house car on approved routes
 - A house car is a vehicle designed or altered and equipped for human habitation
- 48-foot cotton module mover
- B-train assembly when used between the first and second semitrailers (if there is no second semitrailer, it is included in the length measurement of the single semitrailer that it is attached to)
- Forklifts that are being transported on the back of a truck

Vehicle combinations should not exceed a length of 65 feet, although a combination of truck tractor, a semitrailer, and a semitrailer or trailer cannot exceed 75 feet. Importantly, the semitrailers or trailers cannot exceed 28 feet and 6 inches.

Exceptions are made for these length requirements on the National Network and Terminal Access routes if the following conditions are met:

- The semitrailer in exclusive combination with a truck tractor does not exceed 48 feet
- The semitrailer does not exceed 53 feet with two or more rear axles and 40-foot kingpin to rear axle length (for a single axle the kingpin to rear axle length should be no more than 38 feet)
 - Cities, counties, and the department of transportation can restrict the kingpin to rearmost axle length to 38 feet (not less); advisory signs should be posted on highways that have been restricted
 - Cities and counties can prohibit combination vehicles that exceed 60 feet
 - Combination vehicles with kingpin to rear axle lengths between 38 and 40 feet can operate on local highways only where it is deemed to be safe by the vehicle owner/operator
- For doubles, neither the semitrailer nor the trailer can exceed 28 feet 6 inches

Importantly, STAA vehicles are allowed to use highways that provide them access to terminals and facilities for fuel, food, lodging or repair within one road mile of identified exits. Even more, the Department or local authorities may establish a process for STAA trucks to access terminals or services. Denial of a request can only be granted based on safety concerns or engineering analysis. If a request does not receive a response within 90 days or receipt by the department/local agency, the access is automatically approved (and the route is then considered to be open for all other STAA vehicles).

The number of vehicles in combinations are subject to the following distinctions:

- No passenger vehicles or vehicles under 4,000 pounds can tow more than one vehicle (tow dollies excluded)
 - Passenger vehicles includes house cars
- No vehicle under 4,000 pounds can tow a vehicle over 6,000 pounds

Even more, for California residents a Class A driver's license endorsement is required to haul double trailers. Class A driver's licenses allow any combination of vehicles if any vehicle being towed is more than 10,000 pounds and towing any more than one vehicle.

For non-California residents, drivers may tow two trailers without a commercial license so long as their base state allows it. California does, however, require a valid medical certificate (per 12502 CVC).

Further exemptions are made for situational hauling, such as rear fairings (for aerodynamic purposes), agricultural product haulers, tow trucks, auto, boat and camper transporters, household goods movers, motorsports events, livestock haulers and agricultural biomass haulers.

There are specific rules in place for load lengths and the use of extensions.

Width [117]

The width of any vehicle or load cannot exceed 102 inches although cities and counties may limit this width to 96 inches. Some exemptions include:

- When a vehicle is equipped with pneumatic tires, the maximum width should be measured from the outside of the wheels and should not exceed 108 inches
- The width of a cotton module mover (and load) should not exceed 130 inches
- When a vehicle carries a load of loosely piled agricultural products in bulk, the width should not exceed 120 inches
- Special mobile equipment, special construction or highway maintenance equipment, vehicle carrying feed or livestock that are exempt from registration should not exceed a width of 120 inches
- Passenger vehicles are restricted from highways when carrying a load extending beyond the line of the fenders on its left side or more than six inches beyond the line of the fenders on the right side
- Safety devices are not included in the calculation of width
- Recreational vehicles may exceed the maximum width so long as the excess width is from appurtenance (which exceeds no more than six inches beyond either sidewall)
- Required lights, mirrors or devices may extend up to 10 inches on each side
- Door handles, hinges, cable cinchers, warning placard holders may extend up to 3 inches on each side
- Maximum permitted width is 108 inches, although the following should not extend beyond 3 inches on either side of the vehicle
 - Door handles, cable cinchers, chain binders, corner caps, rear and side door hinges and protective hardware, rain gutters, side marker lamps, lift pads for 'piggyback' trailers, tarps, and tarp hardware, tiedown assemblies on platform trailers, wall variations from true flat, weevil pins, and sockets on low bed trailers

Weight [118]

The gross weight (GW) of a one-axle cannot exceed 20,000 pounds and the GW on one wheel or wheels supporting one end of an axle cannot exceed 10,500 pounds (does not apply to loads of livestock).

The maximum wheel load should be the lesser of the following: (a) the load limit established by the tire manufacturer, or (b) 620 pounds per lateral inch of tire width. The axle group weight chart is also available, defining the GW imposed on the highway based on number of axles and the distance between the extremes of any group of two or more consecutive axles. If there are two consecutive sets of tandem axles, they may carry 34,000 pounds each if the distance between the first and last axles is 36 or more feet.

Log haulers are exempt and may exceed tandem weight by 1,500 pounds and carry a GW of 69,000 pounds on two consecutive sets of tandem axles. The total GW of any one set of axles cannot exceed 35,500 pounds and the distance between the first and last axle is 34 feet or more.

Exceptions include:

- Vehicles in the immediate vicinity of unloading and loading areas, or in the process of loading or unloading
- Buses and motorhomes
 - Bus: GW on any one axle cannot exceed 20,500 pounds
 - Buses and motorhomes on interstates: allow bus and motorhomes a maximum weight of 24,000 pounds on any one axle
- Cities and counties may permit loads that exceed the respective previously specified maximum

Further exemptions can be found [here](#).

Appendix E – Summary Pamphlet for Fleets

This section shows a sample summary pamphlet for fleets regarding ZEVs, and all relevant information.

Alternative Fuel Trucks in the San Joaquin Valley

Experience improvements in total cost of ownership, fuel economy, owner and driver satisfaction, and environmental and air quality impacts

What are my options?

The following alternative fuel type vehicles:

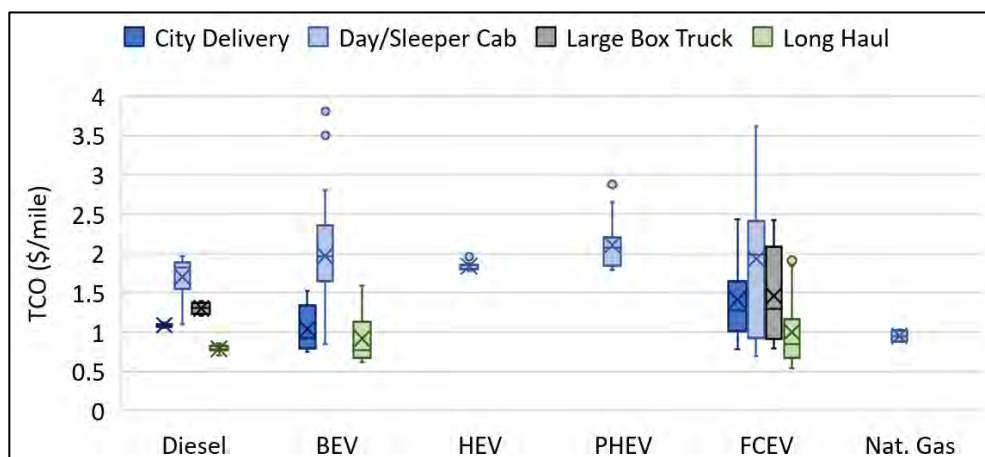
- **Battery Electric Vehicle (BEV)**
- **Hydrogen Fuel Cell Electric Vehicle (FCEV)**
- **Diesel Hybrid Electric Vehicle (HEV)**
- **Diesel Hydraulic Hybrid Vehicle (HHV)**
- **Biodiesel Vehicle**
- **Renewable Diesel Vehicle**
- **E85 Fuel Vehicle**
- **Liquefied Propane Gas Vehicle (LPG)**
- **Compressed Natural Gas Vehicle (CNG)**
- **Liquefied Natural Gas Vehicle (LNG)**

What do they cost?

The purchase price of each vehicle fuel type is summarized in the table below.

	Single Unit Short Haul (\$/veh)	Single Unit Long Haul (\$/veh)	Combination Short Haul (\$/veh)	Combination Long Haul (\$/veh)
Diesel	70,000	75,000	130,000	150,000
BEV	150,000	185,000	242,000	509,000
FCEV	-	-	201,000	255,000
HEV	85,000	90,000	145,000	165,000
HHV	-	-	-	-
Biodiesel	70,000	75,000	130,000	150,000
Renewable Diesel	70,000	75,000	130,000	150,000
E85	-	-	-	-
LPG	78,000	89,000	-	-
CNG	110,000	115,000	170,000	215,000
LNG	100,000	105,000	160,000	200,000

Another important measure is the total cost of ownership (TCO) per mile over the lifetime of the vehicle. Note that these do not include available incentives.



Am I eligible for incentives?

Most available vehicle incentives are from (1) San Joaquin Valley Air Pollution Control District Truck Replacement Program or (2) California's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP). These incentives:

- Range in value from \$20,000 to \$200,000 depending on the vehicle size and model year
- Are available for truck *replacements*
- Are available for operations based in the SJV
- Are intended for operations that are exclusively or primarily in the SJV

More information about these and other incentives (for infrastructure, for example), can be found through:

<https://www.valleyfleetsupport.org/funding-programs/>

<https://ww2.valleyair.org/grants/truck-replacement-program/>

for San Joaquin Valley Air Pollution Control District Truck Replacement Program

<https://www.californiahvip.org/>

for California's HVIP

What else to consider?

1. Ability to perform maintenance and repair needs (mechanics, tools, equipment)
2. Compare current operations to vehicle range and fueling/charging availability at home of operations and on routes used
3. Fuel and infrastructure prices and availability (see current fuel costs below)

What are the advantages and disadvantages?

	Vehicle Range	Fueling/Charging Availability	Fuel Prices	Clean/ Green Tech	TCO
Diesel	+	+	+	-	-
FCEV	+	-	-	+	-
BEVs	-	+	+	+	+
CNG	+	-	+	+	+
LNG	+	-	+	+	-

+ = advantage, - = disadvantage

Appendix F – Total Cost of Ownership

In this section, the total costs of vehicle ownership (TCOs) are broken down according to vehicle size and fuel type. As these technologies emerge and develop the TCOs are expected to change in predictable and unpredictable ways. Given this level of uncertainty, this report aggregates the work of several other TCO studies, outlining the costs included and relevant assumptions. The results are summarized in this section. Because the costs borne to private companies are incurred through vehicle costs, the authors primarily focus on TCOs of vehicle technology rather than infrastructure or support costs; although, a note will be made if these costs are included in the TCO of the vehicle.

Finally, each study was conducted with a distinct set of assumptions and costs considered. Table 42 summarizes the assumptions and costs considered for each TCO study.

Table 42. Summary of TCO Reports

Source	Costs Considered	Details
[39]	For medium-duty and heavy duty BEVs & hydrogen FCEVs: total cost of operation (amortized purchase cost, fuel, maintenance) over 5 (with resale) or 15 years, low discount rate, attempt to capture societal perspective on relative cost	5-year TCO (costs incurred in the initial ownership period)
		15-year TCO (costs incurred in the first 15-years of ownership, meant to be the societal value of the vehicle over its lifetime)
		The mileage markers (150 mi, 300 mi, 500 mi) refer to the assumed range of the BEVs or FCEVs
[119]	For Class 3 passenger vans, Class 6 walk-in step vans, & Class 8 day cab tractor BEVs, & hydrogen FCEVs: vehicle price, taxes, financing, fuel, maintenance, LCFS credit, infrastructure (charging), registration, residual values, midlife costs, discount rate (5%)	2018 constant dollars
		operating life of 12 years, fleet does not replace trucks in 5 years or less
[120]	For compact sedan, midsize sedan, small sport utility vehicle, large sport utility vehicle, pickup trucks, Class 4 delivery, Class 6 delivery, Class 8 bus, Class 8 refuse, Class 8 vocational, Class 8 tractor - day cab, Class 8 tractor - sleeper cab ICEs, HEVs, PHEV, FCEV, & BEVs: purchase cost, depreciation, financing, fuel, insurance, maintenance, repair, taxes, registration fees, tolls and parking, payload capacity, labor	2019 dollars
		10-year vehicle life for medium- and heavy-duty vehicles (15 years for light-duty)
		Including labor fueling costs

Table 43. BEV TCOs

Fuel Type	Vehicle Size	Year	TCO (\$/mi)			Details	Source
			high	base	low		
BEV	(1 MW) Class 8 sleeper cab tractor	2025		2.23		with fueling time costs	[120]
BEV	(2 MW) Class 8 sleeper cab tractor	2025		2.19		with fueling time costs	[120]
BEV	(200 kW) Class 8 sleeper cab tractor	2025		2.56		with fueling time costs	[120]
BEV	(400 kW) Class 8 sleeper cab tractor	2025		2.36		with fueling time costs	[120]
BEV	(50 kW) Class 8 sleeper cab tractor	2025		3.81		with fueling time costs	[120]
BEV	150 mi Class 8 city box delivery	2020	1.43	1.34	1.27	Societal (15-year) TCO	[39]
BEV	150 mi Class 8 city box delivery	2020	1.62	1.53	1.44	Societal (5-year) TCO	[39]
BEV	150 mi Class 8 city box delivery	2025	1.14	1.06	1.02	Societal (15-year) TCO	[39]
BEV	150 mi Class 8 city box delivery	2025	1.29	1.21	1.14	Societal (5-year) TCO	[39]
BEV	150 mi Class 8 city box delivery	2030		1.34		5-year TCO	[39]
BEV	150 mi Class 8 city box delivery	2030	0.91	0.87	0.85	Societal (15-year) TCO	[39]
BEV	150 mi Class 8 city box delivery	2030	0.98	0.92	0.92	Societal (5-year) TCO	[39]
BEV	150 mi Class 8 city box delivery	2035	0.82	0.79	0.77	Societal (15-year) TCO	[39]
BEV	150 mi Class 8 city box delivery	2035	0.87	0.84	0.83	Societal (5-year) TCO	[39]
BEV	150 mi Class 8 city box delivery	2040	0.76	0.75	0.72	Societal (15-year) TCO	[39]
BEV	150 mi Class 8 city box delivery	2040	0.79	0.78	0.75	Societal (5-year) TCO	[39]
BEV	250 mi Class 8 day cab tractor	2020		2.81			[120]
BEV	250 mi Class 8 day cab tractor	2025		1.97			[120]
BEV	250 mi Class 8 day cab tractor	2030		1.79			[120]
BEV	250 mi Class 8 day cab tractor	2035		1.71			[120]
BEV	250 mi Class 8 day cab tractor	2040		1.66			[120]
BEV	300 mi long haul truck	2020	1.40	1.30	1.20	Societal (15-year) TCO	[39]
BEV	300 mi long haul truck	2020	1.52	1.43	1.33	Societal (5-year) TCO	[39]
BEV	300 mi long haul truck	2025	1.05	0.97	0.90	Societal (15-year) TCO	[39]
BEV	300 mi long haul truck	2025	1.14	1.07	0.99	Societal (5-year) TCO	[39]
BEV	300 mi long haul truck	2030	0.80	0.76	0.71	Societal (15-year) TCO	[39]
BEV	300 mi long haul truck	2030	0.82	0.76	0.70	Societal (5-year) TCO	[39]
BEV	300 mi long haul truck	2035	0.70	0.68	0.66	Societal (15-year) TCO	[39]
BEV	300 mi long haul truck	2035	0.71	0.67	0.64	Societal (5-year) TCO	[39]
BEV	300 mi long haul truck	2040	0.66	0.65	0.64	Societal (15-year) TCO	[39]
BEV	300 mi long haul truck	2040	0.63	0.62	0.61	Societal (5-year) TCO	[39]
BEV	500 mi Class 8 day cab tractor	2025		1.97			[120]
BEV	500 mi Class 8 sleeper cab tractor	2020		3.50			[120]
BEV	500 mi Class 8 sleeper cab tractor	2025		2.15			[120]
BEV	500 mi Class 8 sleeper cab tractor	2025		2.46		3-year ownership	[120]
BEV	500 mi Class 8 sleeper cab tractor	2025		2.15			[120]
BEV	500 mi Class 8 sleeper cab tractor	2030		1.84			[120]
BEV	500 mi Class 8 sleeper cab tractor	2035		1.71			[120]
BEV	500 mi Class 8 sleeper cab tractor	2040		1.65			[120]
BEV	500 mi long haul truck	2020	1.57	1.44	1.32	Societal (15-year) TCO	[39]
BEV	500 mi long haul truck	2020	1.70	1.59	1.47	Societal (5-year) TCO	[39]
BEV	500 mi long haul truck	2025	1.14	1.05	0.96	Societal (15-year) TCO	[39]
BEV	500 mi long haul truck	2025	1.25	1.15	1.06	Societal (5-year) TCO	[39]
BEV	500 mi long haul truck	2030	0.85	0.79	0.73	Societal (15-year) TCO	[39]
BEV	500 mi long haul truck	2030	0.85	0.78	0.70	Societal (5-year) TCO	[39]
BEV	500 mi long haul truck	2035	0.73	0.70	0.67	Societal (15-year) TCO	[39]
BEV	500 mi long haul truck	2035	0.72	0.68	0.64	Societal (5-year) TCO	[39]
BEV	500 mi long haul truck	2040	0.67	0.66	0.65	Societal (15-year) TCO	[39]
BEV	500 mi long haul truck	2040	0.63	0.62	0.61	Societal (5-year) TCO	[39]
BEV	Day cab tractor	2025		0.85			[119]
BEV	Day cab tractor	2030		0.88			[119]
BEV	Day cab tractor	2035		0.96			[119]
BEV	Sleeper cab tractor	2030		1.02			[119]
BEV	Sleeper cab tractor	2035		1.10			[119]

Table 44. FCEV TCOs

Fuel Type	Vehicle Size	Year	TCO (\$/mi)			Details	Source
			high	base	low		
FCEV	150 mi Class 8 city box delivery	2020	2.42	2.29	2.17	Societal (15-year) TCO	[39]
FCEV	150 mi Class 8 city box delivery	2020	2.62	2.44	2.25	Societal (5-year) TCO	[39]
FCEV	150 mi Class 8 city box delivery	2025	1.65	1.62	1.59	Societal (15-year) TCO	[39]
FCEV	150 mi Class 8 city box delivery	2025	1.70	1.65	1.61	Societal (5-year) TCO	[39]
FCEV	150 mi Class 8 city box delivery	2030		1.34		5-year TCO	[39]
FCEV	150 mi Class 8 city box delivery	2030	1.26	1.24	1.22	Societal (15-year) TCO	[39]
FCEV	150 mi Class 8 city box delivery	2030	1.30	1.27	1.25	Societal (5-year) TCO	[39]
FCEV	150 mi Class 8 city box delivery	2035	1.02	1.01	0.99	Societal (15-year) TCO	[39]
FCEV	150 mi Class 8 city box delivery	2035	1.07	1.05	1.03	Societal (5-year) TCO	[39]
FCEV	150 mi Class 8 city box delivery	2040	0.78	0.78	0.77	Societal (15-year) TCO	[39]
FCEV	150 mi Class 8 city box delivery	2040	0.85	0.84	0.83	Societal (5-year) TCO	[39]
FCEV	300 mi long haul truck	2020		1.30		Societal TCO	[39]
FCEV	300 mi long haul truck	2020	2.00	1.91	1.82	Societal (15-year) TCO	[39]
FCEV	300 mi long haul truck	2020	2.10	1.97	1.83	Societal (5-year) TCO	[39]
FCEV	300 mi long haul truck	2025		0.89		Societal TCO	[39]
FCEV	300 mi long haul truck	2025	1.18	1.16	1.14	Societal (15-year) TCO	[39]
FCEV	300 mi long haul truck	2025	1.20	1.16	1.13	Societal (5-year) TCO	[39]
FCEV	300 mi long haul truck	2030		0.72		Societal TCO	[39]
FCEV	300 mi long haul truck	2030	0.90	0.89	0.87	Societal (15-year) TCO	[39]
FCEV	300 mi long haul truck	2030	0.90	0.88	0.86	Societal (5-year) TCO	[39]
FCEV	300 mi long haul truck	2035		0.62		Societal TCO	[39]
FCEV	300 mi long haul truck	2035	0.76	0.75	0.75	Societal (15-year) TCO	[39]
FCEV	300 mi long haul truck	2035	0.77	0.76	0.74	Societal (5-year) TCO	[39]
FCEV	300 mi long haul truck	2040		0.54		Societal TCO	[39]
FCEV	300 mi long haul truck	2040	0.64	0.64	0.63	Societal (15-year) TCO	[39]
FCEV	300 mi long haul truck	2040	0.66	0.65	0.64	Societal (5-year) TCO	[39]
FCEV	500 mi long haul truck	2020	1.89	1.82	1.75	Societal (15-year) TCO	[39]
FCEV	500 mi long haul truck	2020	1.94	1.84	1.73	Societal (5-year) TCO	[39]
FCEV	500 mi long haul truck	2025	1.13	1.12	1.10	Societal (15-year) TCO	[39]
FCEV	500 mi long haul truck	2025	1.12	1.10	1.07	Societal (5-year) TCO	[39]
FCEV	500 mi long haul truck	2030	0.86	0.85	0.84	Societal (15-year) TCO	[39]
FCEV	500 mi long haul truck	2030	0.84	0.82	0.81	Societal (5-year) TCO	[39]
FCEV	500 mi long haul truck	2035	0.73	0.72	0.71	Societal (15-year) TCO	[39]
FCEV	500 mi long haul truck	2035	0.71	0.70	0.69	Societal (5-year) TCO	[39]
FCEV	500 mi long haul truck	2040	0.61	0.61	0.60	Societal (15-year) TCO	[39]
FCEV	500 mi long haul truck	2040	0.60	0.60	0.59	Societal (5-year) TCO	[39]
FCEV	Class 8 day cab tractor	2020		3.62			[120]
FCEV	Class 8 day cab tractor	2025		2.41			[120]
FCEV	Class 8 day cab tractor	2025		2.41			[120]
FCEV	Class 8 day cab tractor	2030		2.07			[120]
FCEV	Class 8 day cab tractor	2035		1.99			[120]
FCEV	Class 8 day cab tractor	2040		1.89			[120]
FCEV	Class 8 large box truck	2020		2.42		Societal TCO	[39]
FCEV	Class 8 large box truck	2025		1.76		Societal TCO	[39]
FCEV	Class 8 large box truck	2030		1.30		Societal TCO	[39]
FCEV	Class 8 large box truck	2035		1.04		Societal TCO	[39]
FCEV	Class 8 large box truck	2040		0.79		Societal TCO	[39]
FCEV	Class 8 sleeper cab tractor	2020		3.37			[120]
FCEV	Class 8 sleeper cab tractor	2025		2.30			[120]
FCEV	Class 8 sleeper cab tractor	2025		2.64		3-year ownership	[120]
FCEV	Class 8 sleeper cab tractor	2025		2.30			[120]
FCEV	Class 8 sleeper cab tractor	2030		1.98			[120]

FCEV	Class 8 sleeper cab tractor	2035		1.90		[120]
FCEV	Class 8 sleeper cab tractor	2040		1.82		[120]
FCEV	Day cab tractor	2025		0.93		[119]
FCEV	Day cab tractor	2030		0.86		[119]
FCEV	Day cab tractor	2035		0.89		[119]
FCEV	Sleeper cab tractor	2030		0.70		[119]
FCEV	Sleeper cab tractor	2035		0.73		[119]

Table 45. Diesel-Fueled Vehicle TCOs

Fuel Type	Vehicle Size	Year	TCO (\$/mi)	Details	Source
Diesel	150 mi Class 8 city box delivery	2020	1.06	Societal (15-year) TCO	[39]
Diesel	150 mi Class 8 city box delivery	2020	1.08	Societal (5-year) TCO	[39]
Diesel	150 mi Class 8 city box delivery	2025	1.07	Societal (15-year) TCO	[39]
Diesel	150 mi Class 8 city box delivery	2025	1.09	Societal (5-year) TCO	[39]
Diesel	150 mi Class 8 city box delivery	2030	1.08	Societal (15-year) TCO	[39]
Diesel	150 mi Class 8 city box delivery	2030	1.11	Societal (5-year) TCO	[39]
Diesel	150 mi Class 8 city box delivery	2035	1.09	Societal (15-year) TCO	[39]
Diesel	150 mi Class 8 city box delivery	2035	1.12	Societal (5-year) TCO	[39]
Diesel	150 mi Class 8 city box delivery	2040	1.07	Societal (15-year) TCO	[39]
Diesel	150 mi Class 8 city box delivery	2040	1.10	Societal (5-year) TCO	[39]
Diesel	300 mi long haul truck	2020	0.86	Societal (15-year) TCO	[39]
Diesel	300 mi long haul truck	2020	0.84	Societal (5-year) TCO	[39]
Diesel	300 mi long haul truck	2025	0.85	Societal (15-year) TCO	[39]
Diesel	300 mi long haul truck	2025	0.83	Societal (5-year) TCO	[39]
Diesel	300 mi long haul truck	2030	0.80	Societal (15-year) TCO	[39]
Diesel	300 mi long haul truck	2030	0.79	Societal (5-year) TCO	[39]
Diesel	300 mi long haul truck	2035	0.81	Societal (15-year) TCO	[39]
Diesel	300 mi long haul truck	2035	0.80	Societal (5-year) TCO	[39]
Diesel	300 mi long haul truck	2040	0.77	Societal (15-year) TCO	[39]
Diesel	300 mi long haul truck	2040	0.77	Societal (5-year) TCO	[39]
Diesel	500 mi long haul truck	2020	0.83	Societal (15-year) TCO	[39]
Diesel	500 mi long haul truck	2020	0.78	Societal (5-year) TCO	[39]
Diesel	500 mi long haul truck	2025	0.82	Societal (15-year) TCO	[39]
Diesel	500 mi long haul truck	2025	0.78	Societal (5-year) TCO	[39]
Diesel	500 mi long haul truck	2030	0.77	Societal (15-year) TCO	[39]
Diesel	500 mi long haul truck	2030	0.73	Societal (5-year) TCO	[39]
Diesel	500 mi long haul truck	2035	0.77	Societal (15-year) TCO	[39]
Diesel	500 mi long haul truck	2035	0.74	Societal (5-year) TCO	[39]
Diesel	500 mi long haul truck	2040	0.73	Societal (15-year) TCO	[39]
Diesel	500 mi long haul truck	2040	0.71	Societal (5-year) TCO	[39]
Diesel	Class 8 day cab tractor	2020	1.96		[120]
Diesel	Class 8 day cab tractor	2025	1.89		[120]
Diesel	Class 8 day cab tractor	2025	1.89		[120]
Diesel	Class 8 day cab tractor	2030	1.89		[120]
Diesel	Class 8 day cab tractor	2035	1.88		[120]
Diesel	Class 8 day cab tractor	2040	1.89		[120]
Diesel	Class 8 large box truck	2020	1.21	Societal TCO	[39]
Diesel	Class 8 large box truck	2025	1.26	Societal TCO	[39]
Diesel	Class 8 large box truck	2030	1.31	Societal TCO	[39]
Diesel	Class 8 large box truck	2035	1.35	Societal TCO	[39]
Diesel	Class 8 large box truck	2040	1.39	Societal TCO	[39]

Diesel	Class 8 Refuse	2025	6.01		[120]
Diesel	Class 8 sleeper cab tractor	2020	1.88		[120]
Diesel	Class 8 sleeper cab tractor	2025	1.82		[120]
Diesel	Class 8 sleeper cab tractor	2025	1.86	3-year ownership	[120]
Diesel	Class 8 sleeper cab tractor	2025	1.82	with fueling time costs	[120]
Diesel	Class 8 sleeper cab tractor	2025	1.82		[120]
Diesel	Class 8 sleeper cab tractor	2030	1.81		[120]
Diesel	Class 8 sleeper cab tractor	2035	1.80		[120]
Diesel	Class 8 sleeper cab tractor	2040	1.81		[120]
Diesel	Class 8 Vocational	2025	4.07		[120]
Diesel	Day cab tractor	2025	1.10		[119]
Diesel	Day cab tractor	2030	1.28		[119]
Diesel	Day cab tractor	2035	1.30		[119]
Diesel	Sleeper cab tractor	2030	1.12		[119]
Diesel	Sleeper cab tractor	2035	1.15		[119]
Diesel	Tractor - Day cab	2025	1.89		[120]
Diesel	Tractor - Sleeper	2025	1.82		[120]

Table 46. HEV TCOs

Fuel Type	Vehicle Size	Year	TCO (\$/mi)	Details	Source
HEV	Class 8 day cab tractor	2025	1.86		[120]
HEV	Class 8 sleeper cab tractor	2020	1.88		[120]
HEV	Class 8 sleeper cab tractor	2020	1.96		[120]
HEV	Class 8 sleeper cab tractor	2025	1.80		[120]
HEV	Class 8 sleeper cab tractor	2025	1.86		[120]
HEV	Class 8 sleeper cab tractor	2025	1.80		[120]
HEV	Class 8 sleeper cab tractor	2025	1.86	3-year ownership	[120]
HEV	Class 8 sleeper cab tractor	2030	1.79		[120]
HEV	Class 8 sleeper cab tractor	2030	1.85		[120]
HEV	Class 8 sleeper cab tractor	2035	1.78		[120]
HEV	Class 8 sleeper cab tractor	2035	1.84		[120]
HEV	Class 8 sleeper cab tractor	2040	1.78		[120]
HEV	Class 8 sleeper cab tractor	2040	1.86		[120]

Table 47. Natural Gas Vehicle TCOs

Fuel Type	Vehicle Size	Year	TCO (\$/mi)	Source
Nat. Gas	Day cab tractor	2025	0.95	[119]
Nat. Gas	Day cab tractor	2030	1.03	[119]
Nat. Gas	Day cab tractor	2035	1.02	[119]
Nat. Gas	Sleeper cab tractor	2030	0.89	[119]
Nat. Gas	Sleeper cab tractor	2035	0.88	[119]

Table 48. PHEV TCOs

Fuel Type	Vehicle Size	Year	TCO (\$/mi)	Details	Source
PHEV	125 mi Class 8 day cab tractor	2020	2.65		[120]
PHEV	125 mi Class 8 day cab tractor	2025	2.07		[120]
PHEV	125 mi Class 8 day cab tractor	2030	1.93		[120]
PHEV	125 mi Class 8 day cab tractor	2035	1.86		[120]
PHEV	125 mi Class 8 day cab tractor	2040	1.83		[120]
PHEV	250 mi Class 8 day cab tractor	2025	2.07		[120]
PHEV	250 mi Class 8 sleeper cab tractor	2020	2.88		[120]
PHEV	250 mi Class 8 sleeper cab tractor	2025	2.12		[120]
PHEV	250 mi Class 8 sleeper cab tractor	2025	2.12		[120]
PHEV	250 mi Class 8 sleeper cab tractor	2025	2.29	3-year ownership	[120]
PHEV	250 mi Class 8 sleeper cab tractor	2030	1.92		[120]
PHEV	250 mi Class 8 sleeper cab tractor	2035	1.83		[120]
PHEV	250 mi Class 8 sleeper cab tractor	2040	1.79		[120]

Alternative Fuel Life-Cycle Environment and Economic Transportation (AFLEET) Tool

This section presents other AFLEET results, including the total TCO without externalities (the TCO *with* externalities are presented in Section 4.5), and a breakdown of externalities for each vehicle type. These results are presented for the four truck-types included in the AFLEET analysis, single unit short haul, single unit long haul, combination short haul, and combination long haul.

Single Unit Short Haul Truck

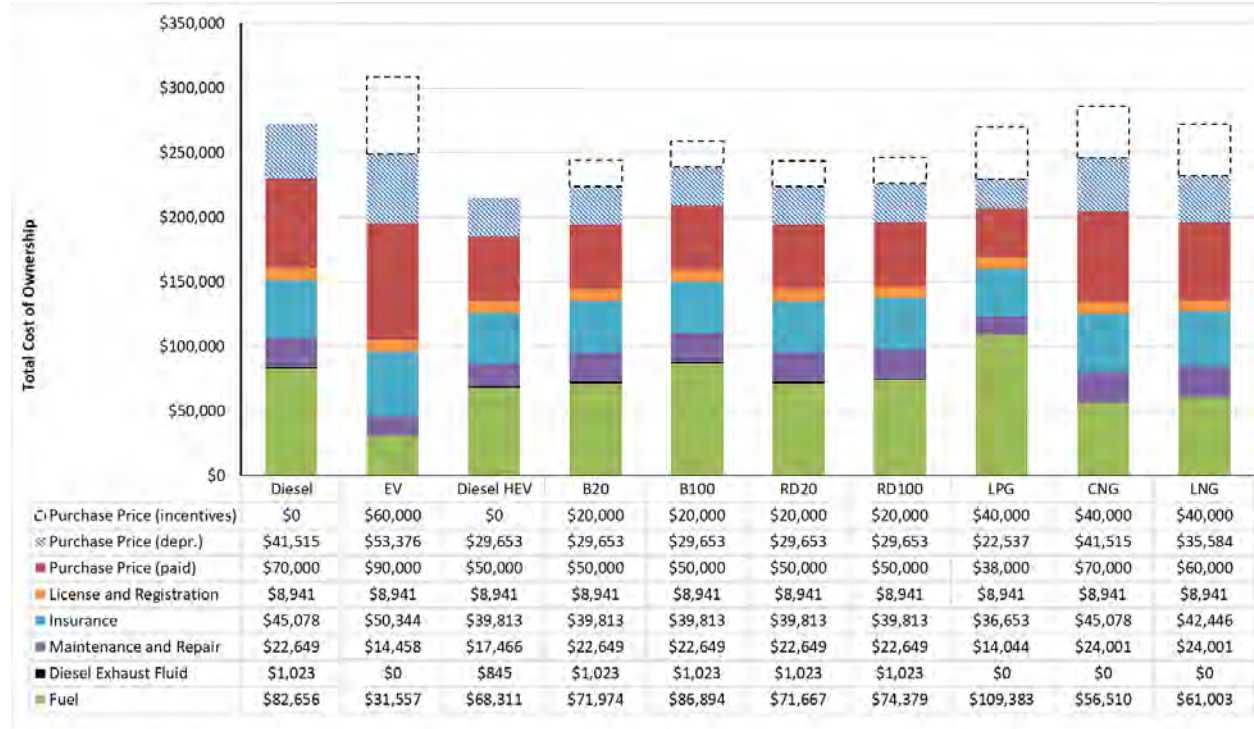


Figure 42. Single unit short haul truck TCO excluding cost of externalities

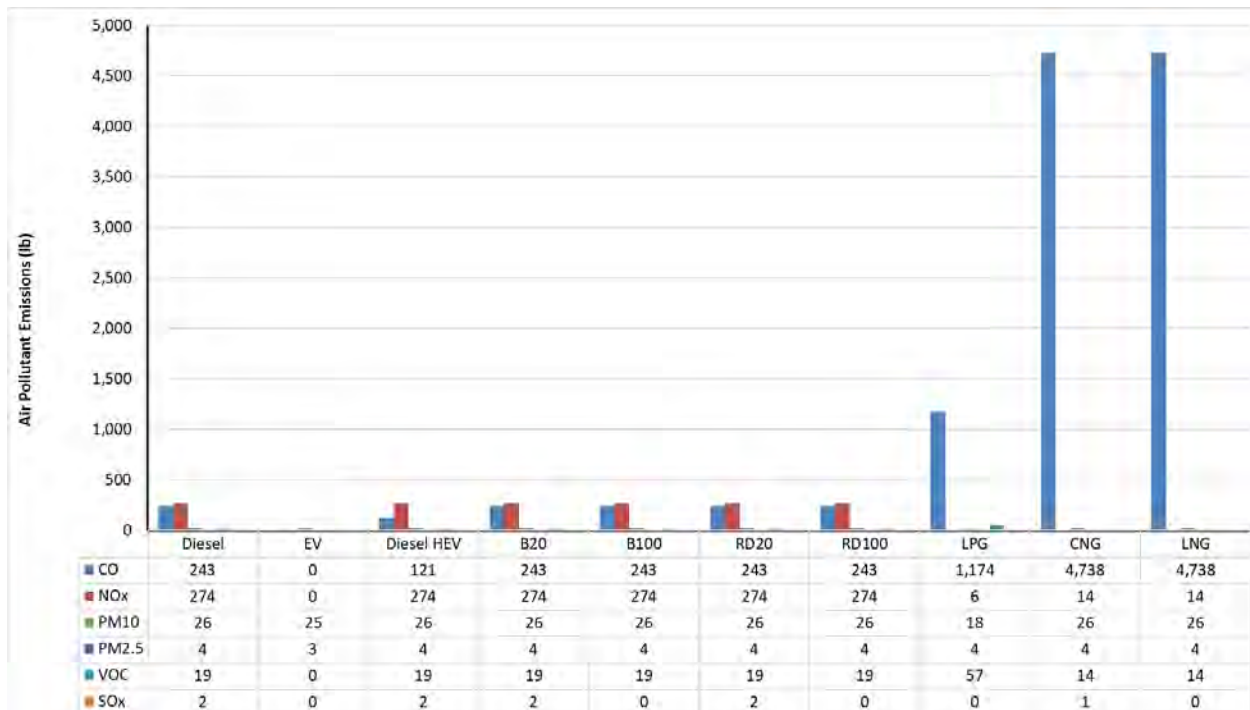


Figure 43. Single unit short haul truck emissions quantities

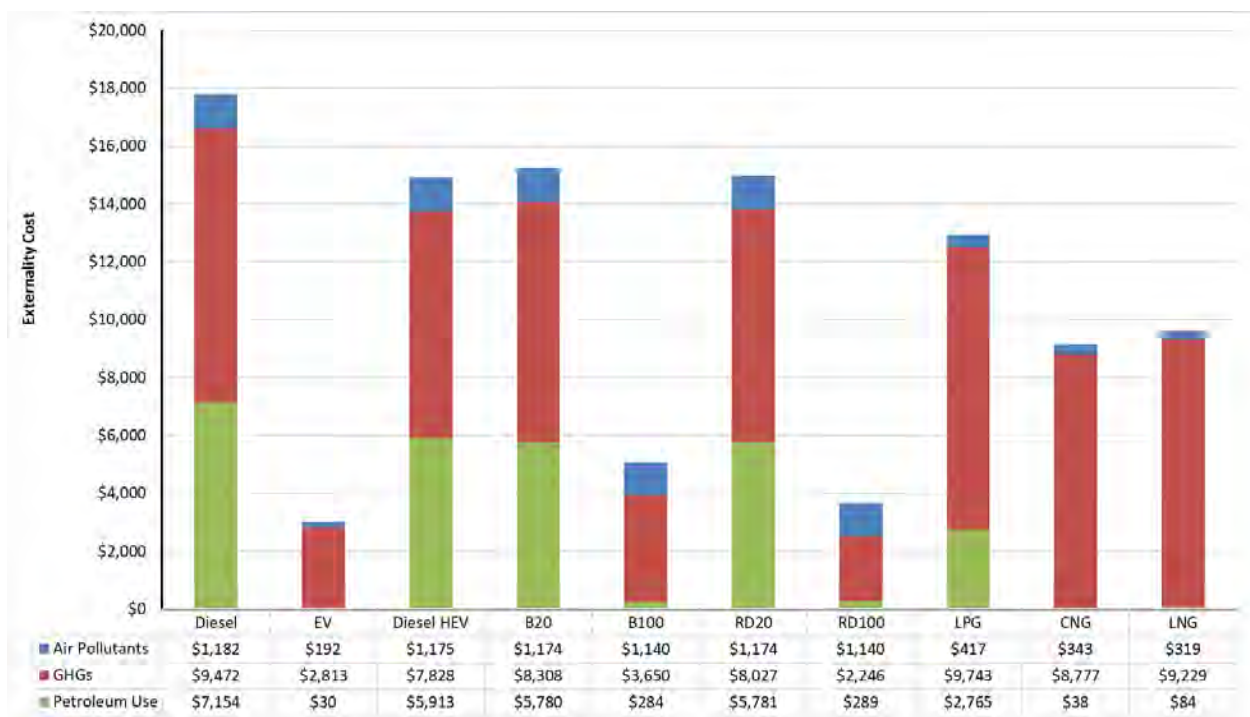


Figure 44. Single unit short haul truck externality cost breakdowns

Single Unit Long Haul Truck

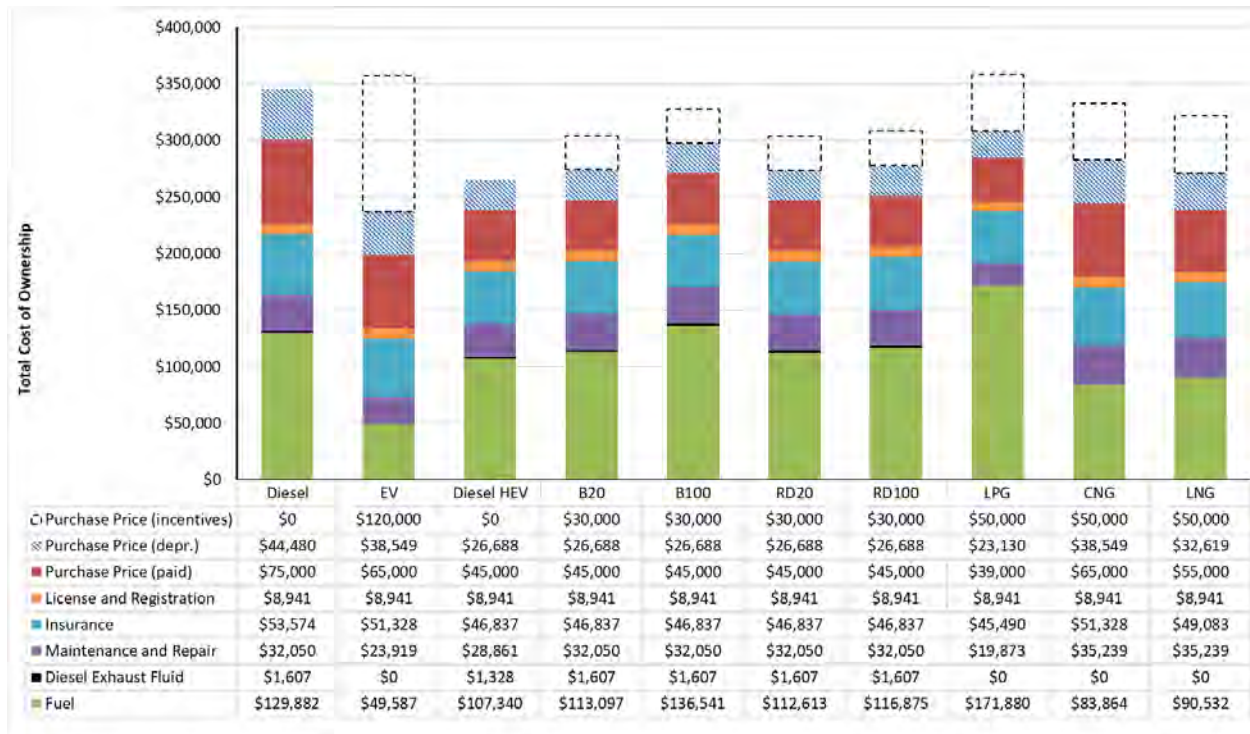


Figure 45. Single unit long truck TCO excluding cost of externalities

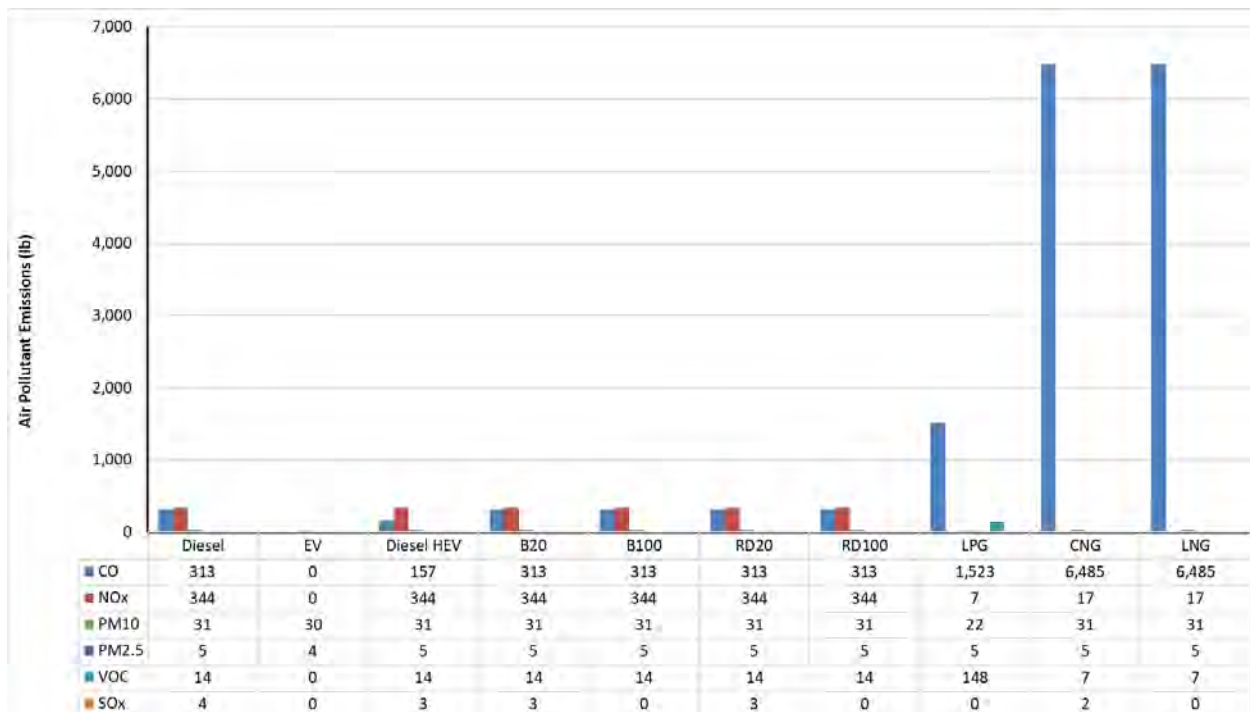


Figure 46. Single unit long haul truck emissions quantities

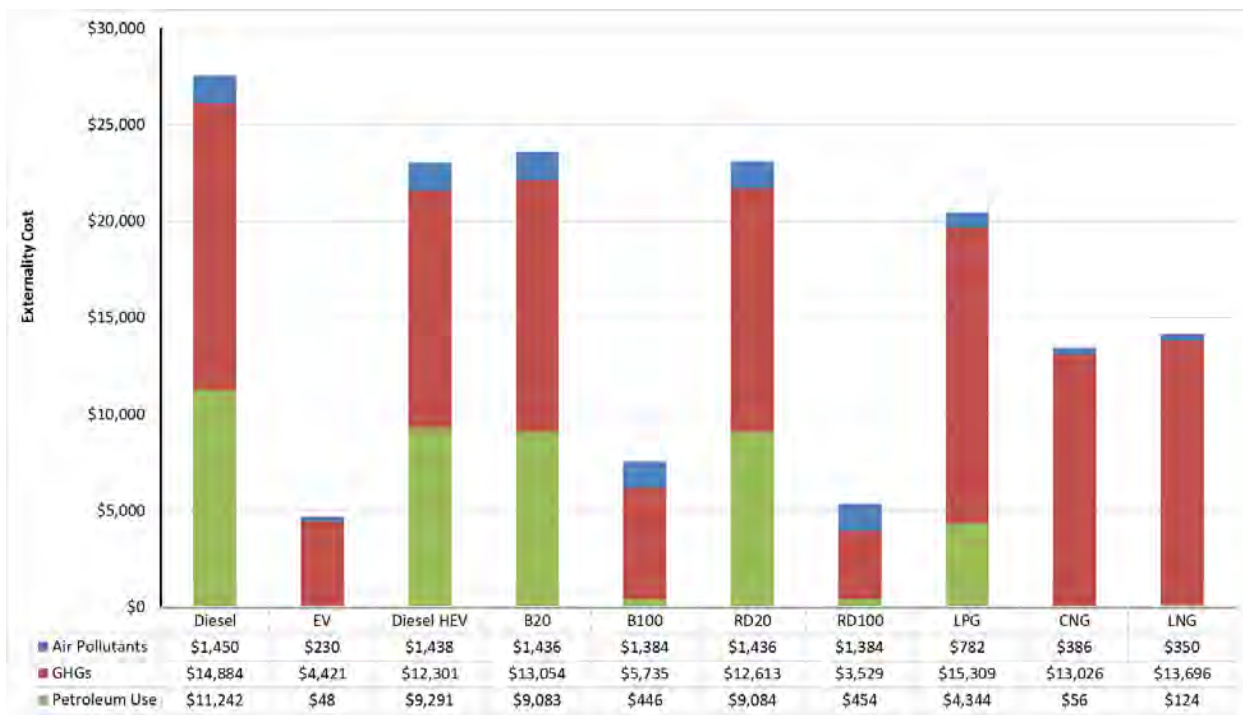


Figure 47. Single unit long haul truck externality cost breakdowns

Combination Short Haul Truck

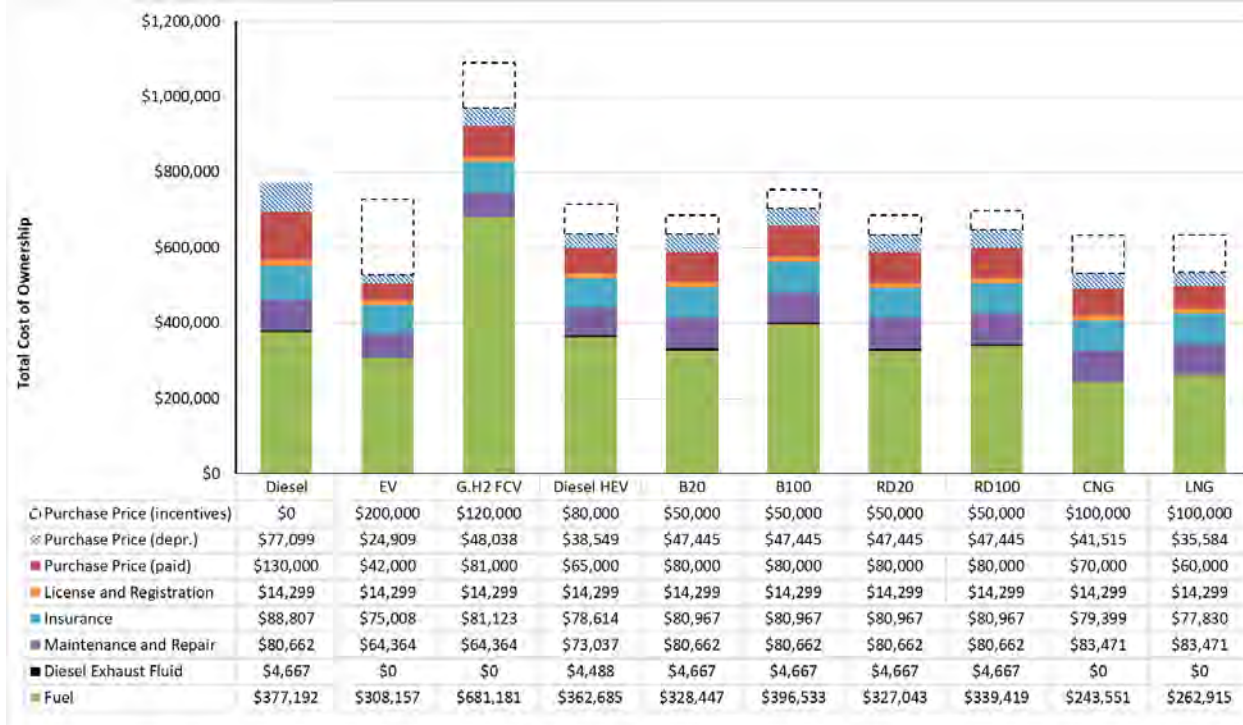


Figure 48. Combination short haul truck TCO excluding cost of externalities



Figure 49. Combination short haul truck emissions quantities

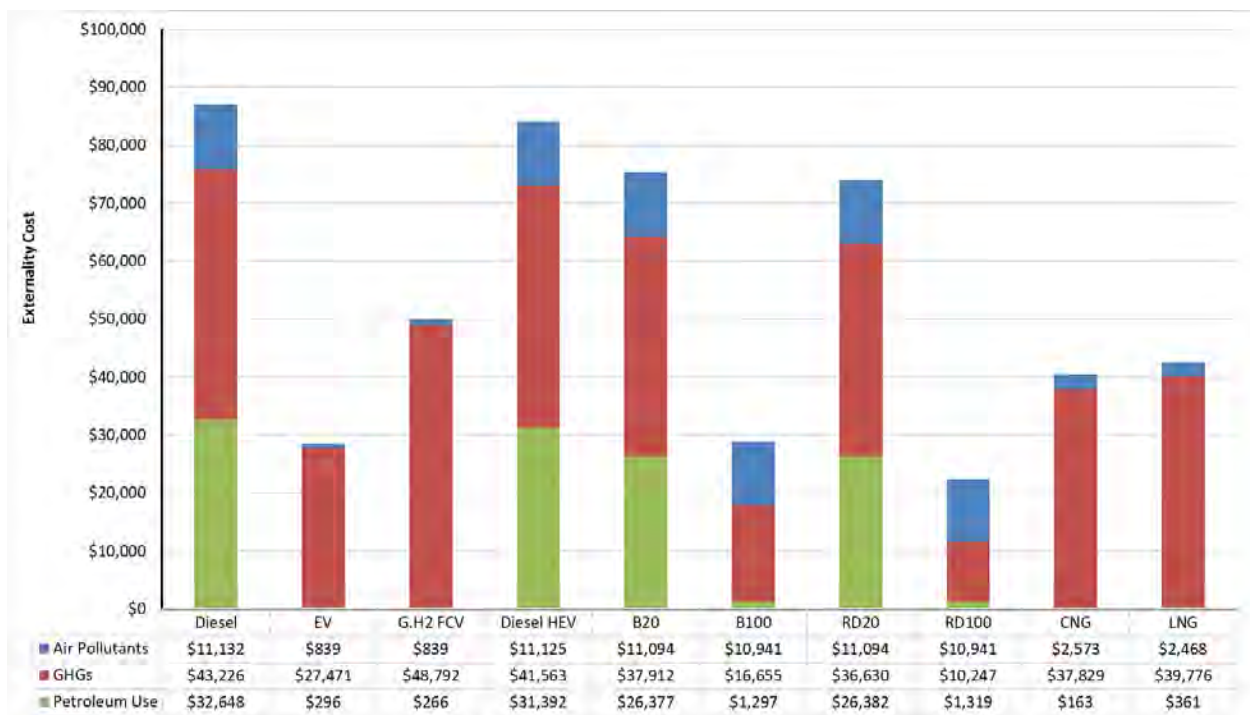


Figure 50. Combination short haul truck externality cost breakdowns

Combination Long Haul Truck

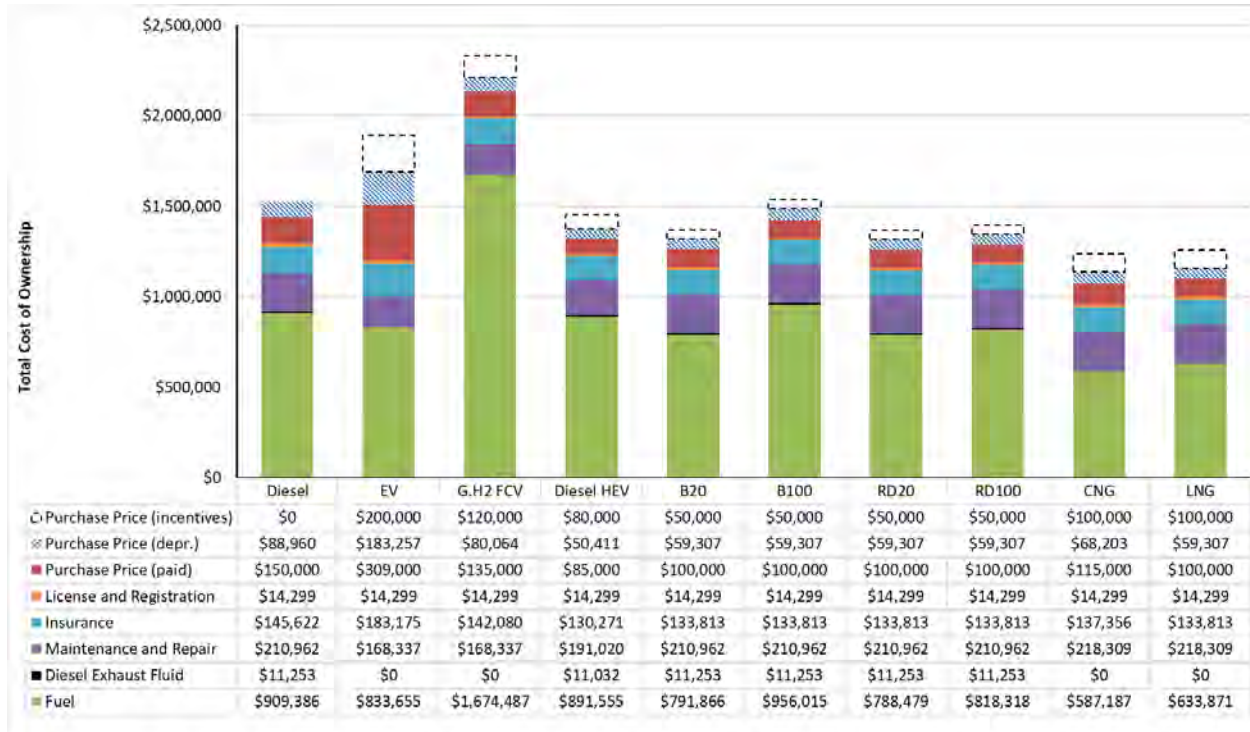


Figure 51. Combination long haul truck TCO excluding cost of externalities

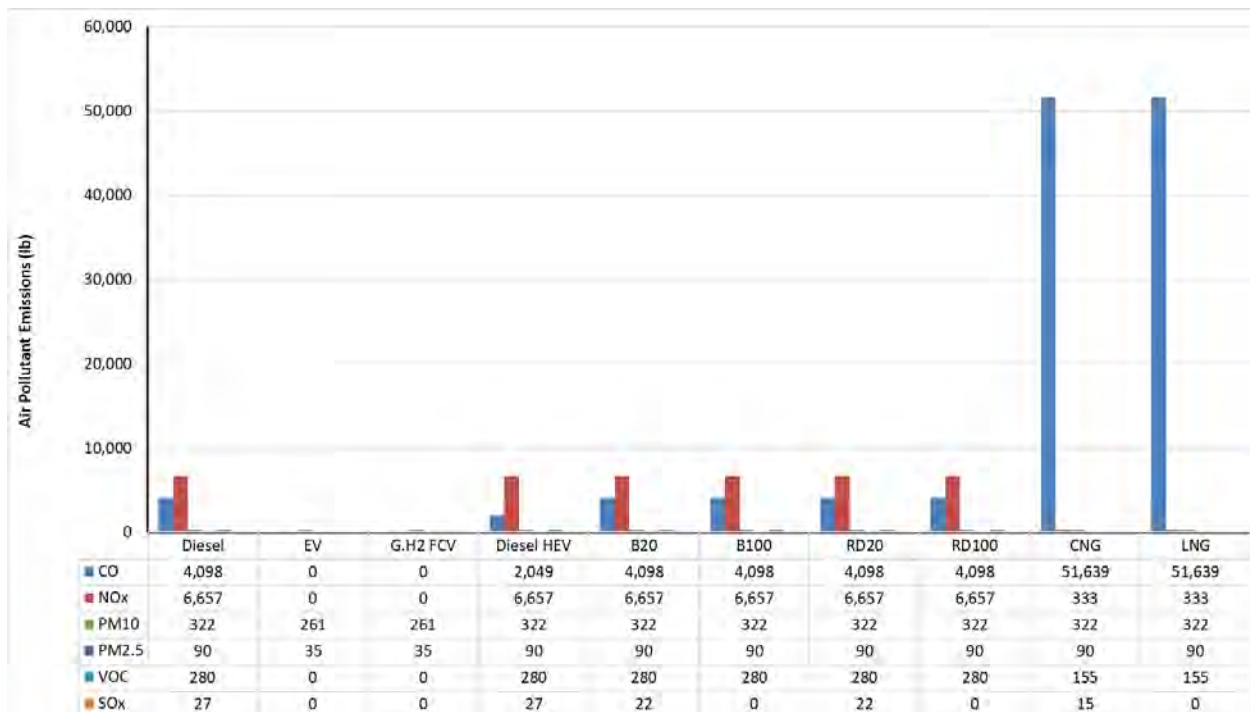


Figure 52. Combination long haul truck emissions quantities

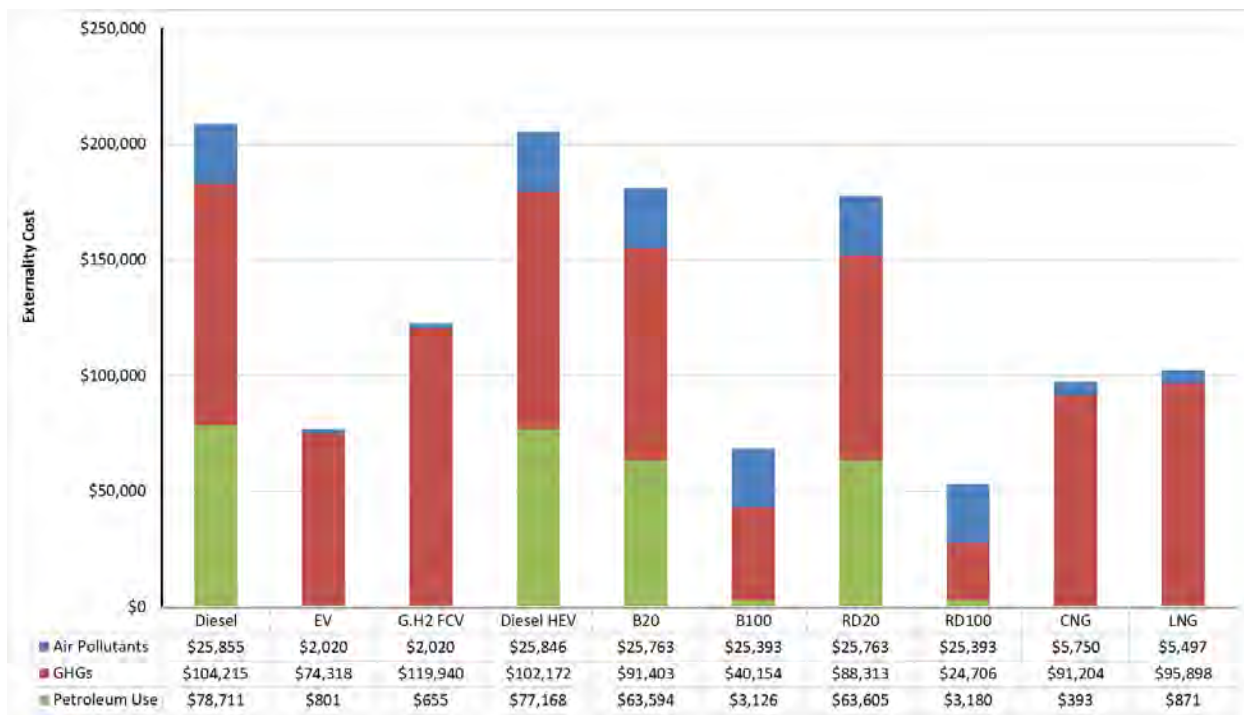


Figure 53. Combination long haul truck externality cost breakdowns