This Master's Project

Challenges Faced in Electrifying Medium and Heavy Duty Vehicles in California and How These Challenges Can be Overcome

by

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Table of Contents

List of Figures

List of Tables

Abstract

California is electrifying medium and heavy vehicles (vehicles weighing over 8,500 pounds) to reduce greenhouse gas emissions and provide environmental justice for disadvantaged communities. These vehicles are used for delivery, construction, refuse collection or long haul trucking. The three main challenges of electrification are infrastructure, policy and funding. To address these challenges, policy analysis was used to review California's policies already in place for electrification of medium and heavy duty vehicles. Comparative analysis was used to look at policies in other countries and environmental programs for strategies to help electrification efforts.

California faces a lack of infrastructure of medium and heavy duty electric vehicle chargers and high upfront costs. These costs can be decreased per vehicle with a larger volume of electric vehicles. California has many policies to help support adoption of medium and heavy duty electric vehicles, however they can be expanded by looking China's program starting electrification in specific cities, Oslo, Norway's involvement of local government and the state's solar rollout for a market pull strategy. California has various funding opportunities but more sustained funding is needed to overcome the $195.06 billion funding deficit.

To tackle challenges faced by electrification of medium and heavy vehicles in California, policy and funding can be coupled to support each other through mandates and partnerships. Emphasis can be placed on infrastructure and initiatives supporting disadvantaged communities. California can start electrification with delivery vehicles because they have the lowest infrastructure costs and provide opportunities for emission reductions and environmental justice across California.

Introduction

In 2006 California passed AB 32 the Global Warming Solutions Act as an effort to reduce its greenhouse gas emissions to 1990 levels by 2020 and 40% below 1990 levels by 2030 (CARB, 2018a). In 2017 California's greenhouse gas emissions were 424 million metric tons of carbon dioxide equivalent (CARB, 2019b). The 2017 greenhouse gas emissions show a decrease of 14% from California's peak in 2001 but there is still room for improvement. The largest sector responsible for greenhouse gas emissions in California is transportation.

Transportation emissions in California account for 40% of California's greenhouse gas emissions (Forrest et al., 2020). Figure 1 shows the breakdown of emissions by sector including transportation as the largest sector.

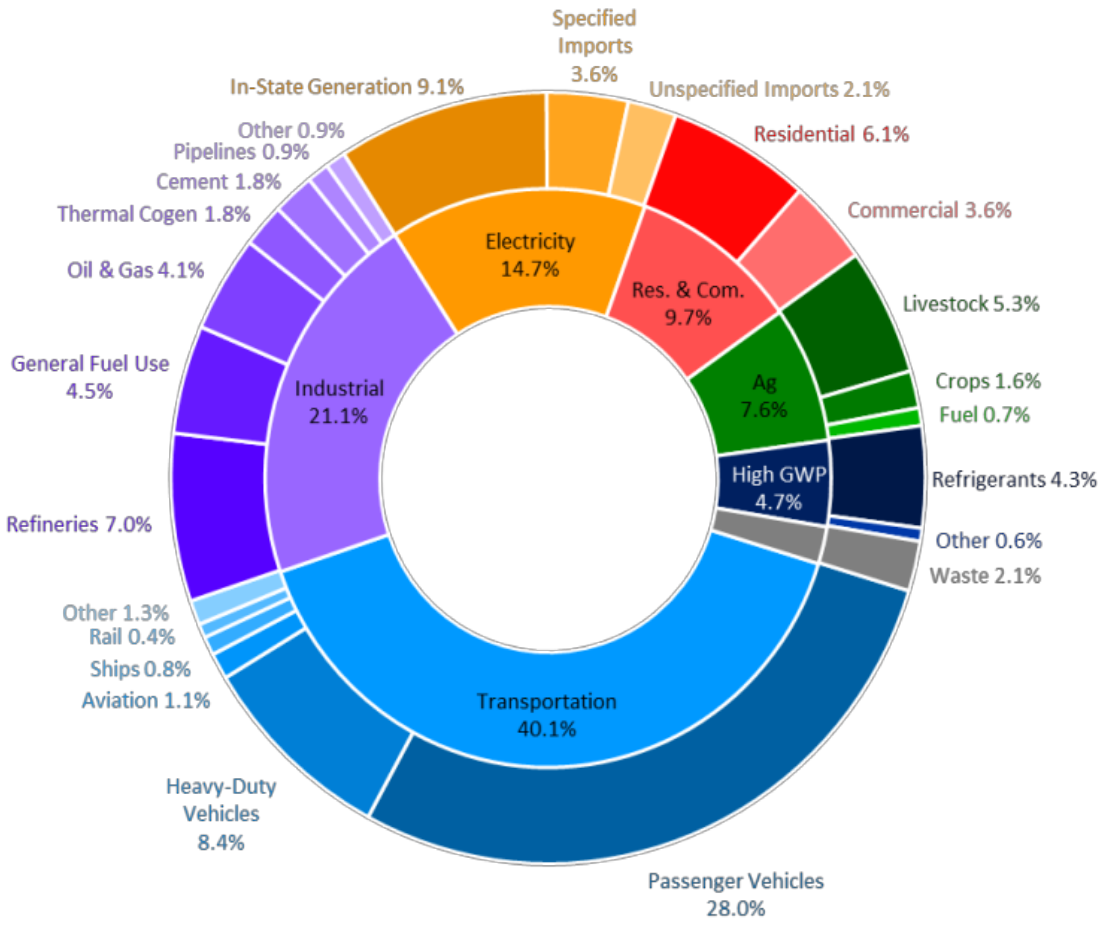
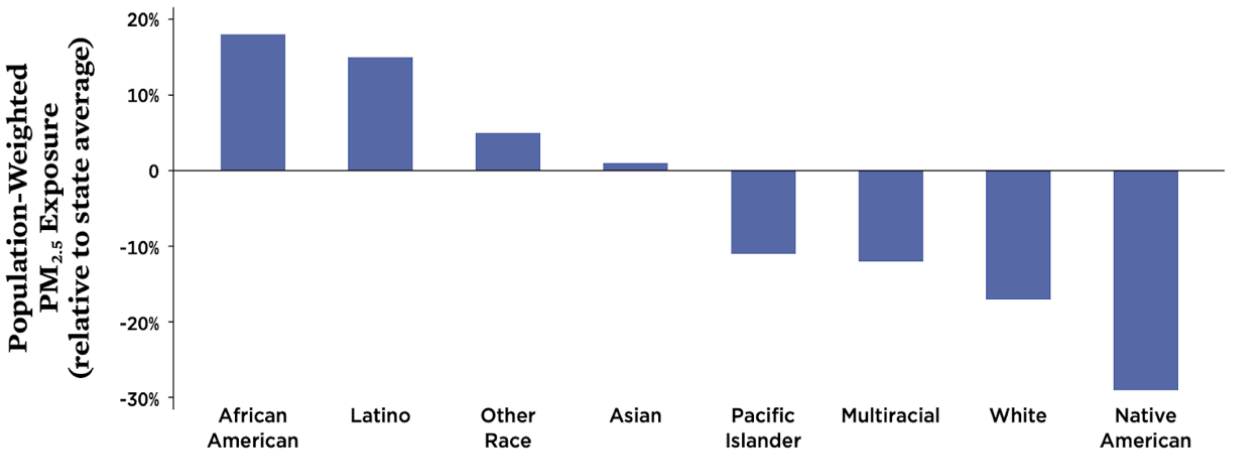


Figure 1: GHG Emissions Inventory in California by Sector (CARB, 2019b)

The transportation sector in total was responsible for 173.84 million metric tons of carbon dioxide equivalent in 2017 based on the total emissions stated in CARB, 2019a. Transportation also accounts for the most emissions of ozone, nitrogen oxides and particulate matter in California (CARB, 2019d). Transportation created 74% of the statewide nitrogen oxide emissions and 95% of the statewide diesel particulate matter emissions in 2017 (CARB, 2019). California has focused on reducing emissions in the passenger vehicles section of transportation and is just starting to move to reducing emissions in medium and heavy duty vehicles.

Emissions from medium and heavy duty vehicles accounts for 8.4% of emissions in California, shown in Figure 1 (CARB, 2019). Using the total emission model from CARB, 2019a, medium and heavy duty vehicle produced 35.62 million metric tons of carbon dioxide equivalent in 2017. Medium and heavy duty vehicles also produce a large amount of particulate matter and nitrogen oxide emissions. In 2017 medium and heavy duty vehicles accounted for 35% of nitrogen oxide emissions in the state and 25% of diesel particulate matter emissions in the state (CARB, 2019). High levels of exposure to nitrogen oxide and particulate matter can cause severe health effects. The populations facing the most exposure to nitrogen oxide and particulate matter from medium and heavy duty vehicle emissions in California are disadvantaged communities.

The California Environmental Protection Agency provides a definition to categorize a disadvantaged community. This definition includes "areas disproportionately affected by environmental pollution and other hazards that can lead to negative public health effects, exposure, or environmental degradation" (CalEPA, 2017). Latino and African American communities are more likely to be located in a disadvantaged area. Latino communities are exposed to particulate matter pollution at rates of 15% higher than the state average and African American communities are exposed to particulate matter pollution at rates of 19% higher than the state average, as shown in Figure 2 (Union of Concerned Scientists, 2019).



African American and Latino Californians have 19 and 15 percent higher exposure to $PM_{2.5}$, respectively, than the state average, while white Californians are exposed to 17 percent lower concentrations.

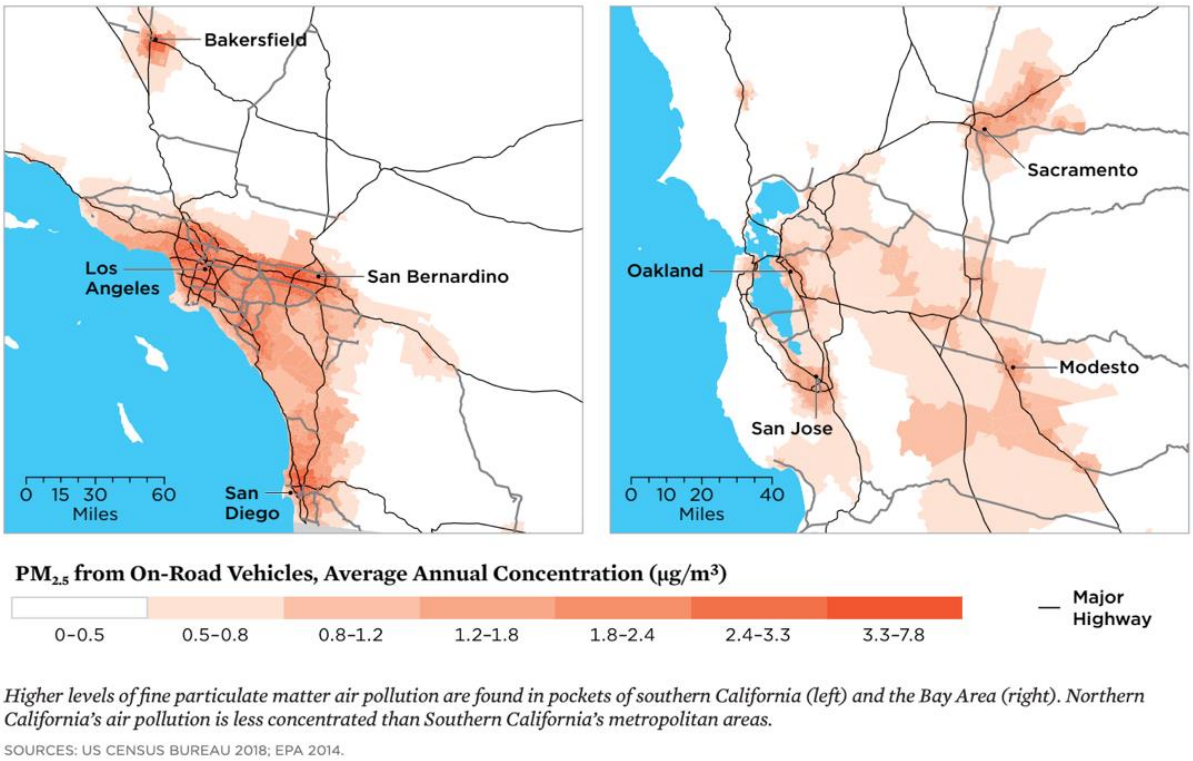
Note: The following US Census Bureau-defined racial groups were used in the analysis: White; Black or African American; American Indian or Alaska Native; Asian; Native Hawaiian or Other Pacific Islander; Hispanic; Latino; and Some Other Race. In the chart above, Latino includes census respondents who select Hispanic, Latino, or both; Other Race includes census respondents who select Some Other Race as their only race.

SOURCES: US CENSUS BUREAU 2018; EPA 2014.

Figure 2: Demographic exposure to PM2.5 in California (Union of Concerned Scientists, 2019)

There is also an overlap of areas in California most heavily impacted by particulate matter pollution from on-road vehicles and disadvantaged communities throughout California. Figure 3 details the levels of particulate matter concentrations caused by vehicles in both Southern California and the San Francisco Bay Area.

Figure 4 shows the disadvantaged communities in the same areas, Southern California and the San Francisco Bay Area, in California. Locations where the particulate matter concentrations are the highest tend to fall into the same area as a disadvantaged community. These disadvantaged communities are facing higher exposures to particulate matter, among other emissions, than communities that are not considered disadvantaged due to emissions from medium and heavy duty vehicles. These high concentrations lead to dangerous health conditions.



Higher levels of fine particulate matter air pollution are found in pockets of southern California (left) and the Bay Area (right). Northern California's air pollution is less concentrated than Southern California's metropolitan areas.

SOURCES: US CENSUS BUREAU 2018; EPA 2014.

Figure 3: PM pollution concentrations caused by on-road vehicles (Union of Concerned Scientists, 2019)

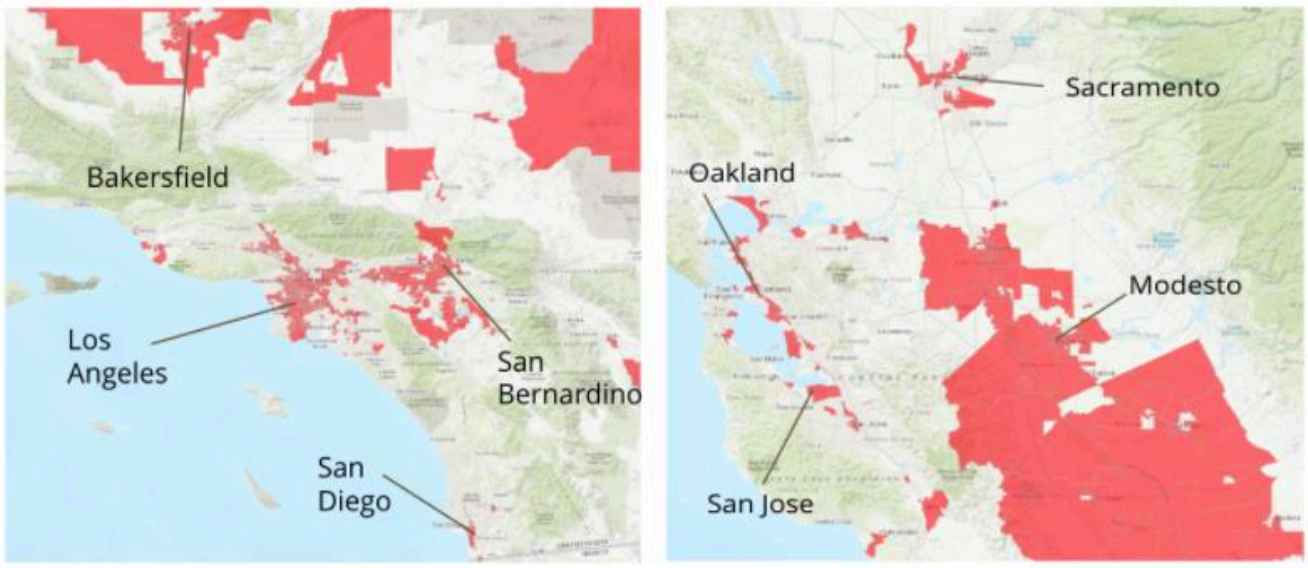


Figure 4: Disadvantaged communities in Southern California and the San Francisco Bay Area (CalEnviroScreen, 2018)

This exposure to particulate matter has significant health impacts. The exposure can lead to lung cancer, asthma and cardiovascular diseases and has caused 31,000 premature deaths per year in California (Union of Concerned Scientists, 2019). Electric medium and heavy duty vehicles are also two to five times more energy efficient than diesel counter parts and reduce greenhouse gas emissions substantially (CARB, 2019a). By working to electrify medium and heavy duty vehicles, California can reduce harmful emissions and provide environmental justice to disadvantaged communities that are facing increased exposure and health impacts.

Research Questions

The research questions for this paper include: What are the main challenges in electrifying medium and heavy duty vehicles in California and how can these challenges be overcome? To electrify medium and heavy duty vehicles in California three main challenges will need to be addressed. The first challenge is creating infrastructure necessary to support widescale electrification. The second challenge is expanding policy to help support and drive adoption of medium and heavy duty electric vehicles. The final challenge is providing enough funding to overcome upfront costs. Electrifying medium and heavy duty vehicles across California will lower greenhouse gas emissions and help provide environmental justice to disadvantaged communities.

Background

The term medium and heavy duty vehicle encompasses a large variety of vehicles used for a few different functions. Simply put, a medium or heavy duty vehicle is a vehicle with a weight over 8,500 pounds (Forrest et al., 2020). This includes part of class 2 vehicles up to class 8 vehicles in Figure 5. Uses of these vehicles include delivery construction, refuse collection and long haul trucking (Forrest et al., 2020).

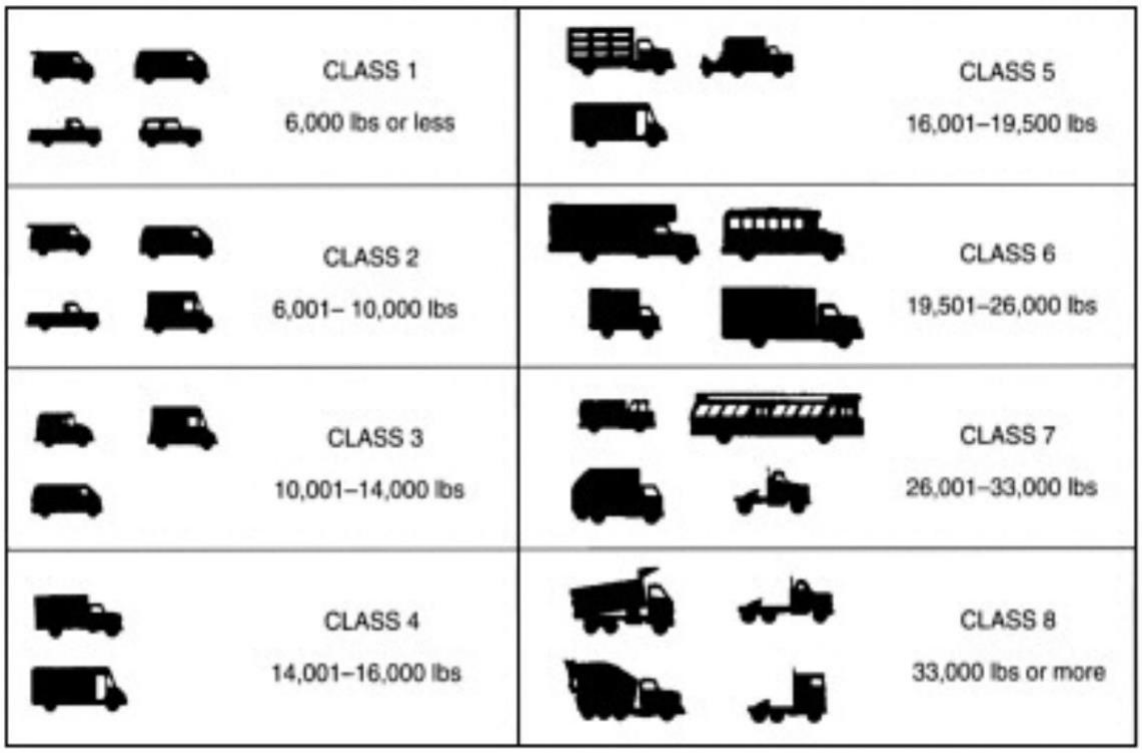


Figure 5: Medium and Heavy Duty Vehicle Classes (CARB, 2019d)

Medium and heavy duty vehicles can also be further broken down into three categories: (1) drayage, (2) delivery and (3) long haul (Hall & Lutsey, 2019). Drayage includes vehicles that carry shipping containers around a port. These vehicles usually have short routes, make frequent stops and operate on surface streets that have a lot of traffic. Delivery is the broadest category and covers all vehicles that are last mile of freight for residential, industrial and commercial addresses. Long haul covers Class 8 tractor-trailers. These vehicles usually service long routes of multi-day travel through multiple cities. Along with differences in class and weight from light duty vehicles, medium and heavy duty vehicles have different needs for electrification.

In 2015, the total number of medium and heavy duty vehicles registered in California was 987,817 (CEC, 2020). The life expectancy of a heavy duty truck is about fourteen years or 1 million miles (Smith et al., 2020). Medium and heavy duty vehicles travel longer daily distances and have bigger per mile energy demands than light duty vehicles. Greater battery capacities and charging rates are needed in medium and heavy duty battery electric vehicles than in light duty vehicles (Forrest et al., 2020). To create electric medium and heavy duty vehicles, changes to batteries used for light duty vehicles will be needed. Chargers will

need to have more power and faster charging to accommodate medium and heavy duty vehicles. Medium and heavy duty vehicles can also face lowered performance due to environmental factors. Electric bus performance can be diminished in cold climates because of battery performance and use of heaters need to warm the bus and its components (Nadel, 2019). This can also happen in hot climates due to air conditioning and decreases the vehicle's range. The technology for electric medium and heavy duty vehicles is still being developed and improved as adoption and electrification becomes more wide spread.

There are two main types of electric vehicle technologies available for medium and heavy duty vehicles. These two technologies are battery powered electric vehicles and fuel cell electric vehicles (Forrest et al., 2020). Battery powered electric vehicles work by providing an electric current for the battery. In fuel cell electric vehicles the current is provided by splitting hydrogen molecules. Battery electric vehicles have been more popular and are the technology that has been used in most light duty electric vehicles in California. Accordingly, this paper will focus on battery electric medium and heavy duty vehicles which will allow current infrastructure and policy for light duty vehicles to be used as a starting point. This starting point and focus on battery electric vehicles will be used to address the main challenges facing electrification of medium and heavy duty vehicles in California which are (1) infrastructure, (2) policy and (3) funding.

Infrastructure

Currently California uses a variety of traditional power plants as well as plants powered by renewable energy but is working towards a goal of carbon free electricity by 2045 (GNA, 2019). The electricity that eventually meets the electric vehicle charger is generated by both traditional power plants, which have sources of coal or natural gas, as well as plants that use renewable energy sources such as hydro, wind or solar power.

Once the electricity leaves the plant it runs through transmission lines to distribution lines which use a step down transformer to transition the electricity coming from the power plants to a lower voltage that it is suitable for commercial and residential equipment, such as electric vehicle chargers. Utility companies are responsible for the capacity of the grid to deliver

electricity and will be involved in any expansions needed to the grid. Adding infrastructure or modifying existing infrastructure will be needed for medium and heavy duty electric vehicle charging and it is important to understand that utilities will need to be involved with infrastructure projects to make sure the correct infrastructure is implemented and that the grid will have the capacity to carry the electricity needed to charge fleets.

Electric vehicle charging infrastructure, Figure 6, brings electricity from a source through a distribution infrastructure then a conduit to a charger which can fall into one of three categories (1) Level 1 charger, (2) Level 2 charger or (3) DC fast charger.

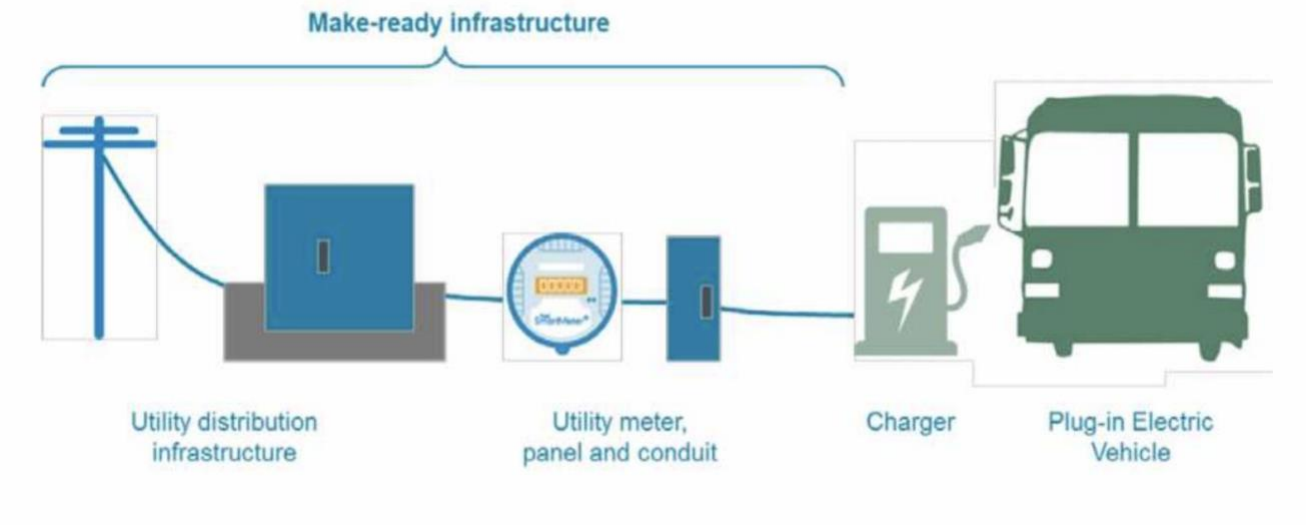


Figure 6: EV Charging Distribution Infrastructure (CPUC, 2017)

All three categories can be used for medium and heavy duty vehicles. However level 2 chargers and DC fast chargers are more commonly used for medium and heavy duty vehicles because they can charge the vehicle faster than a level 1 charger. A level 1 charger could take anywhere from 12.4 hours to 343.8 hours to fully charge a medium or heavy duty vehicle depending on the charger and type of vehicle, so a level 1 charger is not as commonly used (Rhombus Energy Solutions, 2020).

There are three main categories of electric vehicle chargers as seen in Table 1. The first category is level 1. The level 1 charger is most often used for light duty vehicles that are plugged in overnight. Level 1 chargers have the lowest electric and power specifications of the three

categories and take the longest time to charge an electric vehicle. The level 1 specifications for electric and power include 120 Volt, 20 Amp circuit and 1.4 Kilowatts (kW). It takes 17-25 hours for an electric vehicle with a 100-mile battery to fully charge using a level 1 charger (Doyle, 2017).

The second category of electric vehicle chargers is level 2. The level 2 charger is used for offices or public areas where electric vehicle drivers will charger their vehicles for a few hours. The level 2 specifications for electric and power include 208-240 Volt, 40 Amp circuit and 6.2 – 7.6 Kilowatts (kW). It takes 4-5 hours for an electric vehicle with a 100-mile battery to fully charge using a level 2 charger (Doyle, 2017).

Table 1: Different Categories of EV Chargers using concepts from Cal eVIP, 2020 and Doyle,2017

	Level 1 Charging	Level 2 Charging	DC Fast Charging
Electric and Power Specifications	120 Volt, 20 Amp circuit 1.4 kW	208-240 Volt, 40 Amp circuit 6.2 – 7.6 kW	480 + volts, 100+ Amp 50-60kW
Time to Fully Charge an Electric Vehicle with a 100-mile Battery	17 -25 hours	4-5 hours	~ 30 min

The third category of electric vehicle chargers is DC fast. DC fast chargers can recharge a vehicle the fastest out of the three electric vehicle charger categories. These chargers are most often found along interstates that are used by electric vehicles driving a longer route. The DC fast specifications for electric and power include 480+ Volt, 100+ Amp circuit and 50-60 Kilowatts (kW). It takes about 30 minutes for an electric vehicle with a 100-mile battery to fully charge using a DC fast charger (Cal eVIP, 2020).

Infrastructure is an integral part of electrifying medium and heavy duty vehicles in California and proper infrastructure updates and appropriate chargers will be a necessary step.

Challenges

One of the challenges faced in California's electrification of medium and heavy duty vehicles is infrastructure. Some facilities at both fleet and public levels lack adequate infrastructure needed (Nadel, 2019). There are about 56,643 existing level 2 chargers and 4,889 existing DC fast chargers in California and the state has a 2025 goal of reaching 240,000 level 2 chargers and 10,000 DC fast chargers (John, 2020). This lack of necessary infrastructure limits the number of medium and heavy duty electric vehicles that can be in use and contributes to "range anxiety." Range anxiety occurs when drivers are worried about an electric vehicle not being able to drive the distance needed and that there will not be charging stations available along stretches of the trip. Adding more charging stations and infrastructure will help to mitigate both range anxiety and the limitation on number of medium and heavy duty electric vehicles that can be supported.

To further electrifying medium and heavy duty vehicles, infrastructure onsite for fleets and publicly available retail stations will have to meet specifications needed for medium and heavy duty vehicle charging (CARB, 2019d). A challenge of adding additional infrastructure and chargers is the varied cost of installation and maintenance by site. Some sites, such as those that already have light duty vehicle chargers, will need minimal electrical upgrades to support additional or new chargers. Other sites may need to have a completely new electrical infrastructure installed. Locations that need large infrastructure installations or modifications will cost significantly more to complete than sites that need small additions or adjustments. For example, level 2 charging sites updated by the Southern California Edison utility company in 2019 cost $32,702 per site in utility-side infrastructure alone but a site that needs more power or is remote can cost over $1 million per site in just utility-side infrastructure (Nelder & Rogers, 2019).

To complete or upgrade infrastructure as needed for medium and heavy duty vehicle charging stations, multiple agency collaboration will be needed. First, utilities are in charge of the capacity of the grid and will need to be closely involved in infrastructure updates and installations. Other agencies that may be involved include the California Air Resources Board, California Public Utilities Commission and the California Energy Commission. These agencies' involvement will vary with different roles based on funding, policies and increasing regulations.

Coordination with multiple agencies may add additional challenges when trying to implement infrastructure additions and upgrades and make sure all parties are on the same page.

Another challenge in creating adequate charging infrastructure for medium and heavy duty vehicles is electricity costs. The utility companies are in charge of the grid and have the ability to set pricing. Utilities have three main types of pricing (1) fixed fee in dollars per month, (2) charging dependent on usage in dollars per kilowatt-hours and (3) demand charges in dollars per kilowatts (CARB, 2019d).

Electricity costs for these different pricing models can vary depending on multiple factors. The first factor in electricity costs is time of use. Time of use determines the rate of electricity and is based off of demand. Use during higher demand such as a weekday afternoon or evening will lead to higher electricity costs. Demand varies based off of time of day, season, weekday versus weekend as well as holidays (CPUC, 2020b). For example, charging infrastructure added to company facilities may have lower costs because charging would occur overnight which is seen as off peak hours resulting in lower electricity rates.

The varied pricing is put in place to encourage use which is spread more evenly throughout the various factors to use the grid more efficiently. This will apply to medium and heavy duty charging infrastructure and determine costs as well as location of the charging stations. Also, with different utilities using various pricing strategies, electricity costs for medium and heavy duty vehicle charging will not be the same for all infrastructure projects.

To face the challenge of infrastructure in electrifying medium and heavy duty vehicles in California significant investments in infrastructure are needed. These investments will need to address the current lack of infrastructure available, the need for interagency collaboration to complete projects as well as varying electricity prices that will affect the costs of different infrastructure projects.

Analysis

Investment in charging infrastructure will be necessary to electrify medium and heavy duty vehicles in California. This infrastructure investment will have large upfront costs but will last for multiple vehicle lifetimes (CARB, 2019d). This long term investment will be paid back over time. Initial projects will want to be placed in locations on routes that have increased

medium and heavy duty vehicle traffic to most efficiently use increased infrastructure. Costs per vehicle can also be reduced by placing charging infrastructures in locations that will be used overnight or during loading of multiple vehicles. Lowering costs per vehicle through intentional infrastructure placement will not only allow for more vehicles to use the charging infrastructure but help to bring electricity costs down by charging at off peak hours.

Decreasing Costs Per Vehicle with More Vehicles on the Road

Although the overall infrastructure cost is increased from a low volume of vehicles to a high volume of vehicles, costs per vehicle is lowered significantly with a higher volume of vehicles on the road (Hall & Lutsey, 2019). This can be seen across the three different classes of medium and heavy duty vehicles (1) delivery, (2) drayage and (3) long haul. A summary of these volumes and cost breakdowns can be found in Table 2.

For delivery vehicles, infrastructure costs start at $8 million for a low volume of vehicles (100 vehicles) and reach $270 million for a high volume of vehicles (10,000 vehicles). On a per vehicle basis, when there is a low volume of delivery vehicles infrastructure cost is $82,000 per vehicle but decreases to $27,000 per vehicle when high volume is reached.

For drayage vehicles, infrastructure costs start at $6 million for a low volume of vehicles and reach $280 million for a high volume of vehicles. However, when there is a low volume of drayage vehicles infrastructure cost is $58,000 per vehicle but decreases to $28,000 per vehicle when high volume is reached.

For long haul vehicles, infrastructure costs start at $18 million for a low volume of vehicles and reach $700 million for a high volume of vehicles. However, when there is a low volume of long haul vehicles infrastructure cost is $182,000 per vehicle but decreases to $70,000 per vehicle when high volume is reached.

The vehicle class that sees the highest cost savings in infrastructure costs per vehicle as the volume of vehicles expands is long haul. When the number of long haul electric vehicles expands from 100 to 10,000 the infrastructure cost per vehicle decreases by $112,000. Delivery electric vehicles see the next highest infrastructure cost decreases of $55,000 per vehicle as the volume of vehicles goes from 100 to 10,000. Finally, drayage electric vehicles see the smallest infrastructure cost decreases of $30,000 per vehicle as the volume of vehicles goes from 100 to 10,000.

Table 2: Charging Infrastructure Cost Breakdown (Hall and Lutsey, 2019)

Technology	Application	Case	# of Vehicle	Infrastructure Cost (million)	Infrastructure Cost per Vehicle	Vehicle ownership cost difference from diesel
Electric	**Delivery** (Class 6, 9.75 -13 tons)	Low volume	100	$8	$82,000	0% to +5%
		Medium volume	1,000	$40	$40,000	-15% to -10%
		High volume	10,000	$270	$27,000	-25% to -20%
	Drayage (Class 7-8, 13+ tons)	Low volume	100	$6	$58,000	+10% to +25%
		Medium volume	1,000	$38	$38,000	0% to +5%
		High volume	10,000	$280	$28,000	-15% to -10%
	Long Haul (Class 8, 16+ tons)	Low volume	100	$18	$182,000	+13% to +18%
		Medium volume	1,000	$113	$113,000	+5% to +10%
		High volume	10,000	$700	$70,000	-5% to 0%

As medium and heavy duty electric vehicles move from low volume to high volume, vehicle owners will start to see that it will cost less to own an electric vehicle than a diesel vehicle (Hall & Lutsey, 2019). For delivery vehicles, a low volume of electric vehicles results in ownership costing 0% to 5% more than of a diesel vehicle. However once a high volume of electric vehicles is reached, ownership costs 20% to 25% less than of a diesel vehicle. For drayage vehicles, a low volume of electric vehicles results in ownership costing 10% to 15% more than of a diesel vehicle. However once a high volume of electric vehicles is reached, ownership costs 10% to 15% less

than of a diesel vehicle. For long haul vehicles, a low volume of electric vehicles results in ownership costing 13% to 18% more than of a diesel vehicle. However once a high volume of electric vehicles is reached, ownership costs 0% to 5% less than of a diesel vehicle. With greater investment in and planning for medium and heavy duty vehicle infrastructure costs per vehicle as well as vehicle ownership compared to that of diesel will start to decline which can help drive electric vehicle adoption.

To develop the cost breakdowns seen for varying volumes of long haul, drayage and delivery electric vehicles Hall and Lutsey, 2019 estimated the amount of infrastructure needed in Los Angeles as a model. Los Angeles was chosen because it is an area that shows an interest in electrifying medium and heavy duty vehicles partly because there are a high number of disadvantaged communities in the area. Los Angeles' geography helped to define (1) technical specifications, (2) fleet operations, (3) route distances and (4) fueling costs that went into the cost breakdown. The total infrastructure costs are $32 million for the low volume case, $191 million for the medium volume case and $1,007 million for the high volume case. This model of cost breakdowns can be applied to other areas that have high-volume freight activity and an interest in zero emission technology for transformation.

The methodology for creating this model used a mix of fast chargers and slow chargers, used for charging overnight or during loading and unloading of the trucks, to make up the infrastructure needed. Total infrastructure costs are higher for long haul because they travel longer distances, are heavier and consume more energy than drayage or delivery vehicles. Fast chargers are also more costly to install than slow chargers. For long haul fast chargers accounted for 60% of infrastructure costs but only 20% of chargers estimated by number (Hall & Lutsey, 2019).

This approach and model for the cost breakdowns will be a good indicator for infrastructure total costs and cost reductions as a higher volume of electric medium and heavy duty vehicles are on the roads in similar cities. Cities that are similar to Los Angeles and this cost breakdown model will share its interest in applying new technologies and have a large amount of freight activity. However, this model will not accurately show cost breakdowns and reductions for smaller towns and rural areas. This is important to note when looking at the model and

expecting cost reductions with higher volumes of electric vehicles, as smaller towns many not find the same amount of cost savings.

Light Duty Infrastructure Cost Reductions with a Higher Volume of Electric Vehicles

Along with medium and heavy duty electric vehicles, light duty vehicle infrastructure costs see reductions with a larger volume of electric vehicles and more chargers being installed per site (Nicholas, 2019). With more electric vehicles more infrastructure and charging capacity is needed. Installing one 50 kilowatt charger per site costs $45,506 per charger but installing 6-50 50 kilowatt chargers per site has an installation cost of $17,692 per charger (Nicholas, 2019). For a fast charger, installing one 350 kilowatt charger per site costs $65,984 per charger but installing 6-10 350 kilowatt chargers per site has an installation cost of $25,654 per charger (Nicholas, 2019). Nicholas determined costs by reviewing data on charging equipment costs, such as hardware and installation, for different locations and types of chargers. To quantify this cost reduction Nicholas looked at the most populous metropolitan areas in the United States.

There has also been a reduction in total public infrastructure cost per vehicle. The public infrastructure cost per vehicle is the cost of building public infrastructure divided by the number of electric vehicles on the road. As more electric vehicles are on the road the public infrastructure cost per vehicle are lowered. Total public infrastructure costs per electric vehicle is declining from $480 per electric vehicle in 2019 and trending towards $300 per electric vehicle by 2025 (Nicholas, 2019). This reducing cost is due to more chargers and infrastructure, decreasing hardware costs and market growth. As more medium and heavy duty vehicles are in use a similar reduction in costs as seen with light duty vehicle infrastructure can be expected.

Pyramid Approach

Another way to increase adoption of light, medium and heavy duty electric vehicles is to plan for an efficient mix of chargers including some level 1 chargers but more emphasis on level 2 and DC fast chargers. With growing electric vehicle use the Department of Energy estimates 27,000 DC fast chargers and 600,000 level 2 chargers will be needed to serve the estimated 15 million electric vehicles in 2030 across the United States (Nadel, 2019). To support growing numbers of electric vehicles, a pyramid approach to charging stations can be applied.

A pyramid approach includes a large number of overnight chargers, a medium amount of workspace, retail or fleet chargers, usually level 2, and a few DC fast chargers spaced out along interstate routes (Nadel, 2019). For light duty vehicles the overnight chargers can mostly be level 1 but for medium and heavy duty vehicles having level 2 chargers for overnight charging would help charge the vehicles faster than a level 1 charger. This pyramid approach will help to meet the various needs of electric vehicles without creating extra infrastructure costs. DC fast chargers take the largest cost investment and keeping the number lower and supplementing with more level 2 chargers located in both public and private spaces will help balance infrastructure costs.

Disadvantaged Communities

Even with implementation of the pyramid approach, disadvantaged communities are not seeing the same infrastructure growth as other communities. Disadvantaged communities across California are seeing 0.93 level 2 chargers and 0.61 DC fast chargers per 1,000 households compared to 1.08 level 2 chargers and 0.13 DC fast chargers per 1,000 households in communities that are not disadvantaged (Canepa, Hardman, & Tal, 2019). Disadvantaged communities do see a higher number of fast chargers, with 0.61 DC fast chargers per 1,000 households instead of 0.13 DC fast chargers per 1,000 households in other communities, but this may be a result of these disadvantaged communities being located in more urban areas. With less level 2 chargers available it makes it much harder to increase the number of electric vehicles in disadvantaged communities perpetuating the increased risk due to emissions from diesel vehicles. To create greater environmental justice when adding electric vehicle charging infrastructure, more focus on making sure an adequate number of charging stations are available in disadvantaged communities will be needed.

Organizations

Along with the pyramid approach, working with organizations building charging infrastructure will help to make infrastructure investment costs more manageable. There are many organizations that are building charging infrastructure and working with various groups to install a mix of public and private level 2 chargers as well as DC fast chargers in key locations. Some of these companies include ChargePoint, Tesla, Shell and utilities companies themselves such as SoCal Edison. Electrify America, a subsidiary of Volkswagen Group of America created as

part of a court settlement, has $2 billion in funding and is working solely on installing DC fast chargers in highways and cities across America (Nadel, 2019).

California has used the approach of working with various organizations to build out a charging infrastructure for light duty electric vehicles. The State's approaches include various utilities programs, building standards and focusing on corridor charging and workplace charging. One utility program that has been implemented is the Charge Ready program run by SoCal Edison. This program is working to add 1,500 charging stations at 150 workplaces, multi-unit dwellings and destination centers (Governor's Interagency Working Group on Zero-Emission Vehicles, 2018). The program also requires time of use rates and demand response capabilities to be available at the 150 facilities involved in the program. Ten percent of infrastructure additions and investments will take place in disadvantaged communities. California's previous approach of working with organizations to build out light duty electric vehicle charging infrastructure can serve as a model for electrifying medium and heavy duty vehicles.

Buildings and Charging Infrastructure

California also updated building standards to help implement light duty electric vehicle charging infrastructure. Title 24, Part 11 of the Green Building Standards states that new parking lots and housing developments need to have the electrical capacity for electric vehicle chargers put in place during construction. There has also been a focus on infrastructure in corridors and workplaces. For corridor charging, the California Energy Commission has $8.8 million in funding available for 61 DC fast chargers on Interstate 5 and highways 101 and 99 throughout California (Governor's Interagency Working Group on Zero-Emission Vehicles, 2018). To encourage building charging infrastructure at workplaces, electric vehicle charging station financing has been made available to small businesses, multi-unit dwellings as well as disadvantaged communities. Various techniques used to implement light duty electric vehicle charging infrastructure can serve as a model for successful infrastructure implementation in medium and heavy duty vehicles.

Recommendations

Infrastructure is one of the main challenges of electrifying medium and heavy duty vehicles in California. Infrastructure poses a challenge due to lack of current adequate infrastructure, high upfront costs and the need for interagency cooperation. To add the necessary infrastructure there will need to be a combination of fleet and public agency coordination to distribute the initial cost (Hall & Lutsey, 2019). As a high volume of electric vehicles on the road is reached, the per vehicle costs decline for medium and heavy duty vehicles and electric vehicle ownership costs are lower than those of diesel vehicles. Seeing that infrastructure cost per vehicle is decreased with more vehicles on the road is an incentive for fleets to invest in infrastructure now to see lower costs in the future.

With more infrastructure, more vehicles can be added to the road bringing individual costs down. Infrastructure implementation for light duty vehicles has seen success when different agencies are involved in helping to keep initial costs down such as the California Energy Commission did when making funding available for corridor charging infrastructure projects. It will also be beneficial to include other companies, such as those building charging infrastructure and utilities that are creating their own programs to support initial infrastructure installations costs.

It will also be necessary to keep disadvantaged communities in mind when adding new infrastructure. The pyramid approach will help to create levels of different categories of chargers that will support each other but disadvantaged communities have less level 2 charging stations available than communities that are not disadvantaged. One way this can be addressed is by making sure programs specifically set aside funding for additional public infrastructure in disadvantaged communities. The best way to assure cooperation between private companies and government agencies to address covering upfront costs and environmental justice concerns is through the use of policy and varying funding programs and opportunities.

Policy

The second main challenge electrification of medium and heavy duty vehicles is facing is policy. Policy is a key part of making electrification possible and will be needed to support both infrastructure and funding for electrifying medium and heavy duty vehicles. Policies that have been used to promote implementation of electric vehicles fall under five different buckets (Nadel, 2019). The five buckets include the following: incentives, infrastructure, mandates, rate design and targeted efforts for disadvantaged communities as seen in Table 3.

Table 3: Policy buckets used to promote electric vehicles using concepts stated in Nadel, 2019

Policy Bucket	Examples
Incentives	• Varying national, state, local and utilities incentives • Focus on EV purchases and charging equipment
Infrastructure	• Build out electric vehicle charging infrastructure • Many organizations building chargers and infrastructure
Mandates	• Certain percentage of vehicles sold must be electric vehicles
Rate Design	• Alternatives to utility demand charges pricing structures
Targeted Efforts for Disadvantaged Communities	• Shared electric vehicle programs • New or used electric vehicle purchase incentives • Electric bus programs

The first policy bucket focuses on incentives. Policies focused on incentives can range from local to federal. These incentive programs usually offer vouchers or other perks, such as fast lane access, to consumers who purchase a new electric vehicle. Incentives can also be offered to companies or businesses that install and purchase of charging equipment. There are varying programs on different levels including national, state, local and even through utilities.

The second policy bucket focuses on infrastructure. As discussed in the previous section, infrastructure is one of the main challenges faced in electrifying medium and heavy duty vehicles. To adequately build out electric infrastructure supporting policies will be needed. These policies can work on getting more chargers built and installed in pivotal locations. Various organizations are working with policies to help build and supply infrastructure.

The third policy bucket focuses on mandates. In California when working towards electrification of vehicles mandates have been made to say a certain percentage of sales of vehicles need to be either electric or zero emission by a certain date. For example, California mandated that 8% of light duty vehicles needs to be electric vehicles by 2022 (Nadel, 2019).

The forth policy bucket focuses on rate design. Rate design looks at the economics of electric vehicles based off of utility pricing models and charges. Demand charges have a large impact on the overall cost of electric vehicles and moving towards other pricing structures, such as time-of-use rates, can help bring the overall cost down. There are also smart charging, or managed charging, programs which offer discounted pricing and benefits when the utility company is allowed to control when charging of an electric vehicle occurs under the stipulation that the car will be fully charged in the morning. This managed charging can be done by having the charger networked and grouped with other utility customers, with an option for customers to override, and the software allows the utility to schedule when the vehicle will be charged (Thill, 2019).

The fifth policy bucket focuses on targeted efforts for disadvantaged communities. There are a few different ways policies have created targeted efforts. One way is through shared electric vehicle programs. Another is by working with the incentives bucket and providing incentives for disadvantaged communities to purchase new or used electric vehicles and chargers. These targeted policy efforts have also included electric bus programs in disadvantaged communities.

Through its existing policies working towards electrification of medium and heavy duty vehicles, California has implemented strategies from all five policy buckets of (1) incentives, (2) infrastructure, (3) mandates, (4) rate design and (5) targeted efforts for disadvantaged communities.

Defining Success

When looking at a variety of different policies it is important to define what would be considered a successful outcome. Since different policies have different goals to compare them to each other "success" must be defined. For this comparison of policies success will be defined as the goals of the policy being met. For example, if a policy mandates 100% electric vehicles by 2020 was that goal met? If so, that would be considered successful. If a policy has a date in the future, is the policy on track to meet the stated goals? If so, the policy will be considered successful so far. This definition of success will be applied when looking at existing policy in California and across the globe.

Existing Policy

California is a leader in environmental policy and has been working towards electrifying transportation since 2009. Some of the major policies in California helping to drive electrification of the state's transportation include (1) the Low Carbon Fuel Standard, (2) the Sustainable Freight Action Plan, (3) California State Senate Bill 350, (4) the Advanced Clean Truck Rule and (5) Executive Order N-79-20.

Low Carbon Fuel Standard

One of the first policies in California focused on electrifying transportation is the Low Carbon Fuel Standard. It was approved in 2009 and implementation began in 2011. This standard falls under the scoping plan of Assembly Bill 32. The Low Carbon Fuel Standard works to reduce the carbon intensity of California's transportation fuel 20% by 2030 (CARB, 2019c). The standard is part of a set of programs working to reduce greenhouse gas emissions and toxic air pollutants through (1) improved vehicle technology, (2) increased transportation mobility options and (3) reduced consumption of fuel. In 2018 amendments were added to strengthen the benchmarks set for carbon intensity through 2030. By 2018 the Low Carbon Fuel Standard had allowed California to avoid 38,000,000 tons of carbon pollution and saw an increase of 74% for clean fuel

use (California Delivers, 2018). This standard has created successful mandates and other jurisdictions have been implementing the standards as well.

The Pacific Coast Collaborative was formed in 2016 and includes California, Oregon, Washington and British Columbia. This collaborative is using the Low Carbon Fuel Standard to build a strong west coast market for alternative fuels. This collaborative is the fifth largest economy in the world and accounts for 55 million people (Pacific Coast Collaborative, 2020). The collaborative's goal is to build the low carbon economy of the future. As a part of this goal the collaborative is working to reduce transportation emissions. This reduction in transportation emissions will come in part from a transition to zero emission medium and heavy duty vehicles. The collaborative is creating zero emission corridors which means having infrastructure in place to allow medium and heavy duty vehicles to travel up and down the west coast. The collaborative is also working to electrify drayage medium and heavy duty vehicles since there are ports in various cities within the Pacific Coast Collaborative.

Sustainable Freight Action Plan

After the Low Carbon Fuel Standard, the Sustainable Freight Action Plan was the next policy to help electrification of electric vehicles is California. The Sustainable Freight Action Plan arose from Governor Brown's Executive Order B-32-15 on July 17, 2015. This plan works to increase the freight transport system's efficiency by 25%, add 100,000 electric vehicles to the road in California by 2030, increase freight competitiveness and have the various state agencies work together to create an action plan (Forrest et al., 2020).

The state agencies worked together and released their action plan in 2016. This plan noted the need for (1) strategic partnership, (2) well-planned investments, (3) new technologies, (4) infrastructure upgrades and (5) work with community partners in to successfully implement the Sustainable Freight Action Plan (CDT, CEC, GOBED, & CARB, 2016). The action plan also defines what they see as the 3 e's of sustainability (1) environment, (2) economy and (3) equity that will need focus when forming strategic partnerships, planning investments and working with community partners. Integration of investments, policies and programs across state agencies will also be important. The Sustainable Freight Action Plan is using a combination of strategies including infrastructure and targeted efforts for disadvantaged communities from the five policy buckets.

California Senate Bill 350

Shortly after the Sustainable Freight Action Plan California Senate Bill 350 was passed. This senate bill, also known as the Clean Energy and Pollution Reduction Action 2015, was passed on October 7, 2015. This bill sets California's greenhouse gas reduction targets for 2030. These targets include a renewable energy target of 50%, doubling energy efficiency and improving the energy efficiency of travel (De Leon, 2015).

Renewable energy targets will be reached through increasing renewable portfolio standards, which means California will work to increase the percentage of their energy coming from renewable sources such as wind or solar instead or coal or oil. The doubled energy efficiency will be reached through the utility companies developing and submitting integrated resource plans to the state. These plans will outline how utilities will meet resource needs, reduce their greenhouse gas emissions and ramp up their clean energy resources. The improvement of energy efficiency of travel will come with development of technology as well as help from utilities also working on transportation electrification.

This bill will use the mandates and rate design buckets as some of its strategies to achieve its goals. This bill uses a mandate setting a renewable energy target of 50% for California to reach by 2030. This bill uses the rate design bucket because utility companies will need to change their pricing structures to meet resource needs and shift to use more clean energy sources.

Advanced Clean Truck Rule

The Advanced Clean Truck Rule is one of the more recent policies working to electrify medium and heavy duty vehicles in California. The Advanced Clean Truck Rule builds on California Senate Bill 350 and was approved on June 25, 2020. This rule created programs through the California Air Resources Board that encourage the use of medium and heavy duty zero emission vehicles (CARB, 2019). These programs work to incentivize infrastructure upgrades and offsets costs of electrical service upgrades for charging infrastructure.

The Advanced Clean Truck Rule has two primary elements of implementation, summarized in Table 4, which are manufacturer zero emission vehicle sales and large entity reporting (CARB, 2020).

Table 4: Primary Elements of the ACT Rule (CARB, 2020)

Manufacturer Zero Emission Vehicle Sales	Large Entity Reporting
• Must sell Zero Emission Vehicles as a percentage of annual sales	• One time reporting in 2021 • Vehicles, facilities, contracted vehicle services

The Advanced Clean Truck Rule programs work with manufactures to have viable options for medium and heavy duty vehicles. These vehicles need to be cost competitive compared to diesel counterparts already on the market. This will help increase the percentage of zero emission trucks and bus sales in California. The large entity reporting element includes onetime reporting from manufactures, government agencies and retailers to calculate the number of medium and heavy duty vehicles that are currently on the road. This will help to plan out how many and what types of vehicles will need to transition to zero emission vehicles.

The California Air Resources Board plans to use varied approaches under the Advanced Clean Truck Rule to create a market for medium and heavy duty vehicles that is zero-emission, as well as self-sustaining through a mix of supporting projects and legislation. Some of the strategies used from the different policy buckets by the Advanced Clean Truck Rule include mandates, infrastructure and incentives on charging infrastructure and zero emission vehicle sales. For example, a mandate of the Advanced Clean Truck Rule is that manufacturers must sell zero emission vehicles as a percentage of annual sales. The Rule also places focus on the necessity to build out infrastructure and would encourage that build out incentivizing infrastructure upgrades and offsetting costs of electrical service upgrades for these infrastructure sites.

Executive Order N-79-20

The most recent policy working on electrification of vehicles in California is Newsom's Executive Order N-79-20. This executive order was signed September 23, 2020. Executive Order N-79-20 says that 100% of in-state sales of new light duty vehicles and drayage vehicles will be zero emission by 2035 and that 100% of medium and heavy duty vehicle in state will be zero emission for all operations by 2045 where feasible (Newsom, 2020). Under this executive order, the California Air Resources Board will set and monitor progress for the regulation increasing percentages of zero emission vehicles on the road until the target dates are reached. Other state agencies will also be brought in to help achieve these goals. The Zero-Emissions Vehicle Market Development Strategy that will detail how this executive order will be carried out is expected January 31, 2021. This executive order implements strategies from the mandates policy bucket.

Summary of California Policies

California has come up with a variety of different policies to help electrify light, medium and heavy duty vehicles, summarized in Table 5, but it is not the only place using policy to electrify their transportation.

China, Norway and Canada have also implemented varying policies to promote electrification of their vehicles. California has also rolled out other environmental programs, such as solar that can be used as an example of successful policy and implementation of an environmental initiative. Finally, disadvantaged communities need focused policies to benefit from electrification of transportation in California.

Table 5: Policy buckets used to promote electric vehicles using concepts stated in Nadel, 2019 with the addition of specific California Policies

Policy Bucket	Examples	California Policies
Incentives	• Varying national, state, local and utilities incentives • Focus on EV purchases and charging equipment	• Advanced Clean Truck Rule
Infrastructure	• Build out electric vehicle charging infrastructure • Many organizations building chargers and infrastructure	• Sustainable Freight Action Plan • Advanced Clean Truck Rule
Mandates	• Certain percentage of vehicles sold must be electric vehicles	• Low Carbon Fuel Standard • California State Senate Bill 350 • Advanced Clean Truck Rule • Executive Order N-79-20
Rate Design	• Alternatives to utility demand charges pricing structures	• California State Senate Bill 350
Targeted Efforts for Disadvantaged Communities	• Shared electric vehicle programs • New or used electric vehicle purchase incentives • Electric bus programs	• Sustainable Freight Action Plan

Policies Around the Globe

China is one of the world leaders for electrification across the globe. In electrifying their transportation, China has focused on transit buses (Gerdes, 2020). There are currently more electric buses in operation in China than in any other country (Song, Liu, Gao, & Li, 2020). China still has the most electric buses in the world when calculated per person. There are 400,000 electric buses around the globe: 98% of electric buses are in China, or 392,000 buses, 4,000 are in Europe and 1,000 buses are in the United States (Sustainable Bus, 2020). In 2020 the population of China is 1,439,323,776 (Worldometer, 2020c). This means that there are 2.7×10^{-4} electric buses per person in China. In 2020 the population of Europe is 747,636,026 (Worldometer, 2020b). This means that there are 5.4×10^{-6} electric buses per person in Europe. In 2020 the population of the United States is 331,002,651 (Worldometer, 2020a). This means that there are 3.0×10^{-6} electric buses per person in the United States. China currently has the most buses of any country in volume as well as per person when looking at Europe as well as the United States.

In China electrification of transportation has become a central focus of policy. In 2009 the "Ten Cities, One Thousand Vehicles" program was started. This program focused on adding 1,000 electric buses in 10 different cities across China through government subsidies (Song, Liu, Gao, & Li, 2020). In 2010, the electric vehicle industry was declared important and a number of different policies were put in place to help speed up development and implementation. Due to this emphasis on electric vehicles China now has the largest market for electric vehicles (Song et al., 2020). There has also been a focus on electric vehicles specifically in public transportation. China sees plug-in or hybrid buses as the best way to reduce carbon emissions as well as energy consumption.

Another country that has focused on a different part of vehicle electrification is Norway. In Oslo, Norway, zero emission construction sites have been mandated (Gerdes, 2020). The first zero emission construction site was launched in 2019 and it has been mandated that all public construction sites will be zero emission by 2025. This will include electric excavators, loads and dumpers. A few automakers including Hitachi, Komastu and Vovlo are already making electric models. Norway sees great potential for greenhouse gas emission reductions because machinery used in construction sites, such as the excavators, loads and dumpers, are usually diesel powered. Norway is working to create a competitive market for zero emission construction

machinery so it will become more cost comparable to have electric vehicles and machinery on construction sites instead of diesel counter parts (Climate Agency, City of Oslo, 2019). Once this market is created it can be more widely adopted.

Along with mandates such as zero emission construction sites, Norway also uses the incentives policy bucket. Some of the incentives Norway uses include (1) no purchase or import tax, (2) road tax exemptions, (3) reduced car company taxes, (4) no or reduced tolls, (5) free or reduced parking and (6) access to bus lines. Using these different incentives light duty electric vehicles achieved 50% of the market share in Norway in 2018 (Nadel, 2019).

Another country that is working to electrify vehicles is Canada. Canada has taken a similar approach to California by using mandates to implement an increasing percentage of electric vehicles on the road. Canada's mandate states that 10% of all light duty vehicles will be zero emission by 2025 with that percentage increasing to 100% by 2040 (Nadel, 2019). Along with these mandates the government has the ability to sell credits to manufacturers who are not able to reach the percentages mandated on the given timeline (Baker, 2019). Canada's mandates and focus are similar to the ones used in California to electrify transportation where as China and Norway have found other focuses.

Comparing Policies

When comparing China's approach to electrifying transportation compared to California, the focus is different. In California electrification of transportation has focused on light duty vehicles before moving to medium and heavy duty vehicles. However, China's focus was on electrifying public transportation starting with buses. One policy from China that could be used as an example in California is the "ten cities, one thousand vehicles" program. In California one city could be used as focus point to implementing electric buses with the help of government subsidies and provide a model for other cities within the state. Los Angeles may be a good city to use due to its use of public transit and the need for environmental justice for the numerous disadvantaged communities in the area.

Norway also takes a different approach to electrifying transportation. Oslo, Norway emphasizes construction sites which contain a variety of medium and heavy duty vehicles. Oslo, Norway chose to focus a sector where most of the vehicles and machinery are diesel powered because there is a strong opportunity to reduce emissions. The policies set by Oslo show that buy

in from local government is a way to help California to electrify medium and heavy duty vehicles. The city of Oslo's commitment to zero emission construction sites is a step above the country's commitments and not only will help the city itself but is working on creating a market that can be used by the whole country and other countries around the world. Buy in from a major city in California, such as Los Angeles, will help to drive electrification of medium and heavy duty vehicles across the state by creating support for electrification as well as creating a model that can be used by other parts of the state.

Canada, like California, has placed more focus on electrifying light duty vehicles before working to electrify medium and heavy duty vehicles. There are a few reasons a focus on light duty vehicles may have been chosen. First, there are smaller upfront costs associated with light duty vehicles than with medium and heavy duty vehicles. It has also been easier to create and build technology for light duty vehicles. With lower upfront costs and further technology progress there are more manufacturing options for light duty electric vehicles as more automakers start to produce and sell them.

The focus of where to start electrification has been different between these different countries. California and Canada focused more on electrifying light duty vehicles first whereas Norway and China focused electrifying medium on heavy duty vehicles including public transportation and construction sites. However California, Norway, Canada and China have all used mandates to reach their electrification goals. Mandates seems to be the favored policy bucket used in vehicle electrification around the globe.

Solar Policy in California

Another environmental program California rolled out with successful results was solar. Looking at what worked for this solar rollout can help plan for electrifying medium and heavy duty vehicles in California. The solar rollout also falls under California Senate Bill 350. The 2000's solar "market-pull" policies in California have led to market adoption for photovoltaic systems (CEC, 2017). These "market-pull" policies worked to create a demand for (1) solar cells that were cheaper and more efficient, (2) design of solar panels for rooftops that are more aesthetically pleasing and (3) a system that has integrated installation costs through streamlining and standardization of the process. There has also been a solar initiative where there was focus placed on expanding use of solar as a renewable energy source. Renewable portfolio standards

and the expansion of renewable energy targets to 50% of energy use by 2030 under California Senate Bill 350 have helped drive the expansion of solar as well. The progress of the solar rollout has been tracked and overseen by the California Energy Commission and costs for solar panels and installation have decreased over the years.

To successfully electrify medium and heavy duty vehicles in California, the "market-pull" approach used in the solar rollout may be a useful tool. Working to make medium and heavy duty vehicles and charging infrastructure markets more competitive and creating demand will help with implementation of electrification. The Advanced Clean Truck Rule is an example of a policy helping to make the market more favorable for medium and heavy duty vehicle electrification. The policy creates mandates and works with manufacturers to create cost effective alternatives to diesel medium and heavy duty vehicles. Incentives to build charging infrastructure will also be helpful in making the medium and heavy duty electric vehicle market more competitive because more infrastructure will help bring down the individual costs of a vehicle. Using the "market-pull" approach effectively implemented for solar can help medium and heavy duty vehicle electrification see its own success.

Disadvantaged Communities

Along with successfully implementing electrification of medium and heavy duty vehicles, it is important to look at where this implementation is happening to have a meaningful impact. The fifth policy bucket for implementation of electric vehicles, targeted efforts for disadvantaged communities, can help make a meaningful impact by reducing emissions for these communities disproportionately impacted. To make sure these benefits were reaching disadvantaged communities the California Air Resources Board conducted a low-income barriers study as a part of California Senate Bill 350.

This study showed that the barriers were not the same across the stated and each disadvantaged community had differing needs based on demographic, economic, geographic and cultural attributes (CARB, 2018c). Some of the most common barriers included (1) affordability, (2) funding for clean transportation investments, (3) awareness of options for clean transportation and (5) lack of permanent and long term funding. Funding sources are critical to implementing environmental programs in disadvantaged communities. To get this funding state, federal and private sources need to be leveraged. The study also showed that there is a

need for community engagement to understand the barriers to each specific community. The California Air Resources Board has public hearings in disadvantaged communities to get this community engagement and help start to overcome barriers to clean transportation and mobility options. Electrification of medium and heavy duty vehicles is crucial to giving disadvantaged communities some environmental justice in regard to the disproportionate exposure to harmful emissions. Understanding barriers these communities face will help to successful implement electrification of medium and heavy duty vehicles with its intended benefits.

Analysis of Success in Policies

California can look to other policies from different countries as well as other environmental policies within the state to help design policies from electrification of medium and heavy duty vehicles in California that will be successful. As previously stated, success is being defined as reaching a policies goal by the stated date or being on track to reach the goal.

China provides a successful model for electrifying public transportation because it has built out a robust electric bus system. China emphasized electrifying buses in various policies to create the largest market share of electric buses in the world. China has achieved this and has 98% of the electric buses running across the globe (Sustainable Bus, 2020). Along with widespread adoption of electric buses China has seen a reduction in greenhouse gas emissions. In 2017, China's carbon dioxide emissions were reduced by 1.353 million tons and nitrogen oxides and particulate matter emissions were reduced by 431.6 tons (ITDP, 2018).

Norway has been successful in working towards its goal of 100% zero emission construction sites by 2025 (Gerdes, 2020). Norway has already created several zero emission construction sites and is on track to reach the 2025 target. Reaching these 100% zero emission construction site targets will help Norway reduce greenhouse gas emissions as well. Construction sites in Norway have emissions ranging from 120 to 240 megatons of carbon dioxide equivalent annually (Climate Agency, City of Oslo, 2019).

Solar in California is an environmental program that has been very successful and California has even exceeded its goals. California set a goal of installing 3,000 megawatts of solar by 2017 and by 2019 there was 9,607 megawatts of solar installed (CPUC, 2020a). This implementation of solar and widespread adoption has also helped to reduce greenhouse gas

emissions as well. California saw a reduction in annual emissions by 6 million metric tons of carbon dioxide in 2018 due to solar installation (Becker, 2020).

Policies from China, Norway and solar in California have been successful and can provide insight into how to create policy that will be successful in electrifying medium and heavy duty vehicles in California.

Recommendations

Existing policies in California are a good starting point to electrifying medium and heavy duty vehicles but these policies can be built up by (1) developing more mandates, (2) looking to strategies in other countries, (3) learning from other environmental program roll outs and (4) working with disadvantaged communities to overcome their barriers to electrification.

California has used a variety of mandates, including setting targets to increasing percentages for electric vehicles in the market. Another mandate that could be useful and further developed is focusing specifically on the class of vehicles (Burke, 2020). Mandates that are specific to vehicle classes can be helpful because the vehicles will have similar characteristics, use patterns and business models. One way the classes for medium and heavy duty vehicles can be broken out is by delivery, drayage and long haul. By creating mandates for each class separately with different targets may make the goals easier to accomplish.

Another way to expand on existing policy for electrification of medium and heavy duty vehicles in California is to look at what has been done in China and Norway. China has been working to electrify their public transportation. California has goals of having zero emission buses in Los Angeles by 2030, King County by 2034 and San Francisco by 2035 (Pacific Coast Collaborative, 2020). There are economic benefits to electrifying buses as well. The life time costs of an electric bus are 12.5% lower than a diesel bus when considering the initial purchase, fuel and maintenance and these savings climb to 45% when health care costs and carbon costs are taken into consideration (Pacific Coast Collaborative, 2020). In California this has not been a main focus initially but goals for electrification are now being set and there are some partnerships between utilities and organizations building charging infrastructure working towards electrifying buses and providing the needed infrastructure.

Along with China, Norway has been electrifying its medium and heavy duty vehicles by working towards zero emission construction sites. This may be further down the road for California but what has been successful for Norway may be helpful to know down the line for California. By looking at what policies have been successful in China and Norway, California can use these lessons to its own electrification of public transportation and construction sites.

California can also look to the successful roll out of solar to build upon its existing policies for electrifying medium and heavy duty vehicles. "Market-pull" was an effective strategy used in solar policies. Using this strategy and implementing incentives can help make medium and heavy duty electric vehicles and infrastructure more affordable. This will help to create a more competitive electric vehicle market and lead to wide implementation of medium and heavy duty electric vehicles.

When building on existing policy for transportation electrification, it will be necessary to take barriers faced by disadvantaged communities into account. Each community has different needs based on varying attributes so community involvement will help to understand and overcome each communities' unique barriers. Environmental justice for disadvantaged communities is an important part of electrifying medium and heavy duty vehicles in California and it is necessary to take this into account when creating and expanding policies to help with electrification targets.

Current policies focused on electrification of medium and heavy duty vehicles can be added to and strengthened by (1) creating more mandates, (2) learning from strategies in other countries, (3) implementing strategies from other environmental program with successful roll outs and (4) communicating with disadvantaged communities to understand and overcome their barriers to electrification. To expand on existing policies in California working to electrifying medium and heavy duty vehicles more funding opportunities will be needed.

Funding

Challenges

The third main challenge facing electrification of medium and heavy duty vehicles in California is the need for funding to help cover upfront costs. Right now electric medium and heavy duty vehicles have higher upfront cost that diesel and gasoline counterparts (Nadel, 2019). This creates a barrier for businesses and fleets looking to electrify their vehicles. The higher upfront costs for electric medium and heavy duty vehicles comes from the low volume of production of electric alternatives and components, such as batteries, that are more expensive than components of their diesel counterparts (CARB, 2019).

Also adding to upfront costs is the need to significantly expand infrastructure. Infrastructure costs can vary in price depending on how much upgrading the site will need. Some sites will only need slight upgrades where as others will need to be completely redone or have new electric infrastructure put in to support charging infrastructure.

There are a few funding options that businesses and fleets can use to help cover these upfront costs but more money will be needed. There are cost offsets available such as tax credits and fuel and maintenance cost savings (Nadel, 2019). There are also various funding programs through the state, private business and utilities that can help to cover the upfront costs to encourage medium and heavy duty electric vehicle adoption through incentives and vouchers.

Along with needing more funding, education will be needed to help expand electrification of medium and heavy duty vehicles in California. This education would include making fleets and businesses aware of the various funding opportunities available as well as the overall life cycle costs (CARB, 2019d). Electric vehicles will pay back initial costs because they have lower operating costs, educating potential buyers on this pay back may help buyers be more willing to spend the upfront costs to purchase a vehicle and help expand the medium and heavy duty electric vehicle market. The societal benefits of reduced emissions and environmental justice also outweigh the upfront costs and this can also help encourage willingness to not only pay these costs but provide funding to make upfront costs more manageable.

Analysis

To successfully electrify medium and heavy duty vehicles in California more funding support will be needed. A rough total cost estimate for electrifying medium and heavy duty vehicles in California is $198 billion. This cost was calculated using the number of medium and heavy duty vehicles registered in California in 2015, the medium volume infrastructure cost calculated from Hall and Lutsey, 2019, and the average cost of a medium and heavy duty vehicle from ACT News, 2020.

The cost of a class 4-6 electric vehicle ranges from 100,000 to 200,000 and a class 8 vehicle is $300,000 or more (ACT News, 2020). The average cost calculated from this range is $200,000 for an electric medium or heavy duty vehicle. This average cost of $200,000 is then multiplied by 987,817, which was the registered number of medium and heavy duty vehicles in California in 2015 (CEC, 2020). Next, an estimated infrastructure cost is added, the cost used is $191 million which is the total infrastructure cost of delivery, drayage and long haul for a medium volume of electric vehicles from Hall and Lutsey, 2019. The medium volume was chosen to account for the electric medium and heavy duty vehicles already on the road. These calculations show a rough estimate of $198 billion as the total cost of electrifying medium and heavy duty vehicles in California.

It is also important to make sure the funding is sustained to continue to build and expand the early zero emission vehicle market (Slowik, Hall, Lutsey, Nicholas, & Wappelhorst, 2019). This can include a variety of different pieces like incentives to drop upfront costs, infrastructure expansion and outreach campaigns to drive education on options and benefits will all need funding. As time goes on and the market becomes more developed, the sustained funding focuses can shift from incentives and awareness to supporting infrastructure expansion.

One source of funding that could be accessed by businesses with fleets or individual owners of an electric medium or heavy duty vehicle may come from polluter pay policies. These policies tax higher pollution vehicles, owned by fleets or individuals, to have a stream of revenue to offer incentives for purchasing electric medium and heavy duty vehicles. This can create vehicle externalities and minimize government expenses. Some of the available funds from polluter policies can go towards education campaigns as well.

Another source of funding and reductions of upfront costs can be to shift costs away from governments and on to the private sector. This placing costs onto the private sector would allow for a government incentives phase down (Slowik et al., 2019). Consumer campaigns would also shift away from government funding towards normal automaker marketing. Infrastructure costs would shift to investments that are market-lead and ratepayer-funded deployment through utilities. This shift and collaboration between the government and private sector will be important and can help to identify funding gaps that need to be filled to electrify medium and heavy duty vehicles across California.

For sustained funding to be successful, policies will be needed to provide funding for the electrification of medium and heavy duty vehicles in California. Policies that have help to support funding include development of stricter emission guidelines and zero emission vehicle targets (Slowik et al., 2019). Policies like these ensure the medium and heavy duty vehicle market keeps growing and developing and that there is increased investment as well as volume and availability of electric vehicle models. California has developed a variety of funding programs for medium and heavy duty vehicle electrification through different policies.

California Funding Programs

One of the major funding sources for medium and heavy duty vehicle electrification in California comes from California's carbon market. This carbon market comes from California's Low Carbon Fuel Standard and creates a reliable revenue stream to help fund transportation electrification efforts. In 2016, this carbon market generated $92 million which was used to support electrification of vehicles in California (Union of Concerned Scientists, 2018). This carbon market works through a credit system where carbon intense petroleum refiners and importers can buy credits that are generated by clean fuels such as electric vehicles. One credit is equal to one metric ton of carbon dioxide emissions that are avoided. As renewable energy sources and the vehicle electrification markets continues to grow, more credits become available. This carbon market in California is predicted to provide billions of dollars by 2030 that can be used to fund vehicle electrification.

California's carbon market has specific funding options for medium and heavy duty vehicles. These funding opportunities include incentives for transit buses, delivery trucks and freight trucks. Transit agencies can earn up to $9,000 per year for each electric vehicle

purchased. This credit will bring bus charging costs down to $7,000 a year for each electric bus. This is a much lower cost than the average $24,000 spent per year for fuel for diesel counterparts (Union of Concerned Scientists, 2018). By creating a sustainable carbon market that will continue to produce a revenue stream, this program will help to create sustained funding for medium and heavy duty electrification and help bring down upfront costs.

Another policy program put in place to help electrify transportation in California is called Calstart. Calstart covers electrification of light duty as well as medium and heavy duty vehicle electrification. However it does have a specific focus on a truck incentive program in California. This program is referred to as the hybrid and zero-emission truck and bus voucher incentive project (California Climate Investments, 2018). This project provides vouchers for trucks and buses on a first come first served basis. For implementation of the hybrid and zero emission truck and bus voucher incentive Calstart has partnered with the California Air Resources Board.

Along with Calstart the California State Resources Board is also the lead agency for the Volkswagen Mitigation Trust. The Volkswagen Mitigation Trust resulted from the Volkswagen settlement for installing software that cheated emissions tests on their vehicles. California was awarded $423 million from the settlement (CARB, 2018b). Funding for medium and heavy duty vehicle electrification was broken down into two main categories as seen in Table 6.

Table 6: Funding Breakdown from the Volkswagen Settlement for Medium and Heavy Duty Vehicles using concepts from CARB, 2018b

Vehicle Type	Allocation
Zero emission transit, school and shuttle buses	$130 million
Zero emission class 8 freight and port drayage trucks	$90 million

Zero emission transit, school and shuttle buses will receive $130 million in funding. Zero emission class 8 freight and port drayage trucks will receive $90 million in funding.

The part of California's settlements that will be invested in heavy-duty vehicle emission reductions will be implemented through various programs working on electrifying medium and heavy duty vehicles. One of the programs is the Carl Moyer Program which provides locally directed incentives. Another program is the Low Carbon Transportation Investments which provides incentives to reduce emission through transportation electrification. The Proposition 1B Goods Movement Emission Reduction Program is also used by the California Volkswagen Mitigation Trust which provides funding to local agencies to offer incentives to electrify medium and heavy duty vehicles.

In addition to working with California's various policy programs providing funding for electrifying transportation, the California Air Resources Board budgets for its own clean transportation incentives as another source of funding for electrification on medium and heavy duty vehicles. For the 2019-2020 fiscal year, the California Air Resources Board allocated $182 million for investments in trucks, buses and off-road equipment (California Climate Investments, 2019). This funding will be used to demonstrate the advancing technology in medium and heavy duty vehicles. Early commercial pilots for varying electric vehicle models will also be supported by the available funding. Voucher incentives for purchasing new electric medium and heavy duty vehicles and infrastructure will also fall under this funding. California offers a wide variety of funding options from different policy programs and the California Air Resources Board but federal incentives can also be applied to help electrify medium and heavy duty vehicles in California.

Federal Incentives

Along with state programs there are some federal programs that will help mitigate the upfront costs of electrification of medium and heavy duty vehicles in California. One federal program available is the federal tax credit for a new electric vehicle including light, medium or heavy duty vehicles. This program offers up to $7,500 per vehicle based on the battery capacity and is available to the first 200,000 vehicles sold for each manufacturer (Nadel, 2019). Tesla and General Motors have already hit this cap while other automakers, the next three closest being Nissan at 144,913 electric vehicles sold, Toyota at 127,593 electric vehicles sold and Ford at 123,030 electric vehicles sold, are not likely to reach the cap until at least 2022 or 2023 (EV Adoption, 2020). For Tesla, General Motors, Nissan, Toyota and Ford this means there are only

204,464 tax credits left among these top 5 automakers. While this program will help initially, the cap at 200,000 vehicles per manufacturer across the United States will not provide sustained funding to replace all of the 987,817 medium and heavy duty vehicles registered in California in 2015 (CEC, 2020).

Another federal program that offers ongoing funding opportunities is the Low or No Emission Vehicle program. This program offers federal grants to help with electric bus purchases and deployment of electric transit bus infrastructure. This program is run through the Federal Transit Administration as a part of the United States Department of Transportation. For 2020 $130 million has been provided in grant selections for medium and heavy duty electrification projects (Federal Transit Administration, 2020). The Low or No Emission Vehicle program has provided a total of $409 million in funding for projects in the past. Both of these programs provide additional funding opportunities for electrification of medium and heavy duty vehicles in California.

Light Duty Electric Vehicle Funding Programs

Electrification of light duty vehicles in California can be referenced as a successful funding program for electric vehicles. The state of California invested $500 million in consumer rebates for light duty electric vehicles (CARB, 2018b). These customer rebates helped cover upfront costs of buying an electric vehicle which lead to more purchases of light duty electric vehicles and expansion of the market. Today light duty vehicles are much more affordable and almost all major automakers sell their own electric vehicle model.

Utility programs were another successful way to provide funding for light duty vehicle electrification. Many different utilities offered varying levels of rebates with the purchase of an electric vehicle. These utilities programs are summarized in Table 7.

Table 7: Utility Program Rebates for Light Duty Electric Vehicles from concepts in Union of Concerned Scientists, 2018

Utility	Rebate
Pacific Gas and Electric	$500 one time rebate
Sacramento Municipal Utility District	$599 one time rebate OR free level 2 charger
San Diego Gas and Electric	Account credit of $50 annually through 2020
Southern California Edison	$450 one time rebate

One utility program was through Pacific Gas and Electric and offered a onetime rebate of $500. The Sacramento Municipal Utility District's program offered a $599 one time rebate or a free level 2 charger. The program though San Diego Gas and Electric provided an account great of $50 a year through 2020. Southern California Edison offered a $450 one time rebate.

Funding initiatives for light duty vehicle electrification show the importance of utilities providing funding as well. Having the state provide funding is critical but the addition of utility programs helps to drive market expansion and bring down upfront costs of electrification form medium and heavy duty vehicles.

Solar Funding Programs

Another environmental program that has been successful in California and received funding to mitigate upfront costs is solar. One of the main funding programs available for solar funding was Go Solar California. The Go Solar California funding program was a multi-entity $3.3 billion ratepayer funded program working to install 3,000 megawatts of new solar (CPUC, 2020a). This program started in 2007 and ran until 2016 for most funding but it is still working to help roll out solar in disadvantaged communities. The program was overseen by the California Public utilities commission and worked to reduce the cost of solar equipment such as solar panels. By the end of 2019 about 9,607 megawatts of solar have been installed across the state (CPUC, 2020).

The Go Solar California shows the success of having funding programs that help to lower upfront costs. For solar this was the solar equipment and installation. The Go Solar California is a

model that can be used for electrifying medium and heavy duty vehicles in California, showing that mitigating upfront costs can help the market successfully grow and reach outlined goals.

Disadvantaged Communities

Environmental justice for disadvantaged communities is a big part of the push for electrifying medium and heavy duty vehicles in California and there is additional need for funding in these communities. Some of the funding programs in California have taken this into account and have reserved funding for disadvantaged communities. The California Air Resources Board's Clean Transportation Incentives is one of these programs (California Climate Investments, 2019). This program provides additional incentives for projects that take place in disadvantaged communities. The Clean Transportation incentives also focuses on outreach and education in disadvantaged communities.

Calstart is another medium and heavy duty electric vehicle funding program that has set aside funding specifically for disadvantaged communities (California Climate Investments, 2019). Calstart provides vouchers for trucks and buses and offered increased incentives for fleets that are either in or serve disadvantaged communities. Carving out funding that will go to help electrification in medium and heavy duty vehicles in disadvantaged communities will help work towards the needed environmental justice.

Additional Funding Needed

Although the various programs available in California and through the federal government are a good starting point for medium and heavy duty vehicle electrification additional funding is needed. California funding includes $92 million from the Low Carbon Fuel Standard, $220 million from the California Volkswagen Mitigation Trust and $182 million from the 2019-2020 California Air Resources Budget totaling $494 million (California Climate Investments, 2019; CARB, 2018b; Union of Concerned Scientists, 2018). This only puts a small dent in the estimated total cost of $198 billion for electrification of medium and heavy duty vehicles in California with $195.1 billion still needed.

Federal incentives include $1.5 billion for the Federal Tax Credit of $7,500 per vehicle for 204,464 vehicles left to receive a tax credit from the top 5 automakers, and $130 million for the Low or No Emission program totaling $1.7 billion available for the entire United States (Federal

Transit Administration, 2020; Nadel, 2019). Splitting the $1.7 billion of federal funding available evenly across all states, California would receive $33.3 million. Adding this to the existing funding available in California leaves a funding need of $195.06 billion.

There is a large amount of medium and heavy vehicles that will need to be replaced by electric vehicle counterparts which will become more feasible with additional funding opportunities. Significant funding is also needed to build out the supporting infrastructure across the state.

Vouchers or incentives are needed to make the upfront costs of purchasing an electric vehicle more manageable and comparable to its diesel counterpart. Funding is also needed for education programs that will help make potential electric vehicle buyers aware of all the different funding programs available and that the life time costs of an electric vehicle end up being less than those for a diesel vehicle. To continue to electrify medium and heavy duty vehicles across California, more sustainable funding will be needed.

Recommendations

To successfully electrify the medium and heavy duty vehicles in California more education on funding opportunities and sustained funding will be needed. Funding is needed to help mitigate the upfront costs of both purchasing a medium or heavy duty electric vehicle and installing necessary infrastructure. Education is needed to help existing funds reach businesses and fleets interested in electrification.

The best way to get available funding into the hands of fleets and businesses is by providing education. This education can help make fleets and businesses aware of available funding that can be used to purchase ne electric vehicles and install infrastructure. Education can also help potential medium and heavy duty electric vehicle buyers navigate the upfront costs by showing how the vehicle will cost less than a diesel counterpart over the vehicle's life time.

To gain more sustained funding for medium and heavy duty vehicle electrification in California policy and private assistance is need. This sustained funding will be needed to help the medium and heavy duty electric vehicles reach the same price point as their diesel counterparts. Policy that mandates certain percentages of vehicles need to be zero emission by a certain date help to drive electrification and funding. These policies create a demand for an electric vehicle

market and help encourage funding to reach set goals. Utilities and private cooperation and funding also helps drive medium and heavy duty vehicle electrification. Utility companies offer a variety of rebates for electric vehicle purchases and private companies offer various incentives as well.

Funding is a key factor in electrification of medium and heavy duty vehicles in California. To continue to drive this electrification effort sustained funding through policy and private support is needed. Education of funding opportunities is also crucial in overcoming upfront costs facing electrification of medium and heavy duty vehicles in California.

Overall Management Recommendations

The three main challenges faced in electrifying medium and heavy duty vehicles in California are infrastructure, policy and funding. Management recommendations can be made separately for each challenge and brought together for an overall strategy to address California's electrification of medium and heavy duty vehicles.

Infrastructure will need a combination of fleet and public agency coordination to distribute the initial cost (Hall & Lutsey, 2019). Upfront infrastructure costs range per site and sites that need a complete overhaul can run upwards of $1 million. Infrastructure costs per vehicle can also be decreased as a larger volume of electric medium and heavy duty vehicles reaches the roads. The pyramid approach, where there is a large amount of overnight chargers, medium amount of level 2 chargers and low amount of fast chargers that are strategically placed, can also be helpful when building out infrastructure. Policy and funding opportunities are also key to covering up front costs for electric medium and heavy duty vehicle infrastructure.

Policy to successfully electrify medium and heavy duty vehicles in California will need to be added and improved. One policy that could be added is a policy that would develop more mandates that are specific to a class of vehicle with in the medium and heavy duty category. California can also look to policies used in other countries, such as the "ten cities, one thousand vehicles" program in China or buy in from local governments in Oslo, Norway that have been successful in reaching the policy goals or are on track to do so. California can refer to policies used for other environmental programs as well. Solar in California is an environmental program

was successful and has been able to expand past the initial goal by using a market pull strategy that could be applied to electrifying medium and heavy duty vehicles in California. Funding will also need to be paired with policy to successfully electrify medium and heavy duty vehicles in California.

There is some existing funding for medium and heavy duty electric vehicles and infrastructure but it can be better utilized and expanded. Existing funding can be taken advantage of when there is more education on existing opportunities. Education would help make more fleets and businesses aware of funding that is already available to help lower upfront costs of purchasing an electric medium or heavy duty vehicle. Education can also help potential buyers navigate upfront costs and show how the electric vehicle will end up costing less than a diesel counterpart over the vehicle's life time. Along with education on current funding opportunities more sustained funding will be needed. Funding can be expanded with policy assistance. Mandates in policies help to drive electrification as well as expand funding. Private assistance, such as utilities or private businesses, can also be used for expanding funding.

To address all three main challenges, infrastructure, policy and funding, electrification of medium and heavy vehicles in California policy and funding recommendations can be coupled. Policy and funding will support each other through mandates and partnerships. Both new policy and funding opportunities can create an emphasis on the importance of building out necessary infrastructure as well as working to reduce the barrier of upfront costs. Specific funding and policy initiatives should also be created to address disadvantaged communities. This funding and policy focus can work with disadvantaged communities to address their unique barriers and create infrastructure programs to help drive electrification within the disadvantaged communities as well as other communities across California.

Possible Starting Point for California

Electrification of medium and heavy duty vehicles is an important but daunting task for California. Picking a subsection of medium and heavy duty vehicles to electrify first may be helpful. The three subsections of medium and heavy duty vehicles to assess include delivery, drayage and long haul vehicles. A summary of infrastructure, policy, funding, emission reductions and environmental justice breakdowns for each subsection can be seen in Table 8.

Table 8: A Look into what could be a starting point for California when electrifying medium and heavy duty vehicles using concepts from Ambrose & Kendall, 2019; California Climate Investments, 2019; CARB, 2018b; Chandler, Espino, & O'Dea, 2016; Di Filippo, Callahan, & Golestani, 2019; Hall & Lutsey, 2019; Konstantzos et al., 2017; Newsom, 2020; Skydel, 2019; Union of Concerned Scientists, 2018; Woodcraft, 2020

	Delivery	Drayage	Long Haul
Infrastructure (High Volume)	Total cost: $270 million Per vehicle: $27,000	Total cost: $280 million Per vehicle: $28,000	Total cost: $700 million Per vehicle: $70,000
Policy (Newsom Executive Order N-79-20)	100% of new sales zero emission by 2035	100% of new sales zero emission by 2035	100% of new sales zero emission by 2045 where feasible
Funding (Available)	CALIFORNIA $92 million Low Carbon Fuel standard $220 million Volkswagen settlement $182 million CARB budget FEDERAL $7,500 per vehicle federal tax credit $130 million low or no emission grants	CALIFORNIA $92 million Low Carbon Fuel standard $220 million Volkswagen settlement ($90 million set aside for drayage/long haul specifically) $182 million CARB budget FEDERAL $7,500 per vehicle federal tax credit $130 million low or no emission grants	CALIFORNIA $92 million Low Carbon Fuel standard $220 million Volkswagen settlement ($90 million set aside for drayage/long haul specifically) $182 million CARB budget FEDERAL $7,500 per vehicle federal tax credit $130 million low or no emission grants
Emissions Saved	100% electrification is reached by 2040 reduction of 4.42 million metric tons of CO_2e emissions per year	Opportunity to avoid 541,364 tons of CO_2e emissions per year with 100% electrification	100% electrification is reached by 2040 reduction of 50 million metric tons of CO_2e emissions per year
Environmental Justice	Some disadvantaged communities located near delivery hubs	Some disadvantaged communities located near ports (Los Angeles, Oakland)	Truck routes tend to run though disadvantaged communities

Infrastructure costs for a high volume of electric vehicles (10,000 vehicles) from Hall and Lutsey, 2019 include (1) a total cost of $270 million and per vehicle cost of $27,000 for delivery, (2) a total cost of $280 million and per vehicle cost of $28,000 for drayage, and (3) a total cost of $700 million and per vehicle cost of $70,000 for long haul.

The most recent and strictest policy for medium and heavy duty vehicle electrification in California is the executive order N-79-20 from Governor Newsom. This order states 100% of new sales of delivery and drayage vehicles will be zero emission by 2035. It also states 100% of new sales of long haul vehicles will be zero emission by 2045 where feasible.

The funding opportunities for delivery drayage and long haul include both state and funding sources. For California there is $92 million from the Low Carbon Fuel standard, $220 million from the Volkswagen settlement, with $90 million set aside for drayage and long haul vehicles specifically and $182 million written into the California Air Resources Board's budget for 2019-2020. Federal opportunities include $7,500 per vehicle federal tax credit for the first 200,000 electric vehicles sold for each manufacturer and $130 million from the low or no emission grants program.

The emissions saved for delivery trucks was calculated. Electrifying delivery vehicles can save 20 tons of carbon dioxide equivalent emissions per vehicle every year (Skydel, 2019). By 2040 221,000 last mile delivery and service trucks will be zero emission (Woodcraft, 2020). This would lead to 4,420,000 tons of carbon dioxide equivalent emissions per year saved. A reduction of 4.42 million metric tons is about the same amount of carbon dioxide emissions from 1.1 coal-fired power plants in one year (EPA, 2018).

The emissions saved for drayage trucks was calculated. The port of Los Angeles had 378,955 tons of carbon dioxide equivalent emissions in 2010 from drayage vehicles (Konstantzos et al., 2017). There are 13,000-14,000 drayage vehicles in the port of Los Angeles and 20,000 drayage trucks in all of California (Chandler, Espino, & O'Dea, 2016; Di Filippo, Callahan, & Golestani, 2019). Assuming there are 14,000 drayage vehicles in the port of Los Angeles, this would account for 70% of the drayage vehicles in California and 378,955 tons of carbon dioxide equivalent emissions would account for 70% of the state's emissions. Using these assumptions, the total emissions from drayage vehicles in California for 2010 is 541,364 tons of carbon dioxide emissions. Battery electric vehicle options have a 100% reduction in tailpipe emissions (Di

Filippo, Callahan, & Golestani, 2019). Electrifying all drayage vehicles in California will provide the opportunity to avoid 541,364 tons of carbon dioxide emissions per year. A reduction of 541,364 metric tons is about the same amount of carbon dioxide emissions from 0.139 coal-fired power plants in one year (EPA, 2018).

If 100% electrification is reached by 2040 for class 8 vehicles in California it could lead to a reduction of 50 million metric tons of carbon dioxide equivalent emissions per year for a total of about 30% (Ambrose & Kendall, 2019). A reduction of 50 million metric tons is about the same amount of carbon dioxide emissions from 12.8 coal-fired power plants in one year (EPA, 2018).

Delivery, drayage and long haul vehicles all provide opportunities for environmental justice. Delivery hubs, warehouses delivery vehicles go in and out of, tend to be located in disadvantaged communities. For drayage vehicles, some disadvantaged communities are located around ports. Long haul trucking routes also tend to run through disadvantaged communities.

A good starting point for California when electrifying medium and heavy duty vehicles is electrifying delivery vehicles. At a high volume of electric vehicles on the road (10,000 vehicles) delivery infrastructure is the least costly of delivery, drayage or long haul at a total cost of $270 million or $27,000 per vehicle. Delivery vehicles also have one of the closer mandated date to achieve zero emission vehicles as 100% of new sales by 2035. This sector offers the possibility to avoid 4.42 million metric tons of carbon dioxide equivalent per year if 100% electrification is reached by 2040. Delivery vehicles also have the same funding opportunities available as drayage vehicles.

This sector has also seen a great deal of expansion in 2020 due to the growth of e-commerce as well as the pandemic. North America saw a growth in the last mile delivery market of 12.7% and this is expected to continue in the coming years (Business Wire, 2020). Focus on the delivery vehicles would allow California to replace existing diesel delivery trucks with electric vehicles as well as having new vehicles that will be needed to cover the expanding last mile delivery market start out as electric vehicles.

Electrifying delivery vehicles will also help California address environmental justice concerns associated with medium and heavy duty vehicles because delivery hubs tend to be

located in disadvantaged communities. Warehouses for delivery hubs are disproportionately located in disadvantaged communities consistently across California in Los Angeles, San Francisco, San Diego and Sacramento (Yuan, 2019). Electrifying delivery vehicles would help reduce the health impacts faced by disadvantaged communities from delivery vehicles leaving and returning to warehouses in the delivery hubs.

California will need to electrify all medium and heavy duty vehicles across the state but electrifying delivery vehicles is a good starting point. Delivery vehicles have the lowest infrastructure costs but still provide opportunities for emission reductions and environmental justice across the state.

Societal Costs and Benefits

While electrification of medium and heavy duty vehicles still faces upfront costs the societal benefits outweigh the costs as seen Figure 7. This figure shows societal costs and benefits of an electric medium or heavy duty vehicle in 2020 on the left and 2030 on the right.

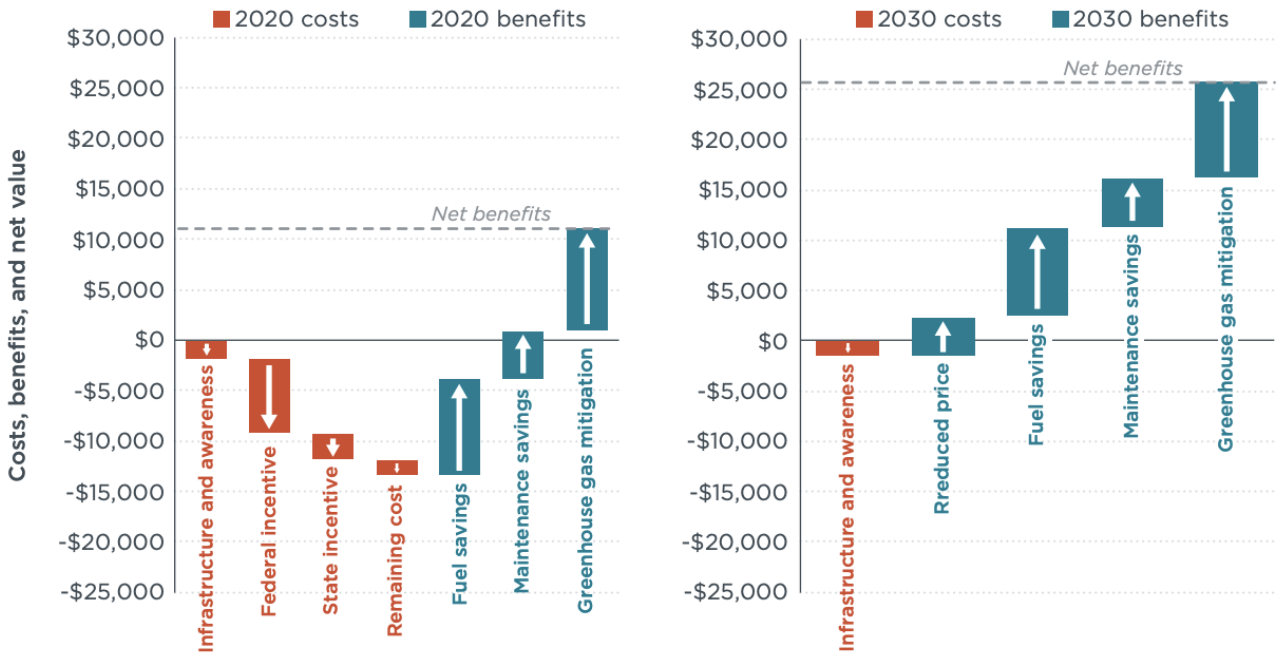


Figure 7: Societal lifetime costs, shown in red including infrastructure and awareness, federal incentives, state incentives and remaining cost not covered by incentives, and benefits, shown in blue including fuel savings, maintenance savings, reduced price and greenhouse gas mitigation, per vehicle for electric medium and heavy duty vehicles in California for 2020 and 2030 (Slowik, 2019)

The societal costs are shown in red and include infrastructure and awareness, federal incentives, state incentives and remaining cost not covered by incentives for 2020. The societal benefits include fuel savings, maintenance savings and greenhouse gas mitigation for 2020 showing there is a net benefit in 2020 of about $11,000. When moving to 2030, the only societal cost is infrastructure and awareness. The societal benefits include fuel savings, maintenance savings and greenhouse gas, all with increased values as well as an added reduction in price. The net benefit increases to $26,000 in 2030 for an electric medium or heavy duty electric vehicle.

Conclusions

Electrification of medium and heavy duty vehicles in California faces three main challenges of infrastructure, policy and funding but the social benefits of electrification outweigh the costs. This Electrification will lead to savings for fleets and owners of medium and heavy duty vehicles, reduce emissions and provide environmental justice for disadvantaged communities across the state. Electrification of medium and heavy duty vehicles across the state could save fleet operations $7-$12 billion and create thousands of new jobs (Busch, 2020).

Looking specifically at greenhouse gas mitigation, electrifying medium and heavy duty vehicles in California can lead to significant reductions in emissions. Electrification of medium and heavy duty vehicles in California could also prevent 17.6 million metric tons of carbon dioxide emissions in the coming years as well as decrease nitrogen oxide emissions by 60,000 tons (Busch, 2020). These reductions in emissions will help to provide environmental justice to disadvantaged communities.

Disadvantaged communities are disproportionately harmed by emissions from medium and heavy duty vehicles in California. By electrifying 100% of instate medium and heavy duty vehicles costs of pollution related health damages can be reduced by $507 million per year by 2025 (Ambrose & Kendall, 2019). Busch, 2020 estimates that public health benefits could reach $9 billion in the future through electrification of medium and heavy duty vehicles in California.

The economic savings for fleet businesses across the state, greenhouse gas emission reductions and gained environmental justice further the importance of electrifying medium and heavy duty vehicles in California. Focusing on electrifying delivery vehicles first gives California the opportunity to reduce emissions and address environmental justice for a lower initial cost than starting with drayage or long haul vehicles. Using policy and funding to support each other and creating a focus on reducing costs to build out infrastructure, the three main challenges of infrastructure, policy and funding for electrifying medium and heavy duty vehicles in California can be overcome.

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