Clean Technology Compendium

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Executive Summary

I. Imminent Need to Reduce Transportation Emissions

The transportation sector, which includes cars, trucks, buses, and trains, accounts for a significant portion of air pollution and greenhouse gas emissions (GHG) in the Southern California Association of Governments (SCAG) region and contributes to poor air quality and negative health outcomes. Resulting from these emissions as well as the unique meteorological condition of Southern California, the region is one of only two areas in the country designated as an "extreme" nonattainment area for the 2015 Ozone National Ambient Air Quality Standards (NAAQS). The region is also prone to climate change impacts, such as heatwaves, droughts, and wildfires, which can be exacerbated by transportation emissions. Reducing transportation emissions in Southern California is a significant logistical and economic challenge, given the region's high volume of freight and port activity, large metropolitan population, and sprawling, car-dependent urban form. SCAG addresses this through land use and transportation planning, promotion of multiple travel choices including transit and active transportation, promotion of policies that reduce vehicle miles traveled (VMT) and a transition to a zero-emission transportation system though use of clean transportation technologies.

In an effort to address air quality and climate change challenges linked to the transportation sector, the SCAG Regional Council adopted the Clean Transportation Technology Policy and Resolution on April 6, 2023, which defines clean transportation technology as zero- and near-zero emission vehicles (ZEV and NZEV, respectively), their supporting infrastructure, and other facilitative products that reduce environmental impact over their life cycle. ZEVs and NZEVs offer a robust technological solution to achieve considerable emissions reductions in the transportation sector. Amongst others, these technologies encompass battery-electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), fuel cell electric vehicles (FCEV) and low NOx natural gas vehicles (NGVs), all of which hold significant potential in reducing both air pollution and GHG emissions. Utilizing electricity, hydrogen or renewable natural gas as a transportation fuel, particularly in California, can significantly reduce overall vehicle emissions and either entirely or substantially eliminate tailpipe emissions. Also critical in the mix of clean technologies are the supporting products for zero and near-zero emissions which include any products or systems that enable the utilization of zero- and near-zero emission technologies. These can include hardware or software solutions, or services targeted at the efficient deployment, maintenance and operation of ZEV and NZEV and their infrastructure. The main objective of these supporting products is to offer a comprehensive solution that aids in the deployment and adoption of clean transportation technologies, with the intention to reduce or eradicate associated environmental impacts, while concurrently enhancing the user experience.

In recent years, federal policies, such as the Infrastructure Investment and Jobs Act (IIJA) and the Inflation Reduction Act (IRA), provide significant funding for clean transportation, with hundreds of billions of dollars of planned investment in transportation systems and technologies over the next decade. At the state level, California has implemented measures to accelerate the adoption of ZEVs, and the South Coast AQMD in Southern California is implementing regulations to promote zero-emission and clean technologies in warehouses, ports, rail, and intermodal facilities.

Despite these unprecedented policies and investments, considerable disparities persist in clean technology ownership and operation between low-income and high-income communities. Factors such as initial purchase cost and lack of needed investment in charging and fueling infrastructure contribute to the observed income-related disparities in ZEV ownership. Given that ZEVs typically have a higher upfront cost compared to traditional vehicles, affordability becomes a major barrier, particularly for low- and moderate-income households. Current incentives often fail to fully offset these costs for lower-income households. Similarly, access to necessary infrastructure, such as charging stations, is limited, particularly in lower-income neighborhoods where personal charging stations may not be feasible. Even with significant federal and state investments, more is needed to bridge the gap in zero-emission infrastructure. The growing demand for such infrastructure further underscores the importance for regional agencies like SCAG to increase efforts in infrastructure deployment to support the transition to clean transportation technologies equitably.

II. Purpose of Technology Compendium

Sound investments in ZEV and NZEV vehicles, infrastructure, and related products hinge on a thorough understanding of the available clean technology options across multiple sectors. The landscape of clean transportation technologies is vast and ever-expanding, varying significantly in readiness, cost, impacts on air pollution and GHG emissions, infrastructure needs, and scalability. In response to these needs, SCAG initiated development of the Clean Transportation Technology Compendium to provide an in-depth overview of zero and near-zero emission transportation technologies, including their charging and fueling infrastructure and other supporting products. With its focus on passenger vehicles, medium and heavy-duty vehicles, transit, and rail sectors, the compendium delves into key characteristics, gaps in knowledge, uncertainties, and strategies to fast-track clean technology deployment in Southern California.

The intent of this compendium is to serve as a resource for technology users, both public and private, who are faced with procurement and investment decisions. Additionally, it provides a guiding tool for public agencies and local municipalities in establishing policies that foster the adoption and support of these technologies. The knowledge shared within is designed to empower stakeholders at all levels to make informed choices that align with the goal of a cleaner and more sustainable future. While this technology compendium is intended to be as comprehensive as possible, the discussion is mainly focused on the overarching technology landscape rather than diving into the intricacies of vendor-specific technologies. Today, a multitude of vendors and companies offer clean transportation technologies, each coming with unique characteristics and features. When deciding on technology procurement, it is important for stakeholders to delve deeper into the specific offerings of each vendor. This ensures that the selected technology aligns seamlessly with their operational and logistical requirements.

III. Technology Specification and Assessment Methodologies

In the development of this technology compendium, SCAG compiled a catalog of various clean technologies and described them based on specific technology specifications. For vehicle technologies, the specifications cover aspects such as GHG emissions reduction, indicating the annual metric ton of CO2 emissions reduction per unit of vehicle replacement. Other specifications include NOx and PM emissions reductions, representing the percentage reduction in emissions. The range specification quantifies the number of miles a vehicle can travel with one refueling. Capital cost specification provides information on the initial investment required for purchasing clean technology vehicles, while the total cost of ownership (TCO) saving specification estimates the incremental cost or savings incurred over the vehicle's life (assumed to be 15 years across all categories). Adoption status specifies the number of vehicles employing the technology deployed in the SCAG region, and availability indicates the number of make/models of vehicles commercially available or expected to be available in the next

Vehicle Technology Specification

- GHG Emissions Reduction
- NOx Emissions Reductions
- PM Emissions Reductions
- Range
- Capital Cost
- Total Cost of Ownership
- Adoption Status
- Availability
- Longevity

three years. Longevity reveals the average number of years covered by the manufacturer warranty for vehicles using the technology.

Infrastructure & Supporting Product Technology Specification

- Capital Cost
- Maintenance Cost
- Adoption Status
- Availability
- Longevity

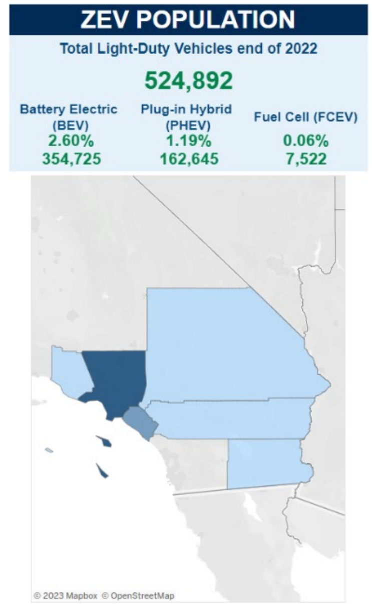
For charging and fueling infrastructure, the specifications include capital cost, indicating the initial investment required for EV chargers, natural gas stations, and hydrogen fueling stations. Maintenance cost represents the ongoing cost of maintaining these infrastructure units. Adoption status specifies the number of charging stations or fueling stations deployed in the SCAG region, while availability assesses the number of vendors or suppliers providing these infrastructure units. Longevity indicates the average number of years covered by the manufacturer's warranty for charging stations or fueling stations. For supporting products, the specifications include capital cost, indicating the upfront cost associated with the technology, and maintenance cost, representing the ongoing cost or subscription fee. Adoption status specifies the number of units of the supporting product deployed in the SCAG region, while availability assesses the number of vendors or suppliers providing the supporting product. Longevity indicates the average length of the manufacturer warranty for the supporting technology.

To evaluate clean transportation technologies, SCAG utilized a variety of data sources and methodologies. These included pre-developed tools such as the AFLEET tool from the Argonne National Laboratory for calculating the TCO of vehicles, the Alternative Fuels Data Center's (AFDC) vehicle search tool for availability of clean technology vehicles, and ICF's EV library for determining vehicle availability and range. California Air Resources Board (CARB) resources, including the Technology Feasibility Assessment for locomotives and the EMFAC2021 model, were also used for information on clean rail technologies and emission quantification.

In cases where existing tools did not provide complete information, internet searches were conducted to gather data on factors like longevity and range. Additionally, a survey was distributed to clean vehicle technology manufacturers and municipalities to gather feedback and fill any knowledge gaps. The survey aimed to gather information on commercial availability, costs, market penetrability, accessibility, and other considerations related to clean transportation technologies. The survey received responses from 20 relevant vendors of which details are provided in Appendix A. These responses played a crucial role in bridging information gaps that could not be addressed through internet searches alone. Furthermore, the project team conducted one-on-one interviews and engaged in discussions with clean technology manufacturers to gain deeper insights into the evolving technology landscape. Participation in conferences and industry gatherings also facilitated face-to-face interactions with these manufacturers.

IV. Light Duty Vehicles

The characterization of light-duty vehicles in the technology compendium includes various body styles such as passenger cars, SUVs, minivans, light-duty pickup trucks, and utility vans. Technologies such as BEV, PHEVs, and FCEVs are described based on predetermined specifications. Currently BEV and PHEVs continue to lead the charge in the clean technology revolution, bolstered by continuous improvements in battery technology. On the other hand, FCEVs, although fewer in model diversity, present an alternative for longer journeys where quick refueling is paramount. Several auto manufacturers are investing in this technology with an aim to expand their offerings. As of December 2022, consumers in California had a broad range of options with 50 passenger BEV models, 51 PHEV models, and 3 FCEV models commercially available for sale. It should also be noted that while PHEVs are considered a ZEV, they are only truly zero emission when operating solely on battery power. Once the battery is depleted, they operate similarly to a conventional hybrid vehicle, utilizing a gasoline engine. The average electric range of PHEVs has steadily increased from 20.5 miles in 2012 to 38.5 miles as of 2021.



The adoption of passenger ZEVs in the SCAG region has steadily increased over the years. ZEV adoption started gaining momentum around 2010 and was initially concentrated in high populous areas and regions with higher socioeconomic status. In the SCAG region, the majority of ZEVs are found in Los Angeles and Orange counties, with Los Angeles County having more than 50 percent and Orange County having more than 25 percent of the total ZEVs in the region. Prior to 2010, the SCAG region had only 122 ZEVs. Since then, the number has surged to approximately 525,000, representing about 3.9 percent of the total light-duty vehicle fleet in the region by the end of 2022. Sales trends indicate that ZEVs are becoming an increasingly significant portion of the market, composing roughly 25% of light-duty vehicle sales as of the second quarter of 2023. BEVs and PHEVs represent the majority of ZEVs in the region, with FCEVs lagging significantly behind, only representing 0.06 percent of ZEVs in the region. It is worth noting that the majority of the BEVs (88 percent) in the region have battery electric ranges over 200 miles. Given the current adoption rates, the region is making significant progress toward the targets set by the state requiring 100% of light duty vehicle sales in the state being ZEV by 2035.

However, despite the rapid increase in ZEV adoption, the upfront cost of ZEVs is still higher than their counterpart internal combustion engine (ICE) vehicles. The latest report from Kelley Blue Book reveals that the average cost for a passenger ZEV is $18,000 more than that of an average ICE vehicle.[1] At the same time, when evaluating the TCO, zero-emission vehicles, except for FCEVs, demonstrate cost savings over the lifetime of the vehicle, despite their higher upfront costs. The lower operating and maintenance costs of zero-emission vehicles offset the initial investment, making them financially advantageous choices in the long run. However, for FCEVs, due to the currently high cost of the fuel, the TCO ends up being higher than that of their counterpart ICE vehicles.

[1] https://mediaroom.kbb.com/2022-05-10-Luxury-Share-Increases-in-April,-Pushing-New-Vehicle-Average-Transaction-Prices-Higher,-according-to-Kelley-Blue-Book

V. Commercial Medium & Heavy-Duty Vehicles

Medium-duty vehicles (MDVs) are Class 2-7 vehicles with a Gross Vehicle Weight Rating (GVWR) between 8,501 and 33,000 lbs. Body styles for MDVs include pickup trucks, cargo vans, passenger vans, step vans, box trucks, and cab & chassis. Technology types evaluated for MDVs include BEV, PHEV, FCEV, and natural gas vehicles (NGVs). Heavy-duty vehicles (HDVs) are Class 8 trucks weighing over 33,000 lbs. and include body styles such as straight trucks, semi-tractors, and refuse trucks. Similar technology types to MDVs are evaluated for HDVs.

Medium-duty battery electric cargo vans such as this Ford E-Transit vehicle run solely on a rechargeable battery. As of 2022, 48 vehicles like this have been deployed in SCAG region.

The landscape of clean technology in the commercial medium and heavy-duty vehicle (MHDV) sector is undergoing significant transformation. There is a growing shift away from traditional fossil fuel-based technologies toward cleaner alternatives driven by advancements in battery electric and hydrogen fuel cell technologies. These cleaner options show promising potential for reducing GHG emissions and improving air quality, particularly in terms of nitrogen oxides and diesel particulate matter emissions. Leading manufacturers are now offering electric and hydrogen-powered models for medium and heavy-duty applications, such as delivery trucks and semi-tractors. According to CALSTART's Zero Emission Technology Inventory, there are currently 134 models of zero-emission MHDVs available in the North American market, with 9 of them being FCEVs and the remainder being BEVs. Unlike light-duty vehicles, the offering of PHEVs in the MHDV sector is currently very limited. While PHEVs have gained traction in the light-duty segment, their availability and adoption in the MHDV sector are considerably lower.

However, the adoption of MHDVs powered by zero-emission technology is still in its early stages in the SCAG region. The region currently has only 178 MHDVs, which comprise 58 heavy-duty vehicles and 120 medium-duty vehicles. Compared to the roughly 36,000 Class 2b – 8 vehicles sold in the SCAG region every year; the current adoption rate is significantly below the 100 percent new vehicle sales target set by the state for 2036 as part of the Advanced Clean Fleet (ACF) regulation. This indicates that the use of zero-emission MHDVs is not yet widespread. Furthermore, the distribution of MHDVs in the SCAG region is not evenly spread. The majority of these vehicles are concentrated in Los Angeles and Orange counties, which are densely populated and heavily trafficked areas.

Aside from ZEVs, the use of NGVs, particularly those utilizing compressed or renewable natural gas (CNG/RNG), is growing in the MHDV sector. NGVs are seen as a cost-effective alternative to diesel trucks, as natural gas tends to be less expensive and more price stable. CARB has implemented stringent emissions regulations for on-road heavy-duty vehicles, including CNG trucks. The HD Omnibus Regulation, established in 2020, requires new heavy-duty engines sold in California to meet a low-NOx standard by 2027. Many CNG truck manufacturers are introducing low-NOx engines to comply with these regulations. CNG trucks with low-NOx engines show promise in reducing GHG emissions and decreasing NOx emissions, which contribute to smog and health issues. However, it is important to continue investing in research and development of cleaner technologies, including ZEVs such as BEV and FCEVs. While CNG trucks are not ZEVs and still emit some emissions, they offer significant emissions reductions compared to diesel trucks. As of 2018, there were approximately 2,240 CNG low-NOx trucks in the region, according to data from CARB's EMFAC model. Similar to light-duty vehicles, except for FCEVs, ZEV and NZEV MHDVs demonstrate cost savings over their lifetime when considering the TCO. Despite the higher upfront cost, the long-term savings in fuel and maintenance expenses make these technologies a financially advantageous option for MHDV fleets.

VI. Buses

Battery Electric Transit Buses such as this BYD Transit Buses are the most common type of medium and heavy-duty transit buses in the SCAG region.

Buses can be classified as Class 4 or greater vehicles, weighing 14,001 lbs. or more, designed primarily for the transportation of passengers. They are commonly used for public transportation systems, school transportation, and private charter services. Within the buses category, various body styles are considered, including single deck buses, double deck buses, articulated buses, school buses, shuttle buses, and cutaways. Each body style is evaluated for different technology types, such as BEVs, PHEVs, FCEVs, and NGVs. The clean technology landscape for buses has evolved significantly over the past few years, with battery electric buses (BEBs) and fuel cell electric buses (FCEBs) gaining traction. These technologies significantly reduce GHG, and criteria pollutant emissions compared to diesel- and natural-gas powered buses, playing a crucial role in decarbonizing public transit, school transportation, and other services. BEBs have become more prevalent due to advancements in battery technology, while FCEBs offer a clean alternative, especially for long-range applications. Currently, there are over 51 models of zero emission buses (transit, coach, and school buses) available in the North American market, including 48 BEBs and 3 FCEBs, according to CALSTART's Zero Emission Technology Inventory. In the SCAG region, zero emission transit buses make up the largest number of heavy-duty zero emission vehicles. According to the Zero Emission Vehicle and Infrastructure Statistics provided by the CEC, SCAG region currently has a total of 476 ZEBs. Among these ZEBs, there are 449 BEBs and 27 FCEBs. Transit buses account for the majority, with 378 ZEBs, while 90 are school buses and 8 are coach buses. LA Metro and the Antelope Valley Transit Authority have the largest fleets, with the latter having the most zero emission transit buses. The Anaheim Transportation Network, City of Los Angeles, and Foothill Transit also have a significant number of zero emission transit buses, while other operators in the region have fewer or none. The current adoption rate of transit ZEBs is approximately 5% of the total transit buses operating in the region. This rate remains significantly below the 100% ZEB target by 2040 established by the state's Innovative Clean Transit regulation.[2] It is noteworthy that transit agencies in the SCAG region have made commitments and developed detailed plans to achieve the state targets, as illustrated in their ZEB Rollout Plans.[3]

Despite higher upfront costs, ZEBs including BEBs and FCEBs, offer lifetime cost savings when considering the TCO. BEBs are particularly advantageous in terms of TCO, while FCEBs may require additional investment to achieve cost parity with the counterpart diesel or NGV. However, overall, ZEBs prove to be cost-effective choices for bus fleets due to reduced operating and maintenance expenses over their lifespan.

[2] https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit
[3] https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit/ict-rollout-plans

VII. Rail

The rail category evaluates freight and passenger rail locomotives that have historically been running on diesel. Technology types include BEV, FCEV, and NGV. Three types of rail technology are discussed: 1) Passenger locomotives specifically designed for pulling passenger trains, ensuring safe and efficient transportation of passengers over long distances or within urban transit systems; 2) freight locomotives designed for hauling freight or cargo trains, optimized for pulling heavy loads and commonly used in the transportation of goods, materials, or containers over long distances or for industrial purposes; and 3) switchers, which are specialized locomotives used primarily for maneuvering or shunting railcars within a railway yard or industrial facility, handling low-speed operations such as coupling and uncoupling of railcars, sorting, and assembling trains in a rail yard.

Adoption of zero-emission technologies in the rail sector is still in its early stages; however, these technologies are relatively mature and have been deployed elsewhere—particularly outside of North America, such as many European and Asian countries—but not yet in the SCAG region. Due to the predictable nature of passenger locomotive operations in terms of routes and schedules, there is a potential opportunity to employ battery-electric technology for shorter routes that allow for convenient charging. Alternatively, fuel cell technology offers more flexibility for passenger rail agencies, enabling them to operate longer routes with faster and less frequent refueling. Caltrans has identified hydrogen locomotives as the most suitable zero emission technology for Amtrak intercity operations and has devised a strategy to transition its rail fleet to 100 percent zero emission by 2035. As advancements in zero emission switch locomotives have shown promise, it is estimated that commercially available zero emission passenger locomotives will be developed by 2030, building upon these technological successes.

The first hydrogen-powered passenger train will debut in 2024, running between San Bernardino and Redlands

Source: SBCTA

Within the SCAG region, a number of agencies have plans to implement these technologies over the coming decade. For example, Metrolink, which serves five of the six counties (all but Imperial County) outlines in its Climate Action Plan that it plans to develop and implement the necessary steps to achieve widespread electrification across its rail fleet fully by 2028. This process will occur in stages, with the Antelope Valley Line expected to be fully electrified by 2025. The plan notes that this will be accomplished by replacing diesel locomotives with electric locomotives. In San Bernardino County, the San Bernardino County Transportation Authority (SBCTA) has laid out plans to debut its hydrogen locomotives in 2024. The project will be funded by the California Transit and Intercity Rail Capital Program and expected to begin testing in late 2023.[4] Also, in April 2023, CARB adopted the In-Use Locomotive Regulation, which mandates passenger locomotives manufactured in 2030 and onward must operate in a zero-emission configuration within California. While this regulation provides a strong policy framework, the region must proactively prepare for the required infrastructure, whether it be hydrogen or battery charging, and focus on technology demonstrations to expedite the adoption of zero-emission solutions in the passenger rail system within the SCAG region.

[4] https://www.gosbcta.com/wp-content/uploads/2022/12/ZEMU-Technology-Fact-Sheet-ENG-120522.pdf

In addition to these initiatives, the California High-Speed Rail (CA HSR) project[5] also aims to connect major urban centers in California, from San Francisco to Los Angeles and eventually extending to Sacramento and San Diego using all-electric trains. Once completed, it will significantly reduce travel times between these cities and serve as a more sustainable transportation alternative to driving or flying. According to CA HSR, this rail will run on electricity supplied entirely from renewable sources.[6] In addition to CA HSR, Brightline West[7] is another anticipated high-speed rail service to connect Southern California with Las Vegas, Nevada. This project will offer a much-needed alternative to the heavily trafficked I-15 corridor, providing faster and more efficient travel options for tourists and business travelers alike. Just like the CA HSR, the Brightline West will be operating all-electric, high-speed trains.

Due to the significantly higher upfront cost associated with zero emission locomotives, often 2-4 times higher than their counterpart diesel locomotives, the rail technology sector has not yet achieved cost parity in terms of TCO. The initial investment required for acquiring and maintaining zero emission locomotives, such as BEV, and FCEV, remains a significant barrier. While these clean technologies offer environmental benefits and long-term cost savings through reduced fuel and maintenance expenses, the higher upfront cost poses a challenge for widespread adoption in the rail industry. However, as advancements in technology continue and economies of scale are realized, it is expected that the costs associated with zero emission locomotives will gradually decrease, making them more financially viable and contributing to the overall decarbonization efforts in the rail sector.

VIII. EV Charging Infrastructure

This category describes various types of EV charging infrastructure, including Level 2 Charging, Direct Current Fast Charging (DCFC) stations, and Innovative Charging Solutions. Level 2 charging stations provide medium charging rates and can be either stand-alone or networked. DCFC stations offer faster charging speeds, with different power levels ranging from low power to ultra-high power. Innovative charging solutions include wireless charging systems, pantograph charging systems, and solar charging canopies. Level 2 charging stations are the most widely adopted, while DCFC stations are more suitable for heavy-duty vehicles with higher power requirements. The industry is also developing megawatt charging technology, with the Charging Interface Initiative leading the way. Standardization of charger connectors and interoperability remains a key challenge in EV charging infrastructure. Various connector standards, such as SAE J1772, CCS, CHAdeMO, and Tesla (also known as NACS), are used for different charging applications and power outputs. In 2023 several major auto manufacturers, including Ford, GM, Rivian, Volvo, Polestar, and Mercedes-Benz announced their plan to integrate NACS ports into their vehicles by 2025.[8]

EV charging infrastructure such as this EVgo DC Fast charger are widely available in SCAG region. Around 3,712 DCFC currently are available in SCAG region provided by 20-30 manufacturers.

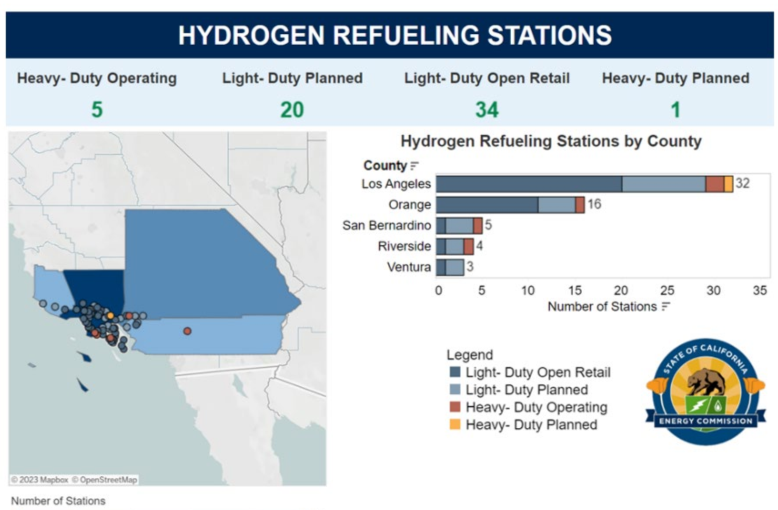
[5] https://hsr.ca.gov/about/
[6] https://hsr.ca.gov/communications-outreach/info-center/get-the-facts/
[7] https://www.brightlinewest.com/
[8] https://driivz.com/glossary/north-american-charging-standard-nacs/#:~:text=Ford%20was%20the%20first%20EV,%2C%20Polestar%20and%20Mercedes%2DBenz.

The shift to clean technologies requires access to charging infrastructure. This can be particularly challenging for people who live in apartments or other multi-unit dwellings, where installing personal charging stations (i.e., home charging) might not be possible. Public charging stations are an alternative, but they require investment in infrastructure that may be lacking in low and moderate-income neighborhoods. Even with the significant investments made at the federal and state levels, those investments alone cannot close the gap. According to CEC AB 2127 report[9], to meet the ambitious goals set by Executive Order N-79-20, nearly 2 million public and shared-private charging facilities will be needed by 2035 to support light-duty vehicles across the state. Within the SCAG region alone, the report indicates the requirement for 1 million charging points (by 2035). Notably, out of these, 689,000 chargers should be publicly accessible stations, while the remaining chargers are anticipated to meet the needs of workplaces and multi-unit dwellings.

As of now, the region hosts approximately 33,000 Level 2 and 3,700 DCFC chargers. Los Angeles County leads the region in this regard, holding 76 percent of all Level 2 chargers and 50 percent of all DC fast chargers, reflecting the large population and EV adoption rates in the county. San Bernardino and Riverside counties have comparable numbers of chargers, highlighting their efforts in expanding the charging infrastructure as well. Unfortunately, the more rural Imperial Countypossesses the fewest chargers in the region. This disparity underscores the need for a more equitable distribution of resources to support widespread ZEV adoption.

The capital cost of EV charging infrastructure varies depending on the type of charging system. For Level 2 charging stations, the capital cost ranges from $2,500 to $4,500 for stand-alone units. Networked Level 2 charging stations may have additional costs associated with the central management system. DCFC stations have higher capital costs due to their faster charging capabilities. Low-power DCFC stations (50 – 100 kW) range from $29,500 to $59,500. Medium-power DCFC stations (>100 – 250 kW) have a capital cost of $59,500 to $115,000. High-power DCFC stations (>250 – 350 kW) range from $115,000 to $139,000. Ultra-high-power DCFC stations (up to 1 MW) have a higher capital cost, typically in the range of $400,000 to $500,000.

IX. Hydrogen Fueling Infrastructure



Hydrogen fueling infrastructure plays a vital role in the transition to clean energy transportation. FCEVs offer zero emission mobility, but their widespread adoption depends on the availability and accessibility of hydrogen fueling stations. Establishing such infrastructure comes with unique challenges, including high capital costs, technical complexities, and safety considerations. Despite these obstacles, investing in hydrogen infrastructure can bring significant environmental benefits and contribute to energy diversity and resilience. Hydrogen is stored onboard vehicles as compressed gas, utilizing high-pressure tanks

[9] https://www.energy.ca.gov/data-reports/reports/electric-vehicle-charging-infrastructure-assessment-ab-2127

capable of storing hydrogen at either 5,000 or 10,000 pounds per square inch (psi). Hydrogen delivery systems include gaseous and liquid hydrogen delivery, as well as on-site production. Gaseous hydrogen can be transported by truck or pipeline, while liquid hydrogen is transported in super-insulated, cryogenic tanker trucks. On-site hydrogen production is an option to reduce transportation costs in remote locations. The hydrogen fueling infrastructure discussion in the compendium includes various station types, including slow fill, fast fill, on-site production, off-grid, mobile, and on-the-go stations, considering factors such as capital cost, maintenance cost, adoption status, availability, and longevity.

In terms of hydrogen fueling infrastructure, Southern California is one of the few regions in the world with a significant network of hydrogen fueling stations. The SCAG region is gradually increasing its hydrogen fueling infrastructure with a total of 39 fueling stations available as of January 2023. The majority of these stations are concentrated in Los Angeles and Orange counties, with only five, four, and three stations located in San Bernardino, Riverside, and Ventura counties, respectively. This lack of infrastructure, and particularly the concentration of fueling stations in high populations centers, speaks to the nascent nature of this technology. While there are currently 34 light-duty retail stations open in the region, 20 additional stations are planned to open in the future. For heavy-duty hydrogen fueling stations, there are currently five operating, with one planned to open in the near future.

The deployment of hydrogen fueling stations brings with it a distinctive set of difficulties that set it apart from traditional fuel or EV charging infrastructure. To begin with, the processes involved in the production, transportation, and storage of hydrogen fuel are both technically complex and financially demanding. Hydrogen is generally derived from natural gas through a method called steam methane reforming (SMR) or from water through electrolysis, both procedures needing considerable energy inputs. Additionally, due to hydrogen's low energy density and high flammability, its transportation and storage present significant logistical and safety issues. Secondly, the initial investment required for setting up a hydrogen fueling station is considerably high, often acting as a barrier for private sector involvement without substantial financial incentives or subsidies. The capital cost of hydrogen infrastructure for fueling stations can range from $400,000 to $8,000,000, depending on factors such as station size and complexity. These costs include the design, engineering, construction, and equipment required for hydrogen production and dispensing. Additionally, the maintenance cost for these stations is estimated to be around $142,000 per year. In addition, there are regulatory complexities to navigate, including obtaining necessary permits and compliance with safety regulations, which can be time-consuming and costly. In addition to these barriers, creating a hydrogen infrastructure is a classic 'chicken-and-egg' problem. Consumers are hesitant to buy hydrogen powered vehicles due to the lack of widespread infrastructure, while providers are reluctant to invest heavily in building out infrastructure until there is a large enough fleet of hydrogen vehicles to justify the investment.

X. Natural Gas Fueling Infrastructure

Natural gas is a cleaner fuel option compared to traditional petroleum-based fuels, as it produces fewer GHG emissions, particulate matter, and smog-forming pollutants. Its availability and existing infrastructure, including pipelines and refueling stations, make it easier to integrate NGVs into transportation systems. Many fleet operators, including transit agencies and delivery companies, have embraced natural gas as a fuel choice. Renewable Natural Gas (RNG) is a low carbon alternative to natural gas, produced by capturing and refining biogas emitted from various sources. RNG undergoes a purification process to remove impurities and increase its methane content, making it a renewable fuel derived from organic waste materials. However, while RNG is a lower-emission alternative, it is not completely carbon-neutral as methane emissions can occur during the production and distribution processes.

Natural gas can be used as Compressed Natural Gas (CNG) or Liquified Natural Gas (LNG) to power vehicles. LNG is created by cooling natural gas to a liquid state, reducing its volume for more efficient storage and transportation. It requires specialized storage tanks, vaporizers, and dispensers to handle cryogenic temperatures. CNG, by comparison, involves compressing natural gas to high pressures and storing it in cylinders or tanks at the fueling station. CNG fueling infrastructure requires compressors and dispensers to achieve the necessary pressure levels for refueling.

Two types of CNG refueling methods are time-fill and fast-fill stations. Time-fill stations are designed for overnight or prolonged refueling periods, typically used in fleet operations where vehicles are parked for extended durations. They utilize lower pressure and flow rates to slowly fill the CNG tanks of multiple vehicles simultaneously, optimizing infrastructure use and taking advantage of non-peak electricity rates. Fast-fill stations, by comparison, are similar to conventional gasoline or diesel stations, providing higher pressure and flow rates for quick refueling. They are suitable for applications where vehicles need rapid refueling, enabling efficient operations for vehicles with higher fuel consumption or limited time availability. Fast-fill stations require larger compressors and storage systems compared to time-fill stations.

The SCAG region has a relatively even distribution of natural gas fueling infrastructure across four out of the six counties. Los Angeles has the highest number of stations at 34, followed by Riverside and San Bernardino counties with 19 each, and Orange County with 13 stations. Ventura County currently has two stations, while Imperial County has only one station. The cost of natural gas infrastructure varies depending on the size and capacity of the station. A starter station, with a daily capacity of 20-40 gasoline gallon equivalents (gge), typically ranges from $45,000 to $75,000. A small station, serving 100-200 gge per day, has an estimated cost between $400,000 and $600,000. For medium stations, which handle 500-800 gge per day, the cost is approximately $700,000 to $900,000. Large stations with a capacity of 1,500 or more gge per day have a higher price range, ranging from $1.2 million to $1.8 million. These costs cover the necessary equipment, installation, and construction required to establish a functional natural gas fueling station.

XI. Supporting Products

As described earlier, the supporting products outlined in this compendium are key facilitators for the widespread adoption and effective utilization of zero and near-zero emission technologies. Each product category plays a unique and integral role in this ecosystem. These products include:

- *Charge management software* not only manages the charging process for EVs, its advanced features and data analytics also ensure the maximum utilization of charging infrastructure. This software optimizes charging schedules and integrates with renewable energy sources to promote efficient energy use.
- *Smart grid technologies*, such as stationary battery energy storage systems (BESS) and vehicle-to-grid (V2G) technologies, enhance power grid stability and facilitate the integration of renewable energy sources. Vehicle-to-grid technologies, for instance, enable bidirectional energy transfer between EVs and the power grid, thereby allowing EVs to support demand response programs and optimize energy usage.
- *Battery Management Systems (BMS),* which include centralized, distributed, and modular types, are crucial for maintaining the safe and optimal performance of BESS. By monitoring various parameters like battery health, temperature, and voltage, BMS ensures the longevity and safety of batteries used in EVs.

- *Fleet management software,* encompassing telematics, predictive maintenance, and smart routing, improves vehicle functionality, safety, and convenience, contributing to advancements in smart mobility. They enable functions such as fleet tracking, diagnostics, navigation, and emergency services.
- *Payment systems* like in-vehicle payments, subscription services, and contactless payment options enhance the convenience and accessibility of EV charging services. They offer seamless transactions, simplified payment plans, and touchless interactions, respectively.

Beyond their roles in promoting zero and near-zero emission technologies, these supporting products also contribute significantly to power system stability. BESS and V2G/V2X technologies respond instantly to fluctuations in power demand or supply, acting as buffers during high demand periods or storing energy when supply exceeds demand. Charging management solutions help avoid sudden demand spikes that could potentially destabilize the power grid by intelligently scheduling charging times based on grid conditions.

Despite their evident potential, detailed knowledge about many of these supporting products remains scarce. There is a significant lack of information on crucial factors such as capital costs, adoption rates, and market acceptance. This gap underscores the pressing need for in-depth research and data-gathering initiatives.

XII. Barriers to Adoption

Despite rapid growth of clean transportation technology adoption, there are still significant challenges and concerns around the implementation of these technologies in the SCAG region. The barriers fall under five categories: cost, technology readiness, infrastructure, consumer knowledge, and regulatory support.

- **Cost**: The high upfront costs associated with ZEV and NZEV technologies pose a substantial barrier to their adoption, particularly for those with financial constraints. The latest report from Kelley Blue Book[10], reveals that the average cost for a passenger ZEV is $18,000 more than that of an average ICE vehicle. The cost disparity becomes much more significant in the heavier application. For instance, a conventional passenger locomotive costs around $2.5 million, while its BEV counterparts cost between $10 to $12 million. The high costs are due to research and development expenses, specialized components, and limited production scales. Also, compliance with various performance standards and regulatory requirements adds to the overall expense, potentially making these technologies less accessible.
- **Technology Readiness**: Technology readiness serves as a significant barrier to the widespread adoption of clean technologies. Many of these emerging technologies are still in early stages of development and lack the level of reliability and performance found in conventional vehicles and equipment. The limited availability of reliable and commercially viable clean technology solutions hampers their market acceptance and slows down the transition toward a cleaner and more sustainable transportation sector.
- **Lack of Charging and Fueling Infrastructure***:* The lack of readily available infrastructure for charging and hydrogen refueling stations presents a major adoption barrier. For example, to support the deployment of 1.8 million FCEVs in California, 1,700 fueling stations will be needed.[11] Constructing these requires significant

[10] https://mediaroom.kbb.com/2022-05-10-Luxury-Share-Increases-in-April,-Pushing-New-Vehicle-Average-Transaction-Prices-Higher,-according-to-Kelley-Blue-Book

[11] Hydrogen Station Network Self Sufficiency Analysis per Assembly Bill 8, California Air Resources Board, November 2020. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-11/ab_8_self_sufficiency_report_draft_ac.pdf

investments and coordination among various stakeholders. For heavy-duty trucks operating interstate, a national network of charging or fueling infrastructure is essential.

- **Lack of Consumer Knowledge & Awareness***:* Many consumers are not aware of the benefits of ZEVs and NZEVs, nor the potential cost savings associated with them. Misconceptions about their reliability and safety also exist. Moreover, potential consumers might be unaware of policies and programs designed to support the adoption of these technologies, which further impacts the demand.
- **Regulatory Support:** The absence of robust regulatory support in setting performance targets and standardizing design protocols for clean technology infrastructure is a significant obstacle. Lack of incentives for purchasing ZEVs and NZEVs, as well as inconsistent regulations across jurisdictions, create a complex landscape, discouraging potential adopters and stifling innovation in the clean transportation sector. The lack of clear and unified permitting processes also poses challenges in deploying crucial infrastructure such as charging and fueling stations.

XIII. Recommendations

To overcome the barriers to the widespread adoption of zero and near-zero transportation technologies, the compendium presents a suite of recommendations. These include:

- **Targeted Incentive Programs**: While state and federal funding and grants can be used to encourage the deployment of ZEVs and NZEVs in the region, more equitable and targeted incentive mechanisms with income-caps and tiers are needed to help bridge disparities in clean vehicle adoption. Additional programs, such as purchase incentives, infrastructure incentives, access incentives, and research and development incentives, also need to be introduced to reduce upfront costs, promote infrastructure development, facilitate access, and support technological advancements in clean transportation.
- **Public Education & Outreach**: Raising awareness of the benefits of ZEVs and NZEVs through informational campaigns, test drive events, workshops and seminars, and community events can accelerate the adoption of clean technologies. These efforts should aim to provide information about available technologies, government support programs, and the positive environmental and economic impact of transitioning to cleaner transportation options.
- **Building Codes:** Local jurisdiction building codes can encourage the development of infrastructure for ZEVs and NZEVs. Examples include EV-ready parking, EV-only parking, EV charging infrastructure in existing buildings, and promoting green building codes. These measures can ensure charging accessibility, increase convenience, and promote sustainability in new and existing constructions.
- **Land Use & Zoning**: Local jurisdictions can update land use and zoning policies to promote the adoption of ZEVs and NZEVs. Strategies include leveraging public property for infrastructure development, land banking for future infrastructure needs, amending zoning and land use regulations to permit charging stations in various zones, streamlining permitting processes, and securing incentives for developers to include charging infrastructure in their projects.
- **Public-Private-Partnership (P3) Business Models**: Public-private partnerships can alleviate financial burdens and accelerate clean technology deployment. Strategies include providing public-private funding, conducting demonstration projects, facilitating training and workforce development, and fostering joint

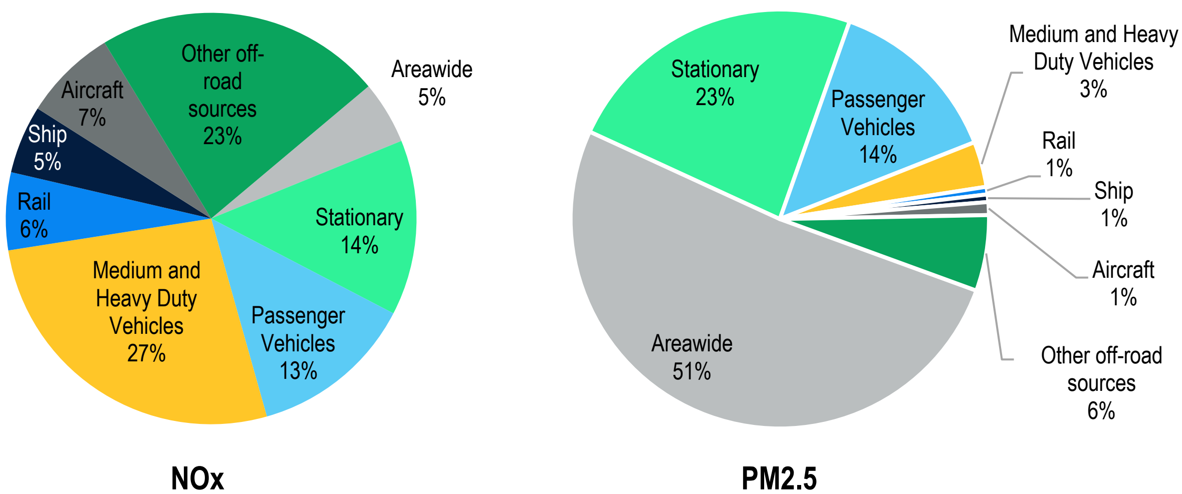
research and development initiatives. Leveraging the resources and expertise of both sectors, these partnerships can drive innovation and advance the adoption of zero and near-zero transportation technologies.

- **Technical Assistance:** Technical assistance can help local partners in evaluating and implementing zero-emission transportation technologies. This includes offering information and resources, developing implementation strategies, conducting feasibility studies, sharing best practices, and advocating for policy and regulatory changes. Such guidance and support can help local jurisdictions navigate the complexities of adopting and integrating clean technologies into their transportation systems.
- **Workforce Development:** Collaboration with educational institutions and training programs to develop educational programs focusing on zero and near-zero transportation technologies can help meet the evolving needs of the clean technology industry. This includes developing curriculum materials, providing funding for student research projects, and nurturing the skills and knowledge required for successful careers in the ZEV and NZEV industry.
- **Lead by Example:** Local governments can lead by example by transitioning their own fleets to zero emission transportation technologies ahead of the state targets. This serves as a demonstration of the effectiveness and practicality of these technologies and provides a market for emerging technology providers. SCAG and its regional partners can consider setting regional clean technology deployment goals and targets, integrating them into future planning efforts, and assisting local jurisdictions with setting and updating their own clean technology adoption targets.

1. The Need for Transition to Clean Transportation Technologies

Nationally, the transportation sector is a major source of greenhouse gas (GHG) emissions, and with the current efforts to decarbonize the electricity grid, it has become the leading cause of total emissions. In California, transportation accounts for approximately 38 percent of total emissions in the state.[12] In the Southern California Association of Governments (SCAG) region, which covers an area of approximately 38,000 square miles and serves a population of over 19 million people, a significant fraction of the region's total GHG emissions comes from the transportation sector[13]. SCAG region faces a particularly significant challenge in reducing transportation emissions due to the high degree of freight and port activity in the region, along with the large number of vehicles and sprawling, car-dependent urban form.[14] For example, the region is home to several major ports and transportation hubs, including the Ports of Los Angeles (POLA) and Long Beach (POLB), which are among the busiest ports in the world. These ports are strategically located near major markets and population centers and have well-developed transportation infrastructure to support the movement of goods and products. As estimated for 2022, mobile sources are projected to account for 81% of nitrogen oxides (NOx) emissions and 25% of fine particulate matter (PM2.5) emissions in the South Coast Air Basin.[15] The presence of criteria pollutants, such as NOx and PM2.5, pose a threat to public health, while GHGs lead to climate change, which worsens extreme heat days, droughts, and wildfires in Southern California. This exacerbates the vulnerability of already susceptible populations, furthering inequities, and posing a threat to economic resilience. Figure 1 below shows the contribution of mobile sources to NOx and PM2.5 emissions in the South Coast air basin.

Figure 1. 2022 NOx and PM2.5 Emissions Contribution of Mobile Sources in South Coast Air Basin[16]



1.1 Clean Technology Definition

To address the air quality and climate change challenges associated with the transportation sector, several initiatives are currently being implemented to encourage the adoption of clean transportation technologies. From the Clean Transportation Policy and Resolution adopted by SCAG Regional Council on April 6, 2023, SCAG defines clean

[12] https://ww2.arb.ca.gov/ghg-inventory-data
[13] According to SCAG's GHG emissions inventory published in 2012, more than 50 percent of the region's GHG emissions were associated with transportation
[14] https://scag.ca.gov/sites/main/files/file-attachments/05-30-12_scag_revised_if_report_final.pdf
[15] https://ww2.arb.ca.gov/applications/cepam2019v103-standard-emission-tool
[16] Emissions from Ocean Going Vessels is only out to 3 nm

transportation technology as zero- and near-zero emission vehicles (ZEV and NZEV), their supporting infrastructure, and other facilitating products that reduce environmental impact over their life cycle. Here life cycle refers to refers to the cumulative effect on the environment resulting from all stages in a product or process's life cycle, from raw material extraction, through production and usage, to disposal or recycling. In this report NZEVs refers to vehicles that emit extremely low levels of pollutants and may be used as bridging technologies where fully zero emission technologies are not feasible or commercially available; near zero implies a significant reduction compared to commonly used technologies.[17]

SCAG's Technology-Neutral Approach towards Advancing Clean Transportation Technologies

As part of its commitment to promote clean transportation technology, SCAG is adopting a technology-neutral approach in its study, advancement, and investment in these technologies. SCAG defines technology neutrality as a stance that does not favor any particular technology, as long as it advances the goal of a zero-emission transportation system that meets or surpasses federal and state targets.

ZEVs and NZEVs are a strong technological solution to achieving significant emissions reductions in the transportation sector. These technologies include battery-electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), fuel cell electric vehicles (FCEV), and low NOx natural gas which offer significant potential in reducing both air pollution as well as GHG emissions. Using electricity, hydrogen, or renewable natural gas as a transportation fuel, especially in California, can significantly reduce overall vehicle emissions and completely eliminate, or significantly reduce tailpipe emissions. Moreover, the state has set ambitious targets for electricity grid renewable energy adoption and has implemented policies, such as the Renewable Portfolio Standard, cap-and-trade program, and the low carbon fuel standard (LCFS), to achieve these goals. As a result, over 34 percent of California's electricity power mix came from renewable energy in 2021, and following the signage of SB100, the grid is expected to be 100 percent carbon free by 2045.[18]

Zero and near-zero emissions supporting products include any products or systems that enable the utilization of zero- and near-zero emission technologies. This can incorporate hardware or software solutions, or services aimed at deploying, maintaining, or operating ZEV and NZEV and their infrastructure efficiently. Examples include solutions for managing charging operations that enable the sustainable, equitable, and efficient use of these technologies. The primary goal of these supporting products is to provide a holistic solution that assists in the deployment and adoption of clean transportation technologies. In doing so, they aim to reduce or eliminate associated environmental impacts, while simultaneously enhancing the user experience.

1.2 Drivers of the Clean Technology Adoption

The shift toward a zero-emission transportation system in the SCAG region is catalyzed by a blend of various elements. Predominantly, the transition is spurred by federal, state, and local policies intended to curb GHG emissions and bolster air quality through an assortment of incentive schemes and regulatory measures. With the United States setting ambitious climate targets, California stands at the forefront, implementing some of the most rigorous environmental

[17] Under the California Advanced Clean Fleet (ACF) regulation, “Near-zero-emissions vehicle” or “NZEV” means a vehicle that is capable of operating like a ZEV using electricity stored on-board the vehicle for a minimum number of miles, or “all-electric range”, as specified and tested in accordance with section 1037.150p(2)(ii) of “California Greenhouse Gas Exhaust Emission Standards and Test Procedures for 2014 and Subsequent Model Heavy Duty Vehicles,” as last amended September 9, 2021. Note that under this definition a low NOx natural gas truck cannot be counted as an NZEV, while under SCAG’s definition, a low NOx natural gas truck is considered as a near-zero emission technology

[18] https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/2021-total-system-electric-generation

laws nationwide. These policies have triggered stricter emission standards for vehicles, stimulated the adoption of clean transportation technologies and led to an increase in investments for infrastructure to back zero-emission transport. A more comprehensive discussion of these policies is provided in Chapter 2.

Beyond the realm of policy, the quest for cleaner air has emerged as a considerable propellant for the switch to a zero-emission transportation system in the SCAG region. Elevated levels of particulate matter and ozone render air pollution a serious public health concern, with the transportation sector largely contributing to the predicament. The integration of clean technology vehicles holds the potential to significantly diminish emissions, thereby improving air quality, which in turn results in a healthier, more habitable environment for residents. This holds particular significance for vulnerable populations who are often most affected by the adverse impacts of poor air quality. Chapter 2 provides more detailed insight on the air quality issues and the imminent needs for reducing transportation emissions in the SCAG region.

1.3 The Need for Clean Technology Compendium

To make informed investments in ZEV and NZEV vehicles, infrastructure, and products, it is critical to have a comprehensive understanding of the available clean technology options across various sectors. While many clean transportation technologies have been developed recently, and more are expected in the future, they can differ significantly in terms of readiness, cost, impact on air pollution and GHG emissions, infrastructure requirements, and scalability. SCAG and the region should prioritize continuous innovation while also meeting standardization and interoperability goals. Additionally, flexibility is crucial to allow different technologies to be applied to different use cases as determined by the investing entity. To address this challenge, SCAG has developed a Clean Transportation Technology Compendium to offer a detailed overview of zero and near-zero emission transportation technologies, their supporting infrastructure, and other supporting products. This compendium is focused on passenger vehicles, medium and heavy-duty vehicles, transit, and rail sectors, addressing essential characteristics, knowledge gaps, uncertainties, and strategies to accelerate clean technology deployment in Southern California. The Compendium will provide an overview of the available zero- and near-zero emissions technologies and assess each technology based on emissions benefits, technology readiness level, implementation status, cost considerations, market conditions, scalability, and other criteria.

The intended audience for this Clean Technology Compendium includes decision makers about technology purchases as well as public agencies that set policy to facilitate clean technology deployment. This may include private investors such as business owners or fleet managers as well as cities, public transit operators, other public fleet managers, planners as well as other regional partners in SCAG region. By equipping these stakeholders with a comprehensive and objective understanding of clean transportation technologies, the Compendium will serve as a valuable resource to support their efforts in advancing sustainable and decarbonized transportation systems. Through this Compendium, SCAG aims to empower decision-makers with the knowledge and tools needed to navigate the evolving landscape of clean transportation technologies. By providing a reliable and accessible source of information, the Clean Technology Compendium will facilitate the transition toward a more sustainable and low-carbon transportation future in SCAG region.

1.4 Overview of the Report

The SCAG's Clean Technology Compendium starts with an Executive Summary that provides a brief overview of the entire content. Following this, Chapter 1 discusses the urgent need for transition to clean transportation technologies, offering definition of clean technology, drivers for adoption, and the need for a clean technology compendium. Chapter 2 dives into various policy drivers including regulations, incentives, and regional efforts with focus on clean air, federal, state, regional, and local policies, and identifying policy gaps. Chapter 3 presents the methodology for clean technology assessment, the scope of clean technologies considered, their specifications, and the methods used to characterize them. Chapter 4 serves as a technology compendium, covering various types of vehicles including light duty, medium and heavy-duty commercial vehicles, buses, rail. This chapter also covers infrastructure for electricity, hydrogen, natural gas, other supporting products, along with knowledge gaps in these areas. This chapter is the core of the document where all the technology characterization and technology inventory is presented.

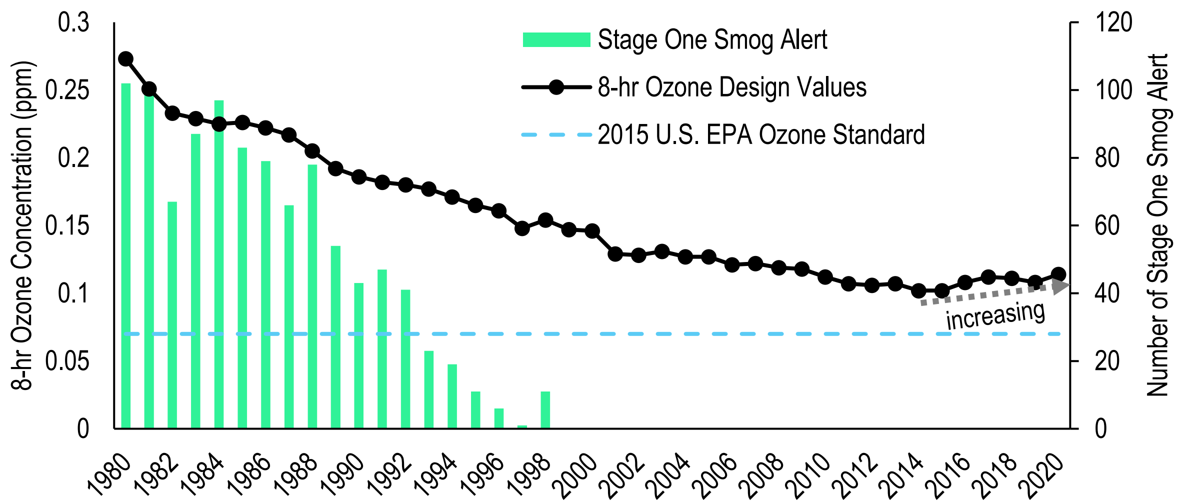
In chapter 5, the project team examines the challenges and barriers to adoption such as cost, technology readiness, lack of charging and fueling infrastructure, lack of consumer knowledge and awareness, and regulatory support, and chapter 6 presents recommendations for SCAG and regional partners on the type of strategies that could be explored to accelerate the adoption of clean transportation technologies. Finally, Chapter 7 outlines the next steps and SCAG's commitments toward advancing clean transportation technologies in the region. The report also includes several appendices covering more detailed information such as the survey methodology, emissions quantification, total cost of ownership, and two-pagers on various clean technology options.

2. Policy Drivers: Regulations, Incentives and Regional Efforts

2.1 Clean Air

Despite ongoing progress, the South Coast Air Basin (SCAB) is still working toward complying with the NAAQS. Despite significant population and economic growth, air quality in the SCAB region has managed to improve significantly over the years. As shown in Figure 2, the 8-hr average ozone design value in the basin has been continuously decreasing from 0.273 parts per million (ppm) in 1980 to approximately 0.114 ppm in 2020. Notably, the number of Stage One smog alerts went down from more than 100 events in 1980 to almost no events since 1999.

Figure 2. 8-hr ozone design values in South Coast Air Basin and Number of Stage One Smog Alerts[19]



Even with substantial progress, many communities in SCAB suffer from high levels of ozone air pollution. Despite significant reductions in NOx and volatile organic compounds (VOC) emissions, ozone concentrations in the SCAB have not been reduced in recent years.

According to the latest Ozone NAAQS established by U.S. EPA in 2015[20], the SCAB is one of only two areas in the country that is designated as an "extreme" ozone nonattainment area. As an "extreme" ozone nonattainment area, South Coast Air Quality Management District (AQMD) has until August 3, 2038, to attain the 2015 Ozone NAAQS for the Basin (dotted line in Figure 2), which is 20 years from the designation as an "extreme" nonattainment area. Aside from the 2015 Ozone NAAQS, the SCAB is still in non-attainment with both 1997 and 2008 Ozone NAAQS of 80 and 75 ppb, respectively. The attainment date for the 1997 80 ppb Ozone NAAQS is June 15, 2024, and for the 2008 75 ppb Ozone NAAQS is July 20, 2032. Table 1 shows the ozone non-attainment classification for the SCAB and their respective attainment deadline.

[19] https://www.aqmd.gov/home/air-quality/historical-air-quality-data/historic-ozone-air-quality-trends

[20] In 2015, the U.S. EPA established a new ozone standard of 70 ppb. The design value of an air basin for the 2015 8-hour ozone standard is determined by the highest ozone value of all stations, based on a 3-year average.

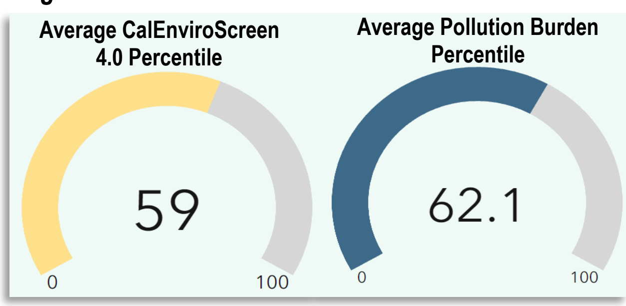
Table 1. Ozone Nonattainment Classification for South Coast Air Basin (from 2022 Air Quality Management Plan[21])

Standard	Level	South Coast Classification	Attainment Date
2015 8-hour Ozone	70 ppb	Extreme	August 3, 2038
2008 8-hour Ozone	75 ppb	Extreme	July 20, 2032
1997 8-hour Ozone	80 ppb	Extreme	June 15, 2024
1979 1-hour Ozone	120 ppb	Extreme	December 31, 2022

Failure to meet these NAAQS would not only have negative public health impacts but could also trigger various federal sanctions, such as highway sanctions, which will impose adverse economic impacts on the region. According to the Clean Air Act (CAA), where a region fails to attain the NAAQS or does not make necessary revisions to its state implementation plan (SIP), no transportation project or grant can be approved other than for safety, mass transit, or transportation improvement projects related to air quality improvement or maintenance. Such federal sanctions will impede the South Coast region's ability to continue moving goods to serve the regional and national demand and impose adverse economic impacts on the region.

As part of the 2022 State SIP Strategy[22] as well as the 2022 South Coast Air Quality Management Plan[23] (AQMP) development, California Air Resources Board (CARB) and the AQMD worked together to determine the necessary reductions for achieving the 70-ppb ozone standard. According to agencies' assessment, meeting this standard remains a priority for reducing overall emissions in the South Coast, and significant reductions beyond those achieved by the current control program will be required by 2037. Although reductions in VOC emissions will bring some short-term benefits in some parts of the South Coast, meeting the 70-ppb ozone standard can only be accomplished through significant reductions in NOx emissions. Air quality models predict that NOx emissions will need to be reduced to 60 tpd, a decrease of approximately 124 tpd from baseline 2037 levels, to achieve compliance in the remaining parts of the region that are not yet meeting the standard. Achieving a reduction of 83 percent in NOx emissions by 2037 will necessitate comprehensive and coordinated efforts to tackle emissions from both stationary and mobile sources, involving both the implementation of existing measures and the development of new ones.

Figure 3. CalEnviroScreen 4.0 Results for the SCAG Region



Source: OEHHA

Air quality is a critical environmental issue that affects everyone, but it is low-income and disadvantaged communities that often bear the greatest burden of its negative impacts. The CalEnviroScreen 4.0[24] is a tool developed by the California Environmental Protection Agency to identify communities in the state that are most impacted by pollution and other environmental and public health stressors. By using this tool, it becomes even more apparent the need for

[21] http://www.aqmd.gov/home/air-quality/clean-air-plans/air-quality-mgt-plan
[22] https://ww2.arb.ca.gov/sites/default/files/2022-08/2022_State_SIP_Strategy.pdf
[23] South Coast AQMD. 2022. Retrieved from: http://www.aqmd.gov/docs/default-source/clean-air-plans/air-quality-management-plans/2022-air-quality-management-plan/final-2022-aqmp/final-2022-aqmp.pdf?sfvrsn=10
[24] https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-40

emissions reduction within SCAG region. Figure 3 shows that SCAG region scores in the 59th percentile across the 20 indicators that are used in the tool. As it relates specifically to air pollution, the region scores slightly better, but remains below acceptable levels.[25] The AQMD's MATES V Study is also another important study that utilizes various tools, including fixed site monitoring, advanced monitoring technologies, and low-cost sensor networks, to measure air toxics levels in residential and commercial areas and identify high risk areas. The study has shown that toxic air pollution in the SCAB has decreased by over 54% between 2012 and 2018. Despite this progress, toxic air contaminants still pose significant health risks such as cancer and chronic diseases. In 2018, residents of the South Coast Air Basin had a 455 in one million chance of developing cancer due to exposure to toxic air contaminants.[26]

Aside from air quality issues, mitigating climate change is also another key driver for clean technology adoption. The impacts of climate change are already being felt in California and around the world, with growing intensity that adversely affects communities and the environment. The science that predicted these impacts is now even stronger and leaves no doubt that urgent action is needed to prevent irreversible damage. The impacts of climate change are felt most heavily by low-income and communities of color, which are also disproportionately impacted by air pollution as described earlier. California has established itself as a global leader in science-based, public health-focused climate change mitigation and air quality control and has established ambitious climate goals. At the state level, these goals include emission reduction goals of 40 percent below 1990 levels by 2030, 85 percent by 2045, and carbon neutrality no later than 2045. Having an electricity grid that is low to zero carbon is crucial to meet climate goals as the state's vehicle fleet transitions to ZEVs, including battery electric vehicles (BEVs) to charge from grid electricity. CARB's 2022 Scoping Plan[27] provides a set of policy recommendations to help California achieve its climate and air quality goals. These recommendations include enhancing existing programs and regulations, such as the Advanced Clean Trucks and Clean Fleets regulations, expanding incentives for ZEVs and infrastructure, and investing in transit and active transportation. The report also suggests developing new regulations, such as those for medium- and heavy-duty vehicle efficiency, as well as adopting a more holistic approach to address the intersectionality of climate change and equity.

2.2 Federal Policies

The transportation sector accounts for one-third of domestic GHG emissions in the U.S. and affects the health and well-being of millions of Americans, particularly those in disadvantaged communities. In response to this, ambitious GHG emissions reduction goals have been set at the federal level for on-road transportation and rail. The targets include a 50 percent goal for new vehicle sales to be ZEVs for light-duty vehicles by 2030.[28] To support this, a complementary target for EV chargers was included, calling for 500,000 stations by 2030.[29] The White House has also created a goal that 100 percent of federal fleet procurement be light-duty ZEVs by 2027. For MHDVs, the goal is to have 30 percent of new vehicle sales be ZEV by 2030 and reach 100 percent by 2040, and also have the federal fleet procurement be 100 percent ZEVs by 2035.[30] As for the rail sector, the focus is on reducing emissions by prioritizing resources toward developing technology pathways to achieve emission reduction targets. To achieve these ambitious goals, in January 2023, the US Departments of Energy, Transportation, Housing and Urban Development, and the

[25] OEHHA. 2022. Retrieved from: https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-40
[26] South Coast AQMD. 2021. Retrieved from: http://www.aqmd.gov/home/air-quality/air-quality-studies/health-studies/mates-v
[27] CARB. 2022. 2022 Scoping Plan For Achieving Carbon Neutrality. Retrieved from: https://ww2.arb.ca.gov/sites/default/files/2022-12/2022-sp.pdf
[28] https://www.whitehouse.gov/briefing-room/presidential-actions/2021/08/05/executive-order-on-strengthening-american-leadership-in-clean-cars-and-trucks/
[29] https://www.fhwa.dot.gov/environment/nevi/
[30] https://www.whitehouse.gov/briefing-room/statements-releases/2021/12/08/fact-sheet-president-biden-signs-executive-order-catalyzing-americas-clean-energy-economy-through-federal-sustainability/

Environmental Protection Agency released the *Blueprint to Decarbonize America's Transportation Sector*[31] which outlines a federal strategy for partnerships to decarbonize the entire US transportation sector, building on the momentum of recent historic investments in transportation infrastructure.

In support of the ambitious GHG emissions reduction goals for the transportation sector, the federal government has also secured historic investments in clean transportation. The Infrastructure Investment and Jobs Act (IIJA) was signed into law by President Biden on November 15, 2021. It is the first infrastructure law in U.S. history to address the climate crisis and invests $660 billion into transportation systems and technologies over five years. The Inflation Reduction Act (IRA), signed on August 16, 2022, is the most aggressive action on tackling the climate crisis in U.S. history. Combined, these laws are projected to lower economy-wide emissions by over 40% by 2030 and position the U.S. to achieve a 50-52% emissions reduction by the end of the decade. The transportation sector will receive historic levels of funding for transit, rail, and active transportation, as well as buildouts of EV charging and sustainable fuel infrastructure, tax credits, rebates, clean ports, and investments along the EV and battery supply chains. For example, the IIJA includes $7.5 billion for the nationwide deployment of EV charging stations, with $5 billion allocated to the National Electric Vehicle Infrastructure (NEVI) Formula Program and $2.5 billion available for a competitive grant program to support communities and corridors. California's share of NEVI funding is estimated to include $384 million over the five-year period, and the California Department of Transportation (Caltrans) and CEC are leading NEVI development in California. The NEVI guidelines require the development of the State Electric Vehicle Infrastructure Deployment Plan, and NEVI funds can only be used on designated Alternative Fuel Corridors initially.[32] The IRA has also introduced a number of tax credits and incentive programs to support the growth of ZEVs and related infrastructure at the federal level. One of the main incentives is the alternative fuel infrastructure tax credit, which provides a tax credit for 30% of the cost of alternative fuel vehicle refueling infrastructure, including EV charging stations. Another incentive is the commercial EV and FCEV tax credit, which provides a tax credit of up to $40,000 for the purchase of new all-electric or fuel cell vehicles. Additionally, the clean heavy-duty vehicle program provides funding for the replacement or retrofit of old heavy-duty vehicles with newer, cleaner models. These incentives are intended to encourage the growth of ZEV and NZEV market, making it easier for individuals and businesses to transition to cleaner transportation options. Table 2 below provides more detailed descriptions of programs being offered under the IRA.

Table 2. Tax credits and incentive programs offered through the IIJA and IRA

Incentive Program	Description
National Electric Vehicle Infrastructure Program (NEVI)	The National Electric Vehicle Infrastructure Program (NEVI) is a $5 billion federal program aimed at reducing GHG emissions by funding clean transportation and energy programs across the US. California's Department of Transportation (Caltrans) and the California Energy Commission (CEC) created a deployment plan for NEVI, which will allocate $384 million in federal funds to build a network of modern, high-powered DC fast chargers along Interstates and National Highways throughout California. The deployment plan was submitted in August 2022. NEVI-funded charging stations will have a minimum of four 150 kW combined Charging System (CCS) connectors and total station power of 600 kW, located no more than 50 miles apart and no more than 1 mile from a freeway exit or highway roadway. At least 40 percent of NEVI benefits will go to disadvantaged, low-income, rural, and Tribal communities, and the CEC will manage funding solicitations on behalf of the state.

[31] https://www.energy.gov/sites/default/files/2023-01/the-us-national-blueprint-for-transportation-decarbonization.pdf
[32] https://highways.dot.gov/newsroom/president-biden-usdot-and-usdoe-announce-5-billion-over-five-years-national-ev-charging

Incentive Program	Description
Electric Vehicle (EV) and Fuel Cell Electric Vehicle (FCEV) Tax Credit	The Inflation Reduction Act of 2022 has updated the Clean Vehicle Credit, formerly known as the Qualified Plug-in Electric Drive Motor Vehicle Credit, effective August 17, 2022, with additional requirements starting January 1, 2023. The Clean Vehicle Credit now includes both EVs and FCEVs, requires a traction battery with at least 7 kWh, and establishes sourcing requirements for critical mineral extraction, processing and recycling and battery component manufacturing and assembly. Vehicles meeting these requirements are eligible for a tax credit of up to $7,500. The percentage of the battery's critical minerals and components that are extracted, processed, recycled, manufactured, or assembled in North America must increase annually to qualify for the tax credit. Eligibility is also subject to a final MSRP limit and modified adjusted gross income threshold.
Alternative Fuel Infrastructure Tax Credit	Alternative Fueling equipment for various fuels can receive a tax credit of 30% of the cost up to $30,000 until December 31, 2022, and after that date, the credit is 30% or 6% for depreciable property up to $100,000, with specific requirements. Additionally, residential fueling equipment purchased between January 1, 2023, and December 31, 2032, can receive up to a $1,000 tax credit.
Commercial Electric Vehicle (EV) and Fuel Cell Electric Vehicle (FCEV) Tax Credit	Starting January 1, 2023, businesses can receive a tax credit for purchasing new electric or fuel cell vehicles, with amounts based on the vehicle's battery capacity and purchase price, not exceeding $7,500 for vehicles under 14,000 lbs. and $40,000 for vehicles over 14,000 lbs. The tax credit cannot be combined with the Clean Vehicle Tax Credit.
Clean Heavy-Duty Vehicle Program	The Inflation Reduction Act (IRA) allocated $1 billion toward replacing polluting heavy-duty vehicles with clean, zero-emission vehicles, supporting zero-emission vehicle infrastructure, and providing workforce development and training. Additionally, funds will be provided for planning and technical activities to promote the adoption and deployment of zero-emission vehicles. The EPA will distribute the funding between now and 2031, with $400 million going to communities in nonattainment areas.
Clean Ports Program	The EPA has launched a $3 billion program to fund grants and rebates for the purchase or installation of zero-emission port equipment or technology, planning and permitting for such equipment, and the development of qualified climate action plans that reduce emissions of GHGs, criteria air pollutants, and hazardous air pollutants at one or more ports. $750M of total funding will be spent in nonattainment areas, and eligible funding recipients include port authorities, state, regional, local or tribal agencies, air pollution control agencies, and private entities that own or operate port-related facilities. The funding expires on September 30, 2027.

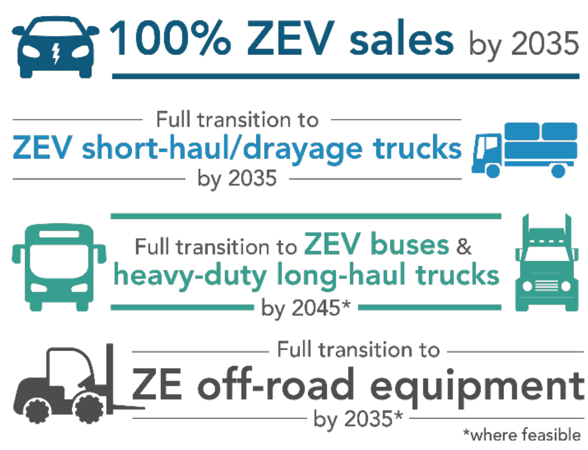
Aside from incentive programs being offered through IIJA and IRA, the federal government has also recently adopted several key regulations that promote the adoption of clean technologies. In December 2021, the U.S. Environmental Protection Agency (EPA) finalized federal GHG emissions standards for passenger cars and light trucks for model years 2023 through 2026[33]. The standards are ambitious but achievable, and are expected to achieve significant GHG emissions reductions, along with reductions in other air pollutants. The standards are the most stringent ever set for the light-duty vehicle sector. The stringency of the GHG emissions standards established under this regulation increases between 5 and 10 percent each year from 2023 through 2026. The final standards are expected to result in average fuel economy label values of 40 mpg. In a separate effort, the Clean Truck Plan[34], announced in November 2021, aims to reduce GHG and criteria pollutant emissions from medium- and heavy-duty trucks by increasing fuel efficiency standards for these vehicles. The plan proposes new emissions standards for diesel and gasoline-powered trucks for model years 2027-2030, as well as the introduction of new efficiency standards for electric and fuel cell-

[33] https://www.epa.gov/regulations-emissions-vehicles-and-engines/regulations-greenhouse-gas-emissions-passenger-cars-and
[34] https://www.epa.gov/regulations-emissions-vehicles-and-engines/clean-trucks-plan

powered vehicles. As part of the Plan, the EPA passed the Heavy-Duty NOx rule in December 2022, which aims to set more stringent emission standards for heavy-duty trucks and engines, reducing NOx emissions and contributing to cleaner air and improved public health.[35]

Aside from the federal policies and incentive, the U.S. EPA also plays an important role in granting waivers to California for establishing its own standards. Despite the usual prohibition against states implementing their own emission standards for new engines and vehicles, the Clean Air Act provides a provision for California to request an authorization to enforce its unique standards. Under the Clean Air Act, California is allowed to request waivers or authorizations from the EPA to enforce its own emission standards for new motor vehicles and nonroad engines and vehicles, if they supersede federal standards. The EPA approve the waiver or authorization unless it finds that California's standards are not as protective of public health and welfare as federal standards, unnecessary due to a lack of compelling and extraordinary conditions, or inconsistent with the Clean Air Act. The Act also enables other states to adopt California's standards without needing EPA approval, provided those standards are identical to the ones for which California received a waiver or authorization.

2.3 State Policies



In an effort to combat climate change and improve air quality, the state has implemented a number of measures to accelerate the adoption of ZEVs and NZEVs. These include mandates requiring automakers to produce a certain percentage of ZEVs, financial incentives for consumers who purchase such vehicles, and investments in charging and fueling infrastructure. In September 2020, Governor Newsom signed Executive Order No. N-79-20 which set a goal of 100% zero-emission passenger vehicles by 2035 and directs state agencies to develop strategies to transition all medium- and heavy-duty vehicles to ZEVs by 2045. The order also includes directives for accelerating the deployment of charging infrastructure, increasing the number of ZEVs in public fleets, and promoting increased consumer awareness and adoption of EVs.[36] This executive order sets the stage for the state to implement policies to accomplish these ambitious targets. A number of regulations have already gone into effect, which were designed to address all vehicle modes, including light-, medium-, heavy-duty, and transit vehicles as well as rail. Table 3 below summarizes the most significant of these regulations.

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[35] https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-and-related-materials-control-air-pollution

[36] https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf

Table 3. California Regulations Supporting ZEV Deployment

Regulation	Description
Advanced Clean Cars II	The Advanced Clean Cars II regulations will reduce light-duty passenger car, pickup truck, and SUV emissions from the 2026 model year through 2035. The regulations amend the Zero-emission Vehicle Regulation to require an increasing number of ZEV, including battery-electric, hydrogen fuel cell electric, and plug-in hybrid electric-vehicles. By 2035, the regulation requires 100% of new passenger vehicles sold in the state to be ZEV. These amendments support California Governor Newsom's executive order that all new passenger vehicles sold in California must be zero emissions by 2035. The Low-Emission Vehicle Regulations were also amended to include increasingly stringent standards for gasoline cars and heavier passenger trucks.
Advanced Clean Trucks Regulation	The ACT regulation requires manufacturers of medium- and heavy-duty vehicles to sell increasing percentages of ZEVs in California, culminating in a requirement for 100% ZEV sales by 2045.
Advanced Clean Fleets Regulation	The regulation requires fleets operating in California to transition to zero emission technology with the goal of transitioning all drayage trucks to zero emission by 2035 and the rest of the MD-HD vehicles to zero emission by 2045. Starting in 2036, manufacturers can only sell zero-emission medium- and heavy-duty vehicles. From January 1, 2024, trucks participating in drayage activities in California must be registered with the CARB Online System, with only zero-emission trucks allowed to register from 2024 onwards. All drayage trucks must be zero-emission by 2035. High priority and federal fleets must either follow the Model Year Schedule, buying only ZEVs from 2024 and phasing out internal combustion vehicles that have passed their useful life starting in 2025, or the optional ZEV Milestones Option, meeting phased-in ZEV targets. State and local government fleets must have 50% ZEV purchases from 2024 and 100% by 2027, although small government fleets and certain counties can start their ZEV purchases in 2027.
Low NOx Omnibus Regulation	The HD Omnibus Regulation requires heavy-duty engines of model year 2024-2026 to meet a 0.05 g/bhp-hr NOx standard, with more stringent standards for subsequent model years, aimed at ensuring real-world emissions performance critical for attaining federal health-based air quality standards for ozone in 2031. Despite the regulation being adopted in 2020 and set to be implemented in 2024, as the 2024 model year certification approached, CARB staff became aware through manufacturer product plans that some truck categories in California would not be able to produce Omnibus-compliant diesel engines. To ease the transition, CARB recently proposed amendments offering flexibility, ensuring engine availability while preserving projected emissions reductions.[37]
Innovative Clean Transit Regulation	The ICT regulation, adopted in December 2018, requires public transit agencies to transition to a 100% zero-emission bus fleet by 2040. All transit agencies that own, operate, or lease buses with a gross vehicle weight rating (GVWR) greater than 14,000 lbs. must comply with the regulation. The ZEB purchase requirements vary depending on the transit agency's size.
In-Use Locomotive Regulation	The proposed in-use locomotive regulation would require locomotive operators in California to fund a spending account based on emissions and use the funds to purchase or upgrade to the cleanest locomotives. Starting in 2030, only locomotives less than 23 years old and those with an original engine build date of 2030 or newer would be allowed to operate in California, and by 2035, all Class I line haul locomotives with an original engine build date of 2035 or newer would need to operate in a zero-emission configuration.
Zero Emission Truck Measure	This measure, as proposed in 2022 State SIP Strategy, would seek to accelerate the number of zero-emissions (ZE) trucks beyond existing measures (including the proposed Advanced Clean Fleets regulation). The measure seeks to upgrade the remaining heavy-duty combustion trucks to new or used ZE trucks rather than cleaner combustion engines. CARB has committed to implementing regulatory strategies to achieve this goal, such as differentiated registration fees, restrictions and fees for combustion trucks entering low and ZE zones, or indirect source rules (ISR). Alternatively, the measure could require combustion truck fleets to be scrapped and replaced with ZE trucks at the end of their useful lives. The measure would potentially be heard by the Board in 2028 as part of the comprehensive strategy to achieve zero-emissions medium- and heavy-duty vehicles by 2045.

[37] https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2023/hdomnibus2023/notice.pdf

To facilitate the transition of state's on-road and rail transportation to zero and near-zero emission, the state has also implemented a number of incentive programs. These include rebate programs, vehicle replacement programs, point-of-sale incentives, and infrastructure incentives. Table 4 below lists incentive programs that are currently in effect and are directly supporting the expansion of ZEVs and infrastructure in SCAG region.

Table 4. California Incentive Program for Clean Technology Adoption

Regulation	Description
Clean Vehicle Rebate Project (CVRP)	The CVRP provides rebates to California residents who purchase or lease eligible clean vehicles. The amount of the rebates offered by CVRP varies depending on the type of vehicle and its all-electric range, but they generally range from $1,500 to $7,000 for most eligible vehicles. The CVRP rebate can be combined with federal, state, or local agency incentives as well as Administrator match funding, if available, to help further buy-down an eligible vehicle's cost
Clean Cars 4 All	Clean Cars 4 All provides incentives to low-income individuals to retire their older, high-emitting vehicles and replace them with clean, electric or hybrid vehicles. The funding amount that applicants receive varies depending on the individual's income, the type of vehicle being purchased or leased, and other factors, but it generally ranges from $2,500 to $9,500 per participant.
California HVIP	HVIP is a point-of-sale incentive program that provides a voucher up to $120,000 for zero-emission trucks. At the time of writing this report, the program has supported the purchase of 2,400 natural gas and 1,800 battery-electric trucks since 2010 (redeemed vouchers), and over half of all voucher requests have come from disadvantaged communities seeking DPM reductions.
CEC Clean Transportation Program	The program provides funding for a range of projects, including research and development, pilot projects, and infrastructure deployment. The amount of funding each applicant receives from the program varies depending on the specific project and the type of funding requested. Generally, applicants can receive funding for up to 100% of their project costs, although some funding programs require a cost share or matching funds from the applicant. The maximum award amount for some programs can be up to several million dollars, while others may provide smaller grants or loans. The specific funding amount for each project is determined through a competitive application process, with awards granted based on project feasibility, environmental benefits, and other factors.
Low Carbon Fuel Standard LCFS	The LCFS is a California regulation that creates a market mechanism that incentivizes low carbon fuels. The regulation requires the carbon intensity of California's transportation fuels to decrease by 20 percent through the 2030 timeframe and maintain the standard afterwards. The number of credits that a fleet generates is based on the amount of electricity used to charge and the carbon intensity of that electricity. Fleets that strategically use renewable electricity for charging, or purchase renewable energy certificates (RECs), can further increase their LCFS revenue streams. In addition to generating LCFS credit for dispensed fuel, the eligible hydrogen station, or DC fast charger can generate infrastructure credits based on the capacity of the station or charger minus the quantity of dispensed fuel. Currently stations intended for light duty vehicles (<1,200 kg/day for hydrogen stations and <350 kW per charger for charging stations) are eligible for the capacity credits. As more ZEVs use the station and the station utilization increases, the site will generate more LCFS fuel credits and fewer infrastructure credits.

2.4 Regional Policies

SCAG region has also been a leader in pushing for local regulations to promote zero-emission and clean technologies. These include regulation pertaining to warehouses, ports, rail and intermodal facilities. South Coast AQMD's Warehouse Actions and Investments to Reduce Emissions (WAIRE) program, also known as Rule 2305, requires large warehouses to reduce their emissions by either implementing specific measures to reduce emissions on site or by investing in off-site projects that achieve equivalent emissions reductions. The program aims to reduce the amount of air pollution generated by the warehousing industry, particularly in communities disproportionately impacted by air pollution.[38] The proposed Indirect Source Rule (ISR) for Commercial Marine Ports is also another potential regulatory actions that intends to reduce emissions from equipment, vehicles and vessels operating at marine ports in Southern California. This program requires that ports develop and implement emission reduction plans that include measures such as equipment turnover and electrification, incentives for the use of cleaner vehicles and equipment, and traffic management strategies.[39] South Coast AQMD is also considering another ISR, designed to prioritize new and current rail yards and intermodal facilities. This particular ISR mandates owners and operators to come up with plans to decrease emissions from locomotives, cargo handling machinery, and trucks used in and around these facilities. The ISR offers various choices for compliance, which includes using zero-emission technology, alternative fuels, and operational improvements to minimize idling and other practices that contribute to emissions.[40]

SCAG has also been working toward a long-term vision of a zero-emission transportation system to mitigate the impacts of transportation on regional air quality. The Connect SoCal 2020[41] plan identified a coordinated approach to electrifying passenger vehicles, transit, and goods movement vehicles. As it relates to ZEVs, the plan includes a number of strategies aimed at promoting the adoption and use of ZEVs in Southern California. These strategies include expanding the availability of charging infrastructure, promoting EV car-sharing programs, incentivizing the purchase of EVs, and encouraging the adoption of clean truck technology. The plan recognizes the role that EVs can play in reducing GHG emissions and improving air quality and seeks to promote their adoption as part of a larger effort to promote sustainable transportation options in the region.

To accomplish Connect SoCal 2020's objectives, SCAG has implemented various projects and funding programs to advance clean transportation. One such example is the grant awards totaling $6.75 million given to six projects in 2022 across the region to decrease harmful emissions during last-mile freight and delivery operations. This is in addition to the 26 clean-energy projects awarded $10 million under SCAG's Last Mile Freight Program, funded by the state's Mobile Source Air Pollution Reduction Review Committee (MSRC) in 2021. Furthermore, SCAG is collaborating with 18 cities in the area to aid them in promoting the development and implementation of EV charging infrastructure. This includes providing customized policy guidance, region-wide site suitability analyses, EV site evaluations, and a passenger EV Infrastructure Plan to support the development of charging stations and encourage EV adoption throughout Southern California. With this progress, SCAG has refreshed this vision in Connect SoCal 2024, providing resources and strategies to accelerate clean transportation. Resolution No. 23-654-5 formalizes SCAG's Clean Transportation Technology Policy with the aim of supporting the development, commercialization, and deployment of a zero-emission transportation system while maintaining technology neutrality to allow operators to invest in the best fit technology for their needs.

2.5 Local Policies

Transportation planning agencies have also established goals and strategies for reducing GHG emissions and to improve air quality. The 2020 Connect SoCal[42] strategies aim to reduce per-capita GHG emissions from automobiles and light trucks by reducing per-capita vehicle miles traveled (VMT) through the implementation of Sustainable

[38] http://www.aqmd.gov/home/rules-compliance/compliance/waire-program
[39] http://www.aqmd.gov/home/rules-compliance/rules/scaqmd-rule-book/proposed-rules/rule-2304
[40] http://www.aqmd.gov/docs/default-source/clean-air-plans/air-quality-management-plans/2022-air-quality-management-plan/final-2022-aqmp/final-2022-aqmp.pdf?sfvrsn=10
[41] https://scag.ca.gov/read-plan-adopted-final-connect-socal-2020
[42] Connect SoCal 2020 is a long-range transportation and land-use plan for the Southern California region, developed by the SCAG. It covers a period of 25 years, from 2020 to 2045, and aims to guide the growth and development of the region in a way that promotes sustainability, equity, and economic prosperity. The plan includes strategies to reduce GHG emissions from transportation, improve mobility and accessibility, and promote diverse housing choices.

Communities Strategies at a regional level. The strategies are focusing on growth near destinations and mobility options, promoting diverse housing choices, leveraging technology innovations, and supporting the implementation of sustainability policies. Of the various strategies identified in Connect SoCal 2020, the Accelerated Electrification strategy is a comprehensive plan to promote the use of EVs in the transportation sector, including passenger, transit, and goods movement vehicles. The strategy expands upon state mandates by coordinating efforts and increasing collaboration to achieve a zero-emissions system. Connect SoCal calls for increased incentives for sales of EVs and expanded charging infrastructure for the light-duty sector. In the transit sector, the goal is to transition to 100% EVs, and in the goods movement sector, to adopt near-zero-emissions technologies and zero emission technologies where feasible.

In addition to policy drivers at the state and regional level, cities are also taking action to support reducing emissions from the transportation sector. For example, Los Angeles released its Green New Deal Plan,[43] which highlights its commitment to reducing GHG emissions and transitioning to a carbon-neutral economy by 2050. The plan outlines strategies to accelerate the adoption of ZEVs, including increasing charging infrastructure and providing incentives for both individual and fleet purchases of EVs. The plan also aims to electrify the city's entire bus fleet by 2028.

As the impacts of climate change become increasingly evident, many local entities in SCAG region are taking action to reduce GHG emissions by implementing a variety of policies and programs. Here is a list of some of the key actions:

The Clean Air Action Plan[44] (CAAP) is a joint initiative between the ports of Long Beach and Los Angeles to improve air quality in the region by reducing emissions from port-related sources. The CAAP includes a range of strategies aimed at reducing emissions from ships, trucks, cargo handling equipment, locomotives, and harbor craft operating in and around the ports, including the adoption of clean technologies such as zero-emission equipment and vehicles, the expansion of on-dock rail infrastructure, and the development of emissions reduction targets and reporting requirements for port tenants and operators. The goal of the CAAP is to promote sustainable growth and reduce the environmental impact of port operations on nearby communities, while maintaining the economic competitiveness of the ports. As part of the CAAP the Clean Truck Fund was established which provides funding to help trucking companies purchase low-emission or zero-emission trucks, with the amount of funding varying depending on the type of truck being purchased. The program is funded through a tariff on containers moving through the ports and is designed to help trucking companies transition to cleaner technologies while improving air quality in the surrounding communities. The program is scheduled to run through 2023 and has provided over $78 million in funding to help replace older, high-emitting trucks with cleaner alternatives.[45]

The Los Angeles County Metropolitan Transportation Authority (LA Metro) released the I-710 Clean Truck Program[46] in 2020, with the goal of introducing 4,000 zero- and near-zero emissions trucks to the I-710 freeway and reducing the number of diesel trucks traveling through I-710 communities. This program is part of the larger I-710 Project, which includes various initiatives like the I-710 Early Action Soundwall Program, I-710 Community Health Benefit Program, and I-710 Congestion Relief Program. In 2020, the LA Metro Board authorized $50 million for the program and directed staff to develop elements of the program and seek additional state and federal discretionary funding to reach a minimum target of $200 million. In response to this direction, the I-710 Zero Emission Truck Program

[43] City of Los Angeles. 2019. Green New Deal Plan. Retrieved from: https://plan.lamayor.org/sites/default/files/pLAn_2019_final.pdf
[44] https://cleanairactionplan.org/
[45] https://cleanairactionplan.org/strategies/trucks/
[46] https://la.streetsblog.org/wp-content/uploads/sites/2/2021/05/I-710-Clean-Truck-Program-Long-Description-09.20.20.pdf

working group was established by LA Metro in November 2021 and includes partner agencies and community advocacy groups.

The Los Angeles Cleantech Incubator (LACI) has established the Transportation Electrification Partnership to accelerate transportation electrification and zero-emissions goods movement in the Greater Los Angeles region, ahead of the 2028 Olympic and Paralympic Games. This partnership, which involves local, regional, and state stakeholders, aims to achieve a 25% reduction in GHG emissions and air pollution beyond existing commitments by 2028. To achieve this goal, the partnership has set specific targets, such as having 30% of all light-duty passenger vehicles on the road and 80% of passenger vehicle sales be electric by 2028 and having 40% of all drayage and short haul trucks and 60% of medium-duty delivery trucks be electric. Additionally, the partnership aims to have 84,000 public and workplace chargers available for single occupancy vehicles and 95,000 available for medium and heavy-duty trucks by 2028.

Southern California Edison (SCE), the largest electricity provider in the region, has created the Charge Ready Program, which provides funding for the installation of charging stations, as well as ongoing support and maintenance. Participants can choose from a variety of charging station options and customize the program to meet their specific needs. The program is designed to support the growth of EV adoption and increase the availability of charging stations, which in turn can help reduce GHG emissions from transportation. The Charge Ready program is part of SCE's broader efforts to promote clean energy and support the transition to a low-carbon future.[47]

Southern California Gas Company (SoCal Gas) is also involved in various clean transportation applications[48], including developing near-zero emission heavy-duty truck engines and compressed natural gas (CNG) hybrid heavy-duty drayage trucks to reduce GHG emissions and improve air quality in the Los Angeles area, particularly in the I-710 corridor, the Port of Los Angeles, and the Port of Long Beach. The company has also worked on demonstrating the benefits of in-home refueling for NGVs and supporting the development of advanced storage tank technologies that offer higher capacity and a smaller ecological footprint. These tanks will allow NGVs to have a trunk carrying capacity that is equivalent to gasoline vehicles, while still providing the benefits of using a cheaper and cleaner alternative fuel. This effort is part of SoCalGas's broader commitment to promoting the adoption of NGVs as a means of reducing GHG emissions and improving air quality.

2.6 Zero Emission Infrastructure Readiness Actions

Make ready programs are critical for the adoption of zero-emission technology as they help address the infrastructure gap that currently exists in the market. ZEVs require specialized charging or refueling infrastructure, and make-ready programs provide financial and technical support to install this infrastructure. Without the necessary infrastructure, potential buyers may be deterred from purchasing ZEVs, as they may be concerned about running out of charge or fuel. Make ready programs can also help reduce the upfront cost of installing infrastructure, making it more accessible to businesses and individuals, and streamline the process for utility customers to access the needed capacity for installing EV chargers. This section outlines several state-level actions that will facilitate and expedite the deployment of infrastructure, particularly charging infrastructure, throughout the state.

The California Public Utility Commission is currently working on transportation electrification planning efforts to prepare the investor-owned utilities (IOU) and the grid for the expected growth in EV adoption over the next several years. By leveraging the existing interagency coordination and planning framework, and closely working with staff from California

[47] https://crt.sce.com/overview
[48] https://www.socalgas.com/sustainability/technology-and-investments/clean-energy-investments

Independent System Operator (CAISO), CEC, and CARB, the Commission will ensure that their processes are ready for the massive influx of EVs. This work includes the adoption of the 2021 CEC's Integrated Energy Policy Report (IEPR) demand forecast, which serves as the starting point for all generation and infrastructure planning within CAISO's territory. The IEPR forecast reflects higher transportation electrification adoption that is consistent with CARB's Advanced Clean Cars II and Advanced Clean Fleets regulations. Following the adoption of several zero-emission freight regulations by CARB in recent years, the CPUC has recently released the Zero-Emissions Freight Infrastructure Planning (FIP) draft proposal.[49] This proposal aims to proactively address the requirements for extended lead time utility-side electrical infrastructure, specifically distribution and transmission, to bolster the rapid progression of transportation electrification. The proposal focuses on creating a uniform set of inputs and assumptions for transportation electrification and on refining processes to direct long-term planning for medium- and heavy-duty grid infrastructure along key freight corridors.

Additionally, CAISO is using the Integrated Resource Planning (IRP) proceeding's 2021 Preferred System Plan, reflecting the CEC's 2021 IEPR forecast, in its 2022-2023 transmission planning process. The proceeding to modernize the electric grid for a high distributed energy resources future has authorized the IOUs to use a variation of the CEC's 2021 IEPR forecast to study the distribution impact of high transportation electrification in their respective 2023 Grid Needs Assessments. Lastly, the CPUC's new proceeding aims to advance demand flexibility through electric rates by considering developing dynamic rates for EV charging. These dynamic rates may facilitate broader EV load management and grid support, which is crucial for ensuring that the grid can accommodate the expected growth in EV adoption over the next decade. Additionally, the overall need of charging stations was analyzed as part of AB 2127 (2021), which developed multiple scenarios of ZEV adoption across the state. According to the report, it is estimated that between approximately 1.2 million and 2 million public and shared private charging stations will be needed in California by 2030 and 2035, respectively, to accommodate the influx of ZEVs. In the SCAG region specifically, the report indicates that by 2035 there will be a need for approximately 1 million charging stations (313,000 DC fast charging stations and the remainder being Level 2) to support the growing number of ZEVs.[50] Note that these numbers also include the charging infrastructure needs for multi-unit dwellings as well as workplace charging. The AB 2127 Report is a biennial report by CEC that examines the charging needs to support California's plug-in EVs. The report is required under AB 2127 and was updated in response to Governor Gavin Newsom's Executive Order N-79-20, which set expanded ZEV adoption targets.

Also, in November 2022, the CPUC adopted a five-year, $1 billion transportation electrification program, which will provide a unified policy-driven funding structure for utility transportation electrification efforts through 2030, with a focus on prioritizing investments in charging infrastructure for low-income, tribal, and underserved utility customers. Under the program, 70% of the funds will go toward charging for medium-and heavy-duty vehicles, while 30% will go to duty charging at or near multi-unit dwellings. The program offers rebates for customer side EV infrastructure investments and provides higher rebates for projects in underserved, disadvantaged, and tribal communities to ensure charging infrastructure reaches these hard-to-reach communities.

Furthermore, in Fall 2021, the CPUC made two resolutions (E-5167 and E-5168) approving new Electric Rules for IOUs to help customers cover costs associated with EV charging. These rules are called the EV Infrastructure Rules and they allow ratepayers to cover the costs of service line extensions and electrical distribution infrastructure for

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[49] https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/infrastructure/transportation-electrification/freight-infrastructure-planning
[50] https://efiling.energy.ca.gov/getdocument.aspx?tn=238851

separately metered or sub-metered EV charging. The EV Infrastructure Rules are a major policy shift as they incorporate utility-side transportation electrification investments into the IOUs' general rate case proceedings. The IOUs began offering service under these rules in mid-2022 and will report data on their implementation in their EV Cost and Load report submitted in 2023. These resolutions also address the issue of energization timing, which is the time between when a customer submits an application with their utility to energize chargers to when the chargers receive power. The CPUC issued Resolution E-5247 in December 2022, which establishes an interim 125-business day average service energization timeline for projects taking service under the EV Infrastructure Rules. The IOUs will collect one year of data to inform an updated proposal for a permanent service energization timeline.

2.7 Policy Gaps

Despite all federal, state, and local incentives and regulations helping to accelerate the adoption of clean transportation technologies, significant disparities in ZEV ownership and operation exist between lower and higher-income communities. A recent study by International Council on Clean Transportation (ICCT) for the International ZEV Alliance[51] found that, despite accelerated adoption and supporting infrastructure, accessibility gaps in electrified transportation persist. ZEV ownership correlates with income and education levels, with high-income communities reporting up to seven times more ZEV ownership than lower-income areas. Some of the key policy gaps contributing to this gap include:

- **Lack of Affordability for Low- & Moderate-Income Communities**: The initial price tag of clean transportation technologies is usually higher than that of traditional vehicles. For example, electric vehicles (EV) often have a higher upfront cost compared to conventional internal combustion engine cars. The latest report from Kelley Blue Book[52], reveals that the average cost for a passenger ZEV is $18,000 more than that of an average ICE vehicle. The cost disparity becomes much more significant in the medium and heavy-duty vehicle. The cost disparity is due to the cost of the battery technology, which represents a significant portion of the EV cost. Higher insurance premiums for EVs also add to the higher upfront cost. Historically, some insurers charged higher rates for EVs due to factors like higher repair costs from specialized components, a greater initial vehicle value, perceived risks from limited historical data, and the potential cost of battery replacement. These elevated premiums can raise the overall cost of owning an EV, deterring potential buyers. While incentives can offset some of this cost, they often still remain out of reach for those with lower income households. These households are already grappling with the high price tags of new vehicles. The situation is further exacerbated when considering the even higher costs that come with acquiring ZEVs. This is why it is critical to develop additional, targeted incentive programs to close the affordability gap in clean transportation technologies. Such programs should be explicitly designed to cater to the needs of low and moderate-income communities, which are often marginalized in the transition to clean energy. This could involve strategies such as up-front rebates or grants to directly reduce purchase costs, subsidized loans, or "scrappage" schemes where older, more polluting vehicles can be traded in for a discount on cleaner ones. It is also important to note that currently the federal incentives are structured as tax credits, which require individuals to wait until the end of the tax year to see financial benefits. This does little to offset the high upfront costs, particularly for low and moderate-income individuals who may not have the financial flexibility to wait. Additionally, those with lower income may not owe as much in taxes, limiting the usefulness of a tax credit.
- **Lack of Investment in Charging & Fueling Infrastructure**: The shift to clean technologies requires access to charging and clean fuel infrastructure. This can be particularly challenging for people who live in apartments or other multi-unit dwellings where installing personal charging stations may not be possible. Public charging stations are an alternative, but they require investment in infrastructure that may be lacking in low and moderate-income neighborhoods. Even with the significant investments made at the federal and state levels, those investments alone cannot close the gap for the zero-emission infrastructure. According to CEC's AB 2127 report, to meet the ambitious goals set by Executive Order N-79-20, which anticipates 8 million ZEVs

[51] https://zevalliance.org/wp-content/uploads/2023/01/Environmental-Justice-Impacts-of-ZEVs_Final-Report.pdf
[52] https://mediaroom.kbb.com/2022-05-10-Luxury-Share-Increases-in-April,-Pushing-New-Vehicle-Average-Transaction-Prices-Higher,-according-to-Kelley-Blue-Book

by 2030, nearly 1.2 million charging facilities (public and shared private[53]) will be required for light-duty vehicles. In addition, to accommodate the expected 180,000 medium- and heavy-duty vehicles by 2030, an extra 157,000 charging stations will be needed. Currently California has 87,700 public and shared private chargers. To address the infrastructure deficit, there is a significant need for an increased pace of charger installation from 2023 to 2030. Specifically, each week during this period, around 3,000 chargers for light-duty vehicles and 430 chargers for heavy-duty vehicles should be constructed. This clearly shows why it is important for regional agencies such as SCAG and their regional partners to intensify their efforts in deploying clean fueling and charging infrastructure throughout their jurisdictions.

- **Alternative Revenue Sources To Replace Fuel Taxes**: As the transportation sector shifts toward ZEV, a critical policy gap emerges concerning the funding of transportation projects. Traditionally, gas tax revenue has been a primary source of funding for these initiatives. As the adoption of ZEVs increases, gas consumption decreases, leading to a significant reduction in gas tax revenue. This decline poses a challenge for maintaining, upgrading, and expanding transportation infrastructure, as the traditional funding mechanism diminishes. Policymakers need to address this gap by exploring alternative revenue streams or restructuring the current taxation model to ensure that the transition to cleaner vehicles doesn't inadvertently hinder transportation infrastructure investments. For example, as part of the Senate Bill 1 which passed in 2017, starting in 2020, a one-time upfront registration fee of $100 is charged for 2020 model year plug-in vehicles in California.

[53] A shared private charging station has parking space(s) designated by a property owner or lessee to be available to and accessible by employees, tenants, visitors, and/or residents. Parking spaces are not dedicated to individual drivers or vehicles

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3. Clean Technology Discussion: Approach and Methodology

3.1 Scope of Clean Technologies Considered

As part of this technology compendium, three categories of technologies were evaluated: 1) ZEV and NZEV technologies, 2) charging and fueling infrastructure, and 3) relevant supporting products. For vehicles, the technologies reviewed include BEVs, FCEVs, PHEVs and natural gas-powered vehicles for on-road applications. For rail, which includes passenger rail, freight rail, switchers, and light rail, technology types reviewed included BEV, and FCEV.

In terms of infrastructure, the project team assessed various charging and clean fueling technologies. These included Level 2 Charging Stations, DC Fast Charging Stations, and Innovative Charging Solutions. Additionally, the assessment encompassed hydrogen fueling infrastructure options such as Slow Fill, Fast Fill, On-Site Production, Off-Grid, Mobile Stations, and On-the-Go hydrogen stations. Furthermore, the team also examined natural gas infrastructure, specifically Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG) options.

In evaluating supporting products, the project team examined a diverse range of technologies to complement and enhance the implementation of zero and near-zero emission technologies. These included:

- **Charge Management Software**: This software enables the efficient management and monitoring of charging stations. It optimizes their use and ensures reliable access to the charging infrastructure.
- **Battery Management Systems (BMS)**: These systems play a crucial role in maintaining the performance and lifespan of vehicle batteries. They ensure optimal energy storage and distribution.
- **Smart Grid Technologies**: These include advanced grid management systems that enable effective integration of renewable energy sources, offer demand response capabilities, and allow for intelligent energy distribution. These technologies facilitate the integration of ZEVs and NZEVs into the existing grid infrastructure, supporting their charging and operation.
- **Fleet Management Software**: This software is designed to optimize fleet operations. It offers functionalities such as route planning, vehicle tracking, and maintenance scheduling. This aids in maximizing the efficiency and productivity of ZEV and NZEV fleets.
- **Payment Systems:** Systems that enable convenient and secure transactions for accessing charging infrastructure or utilizing other mobility services. They offer user-friendly payment options, ensuring seamless transactions and enhancing the overall user experience.

3.2 Specifications

Clean technology specifications encompass a range of factors that contribute to the environmental sustainability, acceptance, and efficiency of a technology or product including emissions benefits, total cost of ownership, adoption status, etc. This compendium utilizes technology specifications to offer a comprehensive elucidation of diverse clean technologies. Its purpose is to equip stakeholders with the essential tools and information required for making informed decisions when selecting technologies that align with their specific applications.

Our approach to the specifications list evolved due to the exclusion of certain categories, either from inadequate data quality or the inability to define a meaningful metric for our analysis. We focused on factors that could be justifiably addressed. For instance, we initially considered an 'equity specification', but due to challenges in identifying a quantifiable metric for each technology, it was excluded. These additional considerations are discussed within each of three types of technologies considered (vehicle, infrastructure, and supporting products) and a comprehensive list is included in Appendix E to this report.

The following tables delineate each specification for the three technology categories under consideration. The specification categories for all categories are consistent, though vehicle technologies include additional unique specifications such as emissions and total cost of ownership. These unique aspects are integral to the broader characterization of vehicle technologies.

Table 5. Technology Specifications - Vehicles

Specification	Metric	Unit of Measurement
Product Description	Brief description of the product (e.g., vehicle body type)	
GHG Emissions Reduction	This metric measures the annual metric ton of life cycle (well-to-wheel) CO2 emissions reduction per unit of vehicle replacement. The unit of measurement is in metric tons per year, providing an assessment of the technology's impact on GHG emissions. Please note that GHG emissions assessed in this study encompass those emitted during all stages of the fuel's life cycle: from extraction and production to distribution and final use. More details can be found in Appendix B. It is also noteworthy to mention that the project has attempted to quantify emission reductions from all technologies, irrespective of their current availability. This is feasible as the project team was able to predict the improvements in efficiency once these technologies are developed and brought to market.	Metric Tons per Year[54]
NOx Emissions Reductions	This specification indicates the percentage of reduction in NOx emissions from conventional gasoline and diesel fuels that the technology offers. It serves as a measure of the technology's contribution to reducing nitrogen oxide emissions.	Percentage
PM Emissions Reductions	This metric represents the percentage of reduction in particulate matter (PM) emissions achieved by the technology. It provides an insight into the technology's effectiveness in reducing fine particulate pollution, with the unit of measurement also being a percentage.	Percentage
Range	This specification quantifies the number of miles that a vehicle utilizing the technology can travel with one refueling. It serves as an important consideration for assessing the practicality and usability of the technology.	Miles
Capital Cost	This metric represents the capital cost associated with clean technology vehicles. It provides stakeholders with information on the initial investment required for purchasing these vehicles.	U.S. Dollar
Total Cost of Ownership (TCO) Saving	This metric represents the total incremental cost or saving (if savings are negative – i.e., TCO of clean technology is higher than baseline technology – the number is shown in parathesis and red color) incurred over the useful life of the vehicle employing the technology. For simplicity, in this analysis, the project team is using 15 years of lifetime. This metric provides stakeholders with an estimation of the financial implications associated with adopting and maintaining the technology. More details can be found in Appendix C.	U.S. Dollar
Adoption Status	This specification indicates the number of vehicles or units employing the technology that have been deployed in SCAG region. It serves as an indicator of the technology's market penetration and adoption level, providing valuable insights into its current usage.	Number of Vehicle/Units

[54] For this analysis, the project team calculated the metric tons per year of GHG emissions reduction to quantify the impact on GHG emissions. This selection provides a comprehensive GHG emission reduction metric that not only accounts for the intrinsic performance of the technology, but also its practical use. This dual consideration ensures that the technology's real-world implementation and its effect on emission levels are accurately captured, offering a more holistic view of its potential in reducing overall GHG emissions.

Specification	Metric	Unit of Measurement
Availability	This metric assesses the number of make/models of vehicles utilizing the technology that are currently commercially available or expected to be available in the next three years. It provides information on the diversity and availability of options for stakeholders considering the adoption of the technology.	Number of Make/Models
Longevity	This specification reveals the average number of years covered by the manufacturer warranty for vehicles using the technology. It serves as an indication of the expected lifespan and reliability of the technology, allowing stakeholders to consider the associated warranty coverage.	Years

Table 6. Technology Specifications – Charging & Fueling Infrastructure

Specification	Metric	Unit of Measurement
Product Description	Brief description of the product (e.g., type of chargers)	
Capital Cost	This metric represents the capital cost associated with EV chargers, natural gas stations (per unit capacity), and hydrogen fueling stations (per unit capacity). It provides stakeholders with information on the initial investment required for installing these infrastructure units.	$/station
Maintenance Cost	This specification indicates the cost of maintaining EV charging equipment, hydrogen stations, and natural gas stations. It helps stakeholders assess the ongoing expenses associated with operating and servicing these infrastructure units	$/year/station
Adoption Status	This metric reveals the number of charging stations or fueling stations that have been deployed in SCAG region. It offers insights into the level of adoption and availability of these stations within the specified area.	Number of Units
Availability	This specification assesses the number of vendors or suppliers that provide charging stations or fueling stations. It informs stakeholders about the diversity and availability of options when it comes to sourcing these infrastructure units	Number of Vendors
Longevity	This metric indicates the average number of years covered by the manufacturer warranty for charging stations or fueling stations. It provides stakeholders with an understanding of the expected lifespan and reliability of the infrastructure units	Years

Table 7. Technology Specifications – Supporting Products

Specification	Metric	Unit of Measurement
Product Description	Brief description of the product (e.g., detailed information about a product's features, functions, and benefits)	
Capital Cost	This metric represents the capital cost or upfront cost associated with the technology. It provides information on the initial investment required to acquire the supporting product or hardware.	$/unit
Maintenance Cost	This specification indicates the ongoing maintenance cost or subscription fee associated with the technology. It helps stakeholders assess the recurring expenses needed to keep the supporting product operational.	$/year/unit
Adoption Status	This metric reveals the number of units of the supporting product that have been deployed in SCAG region. It offers insights into the level of adoption and availability of these products within the specified area	Number of Units

Specification	Metric	Unit of Measurement
Availability	This specification assesses the number of vendors or suppliers that provide the supporting product. It informs stakeholders about the diversity and availability of options when it comes to sourcing these products.	Number of Vendors
Longevity	This metric indicates the average length of the manufacturer warranty for the supporting technology. It provides stakeholders with an understanding of the expected lifespan and reliability of the product	Years

3.3 Technology Identification and Assessment Methods

A variety of pre-developed tools were utilized to complete the technology assessment and characterization:

- **AFLEET:** For calculating the total cost of ownership (TCO), the Argonne National Laboratory's (ANL) Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool was utilized with some modifications to California fuel prices as well as augmenting the vehicle prices with latest available information. More detailed on the TCO analysis is also provided in Appendix C of this report.
- **U.S. Department of Energy (DOE) Alternative Fuels Data Center's (AFDC) Alternative Fuel and Advanced Vehicle Search**[55] was used for the availability of on-road clean technology vehicles
- **ICF's EV library**[56] was used to determine the availability and range of each vehicle type.
- **CARB's Technology Feasibility Assessment for the Proposed In-Use Locomotive Regulation**[57] was used for the availability and cost information associated with various clean rail technologies
- **CARB's EMFAC2021**[58] model along with other sources such as the **U.S. Energy Information Administration** and **CARB's Low Carbon Fuel Standards** (LCFS) carbon intensity data were leveraged for emission quantification.
- **CEC's Zero Emission Vehicle and Infrastructure Statistics** was used to determine the adoption status of light-, medium- and heavy-duty vehicles as well as buses. The tool was also used to extract the latest number of charging and hydrogen fueling stations deployed in the region.

- **Desk research**: In instances where pre-existing tools were not accessible or did not provide complete information, internet searches were conducted to bridge the knowledge gaps. These searches were utilized to gather data on factors such as longevity and range, supplementing the existing information and ensuring a more comprehensive understanding of the subject matter.
- **Clean Technology Survey:** A survey was distributed to clean vehicle technology manufacturers and municipalities. The vendor list was compiled through web searches, industry relationships of the project team, as well as SCAG's listserv and included more than 90 recipients. The survey was distributed via email. In some cases, the information was used to fill in the gaps where existing tools and internet research was lacking. The purpose of this survey was to solicit feedback from technology vendors, manufacturers, and other stakeholders in the clean transportation industry to ensure that the Clean Transportation Technology Compendium is accurate, comprehensive, and up to date. The survey questionnaire is included as an Appendix to this report (Appendix D). Specifically, the project team sought information on the following aspects of clean transportation technologies:

[55] https://afdc.energy.gov/vehicles/search/
[56] The ICF EV Library is a proprietary database containing information on over 500 electric vehicle makes and models (light, medium, and heavy-duty). It includes key details about their specifications and estimated years of commercial availability. The library is compiled from industry announcements, web searches, as well as conversations and interviews with various manufacturers.
[57] https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/locomotive22/appf.pdf
[58] https://arb.ca.gov/emfac/

- **Commercial availability**: Is the technology commercially available? If not, what phase of development is technology currently in?
- **Capital, Operation, and Maintenance Costs**: What are the estimated capital, operation, and maintenance costs of these technologies compared to conventional technologies? How do these costs evolve over time, and what factors influence them (e.g., research and development, prototyping, testing and validation, and commercialization)?
- **Market penetrability:** What is the current market share of the proposed technology? What factors are driving or hindering their growth in the market?
- **Accessibility**: How accessible are these technologies to various user groups, including individuals, businesses, and public entities? What barriers might hinder their adoption and how can they be overcome?
- **Additional factors**: Are there any other considerations, challenges, or opportunities related to the deployment of the technology in Southern California?

The vendor survey yielded a total of 23 responses, out of which 20 were relevant and provided valuable insights. These responses were obtained from a diverse range of vendors, including prominent names such as BorgWarner, Sesame Solar, City of Manhattan Beach, Proterra, Forum Mobility, Exprolink, Inc., GoPowerEV, Volvo Group North America, Hyzon Motors USA, Hydrogen Fuel Cell Partnership, The Mobility House, BayoTech, BP Pulse Fleet North America Inc., Xendee Corporation, Energy, Efficiency & Environment, Inc., and Core States Energy. The responses obtained from the vendor survey played a vital role in the project team's pursuit of comprehensive information. These valuable inputs helped bridge significant information gaps that could not be readily fulfilled through internet searches or literature review alone.

- **One-on-One interviews:** The project team also took a hands-on approach to gather information by engaging directly with various clean technology manufacturers. This approach involved conducting interviews and holding discussions with industry representatives to gain a more nuanced understanding of the evolving technology landscape. Participation in conferences and other industry gatherings also provided opportunities to interact face-to-face with these manufacturers.

4. Technology Compendium

Chapter 4 of the compendium delves into specification tables for each category of clean technology, namely Vehicles, Infrastructure, and Supporting Products. Within each category, various subcategories and associated products are characterized with respect to the technology specifications identified earlier. While there may be slight differences in the specifications for each category, the discussion of individual products generally revolves around their existing condition (current adoption, and pilot projects), emissions reduction impacts, total cost of ownership, maintenance costs, and factors related to performance and commercialization (e.g., range, availability, and longevity). It is important to note that not all the necessary information was readily available, and any cells in the technology characterization tables with "NI" indicate a knowledge gap or lack of available information. Blank cells indicate that the product is not currently commercially available.

4.1 Vehicles

Defining the Vehicles Category: Within the Vehicles category, Light-Duty (LDVs), Medium-Duty (MDVs), and Heavy-Duty (HDVs) on-road vehicles, as well as Rail locomotives were included in this assessment. Each vehicle category is broken down into body styles. For examples in the LDV category, body styles include Passenger, SUV, Minivan, Pickup Truck, and Utility Van. Each body style is broken down further into fuel types such as BEV, PHEV, FCEV, and NGV. Each body and fuel type was evaluated based on the pre-determined criteria (e.g., GHG Emissions Reductions, TCO, Adoption Status, Availability, etc.).

Data Sources and Limitations:

Data sources used to evaluate the technology specifications include the following:

- AFLEET[59]: Used to calculate the total cost of ownership for BEVs, PHEVs, NGVs, and FCEVs.
- ICF's EV Library: Used to calculate the availability and range of BEVs, and PHEVs.
- AFDC Vehicle Search[60]: Used for the availability of on-road clean technology vehicles
- CARB's Technology Feasibility Assessment for the Proposed In-Use Locomotive Regulation[61]: Used for the availability and cost information associated with various clean rail technologies

The project encountered certain limitations with the available data sources. To address the gaps in information, internet searches were conducted as an alternative means to acquire complete data. These searches specifically aimed to determine the availability and range of NGVs and FCEVs. Although the internet searches proved to be helpful in filling some of the knowledge gaps, it is important to note that not all the required information was accessible online. In cases where vendors did not provide the necessary information through the clean technology survey, the corresponding cells in the technology characteristics tables were marked as "NI" meaning that "No information Available." For instance, there were certain instances where TCO data or range data could not be obtained from AFLEET or other publicly available data sources. Since this information was neither available online nor provided through the survey, the respective cells in the table were left as "NI." Additionally in certain cases where the technology did not exist (e.g., there does not exist any FCEV minivans in the market) the cells were left blank.

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[59] AFLEET Tool - Argonne National Laboratory. Accessed June 8, 2023. https://afleet.es.anl.gov/home/.

[60] https://afdc.energy.gov/vehicles/search/

[61] https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/locomotive22/appf.pdf

4.1.1 Light Duty Vehicles

LDVs are class 1 vehicles weighing 6,000 lbs. or less. LDV body styles evaluated included passenger cars, SUVs, minivans, pickup trucks, and utility vans. For each body style, technology types such as BEVs, PHEVs, and FCEVs are evaluated by the pre-determined specifications.

Table 8 displays detailed product descriptions for each body style and technology type.

Table 8. LDV body styles descriptions.

Vehicle Type	Description
Passenger Car	A passenger car, also known as an automobile or sedan, is a four-wheeled vehicle primarily designed for the transportation of passengers. It typically has seating for four to five people, with a separate enclosed area for passengers and a designated trunk space for cargo.
SUV	An SUV is a versatile vehicle that combines elements of both a passenger car and an off-road vehicle. It typically features a higher ground clearance, a more spacious interior, and the ability to accommodate more passengers. SUVs often offer optional four-wheel drive for improved off-road capability.
Minivan	A minivan, also known as a multi-purpose vehicle (MPV), is a spacious vehicle designed to transport multiple passengers, typically with three or more rows of seating. Minivans provide ample interior space, versatile seating configurations, and often have sliding doors for convenient access to the rear passenger area.
Light Duty Pickup Truck	A light duty pickup truck is a type of light duty vehicle characterized by an open cargo bed at the rear, separate from the passenger compartment. Pickup trucks are designed for both passenger transportation and hauling cargo. They often offer towing capabilities and are available in various sizes, from compact to full-size models.
Utility Van	A utility van, also known as a cargo van or commercial van, is a light duty vehicle primarily designed for carrying goods, equipment, or tools. Utility vans typically have a fully enclosed cargo area without rear passenger seating. They offer ample space and security features for efficient transportation and storage of cargo or supplies.

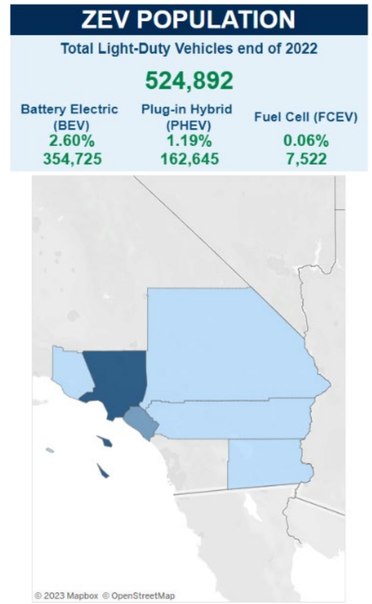
Existing Condition

In 2022, more than 175,000 light duty ZEVs were sold in the SCAG region.

The adoption of clean light duty vehicle technologies in SCAG region has steadily increased over the years. ZEV adoption started gaining momentum around 2010 and was initially concentrated in high populous areas and regions with higher socioeconomic status. In SCAG region, the majority of ZEVs are found in Los Angeles and Orange counties, with Los Angeles County having 54 percent and Orange County having 26 percent of the total ZEVs in the region. Prior to 2010, SCAG region had only 122 ZEVs, but since then, the number has surged to approximately 525,000, accounting for about 3.9 percent of the total light-duty vehicle fleet in the region. Sales trends indicate that ZEVs are becoming an increasingly significant portion of the market, composing roughly 25% of light-duty vehicle sales as of the second quarter of 2023. BEVs and PHEVs represent the majority of ZEVs in the region, with FCEVs lagging significantly behind, only representing 0.06 percent of ZEVs in the region. It is worth noting that the majority of the BEVs (88 percent) in the region have battery electric ranges over 200 miles. [62] As of December 2022, consumers in California had a broad range of options with 50 passenger BEV models, 51 PHEV models, and 3 FCEV models commercially available for sale[63]. Given the current adoption rates, the region is making significant progress toward the targets set by the State to require 100% ZEV sales by 2035.

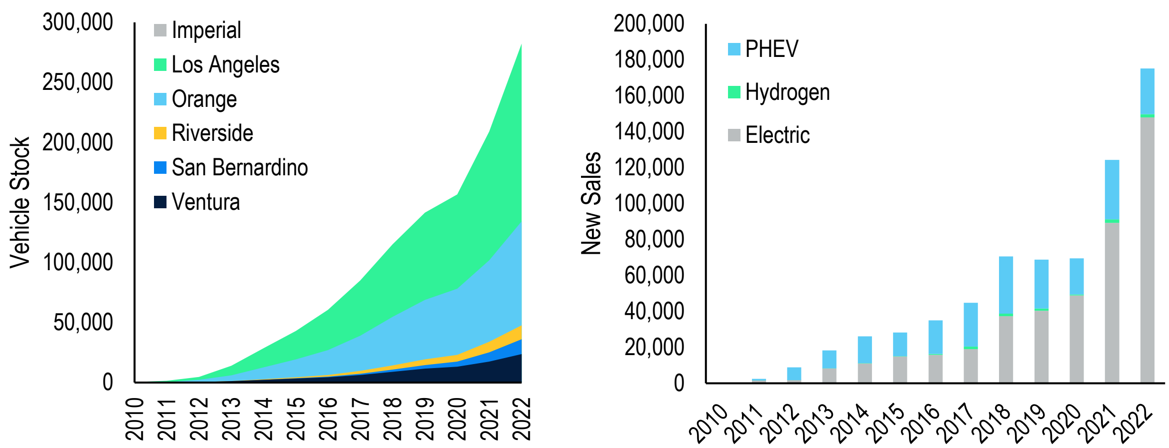
[62] https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/light-duty-vehicle
[63] https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics

The future adoption of light-duty FCEVs is uncertain, as the current higher cost of hydrogen relative to gasoline or electricity, along with the limited availability of hydrogen refueling infrastructure, may present barriers to their widespread adoption in the near term. Additional advances in technology would be necessary for them to increase market share. It should also be noted that while PHEVs are considered a ZEV, they are only truly zero emission when operating solely on battery power. Once the battery is depleted, they operate similarly to a conventional hybrid vehicle, utilizing a gasoline engine. The average electric range of PHEVs has steadily increased from 20.5 miles in 2012 to 38.5 miles as of 2021.[64]



The trend toward ZEV adoption in SCAG region, especially for light-duty vehicles, is encouraging. However, the adoption of FCEVs has been slow, and the majority of ZEVs are still BEVs and PHEVs. Despite this, the fact that the majority of BEVs in the region have battery electric ranges over 200 miles is an indication that range anxiety is becoming less of a barrier to BEV adoption. The increasing adoption of ZEVs in SCAG region is a positive step toward GHG emissions and improving air quality in the region. However, there is still much work to be done to ensure that there is sufficient clean fueling infrastructure, especially for FCEVs, to support continued ZEV adoption in the region. Figure 4 shows the adoption trend of zero emission light duty vehicles (both total vehicle stock and sales) in SCAG regions between 2010 and 2022. The first graph on the left represents the total number of ZEVs currently operating in SCAG region, while the second graph shows how many ZEVs were purchased each year. The future of ZEVs in the light duty sector in SCAG region is bright, with roughly 27.5 percent of vehicles being ZEVs as of 2020, with no signs of slowing down.[65]

Figure 4. Zero Emission Vehicle Stock and Sales in SCAG Region



Source: https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics (Accessed: July 7, 2023)

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[64] https://www.iea.org/data-and-statistics/charts/evolution-of-average-range-of-electric-vehicles-by-powertrain-2010-2021

[65] Data gathered from: https://arb.ca.gov/emfac/fleet-db/067ac056377580f1eb495a6cf58d0205ba4cf295

In addition to the adoption statistics, the region has also undertaken numerous demonstration projects pertaining to the adoption of zero-emission passenger vehicles. Demonstration projects play a critical role in the adoption of clean zero emission technology by providing tangible examples of how the technology can be successfully implemented in real-world scenarios. These projects allow stakeholders to observe the technology in action and assess its performance, which helps to build confidence in the technology's viability and effectiveness. An interesting demonstration project in the region was launched by Southern California Edison (SCE) and seeks to test the viability of vehicle-to-grid (V2G). This demonstration project will test whether EV batteries could be a reliable and efficient source of energy for the power grid. The project will use a mix of passenger EVs at workplace charging sites, electric school and transit buses to validate whether V2G could help reduce customers' electric bills in exchange for energy supplied from their EV batteries. SCE believes that to meet its goal to become carbon neutral by 2045, 75% of all vehicles in California need to be electric by then. With more than 200,000 EVs in its service area and 700,000 in the state, SCE believes that EV batteries could become a viable source of power for the energy grid.[66]

Environmental Impacts

With respect to environmental impact, the assessment included GHG, NOx, and Exhaust PM reductions by body style and technology type. Emissions reductions in terms of tons of CO_2 per year are displayed in Table 9 and Figure 5. Notably, BEVs consistently boast greater reductions in CO_2 per year than PHEVs and FCEVs across all body styles. Meanwhile, emissions reductions for NOx, Exhaust PM, and Brake wear PM are consistent across all body styles and technology types (Figure 6). It is noteworthy to mention that the CO2 emissions also account for the upstream emissions accounting for fuel and electricity production. Note that the project team used 2021 carbon intensity values for California average grid electricity used as a transportation fuel in California as reported by the California Air Resources Board.[67] With respect to NOx and PM emissions (both exhaust and brake wear), the project team utilized the CARB EMFAC2021 model.

Table 9. Environmental impacts of LDV body styles and technology types.

Light Duty Vehicle by Body Style	Technology Type	GHG Emissions Reduction (Metric Ton per Year) [68]	NOx Emissions Reductions	Exhaust PM Emissions Reductions	Brake wear PM Emissions Reductions
Passenger Car	BEV	3.99	100%	100%	50%
	PHEV	2.40	40%	40%	50%
	FCEV	2.61	100%	100%	50%
SUV	BEV	5.71	100%	100%	50%
	PHEV	3.43	40%	40%	50%
	FCEV	3.74	100%	100%	50%
Minivan	BEV	13.19	100%	100%	50%
	PHEV	7.91	40%	40%	50%
	FCEV	8.63	100%	100%	50%
Pickup Truck	BEV	6.08	100%	100%	50%

[66] https://www.sce.com/business/advantages/electric-transportation-programs/vehicle-grid

[67] https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/fuelpathways/comments/tier2/2021_elec_update.pdf?_ga=2.207245524.611557608.1628272571-476568668.1615315573

[68] For FCEVs, the project team assumes that hydrogen is produced through Steam Methane Reforming (SMR) using fossil natural gas, which is currently the most common method for hydrogen production nationwide. However, the project team also explored other options. For information about GHG emissions reductions from hydrogen produced using other feedstocks, please refer to Appendix B.

Light Duty Vehicle by Body Style	Technology Type	GHG Emissions Reduction (Metric Ton per Year) [68]	NOx Emissions Reductions	Exhaust PM Emissions Reductions	Brake wear PM Emissions Reductions
	PHEV	3.65	40%	40%	50%
	FCEV	3.98	100%	100%	50%
Utility Van	BEV	11.87	100%	100%	50%
	PHEV	7.12	40%	40%	50%
	FCEV	7.77	100%	100%	50%

Figure 5. GHG Emissions (well to wheel) reductions of LDV body styles and technology types.

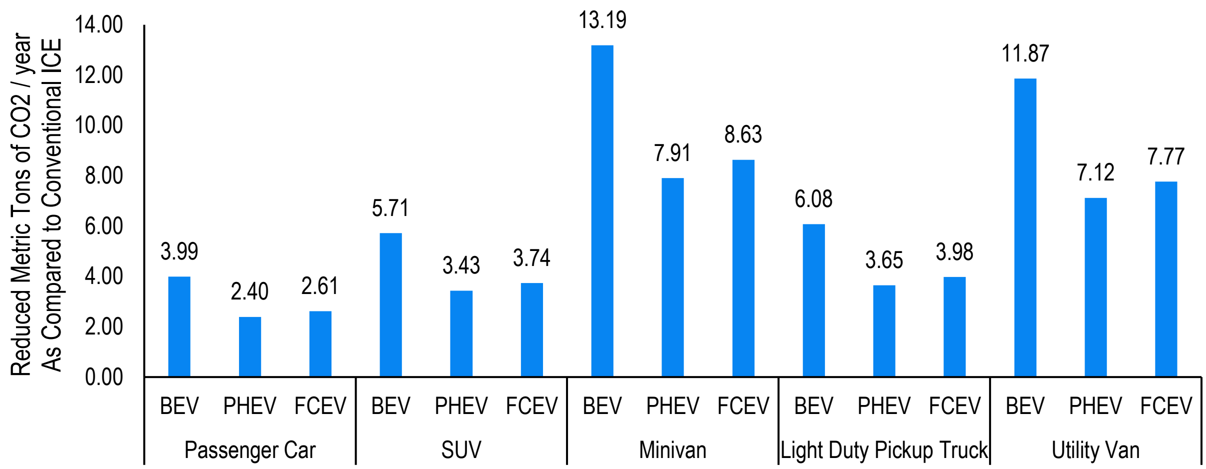
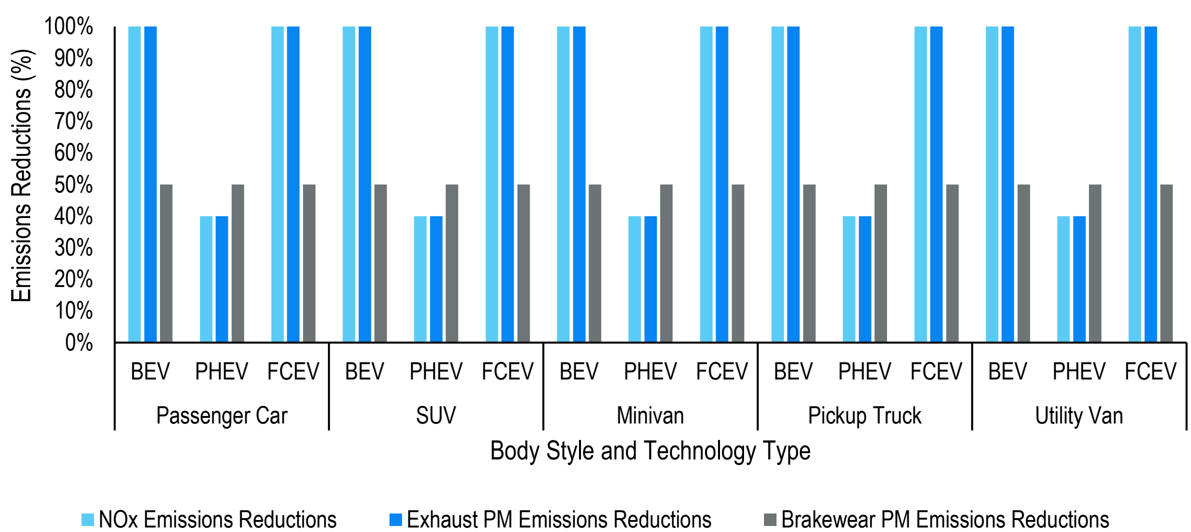


Figure 6. Percentage of NOx emissions reductions, exhaust PM emissions reductions, and brake wear PM emissions reductions by body style and technology type.



Performance & Commercialization

LDVs are the most widely available and adopted category of ZEV and NZEVs. PHEVs have the greatest range (up to 640 miles for a passenger car), followed by BEVs (up to 520 miles for a passenger car). In terms of total cost of ownership, BEVs were less expensive than their combustion engine alternative although the initial purchase cost was greater. It should also be noted that while PHEVs are considered a ZEV, they are only truly zero emission when operating solely on battery power. Once the battery is depleted, they operate similarly to a conventional hybrid vehicle, utilizing a gasoline engine, explaining their longer range. Table 10 displays further details relevant for commercialization and specific technological characteristics. For the availability category, the project team also included vehicles of the same make and model but different trim levels (i.e., sub models). For example, while the Audi e-tron is commonly recognized as a single make and model, the project team distinguished and accounted for four distinct trim levels within this range. These trim levels include the standard e-tron, e-tron S, e-tron S Sportback, and e-tron Sportback. This is why the number of models may not necessarily line up with other sources commonly used in California such as Veloz[69].

Table 10. Technology characteristics of LDVs by body style and technology type.

Light Duty Vehicle by Body Style	Technology Type	Range	Capital Cost	TCO Savings	Adoption Status[70] (Number of Vehicles)	Availability	Longevity
Passenger Car	**BEV**	520 - 114 miles	$37,000	$7,506	212,932	40-50 models	7-10 years
	PHEV	640 - 290 miles	$27,000	$8,080	117,629	20-30 models	7-10 years
	FCEV	391 miles	$50,000	($36,984)	7,512	< 5 models	3-8 years
SUV	**BEV**	350 - 100 miles	$46,000	$13,147	139,236	80-90 models	7-10 years
	PHEV	560 - 370 miles	$38,500	$12,165	40,662	30-40 models	7-10 years
	FCEV	260 - 380 miles	$59,000	($47,720)	10	< 5 models	3-8 years
Minivan	**BEV**	250 miles	$46,000	$45,198	15	< 5 models	7-10 years
	PHEV	520 miles	$38,500	$59,520	4,354	< 5 models	3-5 years
	FCEV						
Pickup Truck	**BEV**	110 – 400 miles	$77,000	($13,675)	2,492	10-20 models	3-10 years
	PHEV	500 miles	$58,000	($3,614)	0	10-20 models	8-10 years
	FCEV						
Utility Van	**BEV**	110 - 175 miles	$55,000	$51,337	15	10-20 models	3-8 years
	PHEV						
	FCEV						

NI indicates "no information" or a knowledge gap
Blank indicates not commercially available

[69] https://www.veloz.org/ev-market-report/
[70] https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/light-duty-vehicle (Accessed: July 7, 2023)

4.1.2 Commercial Vehicles: Medium & Heavy-Duty (excluding Transit Buses)

Medium (MDV) and Heavy Duty (HDV) vehicle are considered as Class 2b – 8 vehicles with GVWR greater than 8,500 lbs. MDVs are considered Class 2-7 vehicles with GVWR between 8,501 – 33,000 lbs. Body styles for MDVs include pickup truck, cargo van, passenger van, step van, box truck, cab & chassis, and cutaway were considered. The technology types evaluated for each body style consisted of BEV, PHEV, FCEV, and NGV. HDVs are considered Class 8 trucks that weigh over 33,000 lbs. Body styles that were considered for HDVs include straight truck, semi-tractor, and refuse vehicles, with technology types including BEVs, PHEVs, FCEVs, and NGVs. Although many buses are also HDVs, these were evaluated in the bus category. Product descriptions are listed below in Table 11

Table 11. MDV & HDV product descriptions by body style.

Vehicle Type	Body Type	Description
Medium Duty Vehicles	Medium Duty Pickup Truck	A medium duty pickup truck is a type of medium-duty truck with an open cargo bed at the rear designed to carry both passengers and cargo. It typically has a separate cabin for passengers and a rear bed for hauling goods or materials.
	Cargo Van	A cargo van is a commercial vehicle primarily designed for transporting goods or cargo. It typically features a closed cargo area without rear passenger seating, offering ample space for loading and transporting goods securely.
	Passenger Van	A passenger van, also known as a passenger minivan, is a vehicle designed to transport multiple passengers. It typically has several rows of seating, accommodating a higher number of passengers compared to standard cars, and may include additional features for passenger comfort.
	Step Van	A step van, also referred to as a walk-in delivery van, is a vehicle primarily used for delivery or mobile service purposes. It usually has a tall and boxy body design, allowing drivers to easily step in and out of the vehicle, often without the need to climb up or down.
	Box Truck	A box truck, also known as a cube truck or box van, is a medium-duty commercial truck characterized by a fully enclosed cargo area. It typically has a separate cabin for the driver and a rectangular-shaped cargo area with a rigid and enclosed box structure, providing secure storage and transportation for various goods or materials.
	Cab & Chassis	Cab & Chassis refers to a vehicle configuration where the manufacturer provides only the cab and the chassis frame, without any additional cargo area or specialized body. This configuration allows for customization by adding different types of bodies or equipment according to specific needs, such as a flatbed, dump bed, or utility body.
Heavy Duty Vehicles	Straight Truck	A straight truck, also known as a box truck or straight-bodied truck, is a class 8 vehicle consisting of a single rigid frame. It typically has a cab for the driver and a cargo area directly behind it. The cargo area is usually enclosed and designed to transport goods or materials securely. Straight trucks are commonly used for local deliveries or as moving trucks.
	Semi-Tractor	A semi-tractor, also known as a semi-truck or tractor-trailer, is a class 8 truck designed to tow semi-trailers. It consists of a powerful engine, a large cab for the driver, and a fifth wheel coupling at the rear to attach and tow trailers. Semi-tractors are commonly used for long-haul transportation of goods over significant distances.
	Refuse Trucks	Refuse vehicles, also known as garbage trucks or waste collection vehicles, are class 8 vehicles specifically designed for collecting and transporting solid waste or refuse. They are equipped with mechanisms for loading and compacting garbage, such as front loaders, rear loaders, or side loaders. Refuse vehicles play a crucial role in waste management systems, ensuring the efficient collection and disposal of waste materials.

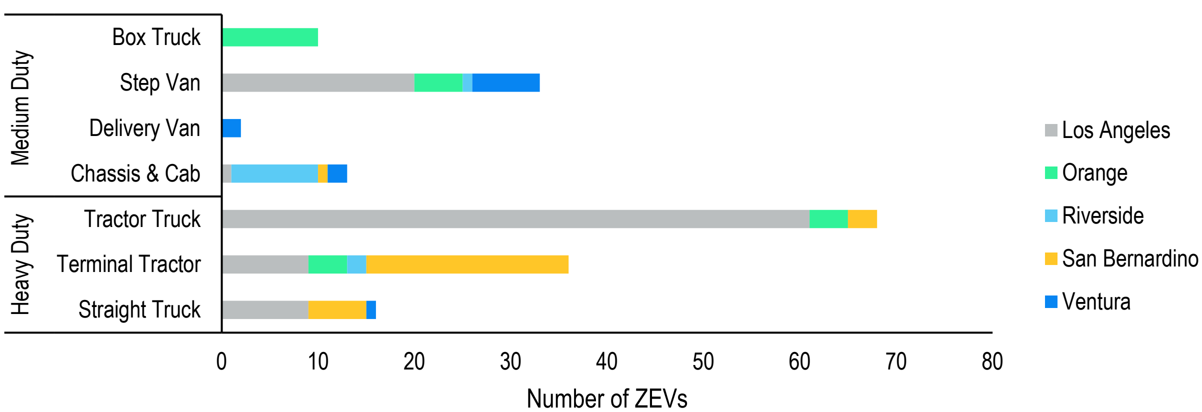
Existing Conditions

Ford E-Transit Medium-duty battery electric cargo vans such as this vehicle run solely on a rechargeable battery. MDVs are class 2b vehicles weighing between 8,501- and 10,000 lbs.

Zero-Emission Vehicles. According to the CALSTART's Zero Emission Technology Inventory[71], there are currently 134 models of zero emission MHDVs available in North American market of which 9 of them are FCEVs and the rest are BEVs. The adoption of MHDVs in SCAG region is still in its early stages. Currently, there are only 178 MHDVs (58 heavy duty and 120 medium duty vehicles) in the region, indicating that the use of MHDVs powered by zero-emission technology is not yet widespread. Moreover, the concentration of MHDVs is not evenly distributed across SCAG region. The majority of these vehicles are concentrated in Los Angeles and Orange counties, which are two of the most densely populated and heavily trafficked areas in the region. This concentration of MHD ZEVs in certain areas may be due to the availability of charging infrastructure as well as operational and logistical considerations that make it more financially viable for businesses to adopt MHD ZEVs. San Bernardino and Riverside counties have a few MHD ZEVs, and Imperial County currently does not have any, many commercial vehicles travel throughout the region, so it is possible that some of the existing trucks are operating in these areas.

The types of MHD ZEVs currently being used in SCAG region are mainly tractor trucks, terminal tractor, and step vans. Tractor trucks, also known as semi-trucks, are primarily used for hauling large quantities of goods by attaching various types of trailers. Terminal tractors, also known as yard trucks, are primarily used in ports, warehouses, and freight terminals for the purpose of quickly moving trailers and containers short distances within these confined areas. Step vans are also typically used for deliveries in urban areas due to their ease of entry and exit, ample cargo space, and maneuverability in tight spaces.

Figure 7. Number of Medium- and Heavy-Duty ZEVs by Vehicle Type and County[72]



[71] https://globaldrivetozero.org/tools/zeti-data-explorer/
[72]https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/medium-and-heavy (Accessed: July 7, 2023)

Two influential pilots project in the region were the Joint Electric Truck Scaling Initiative (JETSI) and Volvo Lights (Low Impact Green Heavy Transport Solutions) demonstration project. The Volvo Lights demonstration project was launched in 2019 to demonstrate the viability of battery-electric heavy-duty trucks for goods movement. The project was a collaboration between Volvo Trucks North America, the South Coast AQMD, and industry partners to showcase zero-emission freight transportation in the greater Los Angeles region. The demonstration project involved the deployment of 30 Class 8 trucks to several operators in the region for a one-year trial period. The trucks were used to transport a variety of goods, including groceries, clothing, and other consumer products. The goal of the project was to collect data on the performance of battery electric trucks (BETs) in real-world conditions and to evaluate their potential to reduce emissions, noise pollution, and operating costs compared to traditional diesel-powered trucks. The results of the demonstration project will help to inform future efforts to transition the goods movement sector to ZEVs.[73] Another demonstration project showcasing the viability heavy-duty ZEVs was the demonstration of a heavy-duty fuel cell electric trucks (FCET). This project, with funding through the California Climate Investments fund, showed that users tended to prefer the ZEV options, stating that they tended to make less noise and commented on the impressive performance. The next demonstration program, JETSI is a collaboration between CARB, the CEC, and several private companies to accelerate the deployment of BETs for goods movement in California. JETSI aims to reduce greenhouse gas emissions and improve air quality by evaluating the performance of battery-electric Class 8 trucks in real-world conditions. The project involves the deployment of 100 BETs and 50 175/350 kW charges to two operators (NFI & Schneider) in the region for a one-year trial period.

There has been a fair amount of movement, especially in the parcel delivery sector, on the medium-duty side. UPS is set to begin adopting electric delivery vans through a partnership with Arrival. Production near UPS's headquarters in Charlotte, North Carolina, is slated to begin in 2023.[74] Amazon, in partnership with Rivian, has already deployed 1,000 electric vans across more than a dozen U.S. cities as of 2022, with plans to further increase the percent of electric vans across their fleet.[75]

Natural Gas Vehicles. The use of NGVs, which tend to use compressed or renewable natural gas (CNG/RNG), continue to increase in the MHDV sector as these vehicles tend to be a cost-effective alternative to diesel trucks, as natural gas is typically less expensive and more stable in price compared to diesel. Also, as described earlier, in 2020 CARB has established strict emissions regulations for on-road HDVs, including CNG trucks. CARB's latest regulation, known as the HD Omnibus Regulation, requires all new heavy-duty engines sold in California to meet the low-NOx standard of 0.02 grams per brake horsepower-hour (g/bhp-hr) by 2027.[76] This standard is 90% lower than the current NOx standards for heavy-duty engines and is among the most stringent in the country. As a result of these regulations, many CNG truck manufacturers are introducing low-NOx engines to meet the new standards.

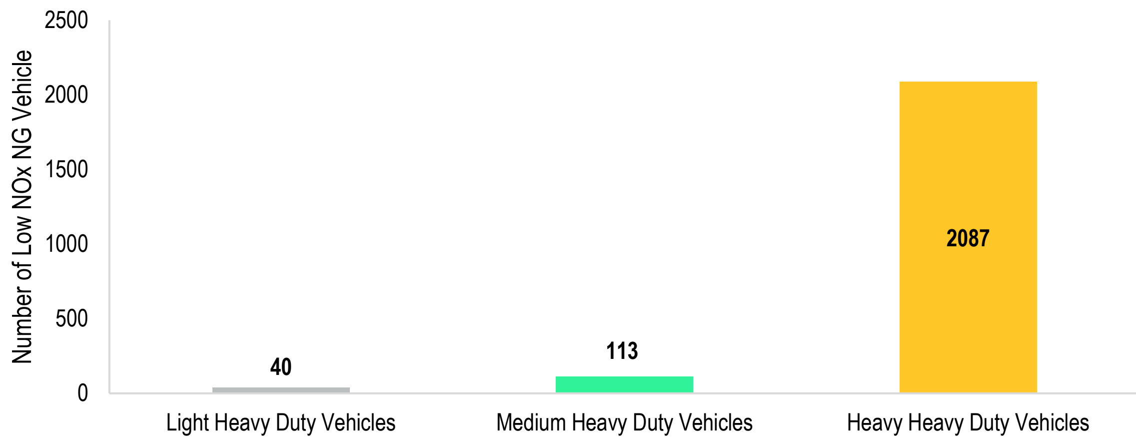
CNG trucks with low-NOx engines are a promising technology for reducing emissions from HDVs. By using RNG instead of diesel fuel, these trucks emit significantly less GHGs compared to diesel trucks. Moreover, when combined with low-NOx engine technology, CNG trucks can further reduce NOx emissions, which is a major contributor to smog and local health problems. It is important to note that CNG trucks are not ZEVs and still produce some emissions during operation. For this reason, it is important to continue to invest in research and development of cleaner technologies,

[73] https://ww2.arb.ca.gov/lcti-volvo-low-impact-green-heavy-transport-solutions-lights-project
[74] https://www.autoweek.com/news/green-cars/a40880333/arrival-ups-ev-van-production/
[75] https://insideevs.com/news/620418/amazon-now-has-1000-rivian-electric-vans-making-deliveries-in-us/

[76] https://ww2.arb.ca.gov/our-work/programs/heavy-duty-low-nox-rule

including ZEV such as battery-electric and fuel cell vehicles. As of 2018, all new model year CNG trucks are equipped with low-NOx engines. According to recent data from CARB's EMFAC model, there are a total of 2,240 CNG low-NOx trucks in the region as shown in Figure 8.

Figure 8. Number of CNG Medium- and Heavy-Duty Vehicles in SCAG Region in 2020



Source: https://arb.ca.gov/emfac/emissions-inventory/ea6d4c86fa75e3fe97260461ffb31426088f5210

Environmental Impacts

MDVs. Table 12, Figure 9, and Figure 10 show GHG and criteria emissions reductions for all MDV body styles and technology types. Consistently, BEVs reduce more GHG emissions than any of the other technology types relative to combustion engines. NOx and PM exhaust emissions are reduced by 100% with a BEV and a FCEV, while PHEVs and NGVs don't eliminate these emissions, but rather reduce them by 40-90%.

Table 12. Environmental impacts of MDVs by body style and technology type.

Medium Duty Vehicle by Body Style	Technology Type	GHG Emissions Reduction (Metric Ton per Year) [77]	NOx Emissions Reductions	Exhaust PM Emissions Reductions	Brakewear PM Emissions Reductions
Medium Duty Pickup Truck	**BEV**	18.38	100%	100%	50%
	PHEV	11.03	40%	40%	50%
	FCEV	12.03	100%	100%	50%
Cargo Van	**BEV**	26.88	100%	100%	50%
	PHEV	16.13	40%	40%	50%
	FCEV	17.60	100%	100%	50%
Passenger Van	**BEV**	20.60	100%	100%	50%
	PHEV	12.36	40%	40%	50%
	FCEV	13.49	100%	100%	50%
Step Van	**BEV**	32.51	100%	100%	50%
	PHEV	19.50	40%	40%	50%
	FCEV	13.50	100%	100%	50%
	NGV	29.79	90%	84%	0%
Box Truck	**BEV**	51.08	100%	100%	50%
	PHEV	30.65	40%	40%	50%

[77] For FCEVs, the project team assumes that hydrogen is produced through Steam Methane Reforming (SMR) using fossil natural gas, which is currently the most common method for hydrogen production nationwide. However, the project team also explored other options. For information about GHG emissions reductions from hydrogen produced using other feedstocks, please refer to Appendix B.

Medium Duty Vehicle by Body Style	Technology Type	GHG Emissions Reduction (Metric Ton per Year) [77]	NOx Emissions Reductions	Exhaust PM Emissions Reductions	Brakewear PM Emissions Reductions
	FCEV	21.21	100%	100%	50%
	NGV	46.82	90%	84%	0%
Cab & Chassis	BEV	58.62	100%	100%	50%
	PHEV	35.17	40%	40%	50%
	FCEV	24.34	100%	100%	50%
	NGV	53.73	90%	84%	0%

Figure 9. GHG emissions (well to wheel) reductions (metric tons of CO2 per year) of MDVs by body style and technology type.

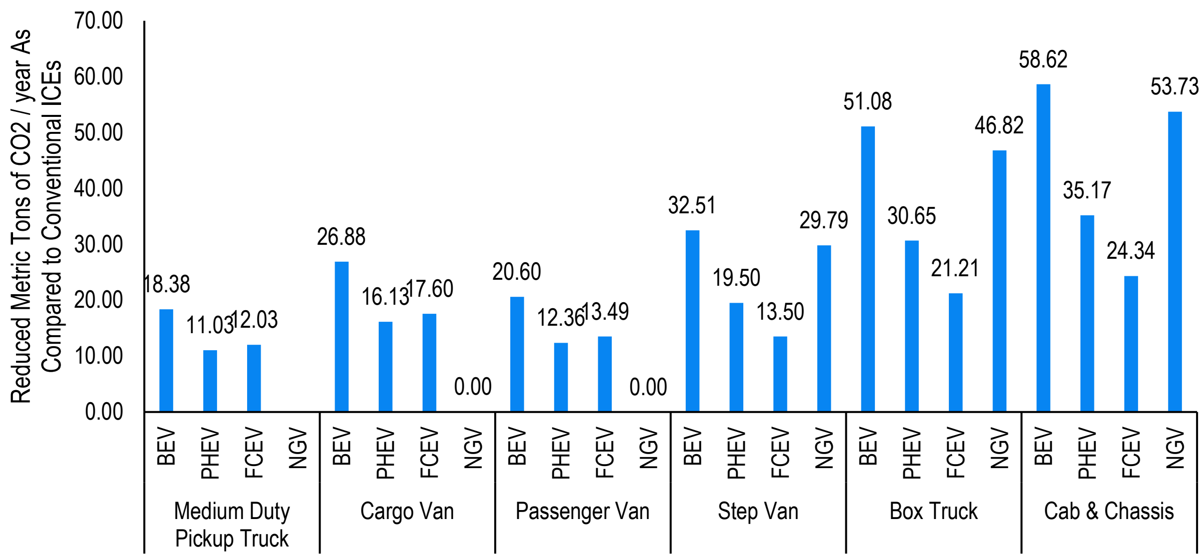
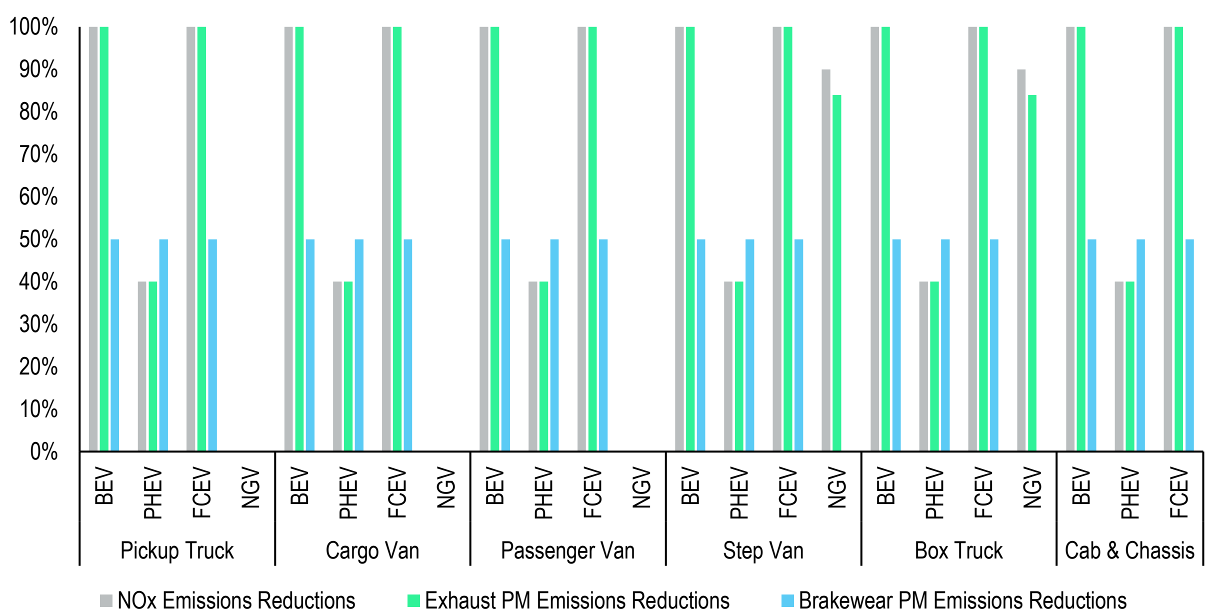


Figure 10. Percentage of NOx emissions reductions, and exhaust PM emissions reductions by body style and technology type.

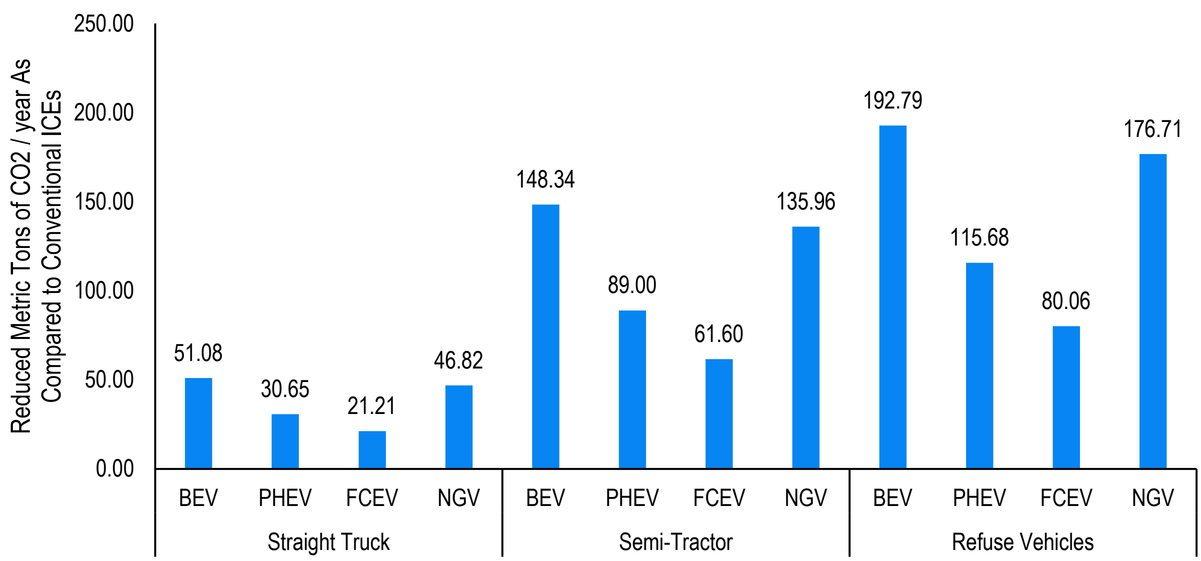


HDVs. Table 13, Figure 11, and Figure 12 illustrate the emissions reductions of both GHG (well to wheel) as well as the criteria pollutants for HDVs of various body types and technologies. Keeping consistent with other vehicle categories, BEVs tended to reduce more GHG emissions than the other technology types relative to the combustion engine alternative. NOx and PM exhaust emissions are reduced by 100% with a BEV and a FCEV, while PHEVs and NGVs don't eliminate these emissions, but rather reduce them by 40-90%.

Table 13. Environmental impacts of HDVs by body style and technology type.

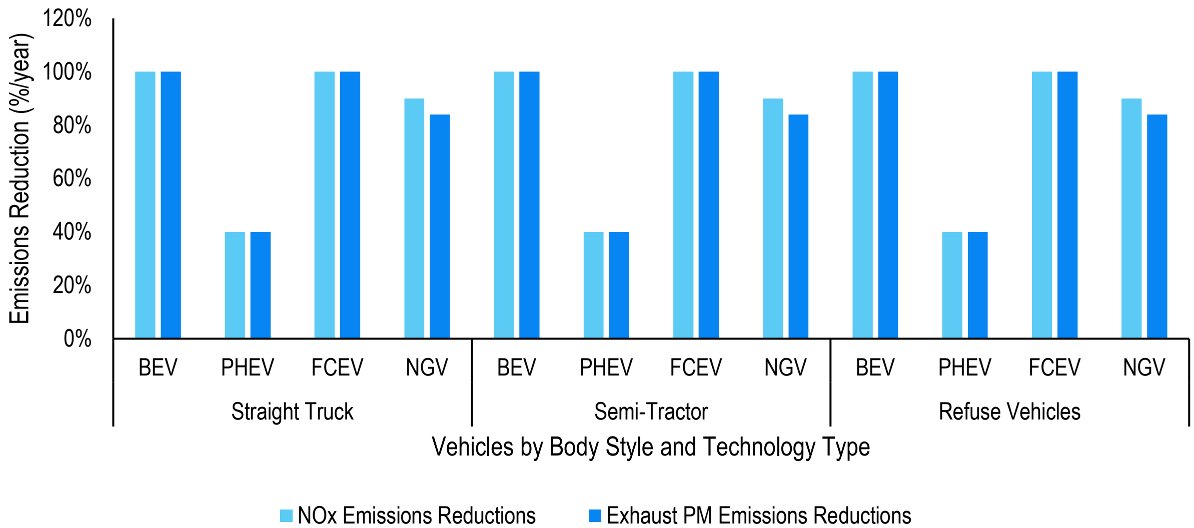
Heavy Duty Vehicle by Body Style (excluding transit)	Technology Type	GHG Emissions Reduction (Metric Ton per Year) [78]	NOx Emissions Reductions	Exhaust PM Emissions Reductions	Brakewear PM Emissions Reductions
Straight Truck	BEV	51.08	100%	100%	50%
	PHEV	30.65	40%	40%	50%
	FCEV	21.21	100%	100%	50%
	NGV	46.82	90%	84%	0%
Semi-Tractor	BEV	148.34	100%	100%	50%
	PHEV	89.00	40%	40%	50%
	FCEV	61.60	100%	100%	50%
	NGV	135.96	90%	84%	0%
Refuse Vehicles	BEV	192.79	100%	100%	50%
	PHEV	115.68	40%	40%	50%
	FCEV	80.06	100%	100%	50%
	NGV	176.71	90%	84%	0%

Figure 11. GHG emissions (well to wheel) reductions (metric tons of CO2 per year) of HDVs by body style and technology type.



[78] For FCEVs, the project team assumes that hydrogen is produced through Steam Methane Reforming (SMR) using fossil natural gas, which is currently the most common method for hydrogen production nationwide. However, the project team also explored other options. For information about GHG emissions reductions from hydrogen produced using other feedstocks, please refer to Appendix B.

Figure 12. Percentage of NOx emissions reductions, and exhaust PM emissions reductions by body style and technology type.



Performance & Commercialization

MDVs. Table 14 presents the technology characteristics for MDVs, highlighting various specifications including the range, TCO, adoption status, availability, and longevity. Similar to light-duty vehicles, the number of models presented Table 14 encompasses a variety of options with different battery capacities and trims. For example, Class 6 Peterbilt 220EV comes in two different battery capacities of 141 and 282 kWh and therefore, this specific model is counted twice for the purpose of demonstrating the availability of box trucks.

- With respect to medium duty vehicles, BEVs are the only technology type adopted in California thus far and offer a diverse range of models across various body styles.
- PHEVs, when available for a specific body style, provide the highest range on a single fill-up.
- Despite higher initial costs, BEVs demonstrate greater cost-effectiveness over 15-year time compared to combustion engine vehicles when total cost of ownership (TCO) is considered.

Table 14. Technology characteristics of MDVs by body style and technology type.

Medium Duty Vehicle by Body Style	Technology Type	Range	Capital Cost	TCO Savings	Adoption Status	Availability	Longevity
Medium Duty Pickup Truck	BEV	110 - 500 miles	$93,000	$42,832	0	5-10 models	3-10 years
	PHEV	500 miles	$67,000	$42,105	0	10-20 models	8-10 years
	FCEV	250 miles	$93,000	($103,434)	0	< 5 models	3-10 years
	NGV	650 miles	$50,000	$63,853	NI	< 5 models	1-5 years
Cargo Van	BEV	110 - 200 miles	$68,000	$94,675	52	5 - 10 models	3-15 years
	PHEV						
	FCEV	125 - 400 miles	$58,000[79]	($35,498)	0	< 5 models	NI
	NGV	250 - 400 miles	$49,000	$88,089	NI	< 5 models	1-5 years
Passenger Van	BEV	110 - 200 miles	$55,000	$74,943	0	< 5 models	3-15 years
	PHEV						
	FCEV	125 - 250 miles	$58,000[80]	($88,976)	0	< 5 models	NI
	NGV						
Step Van	BEV	250 - 80 miles	$150,000	$12,928	33	10-20 models	8-10 years
	PHEV						
	FCEV	250 miles	$150,000	($201,769)	0	< 5 models	5-10 years
	NGV	NI	$110,000	$19,357	NI	< 5 models	1-5 years
Box Truck	BEV	66 - 230 miles	$185,000	$36,221	10	10 - 20 models	8 years
	PHEV						
	FCEV						
	NGV	NI	$115,000	$73,630	NI	< 5 models	1-6 years
Cab & Chassis	BEV	130 miles	$100,000	$212,751	13	< 5 models	8-10 years
	PHEV	NI	$72,000	$185,416	0	< 5 models	5-10 years
	FCEV	NI	$100,000	($238,236)	0	< 5 models	1-10 years
	NGV	NI	$69,000	$214,893	NI	< 5 models	3-6 years

NI indicates "no information" or a knowledge gap
Blank indicates not commercially available

HDVs. Table 15 provides detailed information pertaining to the commercialization and characteristics of Zero- and Near-Zero Emission HDVs. Notably, PHEVs are currently not available in the market for any of the body styles. With significant advancements in battery electric technology, it is increasingly plausible that manufacturers are prioritizing the development and production of BEVs over PHEVs. One possible reason behind this shift is to avoid the complexity and additional components associated with integrating two separate powertrains, namely an electric motor and an internal combustion engine, within the same vehicle. By focusing on BEVs, manufacturers can streamline the design and engineering process, optimizing the vehicle for electric propulsion and maximizing the benefits of a single powertrain solution. With respect to vehicle ranges, FCEVs offer significantly higher mileage range than those of BEVs, with FCEVs capable of reaching up to 800 miles, compared to BEVs with a range of up to 500 miles. In terms of TCO, NGVs consistently exhibited the lowest costs across each body style, followed by BEVs and FCEVs mainly due to the much lower capital cost of the vehicle. Among the technology types, BEVs and NGVs are the only ones currently adopted in California, with BEVs showcasing the highest variety of available models. Similar to the other two vehicle categories, it is important to note that the number of models presented in Table 15 encompasses a variety of options

[79] Price assumed the same as BEV Cargo Van.
[80] Price assumed the same as BEV Passenger Van.

with different battery capacities and trims. For example, Volvo VNR Electric comes in two different trims and therefore, this specific model is counted three times for the purpose of demonstrating the availability of Semi-Tractors.

Table 15. Technology characteristics of HDVs by body style and technology type.

Heavy Duty Vehicle by Body Style (excluding transit)	Technology Type	Range	Capital Cost	TCO Savings	Adoption Status	Availability	Longevity
Straight Truck	**BEV**	230 - 100 miles	$185,000	$36,221	16	5 - 10 models	2-8 years
	PHEV						
	FCEV	150 - 800 miles	$185,000	($301,144)	0	< 5 models	1 year
	NGV	NI	$115,000	$73,630	2,531	< 5 models	5-10 years
Semi-Tractor	**BEV**	500 - 150 miles	$480,000	($453,162)	68	5 - 10 models	5-8 years
	PHEV						
	FCEV	150 - 800 miles	$360,000	($2,361,345)	0	< 5 models	1-3 years
	NGV	NI	$170,000	$340,705	696	< 5 models	1-5 years
Refuse Vehicles	**BEV**	170 - 56 miles	$500,000	$844,039	0	5 - 10 models	5-8 years
	PHEV						
	FCEV						
	NGV	NI	$335,000	$321,411	5,159	< 5 models	1-8 years

NI indicates "no information" or a knowledge gap
Blank indicates not commercially available

4.1.3 Buses

Buses can be Class 4 or greater vehicles, weighing 14,001 lbs. or more. Body styles within the bus category include single deck bus, double deck bus, articulated bus, school bus, shuttle bus, and cutaway. Technology types for each body style include BEVs, PHEVs, FCEVs, and NGVs. More detailed product of each body style and associated technology type is displayed in Table 16.

Table 16. Bus product descriptions by body style and technology type.

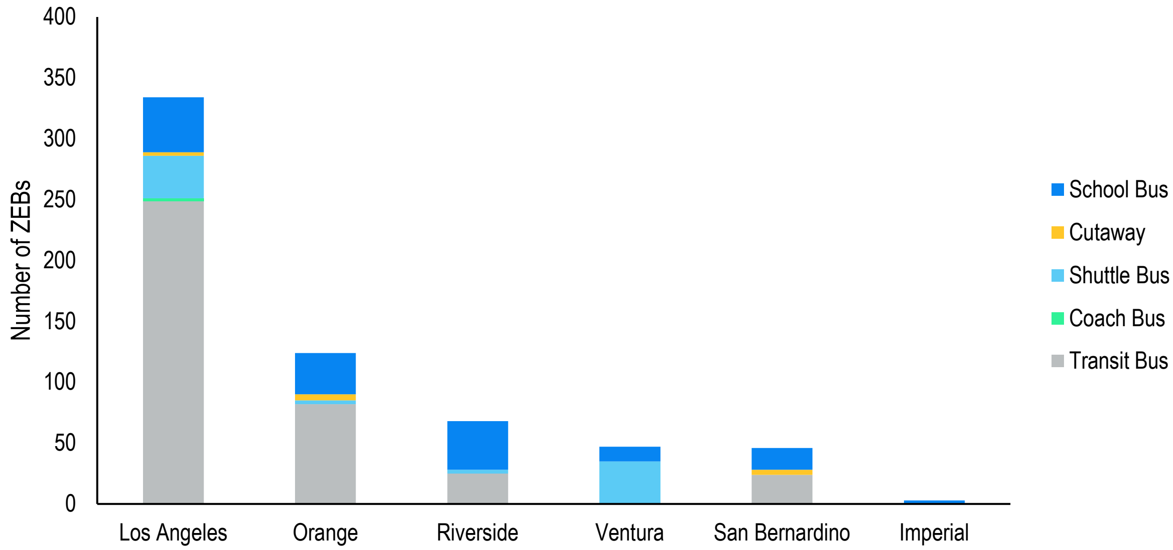
Vehicle Type	Description
Single Deck Bus	A single deck bus is a type of bus with only one level or floor for passenger seating. It typically has a single entrance and exit, with a uniform seating arrangement on the same level throughout the bus.
Double Decker Bus	A double-decker bus is a bus with two levels or floors for passenger seating. The upper level is accessed via stairs located at the rear or front of the bus. Double-decker buses provide increased seating capacity and are often used in urban areas or for tourist transportation.
Articulated Bus	An articulated bus, also known as a bendy bus or articulated coach, is a bus with a joint or flexible section that allows the vehicle to bend in the middle. This design enables better maneuverability and increased passenger capacity. Articulated buses are commonly used in urban transit systems.
School Bus	A school bus is a bus specifically designed to transport students to and from educational institutions. It usually has specific safety features such as high seat backs, flashing lights, and a distinctive yellow color. School buses adhere to specific regulations and guidelines to ensure the safety of students during transportation.
Shuttle Buses	Shuttle buses are small to mid-sized buses used for short-distance transportation, typically within a specific area or between designated locations. They are often used for airport transfers, hotel shuttles, or corporate transportation services.
Cutaway	A cutaway, also known as a cutaway van chassis, refers to a vehicle configuration where the manufacturer provides a cab and chassis with the rear portion of the vehicle left unfinished. It allows for customization by adding different types of bodies or structures, such as shuttle bus bodies, motorhomes, or delivery vans, according to specific needs.

Existing Condition

Buses make up the largest number of heavy-duty ZEVs in SCAG region. The three types of zero emission buses (ZEB) in the region are transit, school, and coach buses, with transit buses having the greatest number, followed by school buses and then coach buses. According to the CALSTART's Zero Emission Technology Inventory[81], there are currently more than 25 models of zero emission transit buses (of which 23 are BEBs and 2 are FCEBs), 17 models of zero emission school buses (all being BEB), and 10 models of coach buses (9 being BEB and 1 being FCEB) available in the North American market. Within SCAG region, Los Angeles County has the highest number of ZEBs, followed by Orange County. San Bernardino and Riverside counties each have a similar number of ZEBs. Imperial County, which is the least populous county in the region, currently only has three school buses that are ZEB. The growing number of ZEBs in SCAG region reflects the increasing focus on transitioning to a low-carbon transit/school bus system.

[81] https://globaldrivetozero.org/tools/zeti-data-explorer/

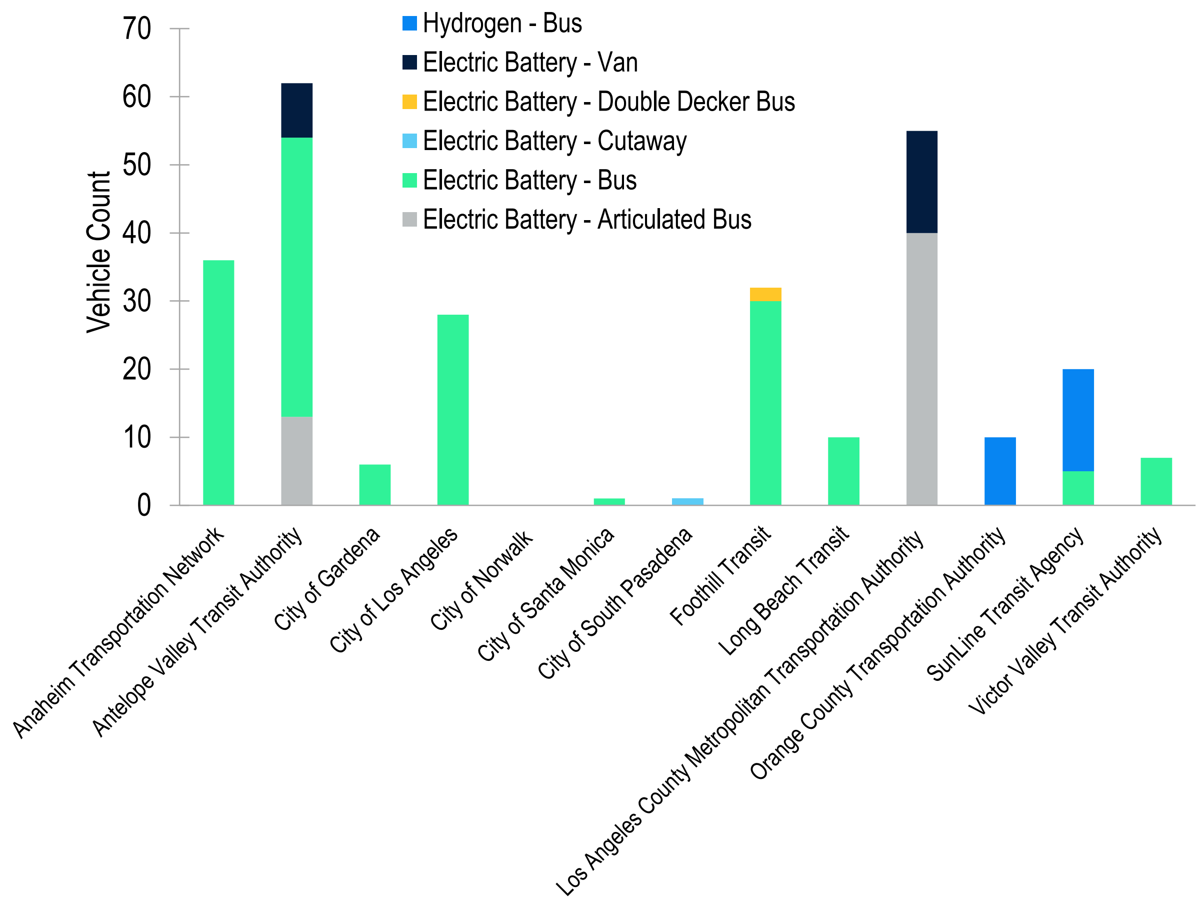
Figure 13. Number of Zero Emission Transit and Coach Buses by County[82]



When looking at the number of ZE transit vehicles by operator in SCAG region, LA Metro and the Antelope Valley Transit Authority have the largest fleets, with the latter having the most ZE transit vehicles in the region. The Anaheim Transportation Network, City of Los Angeles, and Foothill Transit also have a considerable number of ZE transit vehicles, although to a lesser extent. Other operators in the region have a much smaller number of ZEBs or none at all (Figure 14).

[82] https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/medium-and-heavy (Last accessed: July 7, 2023)

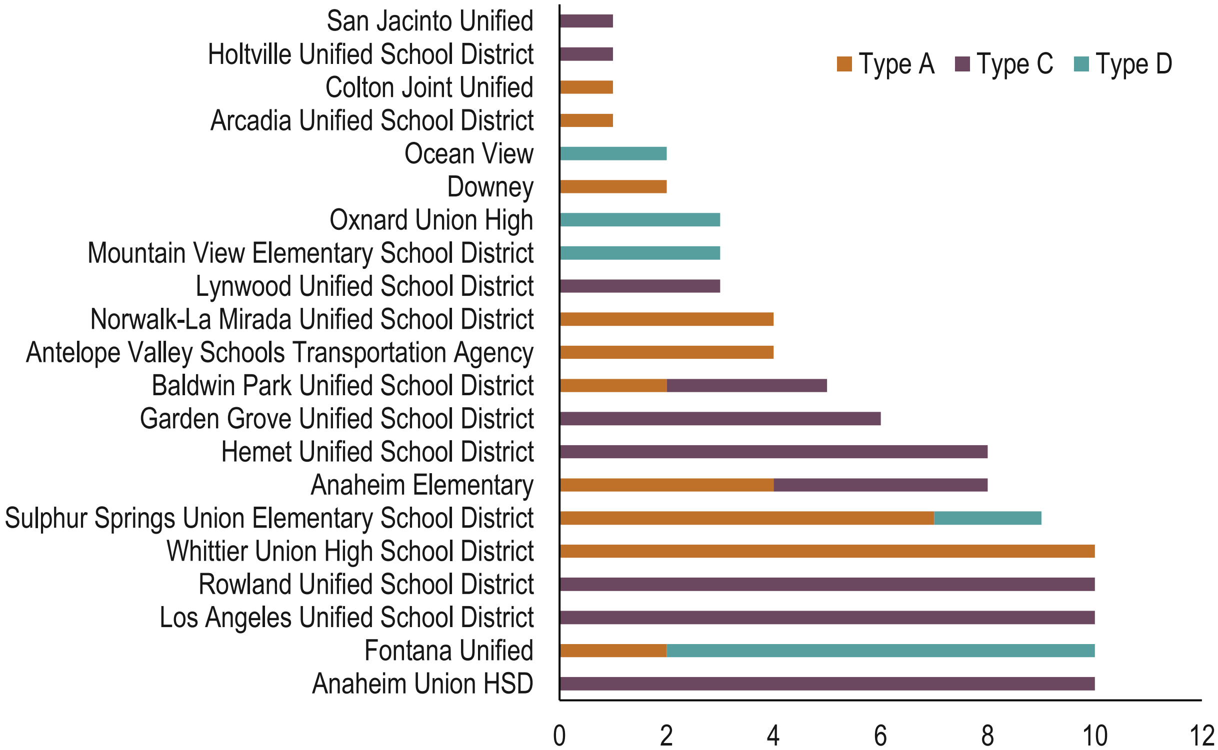
Figure 14. ZEV Transit Numbers by Operator[83]



When considering the number of ZE school buses in SCAG region by school district, there are a variety of districts that have taken steps to adopt this low-carbon transportation option. Some districts have embraced ZEBs more than others, with a handful having a relatively large number of buses in their fleets. Figure 15 shows the progress by school district, with the maximum number of ZEBs per school district being 10.

[83] https://www.transit.dot.gov/ntd/data-product/2021-data-tables (Accessed February 2023)

Figure 15. Number of CEC Funded ZE School Buses by School District[84]



As described earlier, the California ICT regulation is a statewide initiative aimed at reducing emissions from public transit buses. The regulation requires all transit agencies to transition to 100% zero-emission bus fleets by 2040, with interim targets along the way. The ICT regulation has had a significant impact on the adoption of ZEBs in Southern California. Many transit agencies in the region, including the Los Angeles County Metropolitan Transportation Authority (Metro) and the Orange County Transportation Authority, have already begun transitioning to ZEBs with the goal of meeting the ICT targets ahead of schedule. For example, in 2021, Metro has completed its transition to an all-electric bus fleet on the Metro G (Orange) Line[85], replacing its CNG buses with 40 new ZEBs manufactured by New Flyer. The electric buses have a 150-mile range on a single charge and are equipped with rapid en-route chargers installed at stations along the 18-mile corridor. Metro plans to transition to a 100% ZEB fleet by 2030. Also in 2020, OCTA approved the purchase of 10 plug-in battery-electric buses from New Flyer of America for $10.4 million.[86] The move was part of OCTA's plan to convert its fleet to 100% zero-emission technology by 2040, with the pilot program designed to test the buses' performance on Orange County streets. OCTA is also testing hydrogen fuel-cell electric buses to determine which technology, or mix of technologies, works best for its needs. Five of the test buses will run on a new route, with the other five operating throughout Orange County. Additionally, in 2021, the OCTA board has approved a contract with One Source Distributors for 10 battery chargers, which will be used to support testing plug-in battery-electric buses on Orange County streets[87]. The contract, which costs approximately $863,000, includes training for those who will operate and maintain the equipment. The cost of the chargers will be covered by the state's Low Carbon Transit Operations Program. In partnership with Southern California Edison, OCTA will provide necessary electrical

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[84] https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/cec-funded-school (Accessed July 7, 2023)
[85] https://www.metro.net/about/l-a-metro-now-running-all-zero-emission-electric-buses-on-the-g-orange-line-in-the-san-fernando-valley/
[86] https://www.octabonds.com/orange-county-transportation-authority-ca/about/news/i4719?newsId=21266
[87] https://www.octabonds.com/orange-county-transportation-authority-ca/about/news/i4719?newsId=24108

infrastructure at the bus operations base in Garden Grove to support charging of the plug-in battery-electric buses. OCTA plans to move to 100 percent zero-emission technology by 2040, and both pilot programs testing plug-in electric and hydrogen fuel-cell electric buses will help determine which technology will work best for Orange County moving forward.

Environmental Impact

Table 17, Figure 16, and Figure 17 illustrate the emissions reductions of both GHG (well to wheel) as well as the criteria pollutants for buses of various body type and technologies. BEVs (closely followed up by NGVs) tended to lead other technology types in terms of GHG emissions reductions relative to the combustion engine alternative. NOx and PM exhaust emissions are reduced by 100% with a BEV and a FCEV, while PHEVs and NGVs don't eliminate these emissions, but rather reduce them by 40-90%. Brakewear emissions reductions are around 50% across all body styles and technology types. Table 17 provides detailed assessment of GHG (well to wheel) and criteria pollutant impacts of various bus body types and technologies.

Table 17. Environmental impacts

Bus by Body Style	Technology Type	GHG Emissions Reduction (Metric Ton per Year) [88]	NOx Emissions Reductions	Exhaust PM Emissions Reductions	Brakewear PM Emissions Reductions
Single Deck Bus	BEV	145.88	100%	100%	50%
	PHEV	87.53	40%	40%	50%
	FCEV	60.58	100%	100%	50%
	NGV	133.71	90%	84%	0%
Double Decker Bus	BEV	145.88	100%	100%	50%
	PHEV	87.53	40%	40%	50%
	FCEV	60.58	100%	100%	50%
	NGV	133.71	90%	84%	0%
Articulated Bus	BEV	145.88	100%	100%	50%
	PHEV	87.53	40%	40%	50%
	FCEV	60.58	100%	100%	50%
	NGV	133.71	90%	84%	0%
School Bus	BEV	26.09	100%	100%	50%
	PHEV	15.66	40%	40%	50%
	FCEV	10.84	100%	100%	50%
	NGV	23.91	90%	84%	0%
Shuttle Buses	BEV	46.34	100%	100%	50%
	PHEV	27.81	40%	40%	50%
	FCEV	19.25	100%	100%	50%
	NGV	42.48	90%	84%	0%
Cutaway	BEV	46.34	100%	100%	50%
	PHEV	27.81	40%	40%	50%
	FCEV	19.25	100%	100%	50%
	NGV	42.48	90%	84%	0%

[88] For FCEVs, the project team assumes that hydrogen is produced through Steam Methane Reforming (SMR) using fossil natural gas, which is currently the most common method for hydrogen production nationwide. However, the project team also explored other options. For information about GHG emissions reductions from hydrogen produced using other feedstocks, please refer to Appendix B.

Figure 16. GHG emissions (well to wheel) reductions (metric tons of CO2 per year) of buses by body style and technology type.

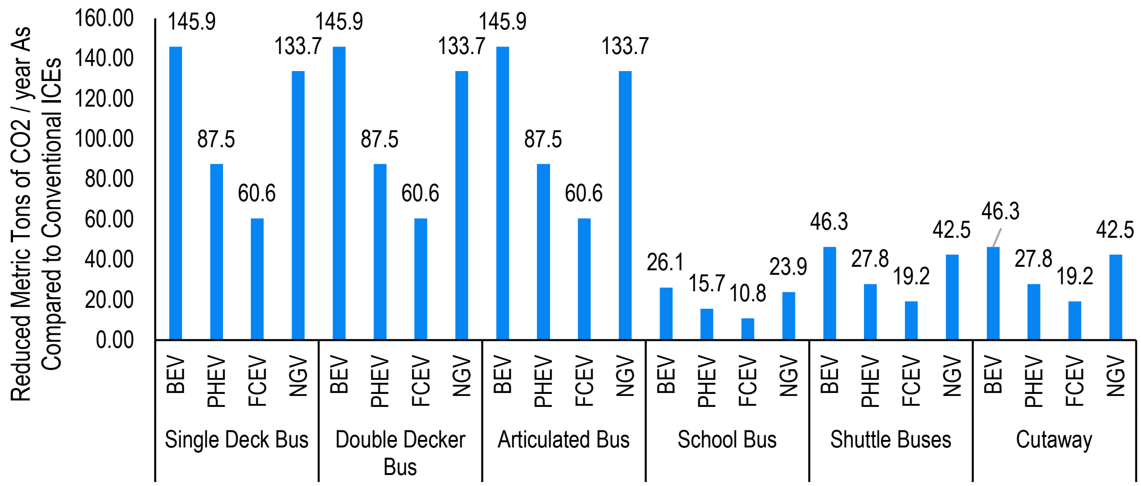
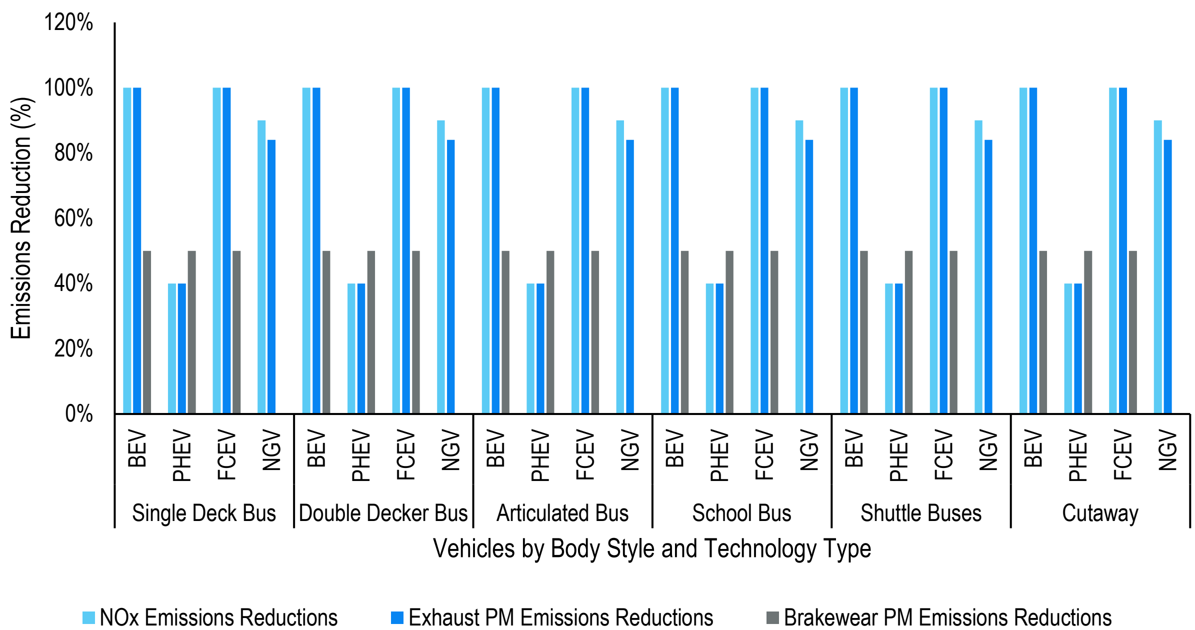


Figure 17. Percentage of NOx emissions reductions, and exhaust PM emissions reductions by body style and technology type.



Performance & Commercialization

BEV and NGV buses are the most consistently available models across all body styles, while PHEVs were unavailable, and the availability of FCEVs are limited to certain types of buses. Currently, BEV and NGV buses are the most widely adopted technology types. They also have a TCO that is lower than FCEVs. FCEV and NGV buses tend to have a longer range than BEVs. Table 18 displays detailed data relevant to commercialization and specific technology characteristics for buses.

Table 18. Technology characteristics of buses by body style and technology type

Bus by Body Style	Technology Type	Range	Capital Cost	TCO Savings	Adoption Status[89]	Availability	Longevity
Single Deck Bus	**BEV**	120 - 330 miles	$900,000	$273,256	315[90]	10 - 20 models	1-5 years
	PHEV						
	FCEV	250 - 350 miles	$1,125,000	($2,022,397)	67[73]	< 5 models	1-5 years
	NGV	350 miles	$540,000	$308,790	5,756	10-20 models	1-5 years
Double Decker Bus	**BEV**	200 miles	$1,050,000	$90,884	NI	< 5 models	8-12 years
	PHEV						
	FCEV						
	NGV						
Articulated Bus	**BEV**	150 - 220 miles	$1,050,000	$90,884	NI	< 5 models	12 years
	PHEV						
	FCEV	350 miles	$1,050,000	($2,022,397)	NI	< 5 models	NI
	NGV	400 miles	$540,000	$308,790	NI	< 5 models	1-3 years
School Bus	**BEV**	70 - 180 miles	$300,000	($45,852)	152	10-20 models	1-5 years
	PHEV						
	FCEV						
	NGV	140 miles	$649,822	$29,048	2,786	< 5 models	2-8 years
Shuttle Buses	**BEV**	70 - 160 miles	$265,000	$143,126	76	< 5 models	1-5 years
	PHEV						
	FCEV	120 - 200 miles	$265,000	($401,421)	0	< 5 models	5-8 years
	NGV	NI	$90,000	$84,483	0	< 5 models	1-5 years
Cutaway	**BEV**	NI	$265,000	$143,126	12	< 5 models	5-10 years
	PHEV						
	FCEV						
	NGV	NI	$90,000	$84,483	NI	< 5 models	5-10 years

NI indicates "no information" or a knowledge gap

Blank indicates not commercially available

[89] https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/medium-and-heavy (Last accessed: July 7, 2023)

[90] Since adoption data (i.e., vehicle stock) for transit buses was not available for single deck versus articulated or double deck, the project team lumped all transit buses into single deck. The coach buses are also included in the single deck buses.

4.1.4 Rail

The rail category evaluates freight and passenger rail locomotives that have historically been running on diesel. Product descriptions for this category are provided in Table 19. Technology types include BEV, FCEV, and NGV. Please note that emissions reductions data and market data were not as readily available as for the other vehicle categories.

Table 19. Rail product descriptions by body style.

Vehicle Type	Description
Passenger Locomotive	A passenger locomotive, also known as a passenger train engine or passenger train locomotive, is a powerful rail vehicle specifically designed for pulling passenger trains. It provides the necessary traction and power to haul passenger cars, ensuring safe and efficient transportation of passengers over long distances or within urban transit systems.
Freight Locomotive	A freight locomotive, also known as a freight train engine or freight train locomotive, is a type of locomotive designed for hauling freight or cargo trains. It is typically optimized for pulling heavy loads and is commonly used in the transportation of goods, materials, or containers over long distances or for industrial purposes.
Switchers	Switchers, also referred to as shunting locomotives or switcher locomotives, are specialized locomotives used primarily for maneuvering or shunting railcars within a railway yard or industrial facility. They are designed to handle low-speed operations, including coupling and uncoupling of railcars, sorting, and assembling trains in a rail yard.

Existing Condition

Adoption of zero-emission technologies in the rail sector is still in its early stages; however, these technologies are relatively mature and have been deployed elsewhere—particularly outside of North America, such as many European and Asian countries—but not yet in SCAG region. Due to the predictable nature of passenger locomotive operations in terms of routes and schedules, there is a potential opportunity to employ battery-electric technology for shorter routes that allow for convenient charging. Alternatively, fuel cell technology offers more flexibility for passenger rail agencies, enabling them to operate longer routes with faster and less frequent refueling. As advancements in zero-emission switch locomotives have shown promise, it is estimated that commercially available zero-emission passenger locomotives will be developed by 2030, building upon these technological successes. Currently, a number of agencies have plans to implement these technologies over the coming decade. For example, Metrolink, which serves five of the six counties (all but Imperial County) outlines in its Climate Action Plan that it plans to develop and implement the necessary steps to achieve widespread electrification across its rail fleet fully by 2028. This process will occur in stages, with the Antelope Valley Line expected to be fully electrified by 2025. The plan notes that this will be accomplished by replacing diesel locomotives with electric locomotives. Additional steps described in the plan include the expansion of on-board energy storage systems that can capture and reuse regenerative braking energy. For lines where electrification is not feasible in the short term the plan lays out a program to replace or retrofit

The first battery and hydrogen-powered passenger train will debut in 2024, running between San Bernardino and Redlands

Source: SBCTA

older locomotives with more energy efficient models that meet the latest emissions standards.[91] In San Bernardino County, the San Bernardino County Transportation Authority (SBCTA) has laid out plans to debut its first battery electric and hydrogen locomotives in 2024. The project will be funded by the California Transit and Intercity Rail Capital Program and expected to begin testing in late 2023.[92] In another project, BNSF Railway will repower a diesel line-haul locomotive with a zero-emission battery-powered locomotive through funding provided by the SCAQMD and the U.S. EPA. The battery-electric locomotive will feature six axles, 8 MWh battery storage capacity, and will operate on a 240-mile route between Los Angeles and Barstow, reducing diesel emissions in disadvantaged communities along the route.[93] At the state level, the California Department of Transportation has set a statewide goal of achieving a fully zero-emission intercity rail by 2035.[94]

In addition to these initiatives, the California High-Speed Rail (CA HSR) project[95] will connect major urban centers in California, from San Francisco to Los Angeles and eventually extending to Sacramento and San Diego, using all-electric trains. Once completed, it will significantly reduce travel times between these cities and serve as a more sustainable transportation alternative to driving or flying. According to CA HSR, this rail will run on electricity supplied entirely from renewable sources.[96] In addition to CA HSR, Brightline West[97] is another anticipated high-speed rail service to connect Southern California with Las Vegas, Nevada. This project will offer a much-needed alternative to the heavily trafficked I-15 corridor, providing faster and more efficient travel options for tourists and business travelers alike. Just like the CA HSR, the Brightline West will be operating all-electric, high-speed trains.

Furthermore, the CARB adopted the In-Use Locomotive Regulation in April 2023, mandating that passenger locomotives manufactured in 2030 and onwards must operate in a zero-emission configuration within California. While this regulation sets a strong policy framework, adequate infrastructure and technology demonstrations are essential to expedite the adoption of zero-emission solutions in the passenger rail system within the Southern California region covered by SCAG.

Environmental Impacts

Three types of technologies are evaluated for the rail: BEV, Diesel Electric, FCEV, and NGVs. Table 20 demonstrates the GHG (well to wheel) as well as criteria pollutant reduction associated with these technologies. Due to the high annual activity of passenger rails per unit in California, they typically offer significantly higher GHG emissions benefits as compared to freight locomotive and switcher. For example, according to CARB[98], an average passenger locomotive in California has an annual activity of approximately 1,828 MWhr, whereas a Class I line haul locomotive only has an annual activity of 351 MWhr within the state. This disparity does not imply that passenger locomotives consume more energy in California; rather, it indicates that passenger locomotives primarily operate within the state. In contrast, line haul locomotives are utilized for long-distance transportation, traversing across the country and therefore their fraction of their activity in California is much less than passenger locomotives.

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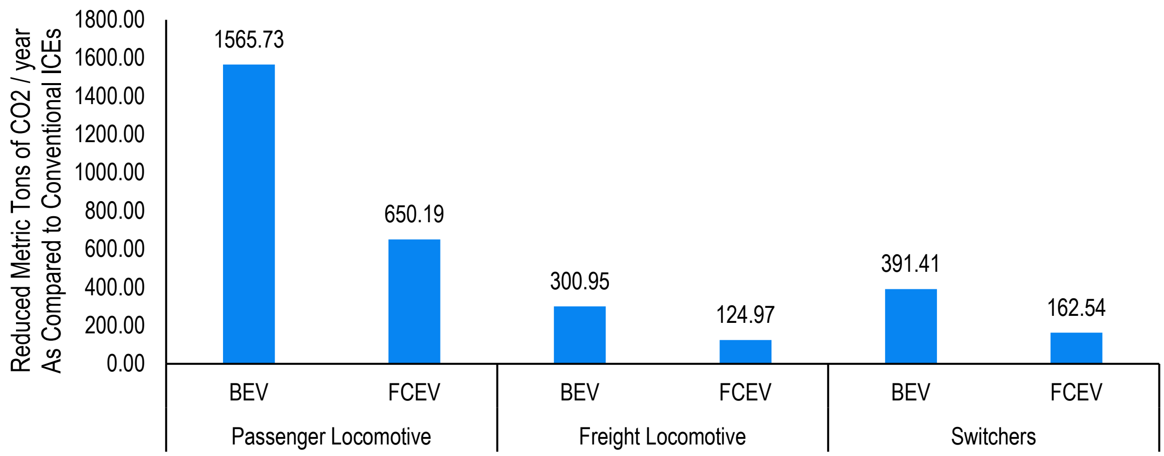
91 https://metrolinktrains.com/globalassets/about/agency/sustainability/climate-action-plan.pdf
92 https://www.gosbcta.com/wp-content/uploads/2022/12/ZEMU-Technology-Fact-Sheet-ENG-120522.pdf
93 https://www.aqmd.gov/home/research/pubs-docs-reports/newsletters/august-september-2022/zero-emission-locomotive
94 https://ww2.arb.ca.gov/sites/default/files/2020-10/Day%201%20Ext%205%20Caltrans%2020201026.pdf
95 https://hsr.ca.gov/about/
96 https://hsr.ca.gov/communications-outreach/info-center/get-the-facts/
97 https://www.brightlinewest.com/
98 https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/locomotive22/appg.pdf

Table 20. Environmental impacts of rail.

Locomotive by Type	Technology Type	GHG Emissions Reduction (Metric Ton per Year) [99]	NOx Emissions Reductions	PM Emissions Reductions
Passenger Locomotive	BEV	1565.73	100%	100%
	FCEV	650.19	100%	100%
Freight Locomotive	BEV	300.95	100%	100%
	FCEV	124.97	100%	100%
Switchers	BEV	391.41	100%	100%
	FCEV	162.54	100%	100%

Figure 18. GHG emissions (well to wheel) reductions (metric tons of CO2 per year) of locomotives by passenger or freight use and by technology type.



With respect to criteria pollutant reductions, it is assumed that BEV and FCEV will offer 100% reduction in NOx and PM emissions. Considering that there are yet no NGV locomotives being deployed in North America, the emission reductions associated with these locomotives is not fully understood and therefore excluded from this analysis. According to Federal Railroad Administration (FRA), the railroad industry is actively investigating the viability of using liquefied natural gas (LNG) and compressed natural gas (CNG) as alternative or supplementary fuels for locomotives[100].

Performance & Commercialization

As mentioned earlier, currently, commercially available zero- and near-zero emission locomotives are still limited, with some technologies only deployed as prototypes or within demonstration projects. As illustrated in Table 21, the initial purchase cost of locomotives varies depending on the technology type and vehicle category. For passenger locomotives, BEVs have an initial purchase cost ranging from $10 to $12 million while FCEVs cost $4.25 million. For freight locomotives, BEVs have an initial purchase cost ranging from $4.5 to $8 million, while FCEVs cost $10 million to $16 million. In the case of switchers, BEVs have an initial purchase cost ranging from $3 – 5 million, while FCEVs

[99] For FCEVs, the project team assumes that hydrogen is produced through Steam Methane Reforming (SMR) using fossil natural gas, which is currently the most common method for hydrogen production nationwide. However, the project team also explored other options. For information about GHG emissions reductions from hydrogen produced using other feedstocks, please refer to Appendix B.

[100] https://railroads.dot.gov/sites/fra.dot.gov/files/fra_net/18511/Liquid%20and%20Compressed%20Natural%20Gas%20and%20Locomotive%20Fuels%20brochure.pdf

cost between $2.75 – 3 million. According to the TCO analysis conducted by the project team, it has been observed that the TCO for BEV and FCEV rail technologies exhibit a higher cost profile when compared to their diesel counterparts. Specifically, the findings reveal that the TCO for both BEV and FCEV technologies ranges from $1 million to $13 million more than the TCO for equivalent diesel rail technologies. The significantly higher TCO observed for FCEV rail technologies appears to be primarily driven by the high cost of hydrogen fuel. When compared to diesel, hydrogen prices are currently substantially higher, thereby inflating the overall cost profile for FCEVs. This factor is a critical consideration in the economic assessment of FCEVs, presenting a formidable challenge to their wider adoption. As the market for hydrogen and related technologies evolves, it will be important to monitor whether these cost dynamics shift in favor of FCEVs. For now, however, the elevated price of hydrogen remains a key contributor to the increased TCO for FCEV rail technologies.

Table 21. Technology characteristics of rail

Vehicle by Type	Technology Type	Initial Purchase Cost[101]	Fuel Cost	Annual Maintenance Cost	TCO Saving	Availability	Longevity
Passenger Locomotive	**BEV**	$10,000,000 - $12,000,000	$0.27 / kWh	$71,100	($4,511,929)	<5 models	NI
	FCEV	$4,250,000	$17.11 / kg	$79,000	($11,113,036)	< 5 models	NI
Freight Locomotive	**BEV**	$4,500,000 - $8,000,000	$0.27 / kWh	$71,100	($3,257,642)	< 5 models	NI
	FCEV	$10,000,000 - $16,000,000	$17.11 / kg	$79,000	($12,893,866)	< 5 models	NI
Switchers	**BEV**	$3,000,000 - $5,000,000	$0.27 / kWh	$71,100	($1,180,533)	<5 models	NI
	FCEV	$2,750,000 - $3,000,000	$17.11 / kg	$79,000	($4,624,008)	<5 models	NI

4.1.5 Other Vehicle Technology Considerations

As discussed earlier, the project team initially contemplated a broader set of clean technology specifications that addressed goals such as equity, accessibility, and resiliency. While criteria such as these are important ones, they are difficult to measure categorically. Similarly, the presence or lack of accessibility features for a given clean technology deployment is likely to be determined by a unique set of variables including vendor or client design specifications or accessibility requirements attached to a particular funding source. Goals such as resiliency that are broadly defined and resist easy measurement posed further challenges and were ultimately removed from the list of specifications. While challenging to measure categorically, these criteria are nevertheless critical ones for SCAG and its member jurisdictions to consider when making policies, plans, or investment decisions. The following outlines a series of additional criteria that should be taken into account when evaluating vehicle technologies. More extensive criteria for consideration are detailed in Appendix E.

Technology Readiness: Technology readiness is a critical factor to consider when deciding on clean technology for several reasons. Firstly, it provides a systematic measurement of technological maturity, helping to mitigate the risks associated with adopting new technologies. Secondly, it aids in understanding the potential challenges and resource requirements for transitioning the technology from its current stage to full-scale commercial deployment. Lastly, understanding the technology readiness can help in making informed decisions about the timeline of implementation and return on investment, crucial aspects when deciding to adopt any new technology. The technology readiness for light-duty vehicles has grown significantly in recent years, with various sustainable and efficient solutions currently in

[101] https://ww2.arb.ca.gov/sites/default/files/2021-03/3.16.21%20Locomotive%20Reg%20-%20Preliminary%20Cost%20Document_Final.pdf

use. However, for medium-duty and heavy-duty vehicles, there remain substantial gaps in readiness, particularly when considering specialized duty cycles and equipment. The problem extends to heavy-duty vehicles in roles requiring them to carry full loads up to 55,000 lbs. Here, the payload capacity presents a considerable challenge for battery-electric trucks due to the excess weight of the battery.[102] The curb weight[103] of a diesel tractor is approximately 15,000 – 17,000 lbs., whereas a battery electric truck could weigh much more due to the excess weight of the battery packs. For example, the Nikola Tre, with the largest available battery pack of 753 kWh has a curb weight of about 29,500 lbs. which is almost 13,000 lbs. higher than an average diesel truck. While the maximum allowable weight for zero emission trucks is 2,000 lbs. more than diesel trucks (82,000 lbs. for zero emission trucks vs. 80,000 lbs. for diesel trucks), the excessive weight of battery electric trucks will limit the maximum payload they can carry today. With battery technology improving, and the on-going increase in battery energy density, it is possible that such weight disparity could diminish in future models. This highlights a key area where technological readiness has not yet caught up with the demands of specific heavy-duty applications. The concern is amplified even more when we turn our attention to the rail industry. While zero-emission rail technologies are gradually being introduced worldwide, most are still in the early stages of development. These solutions have not yet been thoroughly tested in operational settings, revealing another domain where technological readiness lags behind.

Power Acceptance Rate. Power acceptance, often referred to as the fueling rate, is the ability of a system or technology to receive and store energy at a particular rate. For zero and near-zero emission technologies, this translates to how rapidly a vehicle or system can be charged or refueled. This rate is crucial for several reasons. Firstly, it directly impacts operational efficiency; the faster a vehicle or system can be re-energized, the less downtime it experiences, leading to improved productivity. For public transit or commercial vehicles, extended charging or refueling times can disrupt schedules and decrease the viability of the technology. Secondly, high power acceptance can enhance user adoption. For private users, a faster charge or refuel can mirror the convenience of traditional fueling methods, making the transition to zero or near-zero emission technologies more attractive. Currently, BEVs are being offered with various power acceptance rates. While the BYD K9[104] transit bus has a maximum power acceptance rate of 80 kW, the Proterra ZX5+[105] has a maximum charging rate of 132 using plug-in chargers and 330 kW using overhead charger which allows the vehicle to be charged at much faster rate. For instance, the BYD K9 requires a minimum of 15 minutes to charge for 10 miles (based on 2 kWh/mi), whereas the Proterra ZX5+ can achieve the same electric mileage in under 4 minutes using overhead charging.

Adaptability: Technology adaptability in the context of clean vehicle technologies evaluates the degree to which a given technology is perceived as reasonably "future-proof." Future-proof technology is designed with consideration of upcoming advancements and trends, thereby ensuring its relevancy and utility over time. In the realm of vehicles, technology adaptability encompasses several dimensions. Firstly, it relates to the ability of vehicles to integrate with emerging technologies such as vehicle-to-grid (V2G) capabilities, advanced driver-assistance systems (ADAS), or autonomous driving technologies. As these technologies mature, vehicles should be capable of either coming equipped with these technologies or being upgraded to include them. Secondly, adaptability pertains to the capability of a vehicle to respond to changes in user needs. For instance, as consumer demands shift toward faster charging times, longer

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102 The payload capacity varies for different models of zero emission trucks. Battery electric trucks with smaller batteries (hence lower electric range) tends to have high payload capacity while truck technologies with larger batteries (higher range) are assumed to have lower payload capacity.
103 Curb weight is the total weight of a vehicle, including all standard equipment and necessary operating consumables like oil and coolant, but excluding passengers and cargo.
104 https://en.byd.com/wp-content/uploads/2019/07/4504-byd-transit-cut-sheets_k9-40_lr.pdf
105 https://www.proterra.com/wp-content/uploads/2020/09/Proterra-ZX5-Spec-Sheet-40-Foot-Bus-U.S..pdf

driving ranges, and enhanced vehicle performance, adaptable technology should be designed to meet these evolving expectations. Lastly, regulatory shifts are another key factor influencing technology adaptability. As policies and regulations continue to evolve in favor of cleaner and more sustainable transportation, future-proof ZEVs should be designed to comply with these changing regulations. Unfortunately, questions of adaptability are hard to address at the category level and instead specific products should be thoroughly investigated before purchase.

Resilience. Resilience refers to the ability of the clean technology system to maintain functionality and adapt in the face of disruptions or changes in the energy landscape. As the reliance on electric and sustainable transportation grows, the interdependence between the zero emission vehicles and the power grid becomes important. The surge in energy demand, particularly during peak times, can strain the grid. Therefore, when selecting a vehicle technology for adoption, it is essential to consider its impact on power system resilience. Technologies that support bidirectional energy flow, such as V2G, can help stabilize the grid by distributing energy demands more evenly, acting as energy reserves during peak times or outages, and overall, ensuring a reliable and uninterrupted power supply. Adopting technologies that enhance grid resilience safeguards both the transport and energy sectors from potential vulnerabilities, fostering a more sustainable and dependable future.

Integration. Technology integration refers to the deliberate and strategic inclusion of a particular technology into an existing system or framework. This process ensures that the new technology not only functions within the system but also complements and enhances the system's overall performance. When deciding on a specific technology it is critical to consider system integration. This involves not only focusing on the immediate benefits or functionalities of a technology in isolation but understanding its interoperability and compatibility across broader networks. For instance, while a particular rail technology might seem optimal for the SCAG region due to its unique geographical or infrastructural nuances, it is essential to consider its integration potential across a national network. If different rail technologies are siloed regionally, it could lead to inefficiencies, increased costs, and potential disruptions when transferring goods across regions. A technology that integrates seamlessly with existing and potential future systems nationwide will ensure consistent operations, reduce transition costs, and provide scalability.

Reliability: This criterion pertains to the technology's ability to consistently perform well under a broad range of conditions and over extended periods of time. It also implies a low frequency of malfunctions or breakdowns. High reliability is essential to promote user trust and satisfaction, influencing the overall adoption rate of these vehicles. For instance, in the context of EVs, reliability might include the vehicle's ability to deliver the expected range on a single charge under different driving conditions. Factors such as high-speed driving, heavy loads, or extreme weather conditions can significantly affect battery performance. Thus, a reliable EV should provide predictable and consistent range figures despite these variables, thereby reducing 'range anxiety' among users. Another crucial aspect is the longevity and durability of the battery, which should maintain a high degree of its capacity even after several years of use and numerous charging cycles. Premature battery degradation would not only entail high replacement costs but also undermine user confidence in the technology. In the case of FCEVs, reliability might involve the durability of the fuel cell stack and the performance of the hydrogen storage system. Both should function effectively over the vehicle's lifetime, without significant loss in performance.

Safe System: The Safe Systems criterion in the context of vehicles evaluates whether the introduction of a new technology maintains or improves the current safety conditions. It is essential that the implementation of any new vehicle technology does not compromise the safety of drivers, passengers, or other road users, but instead contributes to safer driving and road environments. This criterion emphasizes that no matter the potential benefits a new vehicle technology might deliver in terms of efficiency, sustainability, or cost-effectiveness, safety must always remain a paramount concern.

Shared Use Potential: The Shared Use Potential criterion in the context of vehicles examines whether the technology has potential for applications in transit or shared-use scenarios, contributing to more efficient and sustainable resource usage. It is critical to ascertain whether any new vehicle technology can support shared mobility, thereby optimizing vehicle usage, reducing traffic congestion, and lowering environmental impact. This criterion emphasizes the importance of advancing technologies that promote shared transportation, underscoring a shift toward more sustainable and efficient mobility solutions. This criterion is particularly important for light-duty vehicles and buses.

Spatial Accessibility/Equity: This criterion assesses whether the technology can be deployed effectively in, and primarily benefit, disadvantaged communities. This criterion is particularly important for heavy-duty vehicles like trucks and buses, which often provide crucial transportation and logistical support in these areas. It emphasizes the need for the equitable geographical distribution of such technology, ensuring that marginalized or underserved areas also gain access to the benefits resulting from this technology. This is particularly important as these communities are often disproportionately impacted by pollution from traditional heavy-duty vehicles, so the transition to cleaner technologies can bring significant local health and environmental benefits.

4.2 Infrastructure

Defining the Category: Infrastructure includes stations for refueling or recharging vehicles powered by electricity, natural gas, and hydrogen. This category does not encompass gasoline and diesel stations offering renewable fuels, nor does it include other types of infrastructure that are not related to fueling.

EV charging infrastructure such as this EVgo DC Fast charger are widely available in SCAG region. Around 3,712 chargers are available in SCAG region provided by 20-30 manufacturers.

Data Sources and Limitations:
Several data sources were used for evaluating the zero and near-zero emission infrastructure:

- **Cost Data**: Over the past three years, there have been multiple studies conducted by various non-profit organizations such as International Council on Clean Transportation[106] (ICCT), National Renewable Energy Laboratory[107] (NREL), Rocky Mountain Institute[108] (RMI), Environmental Defense Fund[109] (EDF) to estimate the cost of EV charging infrastructure deployment including the cost of equipment, installation, as well as the needed utility upgrades (e.g., grid interconnections).
- **Adoption Status**: The project team utilized Zero Emission Vehicle and Infrastructure Statistics[110] published by the California Energy Commission (CEC) to determine the number of charger and hydrogen fueling stations deployed in SCAG region. Additionally, the project team leveraged the Alternative Fueling Station Locator[111] published by the U.S. Department of Energy (DOE) Alternative Fuel Data Center to determine the number of natural gas facilities in SCAG region.
- **Availability**: The project team utilized internet searches as a valuable resource to gather information regarding the number of vendors offering charging and fueling infrastructure for various clean technologies.

In contrast to vehicles where cost and technology specifications are generally publicly available, information regarding charging and fueling infrastructure is often scarce. While some studies have provided estimates, these findings are often limited to specific projects and may not be universally applicable. Aside from hardware, the cost of charging and hydrogen fueling infrastructure can be significantly impacted by factors such as installation and maintenance costs, as well as regulatory requirements and potential grid upgrades needed to support the infrastructure. Moreover, the geographical location and the type of establishment (public versus private, urban versus rural) can also contribute to variations in costs due to differences in accessibility, land prices, and demand levels. Note that in this report, our focus is mainly on the hardware costs.

Furthermore, when it comes to innovative infrastructure solutions, such as advanced charging technologies, there is a lack of available information beyond basic technology descriptions. Obtaining details on costs, longevity, and market adoption of these technologies requires substantial effort, including conducting interviews with specific vendors offering such products. Additionally, the availability of this information relies on vendors' willingness to publicly disclose it.

[106] https://theicct.org/sites/default/files/publications/ICCT_EV_Charging_Cost_20190813.pdf
[107] https://www.sciencedirect.com/science/article/pii/S2542435120302312
[108] https://rmi.org/wp-content/uploads/2020/01/RMI-EV-Charging-Infrastructure-Costs.pdf
[109] http://blogs.edf.org/energyexchange/files/2021/03/EDF-GNA-Final-March-2021.pdf
[110] https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics
[111] https://afdc.energy.gov/stations/

4.2.1 Electricity

This category discusses, Level 2 Charging Stations (stand-alone and networked), Direct Current (DC) Fast Charging (DCFC) stations[112] (low power to ultra-high power), and Innovative Charging Solutions (wireless, pantograph, on-the-go, and solar charging systems) in terms of capital cost, maintenance cost, adoption status, availability, longevity, accessibility, and integration. Detailed product descriptions are displayed in Table 22.

Table 22. Electricity infrastructure product descriptions.

Electric Vehicle Charging Infrastructure	EV Charging System Type	Product description
Level 2 Charging Stations	**Stand-Alone**	Level 2 charging stations are individual charging units that provide electrical power to EVs at a medium charging rate. Stand-alone Level 2 stations are not interconnected and operate independently.
	Networked	Networked Level 2 charging stations are connected to a central management system, allowing for remote monitoring, control, and potentially offering features like payment processing and user authentication.
DC Fast Charging Stations	**Low Power (50 - 100 kW)**	These DC fast charging stations provide a relatively lower charging rate compared to higher power variants. They offer faster charging than Level 2 stations but are not as rapid as higher power DC fast chargers.
	Medium Power (>100 -250 kW)	DC fast charging stations with medium power provide a higher charging rate, allowing EVs to recharge their batteries at a faster pace.
	High Power (>250 - 350 kW)	DC charging stations with a maximum output of 350kW. Typically, compatible with medium-heavy duty EVs.
	Ultra-High Power (up to 1 MW)	Ultra-high-power DC fast charging stations offer extremely fast charging capabilities, potentially delivering charging speeds of up to 1 MW. These stations are designed to significantly reduce charging time and enable rapid turnaround for electric vehicles.
Innovative Charging Solutions	**Wireless Electric Vehicle Charging System**	This technology enables charging without the need for physical cables. It utilizes wireless power transfer to charge electric vehicles by aligning the vehicle with a charging pad or system embedded in the ground or infrastructure.
	Pantograph Charging System	Pantograph charging systems employ an overhead arm mechanism that connects to an electric vehicle for charging purposes. These systems are commonly used for charging electric buses or trucks at designated charging stations or depots. These stations can offer up to 600 kW of charging power.
	Solar Charging Canopy	Solar charging canopies incorporate solar panels as overhead structures that provide shade while simultaneously harnessing solar energy to charge electric vehicles. These canopies often integrate with charging infrastructure, enabling sustainable and renewable energy sources for charging.

Level 2 charging stations are the most widely adopted type of EV charging infrastructure and are more suitable for light and medium-duty BEVs and have a power level between 2.5 and 19.2 kW. DCFC are more likely to be needed for Class 7 and 8 trucks and lower weight vehicle classes when fast charging is necessitated due to daily range requirements. DCFCs can currently operate at power levels between roughly 20 kilowatts (kW) and 360 kW, offering a significantly faster charge than Level 2 chargers. For example, a 150 kW and 350 kW DCFC can charge an electric truck in 1.2 hours and 0.5 hour, respectively (assuming a battery capacity of 175 kilowatt-hours (kWh)). In contrast, the same truck would take 8 to 10 hours to charge using a Level 2 charger. A more recent development within the industry

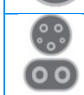
[112] Assumed to be all networked although there might be optioned for stand-alone (non-networked) available too.

is megawatt (MW) charging technology, which has the potential to significantly reduce charging dwell times. Leading the development of a Megawatt Charging System (MCS) is the member-based Charging Interface Initiative (CharIN). The MCS is designed to provide a maximum of 3.75 MW of charging power (Figure 19). It is expected that CharIN will publish the final MCS standard in 2024.[113] In October 2022, Daimler Truck North America hosted an event at their Electric Island[114] facility in Portland, Oregon, where a MSC system was tested on a dozen medium- and heavy-duty vehicles[115].

Figure 19. The Megawatt Charging System (MCS) Connector

Connector standardization is also important to the success of vehicle electrification. While interoperability in charging infrastructure is improving over time, there remains a lack of standardization for charger connectors. Importantly, interoperability goes beyond connector standards; it also includes the software and communications connections between charging stations and charging networks. Table 20 shows existing and upcoming charging connector standards relevant to MD-HD electric vehicles. As shown, Level 1 and 2 chargers simply use the SAE J1772, while DCFC spans several connector standards.

Table 23. Existing and Upcoming Charging Connector Standards[116]

Diagram	Connector Standard	Maximum Output Power	Application Notes
	SAE J1772	19.2 kW AC	Used for Level 1 and Level 2 charging in North America. Commonly found on home, workplace, and public chargers.
	CCS[117]	450 kW DC	Used for DC fast charging most vehicle models in North America. Generally installed at public charging stations.[118]
	CHAdeMO	400 kW DC	Used for DC fast charging select vehicles models in North America. Generally installed at public charging stations[119].

113 Inside EVs. (2022, June 15). CharIN Officially Launches The Megawatt Charging System (MCS). Retrieved from https://insideevs.com/news/592360/megawatt-charging-system-mcs-launch/

114 https://www.bv.com/projects/electric-island-providing-pathway-carbon-free-trucking

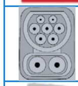
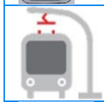
115 https://www.truckinginfo.com/10182667/megawatt-ev-charging-system-tested-at-electric-island

116 California Energy Commission. (2021, July). Assembly Bill 2127 Electric Vehicle Charging Infrastructure Assessment Analyzing Charging Needs to Support ZEVs in 2030. Retrieved from https://efiling.energy.ca.gov/getdocument.aspx?tn=238853

117 North American CCS standard is referred to as Type 1, CCS 2.0 is typically found in Europe.

118 Incentive funding provided by the federal government via the National EV Infrastructure (NEVI) Formula Program is contingent upon certain requirements including that the chargers must include at least four 150kW plugs with CCS ports. This requirement, however, is only to receive federal funding through the NEVI program. Anyone can deploy CHAdeMO charger ports if they want, they just won't qualify for federal NEVI funding. See NEVI funding guidelines here: https://www.fhwa.dot.gov/environment/alternative_fuel_corridors/nominations/90d_nevi_formula_program_guidance.pdf

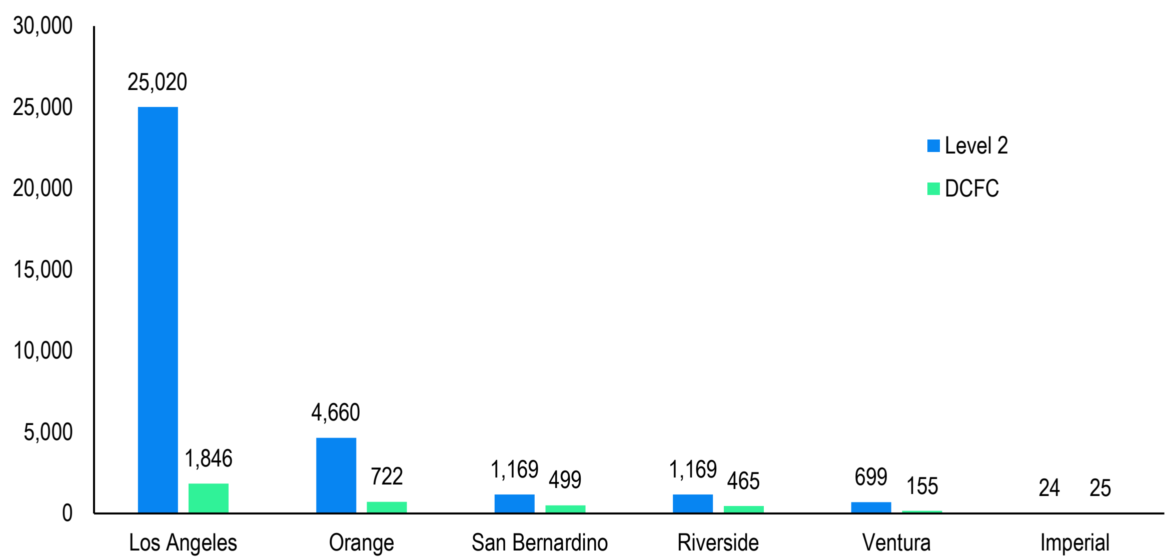
119 It is noteworthy to mention many of the zero emission vehicle manufacturers are moving aways from the CHAdeMO and shifting their products to be compatible with CCS and/or Tesla

Diagram	Connector Standard	Maximum Output Power	Application Notes
	Tesla	22 kW AC 250 kW DC	Used for both AC and DC fast charging for Tesla models only.
	SAE J2954	22 kW light-duty, 200 kW MD/HD	Wireless power transfer. The standard for MD/HD vehicles is under development.
	SAE J3068	133 kW to 166 kW DC	Developed for three-phase charging, which the SAE J1772 and J1772 combo could only accommodate single-phase charging.
	SAE J3105	>1 MW	Automated connection device to charge MD/HD vehicles. Variants include pantograph “up” or “down” and pin-and-socket. LA Metro has already deployed this technology on the G/Orange Line,
	CharIN Megawatt Charging System	4 MW	Conductive MW-level charging for MD/HD road vehicles, ships and planes. The technical specification is expected in 2024.

Existing Condition

The availability of public EV charging infrastructure in SCAG region has made significant progress, however, there remains the need for accelerated growth in order to support the influx of ZEVs. According to the CEC, there are approximately 33,000 Level 2 and 3,700 DCFC chargers in the region. LA County has the highest number of EV chargers in SCAG region; specifically, 76 percent of level 2 chargers and 50 percent of DC fast chargers are located in the most populous county in the region (Figure 20). San Bernardino and Riverside counties have similar numbers of chargers, indicating that these regions are also making efforts to increase the availability of charging infrastructure. Lastly, Imperial County has the fewest chargers in the region. Figure 20 below illustrate the number of charging infrastructure deployed in SCAG region broken down by county.

Figure 20. Number of Public EVSE by County



EV charging stations typically fall under one of three ownership/accessibility categories: private, semi-public, and public. Private charging stations, whether for fleets, workplace chargers with access only granted to employees, or multi-unit dwellings, are not available to the general public. Semi-public charging stations are open to certain fleets or individuals but not open to all of the public. For example, a business may offer their customers the ability to use their charging stations. Lastly, public charging stations are self-explanatory and are available to the broader public. Note that the statistics presented here are for the publicly available EVSE in SCAG region.

Commercialization

Table 23 provides commercialization status of EV charging infrastructure including the capital cost, maintenance costs, adoption status (number of chargers being deployed in SCAG region) as well as the number of vendors offering these charging solutions. In summary, Level 2 charging stations have an estimated cost range of $2.5K to $4.5K. For DC fast charging stations, the cost varies based on power capacity, with low-power (50-100 kW) stations priced around $29.5K to $59.5K, medium-power (>100-250 kW) stations ranging from $59.5K to $115K, high-power (>250-350 kW) stations costing between $115K and $139K, and ultra-high-power (up to 1 MW) stations priced at approximately $400K to $500K. According to CEC's Zero Emission Vehicle and Infrastructure Statistics, currently there are 33,000 Public Level 2, and 3,700 DCFC being deployed in SCAG region. Of these, 21,000 chargers are shared-private whereas 15,000 of them are publicly available chargers.

It shall be noted that while Level 2 and DCFC hardware are not specifically designed for a particular vehicle type, such as light-duty or heavy-duty vehicles, their accessibility can greatly depend on the parking infrastructure surrounding them. For instance, most of the current public charging stations are designed with light-duty vehicles in mind, making it challenging for heavy-duty vehicles to utilize them due to parking layout and space constraints. Consequently, the effectiveness of these charging stations is limited by the physical design and infrastructure of their locations, and not just by their technological capabilities. In the evolving landscape of electric vehicles, the interoperability of chargers becomes increasingly critical. It's essential to consider scenarios where chargers can be shared among various vehicle categories, ensuring the maximum utility and flexibility of charging infrastructure.

Table 24. Technology characteristics of electric charging infrastructure.

Electric Vehicle Charging Infrastructure	EV Charging System Type	Capital Cost	Maintenance Cost[120]	Adoption Status	Availability	Longevity
Level 2 Charging Stations	**Stand-Alone**	$2,500 - $4,500	$400 per charger per year	32,741	40-50 vendors	1-5 years[121]
	Networked		$400 per charger per year		40-50 vendors	1-5 years
DC Fast Charging Stations	**Low Power (50 - 100 kW)**	$29,500 - $59,500	$800 per charger per year	3,712	20-30 vendors	3 years
	Medium Power (>100 -250 kW)	$59,500 - $115,000	$800 per charger per year		20-30 vendors	3 years
	High Power (>250 - 350 kW)	$115,000 - $139,000	$800 per charger per year		20-30 vendors	3 years
	Ultra-High Power (up to 1 MW)	$400k – $500k	NI	NI	NI	NI

NI indicates "no information" or a knowledge gap
Blank indicates not commercially available

Aside from the traditional wired charging solution, there also exist several innovative charging solutions that are further described here.

Wireless Electric Vehicle Charging System: The wireless electric vehicle charging system offers the convenience of charging without the need for physical cables or plug-in connections. It provides a seamless integration into the charging process, enhancing the user experience. However, this technology currently has lower efficiency compared to wired charging systems, resulting in slightly slower charging speeds. It also comes with higher installation costs and limited availability and compatibility with electric vehicle models.

Pantograph Charging System: The pantograph charging system is commonly used in the public transportation sector and is designed for rapid charging of electric buses or trucks. It offers high charging power capacity and automated connection to charging infrastructure, making it efficient for fleet charging scenarios. However, it requires specific infrastructure and equipment, limiting its use for individual or private electric vehicles. The installation costs are typically higher, and compatibility issues between different pantograph designs and vehicle types may arise.

120 Based on data provided at https://afdc.energy.gov/fuels/electricity_infrastructure_maintenance_and_operation.html

121 https://afdc.energy.gov/fuels/electricity_infrastructure_maintenance_and_operation.html

Solar Charging Canopy: The solar charging canopy integrates solar panels as overhead structures, providing shade while harnessing solar energy to charge EVs. One of the key advantages of solar charging canopies is their ability to utilize sustainable energy sources, reducing reliance on the grid and lowering carbon emissions. By harnessing solar power, these canopies enable EVs to charge using clean and renewable energy. Solar charging canopies can be installed in various locations such as parking lots, residential areas, or commercial spaces, providing convenient charging options for electric vehicle owners. They not only offer a means of charging but also provide shading benefits, protecting vehicles from harsh weather conditions. However, there are considerations to keep in mind. The efficiency of solar panels can be influenced by factors such as the amount of sunlight available, orientation of the panels, and potential shading from surrounding structures. This can impact the charging speed and effectiveness of the canopy system. Moreover, the installation of solar charging canopies requires space and investment, which may limit their widespread adoption. Adequate space is needed to accommodate the canopy structure and the number of charging stations desired, which can be a challenge in densely populated areas or locations with limited available land. According to one vendor[122], a 2 – 6 ports solar charging canopy can cost $70,000 – $90,000.

Mobile Charging (EV Charging on the Go): Mobile charging units, also known as portable charging stations or mobile EV chargers, are innovative solutions that offer flexibility and convenience for EV charging as well as for emergency use cases. These units are designed to be easily transportable and can provide charging capabilities in various locations where fixed charging infrastructure may be limited or inaccessible. Mobile charging units typically consist of a compact charging module with built-in power electronics, connectors, and cables. They can be powered by different sources, such as a built-in battery, gas, diesel or natural gas-powered generator, or by connecting to a traditional power outlet. Some mobile charging units may even incorporate renewable energy sources like solar panels for eco-friendly charging on the go. One of the key advantages of mobile charging units is their ability to provide EV charging wherever it is needed, whether it's at events, temporary parking lots, construction sites, or remote areas. They offer convenience for EV owners by providing a charging option outside of the traditional charging network, expanding the accessibility and coverage of EV charging infrastructure. However, it's important to note that mobile charging units typically have lower charging capacities compared to fixed charging stations, as they are designed for temporary or on-demand charging. This means that charging times may be longer, and the number of vehicles that can be charged simultaneously may be limited. An example of these mobile charging solutions is the one BP Pulse Fleet North America Inc. where they offer three mobile and non-permanent charging solutions. The first solution is containerized, which involves upcycled 20' or 40' shipping containers with exterior chargers and electrical switchgear inside. These containers are pre-assembled off-site and can accommodate different charger types and power levels. The second solution is mobile, which consists of fully portable battery-supported charging units on wheels. These units do not require existing access to electricity, allowing for deployment in any location worldwide. The third solution is surface mounted, which utilizes above-ground cable

[122] https://beamforall.com/. Cost data were acquired through personal communication with Beam representatives during the 2023 ACT Expo

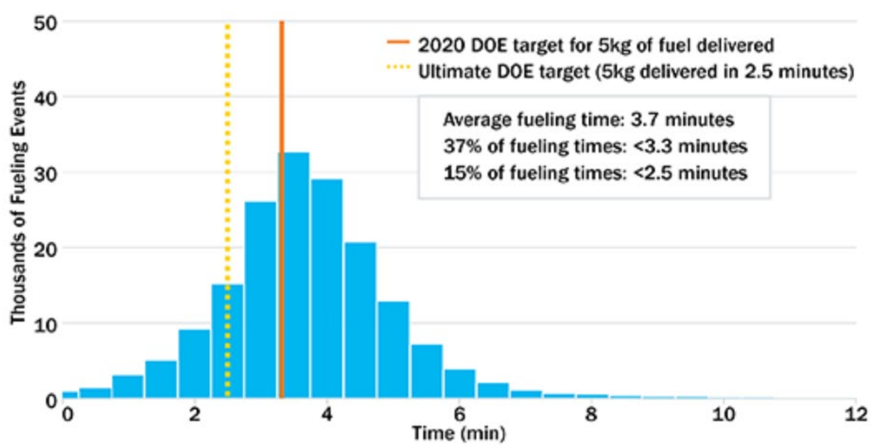
raceways and portable transformers. This solution is compatible with any charger type and does not require trenching for electrical wiring. It offers quick installation and easy relocation while providing the convenience and stability of permanent infrastructure. According to our survey responses the cost for these solutions could vary by scope.

4.2.2 *Hydrogen Infrastructure*

Hydrogen fueling infrastructure is an integral part of the transition toward clean energy transportation. As discussed earlier, FCEVs are an attractive alternative to traditional fossil fuel vehicles, as they emit only water vapor and warm air. However, their adoption relies heavily on the availability and accessibility of hydrogen fueling stations. These stations, similar to traditional gas stations, pump hydrogen gas into the fuel cell of the vehicle. However, the development and deployment of hydrogen fueling infrastructure pose unique challenges, including high capital costs, technical complexities, and safety considerations. Despite these hurdles, investing in hydrogen infrastructure can provide significant environmental benefits and contribute to energy diversity and resilience.

Hydrogen fuel has a low volumetric energy density compared to other liquid fuels, such as gasoline. For this reason, the fuel is stored onboard a vehicle as compressed gas in order to achieve a driving range comparable to conventional vehicles. Current applications often use high-pressure tanks capable of storing hydrogen at either 5,000 or 10,000 pounds per square inch (psi). The emphasis within the industry is hyper focused on achieving fueling times as close as possible to conventional vehicles, such that users in the light-duty, and particularly, the medium- and heavy-duty sector can adopt these ZEVs without significant change to their daily operations. Retail hydrogen dispensers are typically co-located at gasoline stations and are able to fill an average fuel take in roughly 5 minutes. With the DOE's target of achieving fueling times of 2.5 mins (for 5 kg of fuel), continued effort is being targeted at lowering the time to refill. In a study from the National Renewable Energy Laboratory (NREL) found that the average time spent fueling an FCEV is less than 4 minutes, with 37% of fueling times less than 3.3 minutes and 15% of fueling times more than 2.5 minutes (Figure 21). For larger FCEVs, such as busses, refilling times are between 10-15 minutes.[123] For small and large fleets of MHD FCEBs, slow fill dispensing is utilized, which is more economical particularly for vehicles that are domiciled at a central depot and sit overnight.

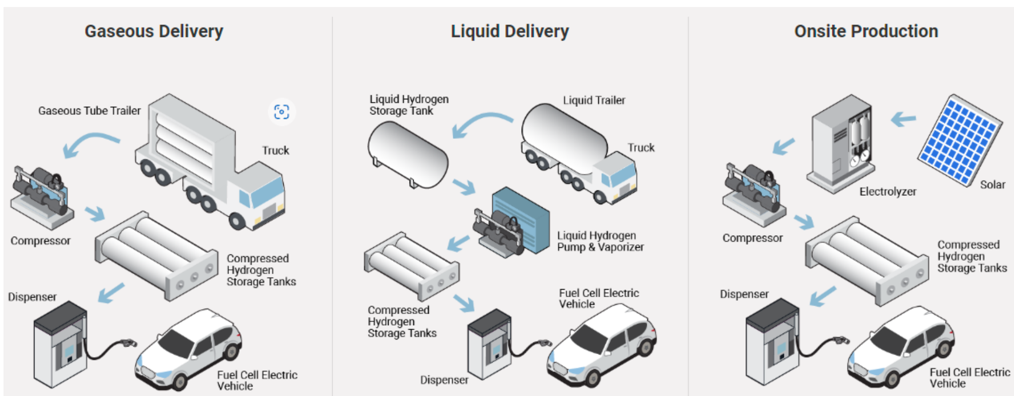
Figure 21. Average Hydrogen Refueling Times



[123] https://afdc.energy.gov/fuels/hydrogen_basics.html

Current hydrogen delivery systems include gaseous hydrogen delivery, liquid hydrogen delivery, and on-site hydrogen production and storage. Gaseous hydrogen delivery entails compressing hydrogen prior to transport, which is then delivered by truck or pipeline to the customer. Liquid hydrogen delivery converts hydrogen to liquid form where it must be cooled to below -423 degrees Fahrenheit using a process called cryogenic liquefaction. It is then transported as a liquid in super-insulated, cryogenic tanker trucks to its end destination. Before dispensing the hydrogen, it is vaporized to a high-pressure gaseous product. One of the advantages of this delivery pathway is that it can be more economical than trucking gaseous hydrogen over long distances. Hydrogen may also be produced on-site using several processes. On-site production can reduce transportation and distribution costs but increase production costs due to the high capital costs of constructing production facilities. On-site production can be particularly suitable for more remote locations where regular delivery of hydrogen is not feasible, with one example being fuel cell electric buses (FCEBs) deployed at Sunline Transit in the Coachella Valley. Figure 22 depicts the three types of hydrogen delivery pathways.

Figure 22. Hydrogen Delivery Pathways[124]



The hydrogen fueling infrastructure category of this compendium evaluates different hydrogen fueling station types in terms of capital cost, maintenance cost, adoption status, availability and longevity. Hydrogen fueling station types include slow fill, fast fill, on-site production, off-grid, mobile stations, and on-the-go stations. Note that almost all of the public hydrogen fueling stations deployed in California are fast-fill hydrogen fueling stations. Detailed product descriptions of each fueling station type can be found in Table 25.

Table 25. Product descriptions for hydrogen fueling infrastructure.

Hydrogen Fueling Station Type	Product description
Slow Fill	These stations fill the hydrogen tank of a vehicle at a slower rate, typically over a period of several hours. This method usually does not require pre-compressed hydrogen or on-site compressors because it slowly compresses the hydrogen as it's being dispensed. These stations are smaller and less expensive to construct and operate than fast-fill stations. Slow-fill stations are ideal for fleet applications where vehicles return to a central location at the end of the day and can be refueled overnight.
Fast Fill	These stations are designed to fill the hydrogen tanks of vehicles rapidly, typically within 3 to 5 minutes, similar to a conventional gasoline fill-up. Fast-fill stations are often larger, more complex, and more expensive to build and operate because they need to store pre-compressed hydrogen or have powerful compressors on-site to fuel vehicles quickly. Fast-fill stations are best suited for public and retail locations where users need to refuel and leave as quickly as possible, similar to traditional gas stations.

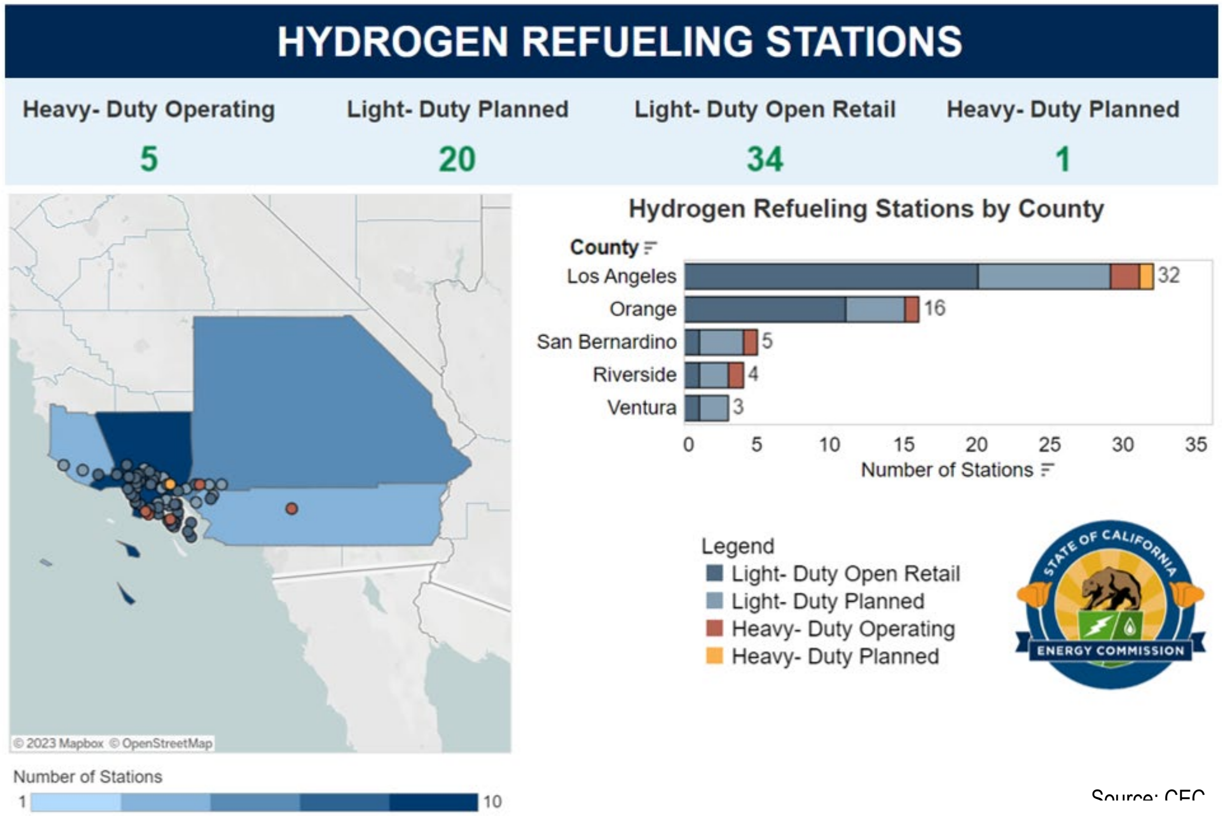
[124] California Fuel Cell Partnership. (n.d.). Costs and Financing. Retrieved from https://h2stationmaps.com/costs-and-financing

Hydrogen Fueling Station Type	Product description
On-Site Production	These stations produce hydrogen on-site using renewable energy or natural gas. On-site production stations can be useful in areas where hydrogen production and transportation costs are high as they can reduce the cost of transporting hydrogen to the station.
Off-Grid	These stations are powered by renewable energy sources such as solar or wind power, allowing them to operate without being connected to the electrical grid. Off-grid stations can be useful in remote locations where grid power is not available, or as a way to reduce the carbon footprint of the hydrogen production process.
Mobile (On the Go) hydrogen stations	On-the-go hydrogen stations are mobile stations that can be used to refuel hydrogen fuel cell vehicles in locations where permanent refueling infrastructure may not be available. These units typically consist of a refueling station mounted on a trailer or other mobile platform, which can be moved to different locations as needed.

Existing Condition

In terms of hydrogen fueling infrastructure, Southern California is one of the few regions in the world with a significant network of hydrogen fueling stations. SCAG region is gradually increasing its hydrogen fueling infrastructure with a total of 39 fueling stations available as of January 2023. The majority of these stations are concentrated in Los Angeles and Orange County, with only five, four, and three stations located in San Bernardino, Riverside, and Ventura counties, respectively. This lack of infrastructure, and particularly the concentration of fueling stations in high populations centers, speaks to the nascent nature of this technology. While there are currently 34 light-duty retail stations open, 20 additional stations are planned to open in the future. For heavy-duty hydrogen fueling stations, there are five currently operating, with one planned to open in the near future (Figure 23).

Figure 23. Number and type of Hydrogen Fueling Stations within SCAG Region by County[125]



Commercialization

Hydrogen is an attractive option for decarbonizing long-haul trucks, buses, and other heavy-duty applications where BEVs may face challenges due to weight, range, or charging infrastructure limitations. Hydrogen fuel cell vehicles offer extended driving ranges and faster refueling times compared to battery electric counterparts, providing operational flexibility for long-distance travel and reducing downtime. However, as illustrated earlier, a significant portion of the existing hydrogen fueling infrastructure in the region is primarily designed to cater to light-duty vehicles and may not be suitable for heavy-duty vehicles. The infrastructure development for heavy-duty hydrogen fueling stations requires additional considerations due to the higher fueling capacity and specific requirements of these larger vehicles. As part of the Clean Transportation Program, the CEC invests in charging as well as hydrogen fueling infrastructure. Table 26 below provides a list of medium and heavy-duty hydrogen fuel stations that are funded through this program. The funding for these projects covers direct and indirect labor for designing, engineering, and building the stations along with the equipment and shipping of the equipment. As shown, the typical cost of these stations is anywhere between $4,00,000-$8,000,000 to build and around $142,000/year to maintain.[126] This information is summarized in Table 27.

[125] https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/hydrogen-refueling
[126] https://ww2.arb.ca.gov/sites/default/files/2021-10/hydrogen_self_sufficiency_report.pdf

Table 26. Cost of H2 Fueling Station - CEC Clean Transportation Program

Recipient Name	Purpose	Capacity	Capital Cost
Equilon Enterprises LLC	Renewable hydrogen fueling station for freight at the Port of Long Beach	1,000 kg/day	$8,000,000
North County Transit District	North County Transit District Next Generation Hydrogen Fueling Infrastructure Project	Under Development	$6,000,000
Sunline Transit Agency	Liquid hydrogen refueling infrastructure for transit buses	1,680 kg/day	$4,986,250
Alameda Contra-Costa Transit District	Division 4 Hydrogen Fueling Infrastructure Upgrade	Under Development	$4,565,975
Center for Transportation and the Environment	NorCAL Drayage Truck Project	1,600 kg/day	$9,898,218
Equilon Enterprises LLC	Shell Multi-Modal Hydrogen Refueling Station (at the Port of West Sacramento for Sierra Northern Hydrogen Locomotive Project)	1,450 kg/day	$4,000,000

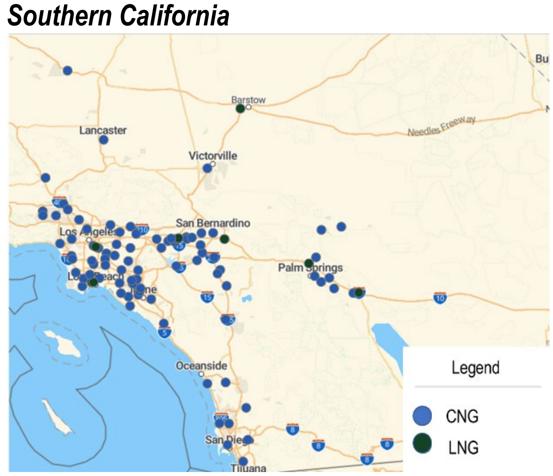
Table 27. Technology characteristics of hydrogen fueling infrastructure

Hydrogen Fueling Station Type	Capital Cost	Maintenance Cost	Adoption Status	Availability	Longevity
Slow Fill	$4,000,000 - $8,000,000	$142,000/year	0	5 - 10 vendors	NI
Fast Fill			39	5 - 10 vendors	NI
On-Site Production	NI	NI	NI	5 - 10 vendors	NI
Off-Grid	NI	NI	NI	5 - 10 vendors	NI
Mobile Stations	NI	NI	NI	5 - 10 vendors	NI
On the Go hydrogen stations	NI	NI	NI	< 5 vendors	NI

NI indicates "no information" or a knowledge gap
Blank indicates not commercially available

4.2.3 *Natural Gas*

Figure 24. CNG and LNG Stations in the Southern California



When burned, natural gas produces fewer greenhouse gas emissions, particulate matter, and smog-forming pollutants compared to traditional petroleum-based fuels. Furthermore, the availability of natural gas infrastructure, such as pipelines and refueling stations, makes it easier to integrate NGVs into existing transportation systems. Many fleet operators, including transit agencies and delivery companies, have adopted natural gas as a fuel option for their vehicles. Similar to diesel, a low carbon alternative to natural gas is Renewable Natural Gas (RNG). RNG is produced through the process of capturing and refining biogas emitted from various sources such as landfills, wastewater treatment plants, agricultural waste, and anaerobic digesters. The biogas captured from these sources primarily consists of methane, carbon dioxide, and trace amounts of other gases. To transform it into RNG, the biogas undergoes a purification process where impurities like carbon dioxide, hydrogen sulfide, moisture, and other trace elements are removed. This purification step increases the methane content to a level comparable to or even higher than conventional natural gas. The resulting RNG is considered a renewable fuel because it is produced from organic waste materials, diverting these materials from landfills and reducing methane emissions, which is a potent greenhouse gas. By capturing and utilizing biogas through RNG production, it provides a valuable strategy for managing organic waste while also generating a sustainable energy source. Despite RNG being a lower-emission alternative, it is not a completely carbon-neutral and zero emission solution. Methane, a potent greenhouse gas, can be emitted during the production, transmission, and distribution of natural gas (or RNG). In addition, while the majority of methane is converted to CO2 upon combustion, a minuscule fraction might not burn completely and could be emitted from the vehicle's tailpipe. Natural gas can be used as compressed natural gas (CNG) or liquified natural gas (LNG) to power vehicles.

LNG fueling involves cooling natural gas to approximately -162 degrees Celsius (-260 degrees Fahrenheit), which transforms it into a liquid state. This liquefaction process reduces the volume of natural gas, making it more efficient to transport and store. LNG is typically stored in insulated cryogenic tanks at atmospheric pressure. When needed, LNG is vaporized back into its gaseous state and then pressurized for injection into the vehicle's fuel tank. LNG fueling infrastructure requires specialized storage tanks, vaporizers, and dispensers capable of handling cryogenic temperatures and ensuring safe fueling operations. LNG is commonly used in heavy-duty transportation applications. CNG fueling, on the other hand, involves compressing natural gas to high pressures, typically around 3,600 to 3,900 pounds per square inch (psi), or even higher for certain applications. Compressed natural gas is stored in high-pressure cylinders or tanks at the vehicle fueling station. When a vehicle is refueled, the compressed gas is directly delivered from the dispenser into the vehicle's onboard storage tanks. CNG fueling infrastructure requires compressors to achieve the necessary pressure levels and dispensers to deliver the compressed gas to the vehicles. CNG is commonly used in light-duty and medium-duty vehicles, such as cars, vans, buses, and some smaller trucks.

Time-fill and fast-fill CNG stations are two different types of compressed natural gas (CNG) refueling methods with distinct characteristics and applications. Time-fill CNG stations are designed for overnight or prolonged refueling periods. They are typically used in fleet operations where vehicles are parked for an extended duration, such as overnight or during off-peak hours. Time-fill stations utilize lower pressure and flow rates to slowly fill the CNG tanks of multiple vehicles simultaneously. This method allows for efficient use of infrastructure by staggering the refueling process and taking advantage of the available time. Time-fill stations are cost-effective and convenient for fleet owners, as they can take advantage of non-peak electricity rates and ensure their vehicles are fully fueled and ready for operation the next day. However, the refueling process is relatively slow compared to fast-fill stations, as it is optimized for longer periods of stationary refueling. On the other hand, fast-fill CNG stations are designed for quick refueling, similar to conventional gasoline or diesel stations. These stations provide higher pressure and flow rates to rapidly fill CNG tanks, allowing for faster turnaround times. Fast-fill stations are suitable for applications where vehicles need to refuel on the go or in a time-constrained manner, such as public transit buses, or other vehicles with demanding schedules. They offer the convenience of rapid refueling, similar to traditional liquid fuel stations, enabling efficient operations for vehicles with higher fuel consumption or limited time availability. However, fast-fill stations require larger compressors and storage systems to meet the higher flow rate demands, making them more expensive to install and operate compared to time-fill stations.

Here in this section, the project team evaluates both types of CNG fueling stations (Time-Fill, and Fast Fill CNG stations), as well as the LNG stations (Table 28).

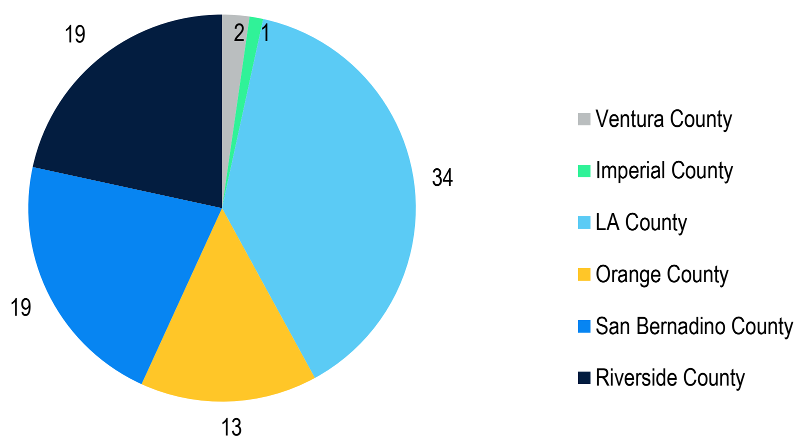
Table 28. Product descriptions for natural gas infrastructure.

Natural Gas Fueling Stations	Natural Gas Fueling Station Type	Product description
Compressed Natural Gas (CNG)	**Time-Fill CNG Stations**	Time-fill stations source CNG from a local utility and refuel vehicles at a low-pressure directly from the compressor. Slow-fill stations are generally used by fleets and fill vehicles with large tanks over the course of multiple hours.
	Fast-Fill CNG Stations	Fast-fill CNG stations source CNG from a local utility line at a low pressure, use a compressor on site to compress the gas into a high pressure and store the CNG in vessels at a high service pressure (4,300 psi). Fast-fill stations refuel vehicles at a similar rate to traditional gasoline pumps.
Liquified Natural Gas (LNG) Stations		LNG fueling stations fill vehicles at a pressure of 30-120 psi. LNG is stored and dispensed as a super-cooled liquefied gas.

Existing Condition

Natural gas infrastructure is also an important component of the region's clean fueling infrastructure. Natural gas fueling infrastructure in SCAG region is spread relatively evenly across four of the six counties within the region. Los Angeles has the most stations at 34, while Riverside and San Bernardino counties both have 19, and Orange County has 13 stations. Ventura County currently only has two stations, and Imperial County has only one station.

Figure 25. Number of CNG/LNG Fueling Stations within SCAG Region by County



Source: https://afdc.energy.gov/stations#/analyze?region=US-CA&fuel=ELEC&ev_levels=all&location_mode=address

Commercialization

Table 29 provides an assessment of various natural gas stations in terms of capital cost, maintenance cost, adoption status, availability, and longevity. As shown, Time-Fill stations, which are designed for overnight or prolonged refueling, can be constructed within a cost range of $5,500 to $850,000. In contrast, Fast-Fill stations, catering to quick refueling needs, involve higher capital investments, typically ranging from $45,000 to $1.8 million, with an average annual maintenance cost of approximately $12,000. LNG stations, which utilize liquefied natural gas, require a higher initial capital investment, averaging around $1.7 million. Meanwhile LNG stations cost around $1.7 million. Notably, fast-fill CNG stations are the most widely adopted type of natural gas fueling station. The adoption status of natural gas fueling stations within region varies depending on the type. There are a total of six time-fill CNG stations, 78 fast-fill CNG stations, and 11 LNG stations. Fast-fill stations are widely embraced, possibly due to their ability to provide quick refueling for vehicles with time-sensitive operations, such as public transit buses and delivery fleets.

Table 29. Technology characteristics of natural gas infrastructure.

Natural Gas Fueling Stations	Natural Gas Fueling Station Type	Capital Cost	Maintenance Cost	Adoption Status	Availability	Longevity
Compressed Natural Gas (CNG)	**Time-Fill CNG Stations**	Base Station (5-10 gge/day): $5,500 - $10,000 Starter Station (20-40 gge/day): $35,000 - $50,000 Small Station (100-200 gge/day): $250,000 - $500,000 Medium Station (500-800 gge/day): $550,000 - 850,000	$12,500/yr	6	30-50 vendors	1-10 years
	Fast-Fill CNG Stations	Starter Station (20-40 gge/day): $45,000 - $75,000 Small Station (100-200 gge/day): $400,000 - $600,000 Medium Station (500-800 gge/day): $700,000 - 900,000 Large Station (1,500+ gge/day): $1.2 - $1.8M	NI	78	30-50 vendors	1-10 years
Liquified Natural Gas (LNG) Stations		$1.7M (includes all design, construction, equipment, installation, project management, inspections, commissioning and project closeout	NI	11	5 - 10 vendors	NI

NI indicates "no information" or a knowledge gap

Blank indicates not commercially available

4.2.4 Other Infrastructure Technology Considerations:

Similar to the discussion provided for vehicles, there are other factors that need to be considered when consumers, whether private or public entities, consider the acquisition of clean technology infrastructure. The following outlines a series of additional criteria that should be taken into account when evaluating infrastructure technologies. More extensive criteria for consideration are detailed in Appendix E.

Technology Readiness: The concept of technology readiness, in the context of infrastructure technology, assesses the maturity and reliability of a technology, gauging its feasibility for broad-scale implementation. Implementing nascent charging and fueling technologies prematurely can lead to unforeseen challenges, potential inefficiencies, and increased costs. For example, ultrafast charging technology, often referred to as high-power charging or megawatt charging, represents the cutting edge of EV charging technologies. As discussed earlier, while foundational technology is proven, its widespread commercial deployment remains in the intermediate stages of technology readiness. This is due to several factors, including the need for substantial power infrastructure upgrades, concerns over grid stability, and the capability of vehicles to handle such rapid charging rates without adverse impacts on battery life. When considering investments or policymaking related to these cutting-edge charging technologies, it is essential to recognize that while the technology holds significant potential for revolutionizing EV charging, its full-scale, broad implementation is still in a maturing phase, necessitating ongoing research, development, and real-world testing.

Refueling Time: When selecting an appropriate charging or refueling system, the availability of refueling or charging time is significant. This factor directly impacts the practicality and efficiency of the system for users. For instance, a long-haul trucking company operating on tight schedules would prioritize fast-charging solutions (e.g., 350 kW chargers) to minimize downtime. Conversely, urban transit systems or private vehicle owners might have overnight periods available, making slower, overnight charging systems (e.g., 50 kW chargers) more feasible and potentially more economical. The selected charging or refueling system should align with the operational patterns and time constraints of the user, ensuring that the vehicles are charged or refueled when needed without causing disruptions or inefficiencies in their primary function. Thus, understanding the temporal dynamics of vehicle usage is crucial in determining the most appropriate and efficient charging or refueling solution. Furthermore, while modern infrastructure offers public chargers with capacities reaching up to 800 kW, it is essential to recognize that not all vehicles can accept such high levels of charging. Every vehicle has a maximum charging or fueling acceptance rate, which sets a limit on how fast a charger or refueling system can operate without causing potential harm or inefficiencies. Therefore, the optimal choice in charging or refueling system should not only align with the operational patterns and time constraints but also the technological capabilities and limits of the vehicles in question.

Physical Accessibility: The measure of physical accessibility refers to whether the technology can be operated and used by individuals with disabilities. This includes, but is not limited to, individuals with mobility impairments, visual impairments, and auditory impairments. For instance, people with mobility impairments might require infrastructure that allows for easy access to charging points, perhaps by means of ramps, automatic doors, or easy-to-use controls that do not require significant physical strength or skill. The design and layout of charging stations should also consider wheelchair users, with enough space for maneuvering and reaching the necessary equipment. For visually impaired individuals, accessibility can involve the implementation of tactile markers, braille instructions, or auditory guidance systems at charging or fueling stations. The use of contrasting colors and large, clear fonts for any visual elements can also make a significant difference. Those with auditory impairments, on the other hand, may benefit from visual alerts and signals, such as light-based indicators for charging or fueling status or system alerts. Text-based communication or sign language interpretation could also be integrated into instructional materials or real-time assistance services.

***Integration**:* Technology integration within the scope of zero-emission infrastructure means that these technologies need to be interoperable, conforming to various industry standards. The central idea is to ensure these technologies can function in harmony with other systems, thereby enhancing user convenience and facilitating seamless operations across a diverse set of platforms and devices. A practical example is EV charging infrastructure. Interoperability in this context means that an EV from any manufacturer should be able to use a charging station from any other manufacturer. This requires standardization in charging connectors, protocols, and power requirements, allowing the infrastructure to accommodate a wide range of vehicles. On a broader scale, zero-emission infrastructure should also be designed to integrate with existing energy grids and demand management systems. For example, EV charging stations could be equipped with smart technologies to align charging cycles with off-peak electricity demand periods, reducing strain on the grid and taking advantage of lower energy prices. Additionally, integration with user-facing technology like mobile apps is also crucial. This allows customers to locate charging stations, reserve charging slots, and pay for services with ease. In essence, technology integration in the context of zero-emission infrastructure is about ensuring these systems not only function independently but also harmonize with the broader technological and operational landscape.

Locality: This measure refers to the presence of technology providers or vendors within a specific region, in this case, SCAG region. A substantial local presence can be highly beneficial, offering numerous advantages, from regional economic development and local employment opportunities to easier coordination with community stakeholders. Firstly, a significant local presence stimulates regional economic development. Investments in zero-emission infrastructure can lead to a direct financial influx into the region. Secondly, a robust local presence of zero-emission technology providers can lead to job creation. This spans a wide range of roles, from the construction of charging or refueling stations to the maintenance, and even roles in research and development. Finally, having technology providers or vendors situated locally can facilitate better coordination and communication with local stakeholders. This includes local government, businesses, and community groups. Local providers would have a better understanding of the regional context, such as environmental conditions, energy infrastructure, and specific community needs, which would enable them to deliver solutions that are tailored to meet these local requirements. Moreover, it can foster stronger relationships and ongoing collaboration, as local stakeholders can easily engage in face-to-face meetings, site visits, and other direct interactions. This proximity can accelerate decision-making processes, enhance the efficiency of project implementation, and ultimately drive the successful and widespread adoption of zero-emission technologies in the region.

Scalability: This criterion refers to the ability to adjust the technology's size, capacity, or functionality to suit different use cases or geographical contexts. This attribute is crucial for the widespread adoption of clean technology, allowing it to meet diverse demands and integrate seamlessly into different environments. When evaluating the scalability of a technology, especially within the context of zero-emission infrastructure, the technology's inherent characteristics such as cost-effectiveness and feasibility for mass production are key determinants. If a technology is prohibitively expensive or not amenable to mass production, it can greatly hinder its scalability. Moreover, the technology should be able to maintain or improve its performance as it scales. A technology that works well at a small scale but experiences significant performance degradation or increased failure rates when scaled up would not be considered scalable.

***Incentivization**:* Incentivization plays a significant role in fostering the development and adoption of zero-emission infrastructure. Adopting new technologies often comes with uncertainties and risks and not all zero-emission infrastructure technologies may be eligible for public incentives, which can influence their financial viability and investment risk. Financial incentives such as grants, subsidies, tax breaks, or rebates can significantly offset the upfront costs associated with the adoption and implementation of zero-emission technologies. However, these incentives may be targeted toward specific technologies, technology types, or sectors based on the public policy objectives. Therefore, when selecting a technology for adoption, it is crucial to identify whether it is eligible for such incentives. If a particular technology is not covered by existing incentive schemes, the financial burden, and thus the overall cost of implementation, may be considerably higher, impacting the financial viability of the project.

4.3 Other Supporting Products

Category Definition

The supporting products category evaluates products that facilitate the use of zero- and near-zero emission products. Evaluated products include charge management software, battery management software (centralized, distributed, and modular BMS), smart grid technologies (stationary battery energy storage, and vehicle-to-grid technologies), fleet management software (telematics, predictive maintenance, smart routing), and payment systems (in-vehicle, subscription services and contactless). More detailed descriptions of each supporting product can be found in Table 30.

Stationary battery energy storage systems like this power bank are able to store energy generated from renewable sources and release it when needed.

Table 30. Product descriptions of supporting products.

Supporting Product	Subtype	Product description
Charge Management Software	**Energy Management System**	Charge management software plays a crucial role in efficiently managing the charging process for electric vehicles. It enables users to monitor and control the charging sessions, optimize charging schedules, and even integrate with renewable energy sources. With advanced features and real-time data analytics, charge management software helps maximize the utilization of charging infrastructure and ensures a smooth charging experience for EV owners.
Battery Management Systems (BMS)	**Centralized BMS**	A battery management system (BMS) is an essential component of battery energy storage systems (BESS). It is responsible for monitoring, controlling, and protecting the battery packs to ensure their safe and optimal performance. BMS encompasses various types, including centralized, distributed, and modular BMS. BMS enables real-time monitoring of BESS health, temperature, voltage, and other critical parameters to ensure safe and efficient battery operation. • A centralized BMS uses one control unit to manage all battery cells in a system. The control is connected to battery cells though multiple cables. • A distributed BMS uses multiple control units to manage battery cells in a system. A board is installed at each cell with a communication cable between the battery and controller. • A modular BMS uses multiple control units. Each unit controls a number of battery cells. Communication cables exist between each control unit.
	Distributed BMS	
	Modular BMS	
Smart Grid Technologies	**Stationary Battery Energy Storage**	A stationary battery energy storage system stores energy and releases it in the form of electricity when needed. The system enables the integration of renewable energy sources, enhance grid stability, and provide backup power during peak demand periods.
	Vehicle-to-Grid Technologies	Vehicle-to-grid technologies enable bidirectional energy flow between electric vehicles and the power grid, allowing EVs to provide grid services, support demand response programs, and optimize energy usage. The California legislature has recently proposed Senate Bill 233[127], mandating that all new electric vehicles (EVs) sold in the state by 2030 should be equipped with bidirectional charging technology. At the time of writing this report, this bill passed the State Senate while it is being considered in Assembly.
Fleet Management Software	**Telematics**	Telematic systems for vehicles refer to integrated use of telecommunications and informatics to provide a range of services and features that enhance vehicle functionality, safety, and convenience. Core services include fleet tracking, diagnostics, navigation, and emergency services, facilitated by on-board sensors, GPS technology, and wireless communication. By monitoring vehicle location and status, these systems contribute significantly to advancements in smart mobility, including optimized fleet management, preventive maintenance, and autonomous driving.

[127] https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202320240SB233

Supporting Product	Subtype	Product description
	Predictive maintenance	Predictive maintenance algorithms analyze vehicle data to identify maintenance needs in advance, optimizing vehicle uptime and reducing maintenance costs.
	Smart routing	Smart routing algorithms help optimize route planning, considering factors like traffic, weather, and charging station availability, to improve fleet efficiency and reduce operating costs.
Payment Systems	**In-vehicle payments**	In-vehicle payment systems enable seamless and convenient payment transactions for EV charging directly from the vehicle.
	Subscription services	Subscription services offer charging plans with fixed monthly fees, providing access to a network of charging stations.
	Contactless payment	Contactless payment options, such as mobile wallets or RFID cards, allow users to make payments without physical contact, enhancing the convenience and accessibility of EV charging services.

Aside from supporting the adoption of zero and near-zero emission technologies, some of these supporting products such as Battery Energy Storage Systems (BESS), Vehicle-to-Grid/Vehicle-to-Everything (V2G/V2X) technologies and charging management solutions can significantly contribute to enhancing power system stability. Power system stability refers to the ability of a power system to regain an equilibrium state after experiencing a disturbance and is crucial in ensuring the continuous and reliable supply of electricity, thereby supporting the smooth functioning of various economic operations. For example, BESS can instantly respond to fluctuations in power demand or supply, providing power during high demand periods or storing energy when supply exceeds demand. V2G/V2X allows electric vehicles to interact with the power grid, either supplying power back during peak times or drawing power in low-demand periods, thus serving as mobile energy storage units. Charging management solutions can intelligently schedule the charging of electric vehicles or other energy storage systems to align with grid conditions, helping to avoid demand spikes that could threaten system stability.

Data Sources and Limitations

Limited information was accessible for many of the supporting products examined. While details on the capital costs of battery management systems, smart grid technologies, and telematics were obtainable, comprehensive information regarding the adoption status of these products was not readily available. This highlights the need for further research and data collection to better understand the current usage and acceptance of these technologies in the market.

Commercialization

Table 31 provides an overview of the available data surrounding capital cost, adoption status and availability of these technologies. As indicated earlier, the cost and adoption data for these supporting products are scarce. For example, our survey responses included two responses on charging management solutions, however, none of them had specific on the potential cost. The first responder indicated that pricing for their charge management system varies depending on factors such as the number of chargers, fleet vehicle size and class, charger voltage, and selected features. They indicated that the cost of the system includes a one-time setup fee and a monthly software subscription fee. The second respondent also did not provide any cost information and mentioned that the price could vary based on the scope of the project and additional information would need to be obtained to determine the pricing. With respect to Vehicle-to-Grid (V2G) technologies, the project team received information from BorgWarner, a vendor that offers high power (60-360kW) DCFC with V2G capabilities. According to the vendor, their product could cost up to $80,000 with an annual maintenance cost of $3,500. Also, in discussion with Nuvve[128], a V2G charging solution provider, their V2G product

[128] https://nuvve.com/technology/. Cost data were acquired through personal communication with Nuvve representatives during the 2023 ACT Expo

could cost anywhere between $45,000 – $60,000 (depending on whether the product is acquired through Sourcewell or not). However, note that these cost estimates are inclusive of the charging solution as well. At the same time, an article by CleanTechnica[129] cites the Alliance for Automotive Innovation, suggesting that the inclusion of V2G technology could add approximately $3,300 to the cost of a new vehicle. This cost is reflected in the table below.

Table 31. Technology characteristics of supporting products

Supporting Product	Subtype	Capital Cost	Adoption Status	Availability
Charge Management Software	**Energy Management System**	NI	NI	30-40 vendors
Battery Management Systems (BMS)	**Centralized BMS**	$300 - $10,000[130]	NI	30-40 vendors
	Distributed BMS		NI	30-40 vendors
	Modular BMS		NI	30-40 vendors
Smart Grid Technologies	**Stationary Battery Energy Storage**	$143 per rated kWh (utility scale)	SoCal Edison: 2,050 MW	30-40 vendors
	Vehicle-to-Grid Technologies	$3,300 for adding the technology to the vehicle	NI	10-20 vendors
Fleet Management Software	**Telematics**	12– $200 per month, per vehicle	NI	30-40 vendors
	Predictive maintenance	NI	NI	20-30 vendors
	Smart routing	NI	NI	10-20 vendors
Payment Systems	**In-vehicle payments**	NI	NI	10-15 vendors
	Subscription services	NI	NI	10-20 vendors
	Contactless payment	NI	NI	20-30 vendors

NI indicates "no information" or a knowledge gap
Blank indicates not commercially available

Other Supporting Product Technology Considerations

Similar to the discussion provided for vehicles and infrastructure, there are other factors that need to be considered when consumers, whether private or public entities, consider the acquisition of clean technology supporting products. The following outlines a series of additional criteria that should be taken into account when evaluating supporting product technologies. More extensive criteria for consideration are detailed in Appendix E.

Interoperability: Similar to the integration metric discussed for infrastructure, this criterion is a crucial factor when evaluating zero-emission supporting products. Interoperability refers to the ability of different systems, devices, applications, or products to communicate, exchange data, and use the information that has been exchanged. This is integral to building an efficient, user-friendly, and universally accessible network for zero-emission technologies. With respect to payment systems, interoperability means that customers should be able to use a variety of payment methods at any charging or fueling station, regardless of the service provider. The technology should support a diverse range

[129] https://cleantechnica.com/2023/05/08/california-ponders-v2g-mandate/
[130] https://poweringautos.com/how-much-does-a-battery-management-system-cost/

of payment platforms, including credit cards, mobile payments, and digital wallets. This not only enhances user convenience but also encourages the use of zero-emission technologies by removing barriers related to payment modes. Interoperability is equally critical for charging management solutions. A fully interoperable system would mean that the charging management system should be capable of communicating with the grid and other smart devices to optimize charging schedules based on electricity demand, pricing, and the state of charge of the vehicle. Such a system should also work with various charging technologies, energy management systems and conform to grid regulations.

Resilience: When evaluating zero-emission supporting products, it is important to consider how well they integrate with the power grid and contribute to its resilience. For consumers, this involves analyzing a technology's capacity to maintain power system stability, manage variable loads, and support system recovery after disruptions. It also includes assessing whether a technology can help the power system adapt to evolving conditions, like the increasing penetration of intermittent renewable energy sources. For example, BESS and charging management solutions offer good examples of technologies that can bolster grid stability and resilience. BESS, particularly when integrated with renewable energy sources, can significantly enhance grid resilience. It can supply power during disruptions or peak demand periods, acting as a backup source to prevent outages. Moreover, BESS can absorb surplus power generated during off-peak times, promoting a more efficient use of renewable energy and enhancing the balance between power generation and consumption. For instance, if a sudden influx of power due to high wind speeds threatens the stability of the grid, BESS can store this excess power, helping to maintain grid stability. Similarly, charging management solutions for EVs can also contribute to grid resilience. They can manage the charging of EVs to align with grid conditions, helping to balance power demand and supply. V2G technology is also an excellent example of how zero-emission supporting products can contribute to grid resilience. For instance, during peak electricity demand periods, instead of firing up an additional power plant or importing power, grid operators can draw upon the energy stored in EV batteries to meet the additional demand. EV owners can set their vehicles to provide power back to the grid when the battery is sufficiently charged, and the vehicle is not in use. This not only helps balance the grid, reducing the risk of blackouts, but can also provide an extra source of revenue for EV owners who are compensated for the power they provide.

Intelligent Transportation Systems: When evaluating zero-emission supporting products, one important criterion is their ability to contribute to the efficient use of existing transportation systems. This involves assessing if the technology can help reduce congestion, improve traffic management, or facilitate better route planning, thus optimizing the overall transportation network. Fleet management systems offer an excellent example of such technologies. They utilize real-time data to monitor vehicle locations and statuses, allowing fleet operators to effectively manage their vehicles and schedule optimal routes. By employing real-time traffic data, these systems can predict and avoid congested areas, reducing travel time and enhancing the overall efficiency of fleet operations. As a result, energy consumption and emissions from vehicles, especially in the case of large fleets, can be significantly reduced. Another exemplary technology is smart routing systems. These technologies use advanced algorithms and real-time traffic information to provide optimal routes for drivers. They can guide vehicles along less congested routes and recommend optimal departure times to avoid rush hours, enhancing the overall flow of traffic. In addition to reducing congestion and travel time, these smart systems can also lead to significant energy savings and emission reductions, particularly beneficial for EVs by optimizing the usage of battery charge. Furthermore, these technologies can contribute to the creation of a connected transportation system, integrating various elements like vehicles, infrastructure, and traffic management systems. Such an integrated system could intelligently manage traffic flow and vehicle movement, further enhancing the efficiency and sustainability of transportation networks

4.4 Knowledge Gaps

As highlighted in the previous sections, there are still significant knowledge gaps related to zero and near-zero emission technologies. This lack of information becomes particularly pronounced for supporting products and to some extent charging and fueling infrastructure, where a comprehensive array of data is not readily available to assist stakeholders in making informed procurement decisions or in crafting policies that champion particular technologies. The scarcity of details regarding cost, current adoption status, longevity, and interoperability make it challenging to accurately evaluate and assess the potential and efficacy of these emerging technologies. For instance, while there is a wealth of information available regarding the adoption status of vehicles and infrastructure in the region, there is a noticeable gap when it comes to specific supporting products. Data on products such as charging management solutions or telematics, which are crucial for a seamless integration and operation of these technologies, is notably sparse. This absence of data hinders a comprehensive understanding of the level of adoption and use of these auxiliary systems.

In addition to the existing knowledge gaps surrounding clean technologies themselves, there is also a pronounced gap in our understanding of how these technologies will evolve and incorporate within the broader transportation ecosystem. As we stand at the cusp of a transportation revolution driven by clean technologies, it becomes important to comprehend not just the intricacies of the technologies in isolation but also their dynamic interplay with existing systems, infrastructures, and user behaviors. The following list provides some of the critical knowledge gaps where further investigation and research are needed to advance the successful adoption of clean technologies:

- **Consumer Behavior**: Understanding and influencing consumer preferences and behaviors is a critical factor in facilitating the successful transition to cleaner transportation technologies. Consumer choices regarding vehicle selection, charging habits, and the acceptance of alternative transportation modes play a pivotal role in shaping the adoption and usage of cleaner transportation options. To achieve widespread acceptance and uptake of these technologies, it is imperative to delve deeper into consumer preferences, motivations, and barriers that influence their decision-making processes. Comprehensive research should explore factors such as cost considerations, range anxiety, infrastructure availability, and the perceived benefits of cleaner transportation options. This research can help identify effective strategies to influence consumer behavior, such as targeted educational campaigns, financial incentives, and the development of convenient and reliable charging infrastructure.
- **Effective Incentive Program Design**: There exists a significant knowledge gap concerning the design of effective incentives that can minimize the presence of free riders[131], and maximize the cost-effectiveness of programs promoting clean transportation technology adoption. This gap pertains to understanding the myriad of factors that influence consumer preferences and how they can be factored into incentive program design to ensure that resources are not expended on those who would have adopted clean technologies even without incentives. Also, it revolves around discerning the optimal mix of incentives to maximize adoption while minimizing program costs. This includes considerations like whether to provide upfront cost reductions, ongoing operational cost savings, or non-monetary benefits such as preferential parking or access to high occupancy vehicle lanes. By filling this gap, regional authorities can design incentive programs that are not

[131] individuals or entities who would have acquired a clean transportation technology even without the incentive, but who take advantage of the program to reduce their costs

only more cost-effective, but also have a greater potential to influence consumer behavior and promote widespread adoption of clean transportation technologies.

- **Technological Advancements**: Improvements in lightweight materials, energy-efficient design, and advanced propulsion systems can significantly reduce the energy consumption and environmental impact of all types of vehicles. Such advancements will be needed for the zero-emission technology including BEVs to become a viable solution across all transportation modes.
- **Battery Technology**: Significant breakthroughs in battery technology are crucial for the successful adoption of battery electric technology, particularly in the heavy freight sector. The heavy freight industry requires vehicles with substantial power and range capabilities to handle long-distance hauling and heavy loads. Current battery technology faces limitations such as limited energy density and long charging times, which impede its viability in meeting the demanding requirements of the heavy freight sector. Additionally, current battery technology also poses the issue of significant weight addition to vehicles or equipment. The additional weight of batteries can disrupt the regular operation of heavy freight vehicles, impacting their payload capacity, maneuverability, and overall efficiency. Breakthroughs in battery technology, such as advancements in energy storage capacity, faster charging rates, and improved durability, are necessary to address these challenges. Addressing issues related to raw material availability and recycling will also be essential.
- **Longevity:** There are several uncertainties and knowledge gaps regarding the longevity of zero-emission technologies, particularly those used in EVs. The primary source of uncertainty is battery degradation, which can cause capacity loss and reduce overall range and performance. Environmental factors such as temperature and humidity can also impact performance and longevity, as can the durability of other components in EVs such as electric motors and power electronics. While ongoing research and development efforts are expected to improve our understanding of these factors, there is still a need for more long-term data on how zero-emission technologies will perform over the lifetime of a vehicle.
- **Safety**: Hydrogen is a highly flammable gas and requires special handling and storage procedures to ensure safety. While FCEVs are designed to be safe, there is still some concern about the potential for accidents or explosions. At the same time, EV batteries can pose safety risks, particularly in the event of a crash or fire. Lithium-ion batteries, which are commonly used in EVs, can catch fire or explode if they are damaged or punctured. There is a need for more research on how to prevent these types of incidents and how to safely manage and dispose of damaged or end-of-life batteries.
- **Ultra-High Power Charging Infrastructure**: While ultra-high power charging infrastructure for electric vehicles offers significant advantages, such as faster charging and reduced range anxiety, there are still several knowledge gaps that need to be addressed. Ultra-high-power charging can cause additional stress on EV batteries, which can lead to faster degradation and reduced battery life. There are also safety concerns related to the high levels of heat and electrical current generated by ultra-high power charging stations, and there is a need for more research on how to minimize these risks.
- **EVSE Standards**: There is currently no universal standard for EVSE. Different charging stations use different connectors and communication protocols, which can make it difficult for drivers to find a compatible charging station. This lack of standardization also makes it difficult for charging station manufacturers to scale up production and for utilities to manage the demand for electricity from EV charging. For example, currently DC fast charging infrastructure could use three different types of connectors: CHAdeMO, Combined Charging

System (CCS), and North American Charging Standard (NACS). While there have been national and regional efforts to standardize technology and improve features such as vehicle communication protocols[132], the lack of universal EVSE standards presents significant challenges and barriers for large-scale EVSE deployment.

- **Grid Integration**: As the number of EVs on the road continues to increase, there is a growing concern regarding the potential impact on the electrical grid. Without adequate planning and integration strategies, the simultaneous charging of a large number of EVs could pose challenges to grid stability and even lead to blackouts. It is crucial to conduct further research to better comprehend the long-term demand for EV charging and its implications for electricity generation and distribution. This research should delve into understanding the patterns and behavior of EV charging, assessing the required infrastructure upgrades, and exploring innovative solutions such as smart grid technologies and demand response programs.
- **Energy Storage**: The intermittent nature of renewable energy sources, such as wind and solar, presents challenges when it comes to charging zero-emission vehicles. As these energy sources rely on natural elements, their generation is subject to variability and intermittency. To mitigate this challenge, energy storage solutions, such as batteries or hydrogen storage, can play a vital role in storing excess renewable energy during periods of high generation and making it available for use during periods of low generation. However, further research is necessary to enhance the effectiveness and efficiency of energy storage systems specifically tailored for transportation applications. This research should focus on optimizing storage capacity, exploring advanced storage technologies, and developing intelligent energy management systems to ensure a seamless integration of renewable energy into the transportation sector.
- **Cybersecurity**: As vehicles become more connected and reliant on software and communication systems, it brings about a new set of cybersecurity risks. The integration of advanced clean technologies opens the possibility of hackers remotely accessing and compromising the vehicle or its systems, which can have serious implications for driver safety and privacy. To ensure the secure and resilient operation of clean technologies, further research is needed in developing robust cybersecurity measures. This research should encompass the exploration of encryption protocols, secure communication frameworks, and intrusion detection systems. Additionally, collaboration between automotive manufacturers, software developers, and cybersecurity experts is crucial to identify and address potential vulnerabilities, proactively prevent cyber-attacks, and swiftly respond to any emerging threats.
- **Automation and Artificial Intelligence**: Given the rapid advancements in clean technologies, a significant knowledge gap exists regarding the role of Automation, Artificial Intelligence (AI), and other IT developments in influencing their deployment and usage. As the transportation sector moves steadily toward a digitally-driven future, the integration of clean technologies with AI and automation holds the potential for transformative change. However, a lack of clear understanding of how these digital innovations will impact adoption patterns, operational efficiencies, and user behaviors with clean technologies not only complicates accurate forecasting and strategic planning but also risks overlooking potential synergies or challenges arising from the merger of clean technology and advanced digital tools.

[132] California Public Utilities Commission, Resolution E-5175, available at https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M424/K359/424359510.PDF

5. Challenges and Barriers to Adoption

This section includes a summary of existing barriers and concerns related to the deployment of ZEV and NZEV technologies in the SCAG region. These barriers encompass various aspects, including cost, technology readiness, charging and fueling infrastructure access, technology awareness, and regulatory support.

5.1 Cost

The high cost of zero and near-zero emission technologies can significantly impede their adoption. The higher upfront cost of these technologies compared to traditional combustion engines can make it difficult for individuals and businesses to justify the investment, particularly for those with limited financial resources. As shown earlier in this report (Tables 10, 14, 15, 18, and 21), the upfront cost of zero and near-zero emission technologies is still much higher as compared to their conventional counterpart. For instance, a battery electric refuse truck may cost $200,000 more upfront compared to a diesel model (Table 1) and a conventional passenger locomotive only costs around $2.5 million, while its BEV models can cost anywhere between $10 to $12 million.[133] The high cost of these technologies is driven by a number of factors, including the cost of research and development, the need for specialized materials and components, and the limited scale of production. As production volumes increase, the cost of manufacturing can be reduced through economies of scale. However, when production volumes are low, the cost of manufacturing is higher, which can drive up the cost of the final product. Current CARB regulations set targets and fleet sales requirements, providing a signal for manufactures to scale up production. Figure 26 presents an example of declining costs of new technologies that CARB has projected as the market expands.[134] As indicated, the purchase price for clean technology vehicles is not anticipated to reach parity with that of their conventional counterparts. Nonetheless, as demonstrated in Section 4.1, some of these technologies present significant cost savings when evaluated based on their Total Cost of Ownership (TCO). Similarly, an NREL analysis has also demonstrated that ZEVs can achieve cost parity (in terms of TCO) with ICEs before 2035 for all MDVs and HDVs, however, the upfront cost is expected to remain higher than their counterpart ICE vehicles for the foreseeable future[135]

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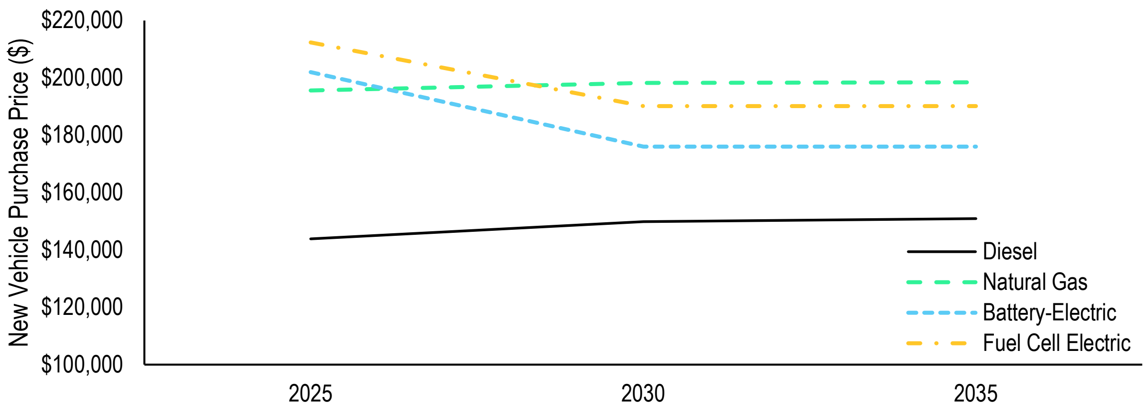
[133] Argonne National Laboratory, Total Cost of Ownership for Line Haul, Yard Switchers and Regional Passenger Locomotives Preliminary Results, https://www.energy.gov/sites/prod/files/2019/04/f62/fcto-h2-at-rail-workshop-2019-ahluwalia.pdf

[134] California Air Resources Board, Advanced Clean Fleets Regulation: Appendix G. Total Cost of Ownership Discussion Document, https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/acf22/appg.pdf

[135] National Renewable Energy Lab, Decarbonizing Medium-& Heavy-Duty On-Road Vehicles: Zero-Emission Vehicles Cost Analysis, https://www.nrel.gov/docs/fy22osti/82081.pdf. Slide 45 demonstrates the vehicle cost projections.

Figure 26. Class 8 Day Cab Tractor New Vehicle Price Forecast.



The difficulties in complying with various performance standards and regulatory requirements can also contribute to the high cost of these technologies. Regulations related to safety, emissions, and vehicle standards can be complex and costly to navigate, particularly for smaller businesses. Compliance with these regulations can drive up the cost of developing and manufacturing zero and near-zero emission technologies. These factors can contribute to higher costs for consumers, which can make these technologies less accessible to a wider range of individuals and businesses.

5.2 Technology Readiness

A criterion for inclusion in the compendium was commercialization status, meaning the technology was available or close to being available. Upon investigation, our survey of products also included technologies in their early stages of development and may not be as reliable as conventional vehicles/equipment. The rail sector faces a significant commercialization barrier due to technology limitations, where less than five models are currently available for each application (Table 21). For example, the large size and weight of freight trains pose unique challenges for zero-emission technology and battery-electric systems may not have the necessary range or power to meet the demands of heavy freight trains without frequent recharging, which can significantly impact operations. Similar issues of vehicle range and compromised vehicle payload due to added battery weight also exist in the on-road heavy-duty truck sector (Table 15). While the emerging ultrafast charging techniques such as MCS may alleviate these concerns, the technologies are yet to be ready for commercialization and large-scale deployment. In another example, one of the primary challenges in the development of ultra high-power charging systems is the lack of reliable technology that can withstand the high-power demands of charging electric vehicles quickly. These charging systems require advanced power electronics and cooling systems to manage the high-power levels involved. In addition, existing technologies can also be further improved to ensure industry sustainability and business profitability. For example, the dependence of battery manufacturing on critical materials should be lessened given the limited mineral resources and the overall manufacturing process of new technologies also needs to be optimized to further reduce capital cost. Developing and improving these systems requires significant investment in research and development as well as rigid and reliable testing protocols to ensure reliability and safety.

5.3 Lack of Charging and Fueling Infrastructure

The availability and accessibility of infrastructure needed to power clean technologies, such as charging or hydrogen refueling stations can be a major barrier to adoption. The insufficient access to infrastructure can significantly limit the practicality of using these technologies. For example, it has been estimated that the SCAG region may need between 185,000 and 564,000 EVCS by the end of the decade, while the region currently only hosts 33,000 Level 2 and 3,700 DCFC stations (Figure 20).[136] The lack of charging access poses severe concerns of regional transition to zero-emission medium and heavy-duty vehicles as the high-power demands and limited range of these vehicles require specialized charging infrastructure. With respect to hydrogen fueling stations, the California Fuel Cell Revolution has projected that 1,800 stations will be needed for the entire state to support the deployment of 1.8 million FCEV operated on-road[137], while there are in total 54 available retail hydrogen stations in California as of August 2023.[138] A majority of these stations will fall within the SCAG region given the critical role it plays in regional passenger and freight transportation, and expanding the current network to meet regional demand requires significant investment in research and development, infrastructure, and coordination among stakeholders in the next decades (Figure 23).

In addition, in order to successfully transition line-haul trucks operating interstate to zero-emission technologies, a national network of charging or fueling infrastructure is a necessity. These heavy-duty trucks, often traveling vast distances across states, will rely heavily on the availability and accessibility of charging or refueling stations. Federal incentive programs such as NEVI and the Clean Heavy-Duty Vehicle Program can facilitate the buildout of infrastructure across state borders, but they cannot ensure sufficient access can be provided to interstate transportation. Due to inconsistent ZEV adoption targets, the time alignment for infrastructure buildout will also be difficult to navigate. The installation of charging and refueling infrastructure for medium and heavy-duty vehicles can be costly and complex, requiring significant investment in electrical infrastructure and coordination among government agencies, utility companies, and private sector stakeholders.

The challenge faced by freight rail is similar to the one mentioned earlier but on a much larger scale. Although battery-electric and hydrogen fuel cell technologies have been developed and utilized in certain light rail and commuter rail systems, achieving zero emissions for freight locomotives necessitates a substantial investment in nationwide charging or fueling infrastructure.

5.4 Lack of Consumer Knowledge & Awareness

According to a recent poll conducted by the Associated Press and the University of Chicago, more than 45% of respondents indicated that they would not purchase an electric vehicle as their next car.[139] Consumers might not be aware of the benefits of zero and near-zero transportation technologies or may be hesitant to switch from their traditional vehicles, which can be a significant barrier to adoption. One of the main reasons for this lack of knowledge and awareness is the limited availability of information and education about these technologies. Consumers may not be aware of the different types of zero and near-zero emission technologies available, their performance characteristics, or the potential cost savings associated with them. Furthermore, there may be misconceptions about the reliability and safety of these technologies. In a survey conducted by SCAG, the top concerns for EV adoption by survey respondents are purchase cost, limited range, lack of public or home access to EV charging, and preferred vehicle type not available.[136] While general consumers may have doubts about reliability of battery-electric vehicles, or the safety of hydrogen fuel cell vehicles, commercial fleets and owners-operators may be concerned with the range,

[136] Southern California Association of Governments, SCAG EV Charging Station Study, https://scag.ca.gov/sites/main/files/file-attachments/final_report_and_regional_pev_plan.pdf?1684341506

[137] California Air Resources Board, Hydrogen Station Network Self-Sufficiency Analysis per Assembly Bill 8, https://ww2.arb.ca.gov/sites/default/files/2021-10/hydrogen_self_sufficiency_report.pdf

[138] Hydrogen Fuel Cell Partnership, FCEV Sales, FCEB, & Hydrogen Station Data, https://h2fcp.org/by_the_numbers

[139] 2023 AP-NORC/EPIC Energy Survey, https://epic.uchicago.edu/wp-content/uploads/2023/04/EPIC-Energy-Policy-Survey-2023_Topline.pdf

charging time, and the additional weight of battery-electric vehicles. According to a recent study conducted by NV Energy, 49% fleet respondents indicated limited driving range remains the biggest barrier to purchase or lease EV, and both charging infrastructure logistics and limited hauling capacity are also among the top 5 choices.[140] In addition, while there have been numerous policies and programs at federal, state, and local level to support the deployment of ZEV and NZEV technologies, consumers (both general consumers as well as fleet) may have limited understanding to fully digest and take advantage of these existing programs and the administrative barriers are high. The lack of consumer knowledge and awareness can also impact demand for these technologies. Without a significant level of demand, manufacturers may be less likely to invest in the research and development necessary to improve the technology, reduce costs, and expand availability.

5.5 Regulatory support

Performance Targets

The lack of robust regulatory support in setting performance targets for vehicles and equipment serves as a significant barrier to the widespread adoption of clean transportation technologies. Regulation plays a critical role in establishing the benchmarks and standards to which manufacturers should aspire, incentivizing technological advancements and encouraging market competitiveness. However, without specific, ambitious targets in place, manufacturers may lack the incentive to develop and integrate cleaner technologies into their vehicles and equipment, impeding the industry's transition toward cleaner technologies. Furthermore, this regulatory gap may contribute to uncertainty among potential adopters of clean technologies, as they cannot rely on a standard baseline of performance or efficiency. A notable example of the lack of ambitious goals and targets slowing technology advancement is the state of rail technology in the U.S., specifically in the context of zero emission rail systems. The most common form of rail propulsion in the country is still diesel-electric, which is not only less efficient but also more environmentally detrimental than zero-emission alternatives. Other countries, such as Germany[141], have already started testing and deploying hydrogen-powered trains. Despite the technology's potential, the U.S. has been slow to set targets or incentives for the adoption of hydrogen or electric rail propulsion.

Standardization

The lack of regulatory guidance in establishing design and standard protocols for clean technology infrastructure is a significant impediment to the uptake of these technologies. Regulatory parameters play a key role in promoting the creation of infrastructure that is universally adaptable and highly efficient, ensuring its suitability for a wide range of vehicles and equipment. However, in the absence of such regulatory frameworks, issues of inconsistency and incompatibility may surface across distinct charging and refueling stations, leading to user inconvenience and hindering adoption. This regulatory void also fosters uncertainty among infrastructure developers and investors, potentially slowing the pace of infrastructure development and diversification. Consequently, without a well-structured, standardized regulatory approach to ZEV infrastructure, the journey toward a fully clean and sustainable transportation network faces notable challenges.

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[140] NV Energy, Fleet Customer EV Survey 2022, https://www.nvenergy.com/publish/content/dam/nvenergy/brochures_arch/cleanenergy/ertep/Fleet-Customer-EV-Survey.pdf

[141] https://www.smithsonianmag.com/smart-news/hydrogen-powered-passenger-trains-are-now-running-in-germany-180980706/

Incentives

The lack of regulatory support, such as incentives for purchasing zero and near-zero transportation technologies or clear performance targets, can also be a barrier to adoption. Furthermore, inconsistent, or ambiguous regulations can create uncertainty and slow down the development and adoption of these technologies. Varying regulations across different jurisdictions create a complex and uncertain landscape for businesses and individuals seeking to invest in and deploy these technologies. Inconsistencies may include conflicting emission standards across state and national borders, differing incentives and subsidies or frequent changes to existing programs, and disparate charging standards or operating protocols. These inconsistencies not only lead to confusion but also impede the scalability of these clean technology solutions. The lack of harmonization between federal and state regulations creates barriers to market entry and expansion, discouraging potential adopters and stifling innovation in the clean transportation sector.

Government support in the form of financial incentives is crucial to address the cost disparity, also known as the "green premium," between clean technologies and conventional counterparts in the near term. These financial incentives help bridge the affordability gap, making clean technologies more accessible and attractive to consumers and businesses. By offsetting the higher upfront costs associated with clean transportation solutions, governments can incentivize adoption and drive market demand. This support is particularly important until economies of scale are achieved, enabling the production and deployment of clean technologies at a larger scale, which can help close the cost gap organically over time. Without this support, the adoption of clean transportation technologies may be significantly slowed down or even stalled altogether and resulting in uneven and delayed adoption across different socioeconomic groups.

Permitting

Regulatory guidelines for permitting can streamline the deployment of crucial infrastructure such as charging and fueling stations and clarify the legal and safety requirements for clean technology implementation. However, the absence of clear and unified permitting processes can result in bureaucratic complexities and delays, hindering efforts to build out necessary infrastructure and adopt clean technologies at a larger scale. This lack of standardized regulatory protocols can also contribute to significant disparities in the availability and accessibility of clean technology infrastructure across different regions, thereby further inhibiting widespread adoption.

6. Recommendations

As part of its ongoing metropolitan planning efforts, SCAG can facilitate regional discussion with stakeholders on potential next steps, roles, and responsibilities to better facilitate the advancement of the clean transportation technologies in the region. This section summarizes a comprehensive list of recommendations to facilitate the regional transition to ZEV and NZEV technologies.

6.1 Targeted Incentive Programs

State and federal funding and grants can be used to encourage regional ZEVs and NZEVs deployment. For instance, in February 2022, SCAG awarded a total of $6.75 million to six projects across the region designed to promote clean transportation and reduce harmful emissions during last-mile freight and delivery operations. These six projects are in addition to 26 clean-energy projects that awarded a total of $10 million in 2021 under SCAG's Last-Mile Freight Program, funded through the state's Mobile Source Air Pollution Reduction Review Committee (MSRC).[142]

While there are a number of incentive programs at the state and federal level, there is still a significant gap for low- and moderate-income communities to deploy NZEVs and ZEVs. For example, a study conducted in California has found income- and advantage-based disparities in the adoption of EVs through CVRP. Equity analysis indicated that the bottom 75% based on median income census tracts receives only 38% of the total PEVs subsidies, while the top 12.5% of the most advantaged census tracts receives a quarter of the total rebate amount. It was also evident that the gradual closing of EV incentive equity gaps is accelerated in the aftermath of an income-cap and low-income rebate increase policy, which was implemented in 2016.[143] Therefore, it is important to develop and adopt more equitable incentive mechanisms, potentially including income-caps and tiers, adding pre-owned vehicles to subsidized inventory, and taking into consideration regional socio-economic characteristics in order to bridge existing disparities in the adoption of clean vehicles.

Given the existing grants and funding programs discussed in Section 2, potential additional incentive programs should focus on reducing the upfront costs of ZEV and NZEV equipment and prioritizing clean technology deployment in Disadvantaged Communities (DACs) or low-income communities (LICs).

- **Purchase incentives:** Provide financial incentives to consumers who purchase clean transportation technologies, such as electric or hydrogen fuel cell vehicles. These incentives can take the form of rebates, or grants, such as targeted incentive programs for pre-owned vehicle purchase and electrical mobility, or programs designated to low-income applicants, small businesses or independent owner-operators, etc.
- **Infrastructure incentives:** Provide incentives for the installation of infrastructure, such as charging or refueling stations, to support the use of clean transportation technologies. This can include grants or other financial support for the construction or operation of these facilities. SCAG has already published an EV Charging Station Funding Guide[144] that documented all the existing funding opportunities provided by federal, state, and local jurisdictions within in the region to reduce the cost of EV infrastructure or EVs for municipal and commercial fleets specific to Passenger Electric Vehicles (PEV). Additional programs may be needed to

[142] California Association of Councils of Governments, SCAG Awards $7 Million for Last Mile Freight Electrification, https://calcog.org/scag-last-mile-freight-electrification/
[143] Guo et al., Disparities and Equity Issues in Electric Vehicles Rebate Allocation, Energy Policy (154), 2021, https://www.sciencedirect.com/science/article/pii/S0301421521001609
[144] SCAG, EV Charging Station Funding Guide, https://scag.ca.gov/sites/main/files/file-attachments/ev_funding_guide.pdf?1684340967

accelerate the deployment of charging and fueling infrastructure within DACs and LICs, and to encourage clean and renewable energy generation and distribution.

- **Access incentives:** These types of incentives can promote the use of clean transportation technologies in certain areas or for certain purposes. For example, cities and local jurisdictions can fund programs such as free parking or toll discounts for electric or hydrogen fuel cell vehicles and launch low or zero-emission zones. As early as 2020, SCAG already partnered with the Los Angeles Cleantech Incubator (LACI) to launch the country's first Zero Emission Delivery Zone (ZEDZ) Pilot in the City of Santa Monica, followed by a similar program launched in Los Angeles in 2021.[145,146] The pilot program lasted for about two years and incentivized clean, electric delivery vehicles by offering priority curb space in a one-square mile test zone in Downtown Santa Monica and along Main Street. Funded through a DOE grant, SCAG and LACI built upon these efforts to harness curb management to prioritize ZEVs by extensively scaling to deployments in two U.S. metropolitan areas with the worst air quality, the Los Angeles area and Pittsburgh, PA. By utilizing data – both from initial deployments in the two Los Angeles area cities and Pittsburgh enabled by computer vision – this program informed real-world implementation and scale up of urban zero emission curb zones and provided cities across the country with a roadmap for using curbside management as a key tool to accelerate electrification and improve efficiency and accessibility in the transportation sector, specifically for delivery and TNCs. This project demonstrates a role for access or operational incentives. Providing more similar funding opportunities can help deploy, implement, and utilize ZEV or NZEV technologies in various areas across the region.
- **Research and development incentives**: Provide funding or other support for research and development of new clean transportation technologies, including funding for research institutions or startup companies. As mentioned in Section 5, large-scale deployment of ZEV and NZEV technology will rely heavily on technological advancements, and funding can support scientific research that aim to reduce battery weight and cost, optimize battery manufacturing process, improve charging time and cycle, advance V2G technology, upgrade current clean vehicle design, and generate clean upstream energy.

6.2 Public Education & Outreach

Public education and outreach play a critical role in accelerating the adoption of clean technologies. By raising awareness and knowledge about the benefits and availability of clean technologies, the public can make informed choices and actively participate in the clean technology transition. Additionally, effective outreach efforts can address misconceptions, dispel myths, and alleviate concerns surrounding clean technologies, fostering greater acceptance and confidence in their use. The project team has identified several outreach and engagement strategies that can support identifying, understanding, and addressing concerns and barriers related to regional clean technology deployment. Public education campaigns can increase awareness of the benefits of zero and near-zero transportation technologies, such as reduced emissions and lower operating costs. These campaigns can include information on available technologies, incentives and other government support programs, and how to access them. Existing programs and resources can be leveraged, such as the General Assembly[147], the Regional Planning Working Groups

[145] City of Santa Monica, Zero Emission Delivery Zone, https://www.santamonica.gov/zero-emission-delivery-zone
[146] City of Los Angeles, Zero Emission Delivery Zone, https://clkrep.lacity.org/onlinedocs/2021/21-0147_rpt_dot.pdf
[147] SCAG, General Assembly, https://scag.ca.gov/leadership-general-assembly

(RPWG)[148] or through sponsorships or collaborations with others. Specific education and outreach programs can include:

- **Informational campaigns**: This could include a platform (e.g., website, smart phone app, or article subscriptions service) that can help **to educate** the public about the benefits of zero and near-zero transportation technologies. These campaigns can include information about the technologies themselves, available government support programs and incentives, and the environmental and economic benefits of switching to cleaner transportation options.
- **Test drive events**: Local manufacturers and dealerships can organize test drive events for zero and near-zero transportation technologies to provide the public with hands-on experience and demonstrate the practicality and effectiveness of these technologies.
- **Workshops and seminars**: Workshops and seminars are useful tools to educate the public about the technical aspects of zero and near-zero transportation technologies, such as charging or refueling infrastructure, battery technology, and energy management systems.
- **Public-private partnerships**: Collaboration between public and private sector partners, such as auto manufacturers or technology companies, can support joint education and outreach events, such as technology showcases or seminars.
- **Community events**: Collaboration between local jurisdictions, communities, and non-profit organizations to leverage community events, such as fairs and festivals, can promote zero and near-zero transportation technologies and provide information about government support programs and incentives. Through the recent PEV Study, SCAG conducted such outreach at 15 community events.

6.3 Building Codes

Local jurisdictions can implement building codes that encourage the development of infrastructure to support zero and near-zero transportation technologies. For example, in early 2023, the City of Los Angeles has just announced its amendments to its previous code, the 2020 Los Angeles Green Building Code (GBC) to increase requirements for electric vehicle parking. The updated GBC has set a 30% EV capable requirement for multifamily developments within the city.[149] Building codes can play an important role to ensure access to charging for multifamily housing, commercial districts, hotels, and recreation areas, etc. In addition, they also help to improve accessibility for people with disabilities. Several building code updates that local jurisdictions within the region can consider include:

- **EV-Ready parking**: Requiring new developments to have a certain number of parking spaces that are "EV-Ready," means they have the necessary infrastructure in place to support the installation of electric vehicle charging stations. This can include provisions for conduit, wiring, and other necessary electrical infrastructure for as many variations of zoning as possible.
- **EV-Only parking**: Designated "EV-Only" parking spaces can help to encourage the use of electric vehicles and promote the development of charging infrastructure.

[148] SCAG, Regional Planning Working Groups, https://scag.ca.gov/regional-planning-working-groups
[149] City of Los Angeles Department of Building and Safety, Green Building, https://www.ladbs.org/forms-publications/forms/green-building

- **EV charging infrastructure in existing buildings**: Requiring the installation of EV charging infrastructure in existing buildings, such as parking garages and office buildings, can help to expand the availability of charging infrastructure and make it more convenient for electric vehicle owners. Local governments may also establish policies where other building upgrades trigger the need for parking to be become EV ready.
- **Green building codes (GBC)**: Adoption of GBCs could require new buildings to meet certain sustainability standards, such as energy efficiency and the use of renewable energy sources, informed by best practices that have already been developed and implemented by sister agencies such as City of San Diego's Zero Emissions Municipal Buildings and Operations Policy (ZEMBOP).[150] This can help to promote the adoption of zero and near-zero transportation technologies, as they are often used in conjunction with renewable energy sources.

6.4 Land Use & Zoning

Land use policies, and zoning regulations are also effective strategies at the local level to ensure charging and fueling is an allowed land use (either as an accessory or a principal use) in a variety of zoning classifications and to promote adoption of zero and near-zero emission technologies. Innovative planning and local development projects aimed at optimally coordinating land use with transportation measures to enhance mobility, livability, prosperity, and sustainability within the region will help local jurisdictions to balance future mobility and transportation needs with economic, environmental, and public health goals. Specific examples to update land use and zoning policies include:

- **Leverage Public Property:** Cities and municipalities can identify and allocate public land for ZEV infrastructure development, such as government-owned parking lots, parks, or underutilized spaces. This can help reduce land acquisition costs, streamline the development process, and provide accessible charging and fueling facilities to the public. The Los Angeles Department of Water and Power (LADWP), for example, has installed chargers on streetlamp posts near curbside parking through its incentives for low-income households to adopt EVs.[151]
- **Land Banking:** Local governments can develop policies and programs to acquire and hold land specifically for future ZEV infrastructure development. This proactive approach can help ensure that suitable land is available as demand for ZEV infrastructure increases.
- **Amend Zoning and Land Use Regulations:** Cities and counties can revise zoning and land use regulations to facilitate ZEV infrastructure development. This could include permitting charging stations in residential and commercial zones and creating designated zones for hydrogen refueling stations. For example, ever since Petaluma banned the creation, expansion, reconstruction, and relocation of gas stations in 2021, multiple California cities have also been consider taking similar measure through zoning amendment to encourage the transition to stations that serve electric and hydrogen-powered vehicles.[152]
- **Streamline Permitting Processes:** Local jurisdictions can simplify and expedite permitting processes for ZEV infrastructure projects, reducing bureaucratic hurdles and approval times. This can encourage private

[150] City of San Diego, Municipal Energy Implementation Plan, https://www.sandiego.gov/sites/default/files/city_of_san_diego_municipal_energy_implementation_plan_0.pdf

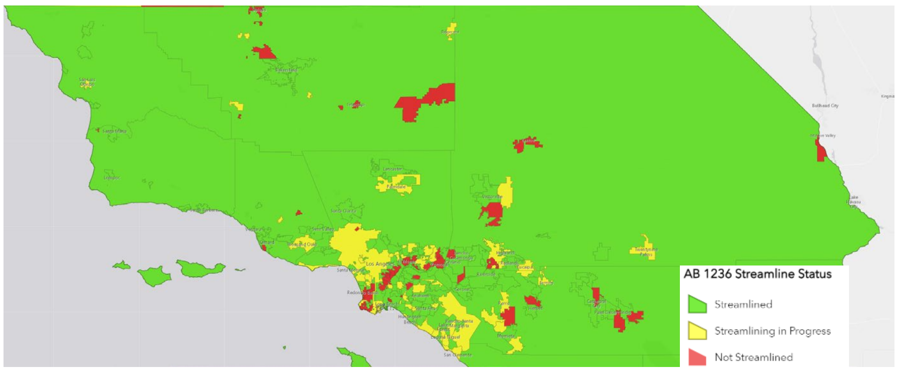
[151] LA Lights, Streetlight EV Charging Stations, https://lalights.lacity.org/connected-infrastructure/ev_stations.html

[152] Los Angeles Times, Petaluma first city in nation to ban new gas stations, https://www.latimes.com/california/story/2021-03-04/sixteen-gas-stations-for-60-000-people-thats-enough-petaluma-says

developers to invest in ZEV infrastructure. AB 1236 (Chiu, 2015), also known as California's permit streamlining law, requires all jurisdictions to enact and implement a streamlined permitting process for charging station applications.[153] The "EVCS Permit Streamlining Map" shows the status of permit streamlining across the region (Figure 26). Most of the local jurisdictions have already streamlined the permitting process and some also hosted listening sessions to better understand regional barriers facing EVCS permitting.[136]

- **Incentives for developers**: Local governments can secure incentives for developers to include EV charging infrastructure in their projects, such as by offering tax credits or grants for the installation of charging stations.

Figure 27. EVCS Permit Streamlining Map for SCAG. Accessed June 2023[154]



6.5 Promoting Public-Private-Partnership (P3) Business Models

While SCAG, local jurisdictions, and municipal agencies will continue to provide funding for clean technology deployment, promoting public-private partnerships and exploring alternative financing or ownership models can help to further relieve financial burdens. As mentioned in the SCAG EV Charging Station Funding Guide, there are many existing P3 models that aim to bring together the resources and expertise of both the public and private sectors to accelerate the deployment of clean technologies. The existing Clean Cities Coalition[155] can be leveraged to coordinate the activities for both private and public sector proponents of clean technologies to discover commonalties, collaborate on public policy, and investigate opportunities for joint project. Collaboration with private sector partners, such as utility companies, can help develop and implement infrastructure and technology projects. This can include the development of charging or refueling stations, investment in renewable energy sources, or partnerships to develop new technology solutions. Specific strategies include:

- **Public-private funding**: Apply and provide fundings to private sector companies, such as through grants or loans, to support the development of zero-emission transportation technologies, infrastructure, and related research and development.

- **Demonstration projects**: Partner with private sector companies to develop and implement demonstration projects for zero-emission transportation technologies, such as pilot programs for electric or hydrogen fuel cell buses or zero emission freight rail. These projects can help demonstrate the viability and effectiveness of

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[153] AB 1236, as amended, Chiu. Local ordinances: electric vehicle charging stations, http://www.leginfo.ca.gov/pub/15-16/bill/asm/ab_1201-1250/ab_1236_bill_20150827_amended_sen_v95.htm

[154] CA Electric Vehicle Charging Station Permit Streamlining Map, https://california.maps.arcgis.com/apps/webappviewer/index.html?id=5b34002aaffa4ac08b84d24016bf04ce

[155] SCAG, Clean Cities Coalition, https://scag.ca.gov/clean-cities

these technologies and pave the way for wider adoption. A great example of public-private partnerships on demonstration projects is the Joint Electric Truck Scaling Initiative (JETSI) project which aimed at introducing cutting-edge innovation and best practices to facilitate the large-scale deployment of Class 8 battery-electric trucks in North America. Spearheaded by the South Coast Air Quality Management District (South Coast AQMD), JETSI is a collaborative effort involving various public and private organizations, with a mission to deploy 100 battery electric regional haul and drayage trucks in Southern California.

- **Training and workforce development**: Work with private sector partners to provide training and workforce development programs for the deployment and maintenance of zero-emission transportation technologies. This can help to create a skilled workforce that is prepared to support the growing demand for these technologies. Organizations and institutions such as vocational rehabilitation programs, non-profits, school districts, community college consortiums can develop training programs for ZEV and NZEV workforce, and design targeted programs for DACs.
- **Joint research and development**: Partner with local universities and research institutions to conduct joint research and development on zero-emission transportation technologies, such as battery technology or fuel cell technology. This can help to accelerate the development of new and more effective technologies and reduce costs through economies of scale.

6.6 Technical Assistance

Providing technical assistance to local partners, such as transit agencies or local governments, can help them evaluate and implement zero-emission transportation technologies. This can include providing guidance on vehicle procurement, infrastructure development, and policy and regulatory issues. Specific strategies include:

- **Providing information and resources**: Provide regional partners with information and resources related to zero and near-zero emission technologies, such as vehicle types and specifications, charging and refueling infrastructure, and funding and incentive programs available for their implementation. SCAG has already led the development of a visionary Regional Data Platform (RDP), which serves as a clearinghouse of demographic, economic, land-use and transportation data while providing technical resources for in-depth analysis locally and regionally.[156] Tools such as RDP can be updated and expanded for future ZEV and NZEV information and resource sharing.
- **Developing implementation strategies**: Assist local partners in developing implementation strategies for zero and near-zero emission technologies, such as developing plans for fleet conversions or establishing partnerships with private sector companies for infrastructure development. For example, currently SCAG is developing plan for a zero-emission charging and fueling network for medium and heavy-duty vehicles in the region. The projects involve studying truck travel patterns, understanding fueling needs, and involving key stakeholders, with the goal of establishing a blueprint for deployment of the needed infrastructure to support zero emission medium- and heavy-duty operation in the region.

[156] SCAG, Final SCAG Future Communities Framework, https://scag.ca.gov/sites/main/files/file-attachments/final_scagfuturecommunitiesframework.pdf?1604269152

- **Conducting feasibility studies**: Conduct feasibility studies to assess the potential for the adoption of zero and near-zero emission technologies in different local contexts, such as city centers, rural areas, or the Port, and provide guidance on the most effective strategies for implementation.
- **Sharing best practices**: In January 2021, SCAG kicked off the Electric Vehicle Charging Station Study (EVCSS), partnering with 18 cities to help local jurisdictions promote development and deployment of EV charging infrastructure to accelerate transportation electrification. This program has offered valuable opportunities for members to share policy guidance around station permitting, outreach materials and findings, EV planning guides for cities and property developers, a regionwide Site Suitability Analysis to target areas for future EV charging infrastructure, and initial conceptual plans for site locations. Sharing best practices and lessons learned from successful implementation of zero and near-zero emission technologies in other regions, as well as providing guidance on how to overcome barriers and challenges in their implementation, can help local jurisdictions navigate the complexities of adopting and integrating clean technologies into their transportation systems.
- **Advocating for policy and regulatory changes**: Advocate for policy and regulatory changes at the state or federal level to support the adoption of zero and near-zero emission technologies, such as emissions standards, tax incentives, or funding programs. As SCAG shares its border with Nevada, Arizona, and Northern Baja California, inconsistent ZEV or NZEV policies across state and national borders may place significant barriers for both passenger and goods movements across borders.

6.7 Workforce Development

With the large-scale adoption of ZEV and NZEV technology, the skills, knowledge, and experience required by workers in passenger and freight transportation, utilities, and vehicle operation and maintenance industry will significantly differ from those in the conventional realm. School districts, training programs, community colleges and universities can develop educational programs that focus on zero and near-zero transportation technologies. Specific strategies may include:

- **Developing curriculum materials**: The U.S. Bureau of Labor Statistics has highlighted the importance to generate demand for labor in three main areas: the design and development of electric vehicle models, the production of batteries that power them, and the installation and maintenance of charging infrastructure.[157] To ensure a functional and sustainable transition to clean technologies, resources and educational supplies are needed to prepare regional workforce, which includes, but not limited to technicians, drivers, electricians, assemblers and fabricators, urban planners, chemists, software and hardware engineers, etc.
- **Providing funding for student research projects**: This report has emphasized the importance of research and development to technological advancement on multiple occasions. In addition to assisting professionals to better adjust and adapt to the transition, it is also important to secure and provide funding for student research projects that can enhance the sustainable development of the clean technologies and foster technological innovations. For instance, multiple research institutes across Southern California have already been awarded with DOE grants to produce, store, and deploy clean hydrogen, such as a photoelectrochemical hydrogen generator project led by the California Institute of Technology and a high-performing fuel cell MD/HD

[157] Bureau of Labor Statistics, Charging into the Future: the Transition to Electric Vehicles, https://www.bls.gov/opub/btn/volume-12/charging-into-the-future-the-transition-to-electric-vehicles.htm

application study conducted by the University of California, Irvine.[158] Expanded funding opportunities can also nurture interests and prepare the young generation to be equipped with the knowledge and the expertise required for successful careers in the ZEV and NZEV industry.

6.8 Lead by Example

Local governments and public agencies can lead by example by converting their own fleets to zero and near-zero transportation technologies. This can serve as a demonstration of the technology's effectiveness and practicality, as well as provide a market for emerging technology providers. In addition, integrating regional or local ZEV or NZEV deployment goals and targets can be developed and integrated into future planning efforts to set and update local clean technology adoption targets. Specific strategies include:

- **Setting targets**: Local and regional governments can set ambitious targets, ahead of the state mandated goals, for the adoption of zero-emission transportation in their own fleets and establish a timeline for achieving these targets. Metrics and methodology to monitor the progress of clean technology adoption and impact of ZEV and NZEV adoption on local air quality can be developed in collaboration with local jurisdictions and air districts.
- **Fleet Transition**: Local jurisdictions can convert their own fleets to ZEVs or NZEVs, demonstrating the technology's effectiveness and practicality, as well as provide a market for emerging technology providers. As part of this, these public agencies can share lessons learned from fleet transition, which may provide valuable insights and facilitate a greater understanding of the benefits and challenges associated with adopting clean technologies.
- **Developing charging and refueling infrastructure**: Local and regional governments can seek grants and funding to develop the necessary infrastructure to support zero-emission transportation, such as charging or refueling stations, in their own facilities and public spaces.

[158] U.S. Department of Energy, Selections for Funding Opportunity in Support of the Hydrogen Shot and a University Research Consortium on Grid Resilience, https://www.energy.gov/eere/fuelcells/selections-funding-opportunity-support-hydrogen-shot-and-university-research

Appendix A: Technology Compendium Survey

The technology compendium survey received a total of 23 responses. However, upon careful evaluation, three did not meet the eligibility criteria for inclusion in this compendium. In this document, we are providing summaries of 19 out of these 20 acceptable responses. It is noteworthy that Exprolink had initially provided two separate entries, but for the purposes of this summary and to avoid redundancy, we have combined them into a single entry. The information provided in these summaries underscores the diverse range of companies working in the zero- or near-zero emission transportation technology space, each contributing distinct solutions to advance this critical field.

Alternative fueling/charging infrastructure

1. **Anonymous Vendor**
   - Manufactures Level 2 Charging stations and aggregated all of the DCFC manufacturers, also develops the software systems that operate these machines.
   - Annual production capacity of 100,000 units.
   - Challenges include regulatory hurdles, knowledge gaps, and insufficient public incentives.
   - The product retails for $4200 with an annual software cost of $450/year/port.
   - Annual maintenance costs of $450, which includes lifetime warranty costs as long as the customer continues using the software
   - Compatible with various vehicles and chargers.
   - Power system stability: Local load management capabilities, OpenADR certified.

2. **Sesame Solar**
   - Manufactures off-grid, renewable powered nanogrids using solar and green hydrogen.
   - Annual production capacity of 500-1000 units.
   - Challenges include their primary focus on decarbonizing disaster response.
   - Costs range from $150,000 to $400,000 depending on design requirements.
   - Annual maintenance costs are still under development.
   - Compatible with transit buses, commercial vehicles, and residential use.
   - Power system stability: Nanogrids can serve as backup energy to facilities.

3. **City of Manhattan Beach**
   - Installs public EV charging stations.
   - Faces supply chain issues, regulatory hurdles, and insufficient public incentives.
   - Annual maintenance cost includes electric usage costs.

4. **GoPowerEV**
    - Provides scalable and affordable EV charging for multifamily.
    - Production capacity is in the thousands.
    - Challenges include insufficient public incentives and support programs.
    - Total installed cost is typically less than $2000 per parking space.
    - Annual maintenance cost is $15/month or <$200 per year.
    - Power system stability: Shifts charging to off-peak hours for grid optimization.

5. **Hydrogen Fuel Cell Partnership**
    - Helps all stakeholders advance their collective efforts, but does not manufacture, sell, or regulate specific technology.
    - Challenges include supply chain issues, regulatory hurdles, labor constraints, and more.
    - Pricing and maintenance cost information is not applicable for this respondent.

6. **BayoTech**
    - Produces hydrogen which can be net-zero with RNG, produces trailers which can transport gaseous H2 to support fuel cell applications.
    - Has 2 production units and 75 transports.
    - Challenges include supply chain issues, regulatory hurdles, manufacturing constraints.
    - Transport costs between 200k - 1.1M and production costs 10-15M.
    - Annual maintenance cost for transport is 50k-100k.
    - Compatible with transit buses and Fuel Cell fueling station resupply.

7. **BP Pulse Fleet North America Inc. (- Charging Solutions**
    - Provides Level 2 and DC fast chargers, Inrush, mobile and non-permanent charging solutions.
    - No maximum capacity limitation.
    - Challenges include knowledge gaps and insufficient public incentives.
    - Cost and maintenance fees are dependent on the solution selected. More complex solutions result in higher costs and maintenance fees.

8. **Core States Energy**
    - Provides turn-key design-build solutions for zero-emission vehicle infrastructure and distributed energy systems, including DC fast charging stations.
    - The annual production capacity is 5000.

- Challenges include supply chain issues, regulatory hurdles, manufacturing constraints, labor constraints, power grid constraints, knowledge gaps, insufficient public incentives, and insufficient support programs.
- Each DCFC dispenser costs $200,000 and the annual maintenance cost is 5% of the design-build.

<u>Vehicles</u>

9. Proterra

- Manufactures the leading battery electric bus with the highest amount of energy.
- Annual production capacity of 500 to 750 buses.
- Challenges include supply chain issues.
- Costs range from $900,000 to $1,000,000 per bus.
- Annual maintenance costs average around $0.70/mile.
- Buses and chargers work with all types of chargers and buses.
- Power system stability: Buses, charge management, and fleet microgrid solutions enhance stability in power systems.

10. Forum Mobility

- Develops, owns, and operates heavy-duty charging infrastructure for Class 8 electric trucks. They also purchase Class 8 electric trucks and lease them to Owner/Operators, Carriers and other Fleets.
- Developing facilities to charge over 600 Class 8 electric trucks.
- Challenges include supply chain, regulatory hurdles, manufacturing constraints, labor constraints, and more.
- Construction costs between $10MM to $20MM.
- Maintenance cost is to be determined.
- Power system stability: Integrating onsite Distributed Energy Resources and Vehicle to Grid capabilities.

11. Exprolink, Inc.

- Offers all electric compact street sweeper and ride-on litter vacuums applicable to municipal, county, private, industrial, and commercial entities
- Can produce 30-50 units annually.
- Challenges include manufacturing constraints.
- Pricing and maintenance cost information is not provided.

12. **Volvo Group North America**
    - Offers medium- and heavy-duty trucks (short-haul), refuse trucks, transit buses, construction equipment, and more.
    - Challenges include supply chain issues, regulatory hurdles, manufacturing constraints, and more.
    - Pricing and maintenance cost information is not disclosed but refers to HVIP/CORE program documents for products part of the programs.

13. **Hyzon Motors USA**
    - Offers hydrogen fuel cell electric Class 8 trucks for up to 82,000 lbs. GCVWR (Gross Combination Vehicle Weight Rating).
    - Large production capacity.
    - Challenges include insufficient public incentives.
    - Vehicles are priced starting at $590,000.
    - Estimated annual maintenance cost is about $0.18/mi.

14. **Energy, Efficiency & Environment, Inc.**
    - Offers a prototype semi-tractor for on-road heavy-duty vehicle application, and a transport refrigerated unit/In-field pre-cooling unit with zero emissions.
    - In the next two years, they plan to produce 50 units.
    - The challenge they face is getting sufficient investment.
    - Each 6 cube, 53' trailer costs $262,000 and the annual maintenance cost per 6 cube chassis is $5,500 annually.
    - Utilizes standard kingpin, compatible with various chassis types.

<u>Supporting Products</u>

15. **BorgWarner**
    - Offers high power (60-360kW) DCFC with V2G/V2X capabilities and options for sequential or parallel charging, compliant with the NEVI program.
    - Can produce 6,000 units annually.
    - Facing knowledge gaps as a barrier.
    - Product costs range from up to $80,000 with an annual maintenance cost of $3,500.
    - Compatible with passenger vehicles, MD/HD vehicles, as well as school and transit buses.
    - Power system stability: V2G/V2X capabilities

16. Anonymous Vendor

- Focused on developing transportation electrification (charging) infrastructure for large institutions' vehicle fleets.
- Effectively unlimited production capacity.
- Unknown in the electric vehicle supply equipment (EVSE) market segment.
- Comprehensive pricing and maintenance costs table available upon request.
- Can support fleets with light, medium, and heavy-duty vehicles.
- Power system stability: Charging Management Software and Energy Management Software optimize energy demand and supply.

17. The Mobility House

- Offers ChargePilot, a local hardware and cloud-based, interoperable charge management system.
- Can produce over 1000 units annually.
- Challenges include regulatory hurdles and knowledge gaps.
- Pricing depends on several factors including the number of chargers, fleet size, and voltage.
- Maintenance costs are covered under the software subscription model.
- Supports all EVs and chargers using industry standard protocols.
- With respect to limitations, chargers not using OCPP 1.6J or allowing third-party control are not compatible.
- Power system stability: Enhances stability by controlling EV load and responding to changing conditions.

18. BP Pulse Fleet North America Inc. - Omega™ CMS

- Produces a charge management system that optimizes charging, improves reliability of operations, and dynamically responds to events in real-time.
- There's no maximum capacity. It's hardware agnostic and can be added to chargers to improve operations.
- Challenges include power grid constraints, knowledge gaps, and insufficient public incentives and support programs.
- Pricing is based on scope, and no maintenance cost is incurred.
- Hardware agnostic, I.e., supports various charger types and power levels.
- Power system stability: Staggers charging load, optimizes energy demand, and reduces grid impact.

19. Xendee Corporation

- Provides services from feasibility studies through planning, design, and operation of net-zero charging infrastructure, as well as a Software as a Service solution for EV charging solutions modeling.
- Can analyze the potential for EV Fast Charging across thousands of sites in minutes.
- Main challenge is knowledge gaps.
- Planning software is available starting at $150/month per user. The cost starts at $150/month/user and requires no ongoing maintenance or IT expenses.
- Supports various vehicles, chargers, and charging infrastructure.
- Power system stability: Managed load growth and balancing, ancillary services, and Demand-Response capabilities.

Appendix B: Emissions Quantification Methodology

To calculate the well-to-wheel greenhouse gas (GHG) emissions benefits associated with the adoption of zero and near-zero emission technologies, the project team relied on three critical pieces of information. Firstly, the annual mileage of the vehicles or the annual activity of the locomotives was taken into account to estimate the extent of the usage of these technologies. Secondly, the average fuel economy of the vehicles, or the brake specific fuel consumption associated with diesel locomotives, was factored in to ascertain the efficiency of the fuel used. Finally, the carbon intensity of both traditional fuels, such as gasoline and diesel, as well as that of alternative fuels, like electricity, hydrogen, and natural gas, was analyzed. The carbon intensity of fuels refers to the amount of carbon (in CO2 equivalent) released per unit of energy. This measure includes all emissions resulting from the production, processing, distribution, and use of the fuel, which is also known as a "well-to-wheel" analysis. For example, with gasoline, the life cycle carbon intensity would account for emissions from the extraction of crude oil, its transportation to a refinery, the refining process to turn the crude oil into gasoline, the transportation of gasoline to service stations, and the combustion of gasoline in vehicles. For electricity used in electric vehicles, the life cycle carbon intensity would depend on the mix of energy sources used to generate the electricity (e.g., coal, natural gas, nuclear, wind, solar) and would include emissions from the extraction, processing, and combustion of fossil fuels, or the manufacture and installation of renewable energy systems, as well as the transmission and distribution of electricity and its use in vehicles.

Here are the data sources that were used to extract this information:

- Annual mileage as well as the average fuel efficiency of the on-road vehicles was extracted from ANL's AFLEET tool at: https://afleet.es.anl.gov/home/
- For locomotives, the project team relied on the CARB's 2022 In Use Locomotive Emission Inventory at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/locomotive22/appg.pdf
- Carbon intensity of the gasoline and diesel are based on the CARB's LCFS certified pathways at: https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/fuelpathways/current-pathways_all.xlsx (accessed on June 21, 2023). For gasoline, the project team assumed a carbon intensity of 100.82 gCO2/MJ and for diesel assumed 100.45 gCO2/MJ
- Carbon intensity of natural gas is based on CARB's LCFS Compliance Calculator at: https://www.arb.ca.gov/fuels/lcfs/2018-0815_illustrative_compliance_scenario_calc.xlsx. For transportation natural gas, the project team assumed a blend of 94 percent landfill gas and 6 percent dairy gas.
- Carbon intensity of the electricity is based on CARB's 2021 Carbon Intensity Values for California Average Grid Electricity Used as a Transportation Fuel in California and Electricity Supplied Under the Smart Charging or Smart Electrolysis Provision: https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/fuelpathways/comments/tier2/2021_elec_update.pdf?_ga=2.207245524.611557608.1628272571-476568668.1615315573
- Carbon intensity of hydrogen is based on the CARB's LCFS certified pathways at: https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/fuelpathways/current-pathways_all.xlsx (accessed on June 21, 2023). Note that the existing feedstock mix, which is currently responsible for producing a small amount of transportation hydrogen in California, might not accurately reflect the carbon intensity of hydrogen production if demand significantly increases. The increased demand could potentially necessitate the sourcing

of hydrogen from different feedstocks, with potentially varied carbon intensities. In essence, the carbon intensity of the current feedstock mix might not be scalable. This is why in the main document, the project team decided to present the GHG emissions based on the most common feedstock used for hydrogen production today (i.e., hydrogen produced through SMR[159] with fossil natural gas), while here in this appendix, the project team is presenting the GHG emissions over various feedstock. By modeling GHG emissions benefit on a feedstock-by-feedstock basis, the project team is able to assess each potential source of hydrogen individually. This approach provides a more accurate representation of the potential future carbon intensity of large-scale hydrogen production. It takes into account the fact that some feedstocks might be more feasible or efficient at a larger scale or might become more feasible due to technological advancements. It also offers the flexibility to model different scenarios. For instance, one can anticipate the effect on carbon intensity if one feedstock becomes dominant due to cost reductions, policy changes, or other factors.

Using this information, the project team calculated the annual well to wheel GHG emissions reductions associated with replacement of one unit of vehicle/equipment with a near-zero or zero emission technology following the equation below:

GHG Emissions Reduction = Annual Activity (miles or MWh) x Average Fuel Efficiency (gallons/mile or gallons/bhp-hr) x (Carbon Intensity of Base Fuel (gCO2/gallon) – EER[160].Adjusted Carbon Intensity of Alternative Fuel (gCO2/gallon-equivalent)) *(Equation 1)*

Table 33, Table 34, and Table 35 provides the assumptions that are used to calculate the annual GHG emissions reductions associated with various vehicle categories discussed in this compendium. For PHEVs, the project team assumed that only 40% of the time those vehicles are operating on electricity[161] and therefore, their emissions benefits are assumed to be smaller than BEV or FCEVs.

Table 32. Assumptions for On-Road Vehicles

Category	Vehicle by Body Style	Base Fuel	AFLEET Vehicle Category	Annual Miles per Year	Average MPG
LDV	Passenger Car	Gasoline	Car	12,400	30.9
	SUV	Gasoline	SUV	13,000	22.7
	Minivan	Gasoline	SUV[162]	30,000	22.7
	Light Duty Pickup Truck	Gasoline	Light-Duty Pickup Truck	11,400	18.7
	Utility Van	Gasoline	SUV	27,000[163]	22.7
MDV	Medium Duty Pickup	Gasoline	Medium-Duty Pickup Truck	24,000	13.0
	Cargo Van	Gasoline	Utility Cargo Van	27,000	10.0
	Passenger Van	Gasoline	Shuttle/Paratransit Van	30,000	14.5
	Step Van	Diesel	Delivery Step Van	16,500	6.3
	Box Truck	Diesel	Delivery Straight Truck	23,000	5.6

159 Steam Methane Reforming

160 The Energy Economy Ratio (EER) is a measure used to compare the energy efficiency of different fuel types, especially when comparing traditional fuels like gasoline or diesel with alternative fuels like electricity or hydrogen. EER is often used in the context of vehicle fuel economy and emissions analysis. The EER is defined as the energy content of a conventional fuel (like gasoline) divided by the energy content of an alternative fuel (like electricity). For example, when comparing an electric vehicle (EV) to a gasoline vehicle, the EER would be the energy content of the gasoline that would be used in an internal combustion engine vehicle divided by the electrical energy used by the EV. This ratio accounts for the fact that electric motors are much more efficient than internal combustion engines. In essence, EER is a way to normalize energy efficiencies across different energy types, allowing for more accurate comparisons when assessing the environmental impact or economic feasibility of various energy sources.

161 Appendix G of the 2017 Advanced Clean Cars Midterm Review. California Air Resources Board. Available at: https://ww2.arb.ca.gov/sites/default/files/2020-01/appendix_g_pev_in_use_and_charging_data_analysis_ac.pdf

162 Assumed the same annual mileage as Shuttle/Paratransit Buses while the fuel economy is similar to SUVs

163 Assumed the same annual mileage as cargo van but the fuel economy is similar to SUVs

Category	Vehicle by Body Style	Base Fuel	AFLEET Vehicle Category	Annual Miles per Year	Average MPG
	Cab & Chassis	Diesel	Tow Truck	37,000	7.8
HDV	Straight Truck	Diesel	Delivery Straight Truck	23,000	5.6
	Semi-Tractor	Diesel	Regional Haul Freight Truck	65,000	5.4
	Refuse Vehicles	Diesel	Refuse Truck	23,400	1.5
Buses	Single Deck Bus	Diesel	Transit Bus	45,000	3.8
	Double Decker Bus	Diesel	Transit Bus	45,000	3.8
	Articulated Bus	Diesel	Transit Bus	45,000	3.8
	School Bus	Diesel	School Bus	15,000	7.1
	Cutaway	Diesel	Shuttle/Paratransit Bus	30,000	8.0
	Shuttle Buses	Diesel	Shuttle/Paratransit Bus	30,000	8.0

Table 33. Assumptions for Locomotives

Vehicle by Body Style	Base Fuel	Annual Activity (MWHr)	Annual Fuel Use (gallons)
Passenger - Heavy Rail	Diesel	1827.7	126,692
Freight - Heavy Rail	Diesel	351.3	24,351
Switchers	Diesel	456.9	31,671

Table 34. Carbon Intensity of Base and Alternative Fuels

Fuel Type	Base Fuel	GHG Emissions (gCO2/MJ)	GHG Emissions (gCO2/mmBtu)	Energy Intensity (BTU/gallon)	gCO2/gallon (EER Adjusted)
Gasoline	Gasoline	100.82	106,371	120,238	12,790
Diesel	Diesel	100.45	105,980	137,381	14,560
Electricity - LDV	Gasoline	75.93	80,111	120,238	2,833
Electricity - HDV	Diesel	75.93	80,111	137,381	2,201
California NG	Diesel	22	23,528	137,381	3,232
Hydrogen - LDV - SMR Fossil NG	Gasoline	124	130,385	120,238	6,271
Hydrogen - LDV - SMR LFG	Gasoline	99	104,955	120,238	5,048
Hydrogen - LDV - SMR Dairy	Gasoline	-210	-221,349	120,238	-10,646
Hydrogen - LDV - Green H2	Gasoline	11	11,089	120,238	533
Hydrogen - HDV - SMR Fossil NG	Diesel	124	130,385	137,381	9,428
Hydrogen - HDV - SMR LFG	Diesel	99	104,955	137,381	7,589
Hydrogen - HDV - SMR Dairy	Diesel	-210	-221,349	137,381	-16,005
Hydrogen - HDV - Green H2	Diesel	11	11,089	137,381	802

Table 32 shows the resulting annual GHG emissions benefits (in unit of metric ton CO2 per year) by switching from base fuel to alternative fuels (i.e., BEV, PHEV, FCEV, NGV). Note that for FCEV, the project team has four different emissions benefits depending on the feedstock used for producing hydrogen.

Table 35. Annual GHG Emissions Benefits of Alternative Fuel Technology

Vehicle by Body Style	Technology Type	Annual GHG Emissions Reduction (Metric ton of CO2e per year)
Passenger Car	BEV	3.99
	PHEV	2.40
	FCEV - SMR Fossil NG	2.61
	FCEV - SMR LFG	3.10

Vehicle by Body Style	Technology Type	Annual GHG Emissions Reduction (Metric ton of CO2e per year)
	FCEV - SMR Dairy	9.40
	FCEV - Green H2	4.91
SUV	BEV	5.71
	PHEV	3.43
	FCEV - SMR Fossil NG	3.74
	FCEV - SMR LFG	4.44
	FCEV - SMR Dairy	13.45
	FCEV - Green H2	7.03
Minivan	BEV	13.19
	PHEV	7.91
	FCEV - SMR Fossil NG	8.63
	FCEV - SMR LFG	10.25
	FCEV - SMR Dairy	31.04
	FCEV - Green H2	16.23
Light Duty Pickup Truck	BEV	6.08
	PHEV	3.65
	FCEV - SMR Fossil NG	3.98
	FCEV - SMR LFG	4.72
	FCEV - SMR Dairy	14.30
	FCEV - Green H2	7.48
Utility Van	BEV	11.87
	PHEV	7.12
	FCEV - SMR Fossil NG	7.77
	FCEV - SMR LFG	9.23
	FCEV - SMR Dairy	27.94
	FCEV - Green H2	14.61
Medium-Duty Pickup Truck	BEV	18.38
	PHEV	11.03
	FCEV - SMR Fossil NG	12.03
	FCEV - SMR LFG	14.29
	FCEV - SMR Dairy	43.27
	FCEV - Green H2	22.63
Cargo Van	BEV	26.88
	PHEV	16.13
	FCEV - SMR Fossil NG	17.60
	NGV	0.00
	FCEV - SMR LFG	20.90
	FCEV - SMR Dairy	63.28
	FCEV - Green H2	33.09
Passenger Van	BEV	20.60
	PHEV	12.36
	FCEV - SMR Fossil NG	13.49
	NGV	0.00
	FCEV - SMR LFG	16.02
	FCEV - SMR Dairy	48.49
	FCEV - Green H2	25.36
Step Van	BEV	32.51
	PHEV	19.50
	FCEV - SMR Fossil NG	13.50
	NGV	29.79
	FCEV - SMR LFG	18.34

Vehicle by Body Style	Technology Type	Annual GHG Emissions Reduction (Metric ton of CO2e per year)
	FCEV - SMR Dairy	80.39
	FCEV - Green H2	36.19
Box Truck	BEV	51.08
	PHEV	30.65
	FCEV - SMR Fossil NG	21.21
	NGV	46.82
	FCEV - SMR LFG	28.81
	FCEV - SMR Dairy	126.33
	FCEV - Green H2	56.86
Cab & Chassis	BEV	58.62
	PHEV	35.17
	FCEV - SMR Fossil NG	24.34
	NGV	53.73
	FCEV - SMR LFG	33.07
	FCEV - SMR Dairy	144.99
	FCEV - Green H2	65.26
Straight Truck	BEV	51.08
	PHEV	30.65
	FCEV - SMR Fossil NG	21.21
	NGV	46.82
	FCEV - SMR LFG	28.81
	FCEV - SMR Dairy	126.33
	FCEV - Green H2	56.86
Semi-Tractor	BEV	148.34
	PHEV	89.00
	FCEV - SMR Fossil NG	61.60
	NGV	135.96
	FCEV - SMR LFG	83.67
	FCEV - SMR Dairy	366.87
	FCEV - Green H2	165.14
Refuse Vehicles	BEV	192.79
	PHEV	115.68
	FCEV - SMR Fossil NG	80.06
	NGV	176.71
	FCEV - SMR LFG	108.74
	FCEV - SMR Dairy	476.81
	FCEV - Green H2	214.62
Single Deck Bus	BEV	145.88
	PHEV	87.53
	FCEV - SMR Fossil NG	60.58
	NGV	133.71
	FCEV - SMR LFG	82.28
	FCEV - SMR Dairy	360.78
	FCEV - Green H2	162.40
Double Decker Bus	BEV	145.88
	PHEV	87.53
	FCEV - SMR Fossil NG	60.58
	NGV	133.71
	FCEV - SMR LFG	82.28
	FCEV - SMR Dairy	360.78
	FCEV - Green H2	162.40

Vehicle by Body Style	Technology Type	Annual GHG Emissions Reduction (Metric ton of CO2e per year)
Articulated Bus	BEV	145.88
	PHEV	87.53
	FCEV - SMR Fossil NG	60.58
	NGV	133.71
	FCEV - SMR LFG	82.28
	FCEV - SMR Dairy	360.78
	FCEV - Green H2	162.40
School Bus	BEV	26.09
	PHEV	15.66
	FCEV - SMR Fossil NG	10.84
	NGV	23.91
	FCEV - SMR LFG	14.72
	FCEV - SMR Dairy	64.53
	FCEV - Green H2	29.05
Shuttle Buses	BEV	46.34
	PHEV	27.81
	FCEV - SMR Fossil NG	19.25
	NGV	42.48
	FCEV - SMR LFG	26.14
	FCEV - SMR Dairy	114.62
	FCEV - Green H2	51.59
Cutaway	BEV	46.34
	PHEV	27.81
	FCEV - SMR Fossil NG	19.25
	NGV	42.48
	FCEV - SMR LFG	26.14
	FCEV - SMR Dairy	114.62
	FCEV - Green H2	51.59
Passenger - Heavy Rail	BEV	1565.73
	FCEV - SMR Fossil NG	650.19
	NGV	1435.09
	FCEV - SMR LFG	883.14
	FCEV - SMR Dairy	3872.27
	FCEV - Green H2	1743.01
Freight - Heavy Rail	BEV	300.95
	FCEV - SMR Fossil NG	124.97
	NGV	275.84
	FCEV - SMR LFG	169.75
	FCEV - SMR Dairy	744.29
	FCEV - Green H2	335.02
Switchers	BEV	391.41
	FCEV - SMR Fossil NG	162.54
	NGV	358.75
	FCEV - SMR LFG	220.77
	FCEV - SMR Dairy	968.02
	FCEV - Green H2	435.73

As noted earlier, while in the main body of the document, the project team decided to focus on GHG emissions benefits of FCEV as they relate to the most prevalent method of hydrogen production presently employed, namely, hydrogen generated through SMR with fossil natural gas, in this appendix, the team expands this scope to include GHG emissions benefits as they pertain to a variety of feedstocks. The following figures provide a comparative analysis of the GHG emissions benefits that can be realized by transitioning to FCEVs that utilize hydrogen produced from diverse feedstocks.

Figure 28. GHG Emissions Benefits from Transitioning Conventional LDVs to FCEVs

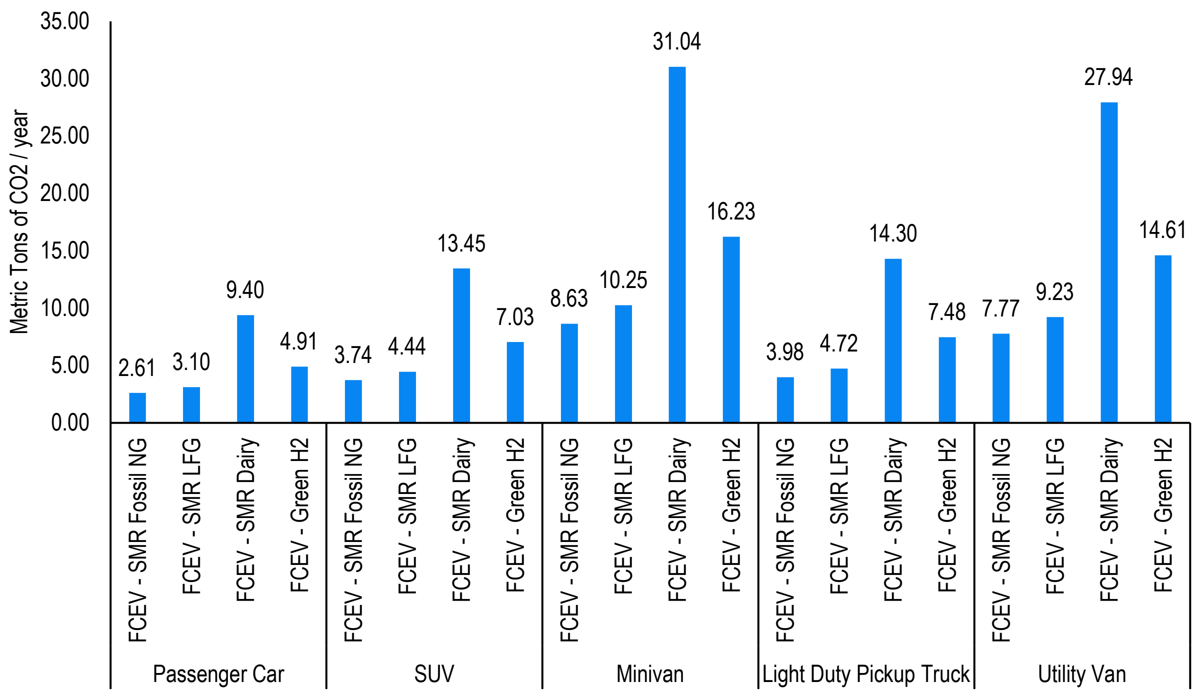


Figure 29. GHG Emissions Benefits from Transitioning Conventional MDVs to FCEVs

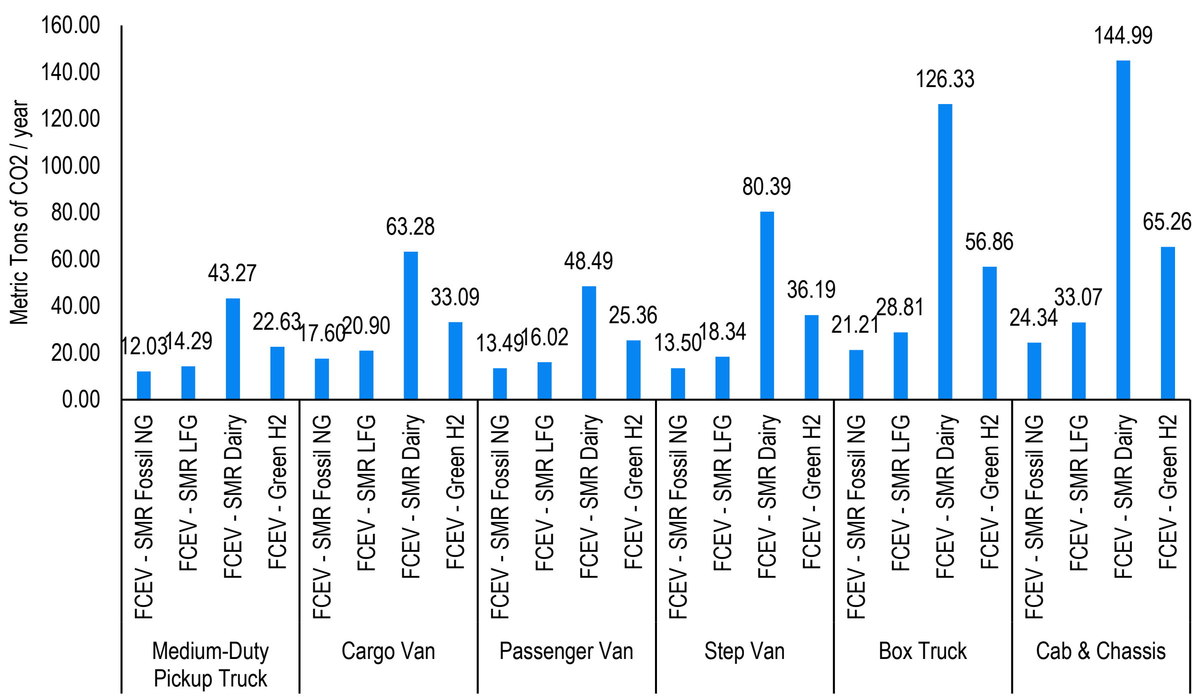


Figure 30. GHG Emissions Benefits from Transitioning Conventional HDVs to FCEVs

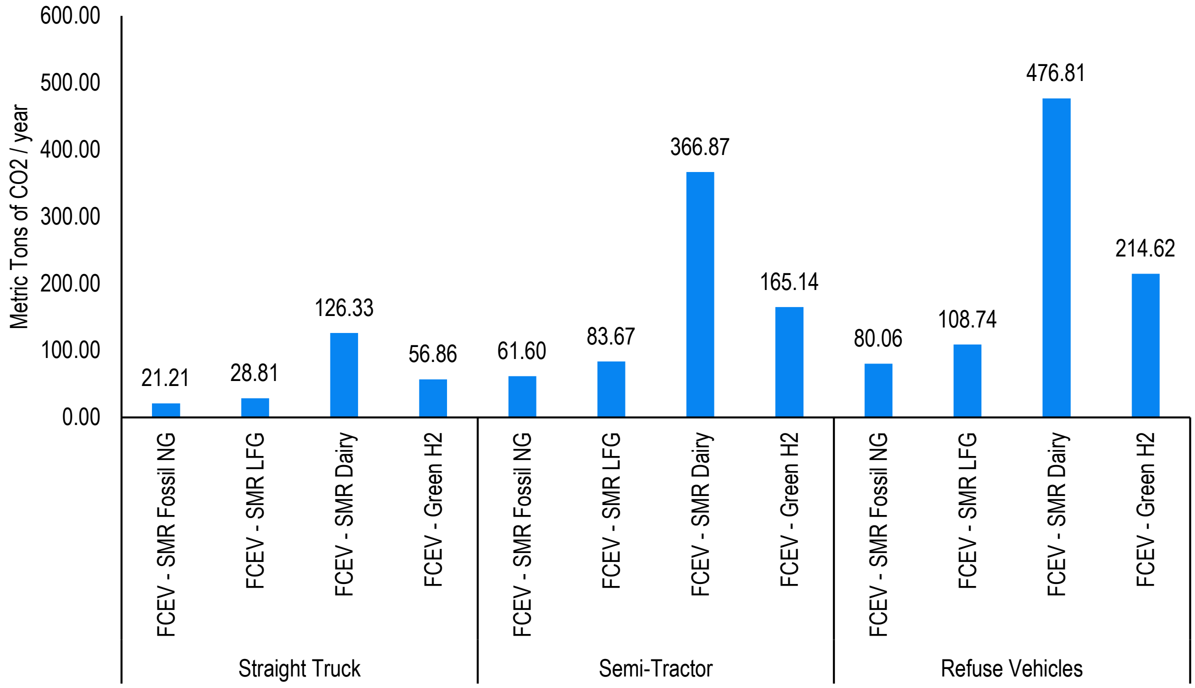


Figure 31. GHG Emissions Benefits from Transitioning Conventional Buses to FCEVs

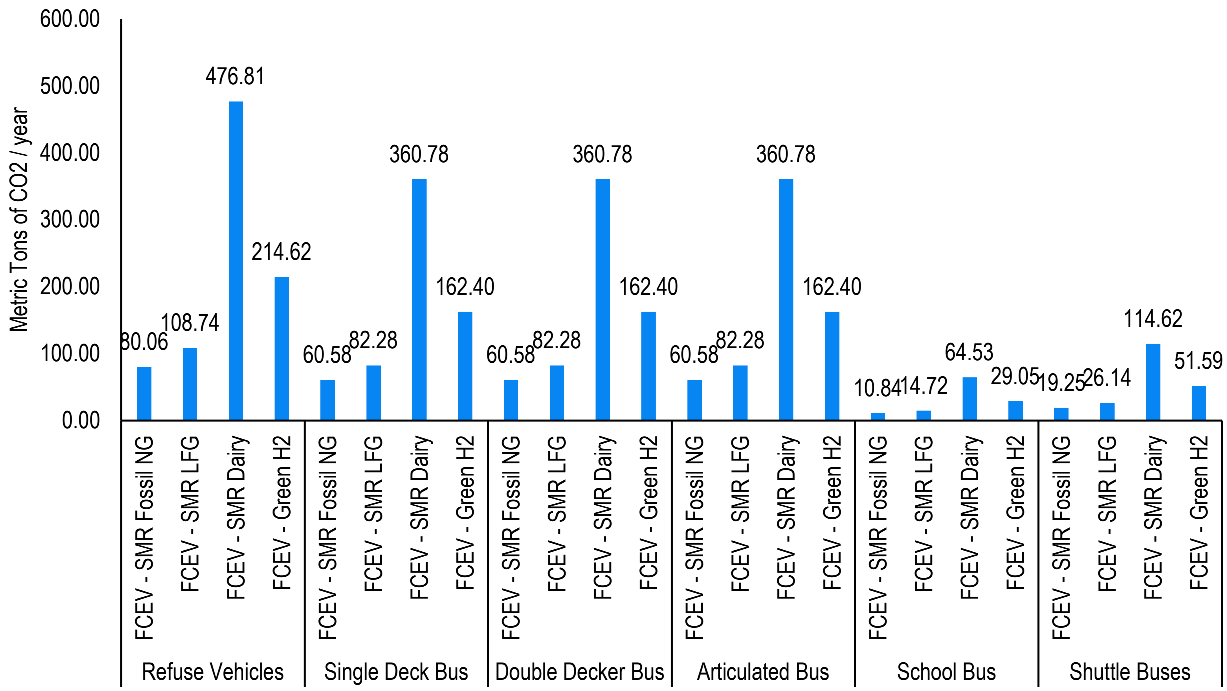
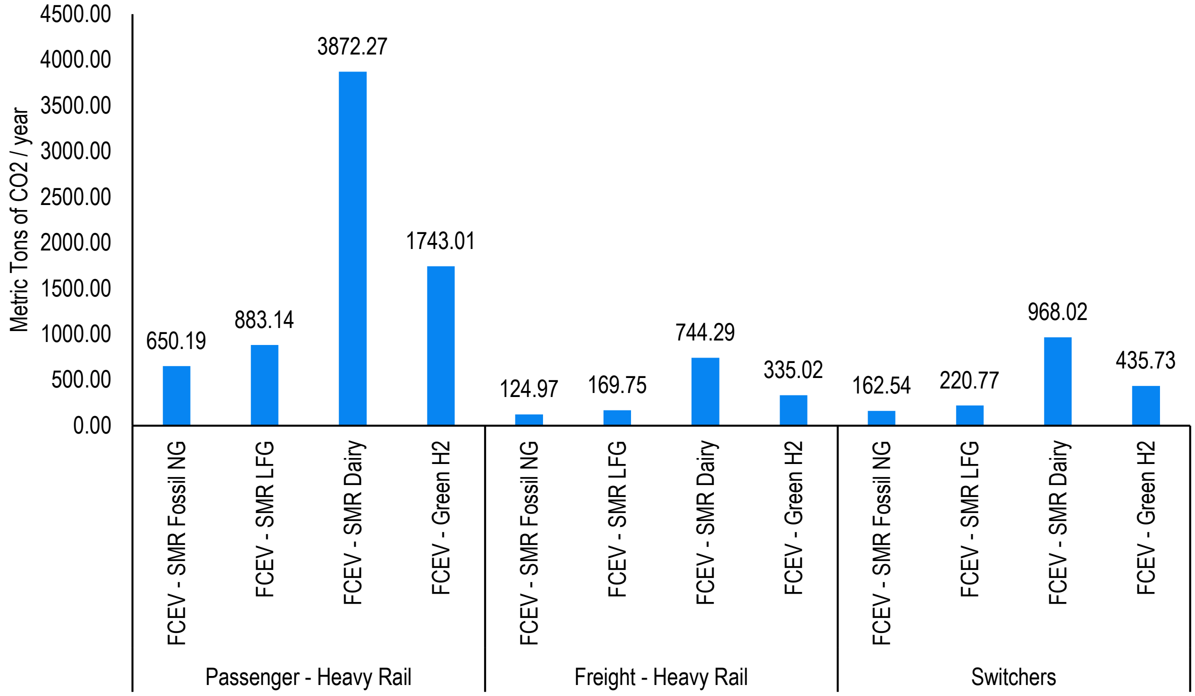


Figure 32. GHG Emissions Benefits from Transitioning Conventional Locomotives to FCEVs



Appendix C: Total Cost of Ownership Methodology

Total Cost of Ownership (TCO) refers to the comprehensive assessment of all the costs associated with the purchase, use, and maintenance of a product or system over its entire life cycle. TCO is often used in business decision-making to determine the financial impact of procuring and operating an asset. To calculate the TCO of various clean technology types, the project team leveraged the Argonne National Laboratory' (ANL) Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) tool. The tool was accessed via downloadable spreadsheet. Both the TCO calculator and the fleet footprint calculator were used in this assessment.

The data from AFLEET was largely comprehensive; however, some modifications were necessary. For instance, AFLEET did not include the initial purchase cost for PHEV utility cargo vans or PHEV tow trucks. To compensate for this data deficit, the project team sourced the initial purchase costs from the PG&E Vehicle Catalog.[164]

Aside from capital costs, the project team also updated the fuel cost data in the AFLEET tool to reflect the latest gasoline, diesel, CNG, and electricity prices in California. Fuel costs were checked against data from AFDC fuel pricing report and CNG costs were modified in the AFLEET tool from $2.66/GGE to $2.3/GGE[165].

Table 33, Table 34, and Table 35 provide the assumptions used to calculate the TCO saving associated with each vehicle body style and technology type. Please note that not all body styles were represented in the AFLEET tool. For example, Minivan and Cab and Chassis were not represented in the AFLEET tool. To remedy this lack of data, SUV and Tow Truck were used as surrogates respectively, and annual miles per year were adjusted to better reflect actual performance characteristics.

In addition, to ensure consistency across vehicle category comparisons, the project team has chosen to calculate the TCO over a 15-year lifespan. While this assumption may be applicable to most vehicles, certain specific types, such as refuse trucks, may have a shorter lifespan due to excessive wear and tear.

Table 36. Assumptions for On-Road Vehicles TCO Analysis

Category	Vehicle by Body Style	Base Fuel	AFLEET Vehicle Category	Annual Miles per Year	Average MPG
LDV	Passenger Car	Gasoline	Car	12,400	30.9
	SUV	Gasoline	SUV	13,000	22.7
	Minivan	Gasoline	SUV[166]	30,000	22.7
	Light Duty Pickup Truck	Gasoline	Light-Duty Pickup Truck	11,400	18.7
	Utility Van	Gasoline	SUV	27,000[167]	22.7
MDV	Medium Duty Pickup	Gasoline	Medium-Duty Pickup Truck	24,000	13.0
	Cargo Van	Gasoline	Utility Cargo Van	27,000	10.0
	Passenger Van	Gasoline	Shuttle/Paratransit Van	30,000	14.5
	Step Van	Diesel	Delivery Step Van	16,500	6.3
	Box Truck	Diesel	Delivery Straight Truck	23,000	5.6
	Cab & Chassis	Diesel	Tow Truck	37,000	7.8
HDV	Straight Truck	Diesel	Delivery Straight Truck	23,000	5.6
	Semi-Tractor	Diesel	Regional Haul Freight Truck	65,000	5.4
	Refuse Vehicles	Diesel	Refuse Truck	23,400	1.5
Buses	Single Deck Bus	Diesel	Transit Bus	45,000	3.8

164 PG&E Fleets: Vehicles. Retrieved June 23, 2023, from https://fleets.pge.com/vehicle-catalog
165 Alternative Fuels Data Center: Fuel Prices. April 2023. Retrieved June 23, 2023, from https://afdc.energy.gov/fuels/prices.html
166 Assumed the same annual mileage as Shuttle/Paratransit Buses while the fuel economy is similar to SUVs
167 Assumed the same annual mileage as cargo van but the fuel economy is similar to SUVs

Category	Vehicle by Body Style	Base Fuel	AFLEET Vehicle Category	Annual Miles per Year	Average MPG
	Double Decker Bus	Diesel	Transit Bus	45,000	3.8
	Articulated Bus	Diesel	Transit Bus	45,000	3.8
	School Bus	Diesel	School Bus	15,000	7.1
	Cutaway	Diesel	Shuttle/Paratransit Bus	30,000	8.0
	Shuttle Buses	Diesel	Shuttle/Paratransit Bus	30,000	8.0

Table 37. Fuel Price Assumptions Used

Fuel Type	Fuel Unit	Price ($/fuel unit)
Gasoline	gasoline gallon	$4.75
Diesel	diesel gallon	$5.10
Electricity	kWh	$0.27
G.H2	hydrogen kg	$17.11[168]
CNG	CNG GGE	$2.66

Note that TCO presented in this report is the net present value (NPV) of depreciation, operating and maintenance cost over a 15-year lifespan. A discount factor of 1.24%[169] (default value in AFLEET tool) is used. Also, it is important to note that the costs of charging or fueling stations are not included in the TCO. This is primarily due to the variability of infrastructure prices and the mix of public versus private stations potentially utilized for each category. For instance, a line haul Class 8 semi-tractor may predominantly depend on public charging stations, while a regional haul Class 8 semi-tractor may rely exclusively on depot charging. To avoid subjective assessment of infrastructure needs, the project team decided to leave the cost of infrastructure outside of the TCO analysis. The insurance cost is also directly related to the purchase price of the vehicles. The higher the purchase price, the higher the insurance cost. With respect to registration fee, BEV and FCEVs are assumed to have an additional registration fee of $100 per year.

Tables 35 through 54 show the TCO outputs for each body style and technology type. For light duty (and some of the medium duty vehicles) the baseline fuel is assumed to be gasoline (i.e., clean technologies are compared against gasoline), while for heavy duty vehicles, the baseline fuel is diesel. Note that for diesel vehicles, in addition to fuel cost, the project team also included the cost of diesel exhaust fluid (DEF) which is an operational cost for diesel vehicles equipped with Selective Catalytic Reduction (SCR) system.

Table 38. Lifetime Cost of Ownership Outputs- Sedan

	Gasoline	Gasoline PHEV	EV	G.H2 FCV
Capital Cost[170]	$20,000	$27,000	$37,000	$50,000
Depreciation	$17,662	$23,844	$32,675	$44,155
Fuel[171]	$33,511	$21,234	$16,482	$45,022
Maintenance and Repair	$34,771	$30,348	$21,922	$21,922
Insurance	$20,600	$23,038	$26,522	$31,051
License and Registration	$1,837	$1,837	$3,215	$3,215

[168] For the purpose of the TCO analysis presented in this report, the project team used the same fuel price as assumed by the AFLEET tool. While AFDC April 2023 Fuel Report, provide an average hydrogen price of $23.63/GGE, the report claims that this number is based on a very small sample (21 points) of hydrogen information received. See footnote 4 of https://afdc.energy.gov/files/u/publication/alternative_fuel_price_report_april_2023.pdf.
[169] Based on 5-year average certificate of deposit rates in 2020
[170] Capital Cost is displayed for reference. It is not included in this TCO output calculation.
[171] Fuel costs were changed from the original AFLEET tool assumptions to recent data from 2021-2023. Gasoline fuel price was based on the average California gas prices from 2021 and 2022: California Gasoline and Diesel Retail Prices (eia.gov). Electricity rates were based on California residential rates from 2023: California Profile (eia.gov)

	Gasoline	Gasoline PHEV	EV	G.H2 FCV
Total Cost of Ownership	$108,381	$100,301	$100,815	$145,365

Table 39. Lifetime Cost of Ownership Outputs- Light- Duty SUV

	Gasoline	Gasoline PHEV	EV	G.H2 FCV
Capital Cost	$29,000	$38,500	$46,000	$59,000
Depreciation	$25,610	$34,000	$40,623	$52,103
Fuel[172]	$47,976	$28,893	$26,407	$71,264
Maintenance and Repair	$37,592	$32,811	$23,701	$23,701
Insurance	$23,735	$27,045	$29,658	$34,186
License and Registration	$5,214	$5,214	$6,592	$6,592
Total Cost of Ownership	$140,127	$127,962	$126,980	$187,847

Table 40. Lifetime Cost of Ownership Outputs- Minivan

	Gasoline	Gasoline PHEV	EV
Capital Cost	$29,000	$38,500	$46,000
Depreciation	$25,610	$34,000	$40,623
Fuel[173]	$110,714	$64,850	$60,938
Maintenance and Repair	$86,751	$75,718	$54,694
Insurance	$23,735	$27,045	$29,658
License and Registration	$5,214	$5,214	$6,592
Total Cost of Ownership	$252,024	$206,826	$192,504

Table 41. Lifetime Cost of Ownership Outputs- Light-Duty Pickup Truck

	Gasoline	Gasoline PHEV	EV
Capital Cost	$37,000	$58,000	$77,000
Depreciation	$32,675	$51,220	$67,999
Fuel[174]	$51,013	$33,594	$28,078
Maintenance and Repair	$37,960	$33,132	$23,933
Insurance	$26,522	$33,838	$40,457
License and Registration	$5,214	$5,214	$6,592
Total Cost of Ownership	$153,384	$156,998	$167,059

[172] Fuel costs were changed from the original AFLEET tool assumptions to recent data from 2021-2023. Gasoline fuel price was based on the average California gas prices from 2021 and 2022: California Gasoline and Diesel Retail Prices (eia.gov). Electricity rates were based on California residential rates from 2023: California Profile (eia.gov)

[173] Fuel costs were changed from the original AFLEET tool assumptions to recent data from 2021-2023. Gasoline and diesel fuel price was based on the average California gas prices from 2021 and 2022: California Gasoline and Diesel Retail Prices (eia.gov). Electricity rates were based on California residential rates from 2023: California Profile (eia.gov)

[174] Fuel costs were changed from the original AFLEET tool assumptions to recent data from 2021-2023. Gasoline fuel price was based on the average California gas prices from 2021 and 2022: California Gasoline and Diesel Retail Prices (eia.gov). Electricity rates were based on California residential rates from 2023: California Profile (eia.gov)

Table 42. Lifetime Cost of Ownership Outputs- Utility Van

	Gasoline	EV
Capital Cost	$29,000	$46,000
Depreciation	$25,610	$40,623
Fuel[175]	$99,643	$54,845
Maintenance and Repair	$78,076	$49,224
Insurance	$23,735	$29,658
License and Registration	$5,214	$6,592
Total Cost of Ownership	$232,278	$180,941

Table 43. Lifetime Cost of Ownership Outputs- Medium-Duty Pickup Truck

	Gasoline	Gasoline PHEV	EV	G.H2 FCV	CNG
Capital Cost	$42,000	$67,000	$93,000	$93,000[176]	$50,000
Depreciation	$37,090	$59,168	$82,129	$82,129	$44,155
Fuel[177]	$154,319	$96,003	$89,658	$235,924	$80,614
Maintenance and Repair	$114,616	$100,040	$72,262	$72,262	$114,616
Insurance	$28,264	$36,974	$46,031	$46,031	$31,051
License and Registration	$675	$675	$2,053	$2,053	$675
Total Cost of Ownership	$334,965	$292,859	$292,133	$438,399	$271,112

Table 44. Lifetime Cost of Ownership Outputs- Cargo Van

	Gasoline	EV	G.H2 FCV	CNG
Capital Cost	$33,000	$68,000	$68,000	$49,000
Depreciation	$29,143	$60,051	$0	$43,272
Fuel[178]	$225,691	$131,124	$345,038	$117,898
Maintenance and Repair	$120,663	$76,074	$76,074	$120,663
Insurance	$25,129	$37,322	$13,632	$30,703
License and Registration	$675	$2,053	$2,053	$675
Total Cost of Ownership	$401,300	$306,625	$436,798	$313,211

[175] Fuel costs were changed from the original AFLEET tool assumptions to recent data from 2021-2023. Gasoline fuel price was based on the average California gas prices from 2021 and 2022: California Gasoline and Diesel Retail Prices (eia.gov). Electricity rates were based on California residential rates from 2023: California Profile (eia.gov)

[176] Assumed the same as BEV

[177] Fuel costs were changed from the original AFLEET tool assumptions to recent data from 2021-2023. Gasoline fuel price was based on the average California gas prices from 2021 and 2022: California Gasoline and Diesel Retail Prices (eia.gov). Electricity rates were based on California residential rates from 2023: California Profile (eia.gov)

[178] Fuel costs were changed from the original AFLEET tool assumptions to recent data from 2021-2023. Gasoline fuel price was based on the average California gas prices from 2021 and 2022: California Gasoline and Diesel Retail Prices (eia.gov). Electricity rates were based on California residential rates from 2023: California Profile (eia.gov)

Table 45. Lifetime Cost of Ownership Outputs- Passenger Van

	Gasoline	EV	G.H2 FCV
Capital Cost	$38,000	$68,000[179]	$68,000
Depreciation	$33,558	$60,051	$60,051
Fuel	$172,943	$100,478	$264,397
Maintenance and Repair	$110,410	$69,610	$69,610
Insurance	$26,871	$37,322	$37,322
License and Registration	$675	$2,053	$2,053
Total Cost of Ownership	$344,457	$269,515	$433,434

Table 46. Lifetime Cost of Ownership Outputs- Step Van

	Diesel	EV	G.H2 FCV	CNG
Capital Cost	$70,000	$150,000	$150,000	$110,000
Depreciation	$55,685	$119,325	$119,325	$87,505
Fuel[180]	$205,717	$105,780	$320,477	$128,367
Diesel Exhaust Fluid	$2,297	$0	$0	$0
Maintenance and Repair	$73,718	$51,246	$51,246	$78,119
Insurance	$101,460	$149,597	$149,597	$125,529
License and Registration	$18,258	$18,258	$18,258	$18,258
Total Cost of Ownership	$457,135	$444,207	$658,904	$437,778

Table 47. Lifetime Cost of Ownership Outputs- Box Truck

	Diesel	EV	CNG
Capital Cost	$75,000	$185,000	$115,000
Depreciation	$59,663	$147,168	$91,483
Fuel[181]	$323,253	$166,217	$190,503
Diesel Exhaust Fluid	$3,610	$0	$0
Maintenance and Repair	$104,316	$84,780	$114,695
Insurance	$120,285	$176,740	$140,814
License and Registration	$18,258	$18,258	$18,258
Total Cost of Ownership	$629,384	$593,163	$555,754

[179] Same assumption as cargo vans

[180] Fuel costs were changed from the original AFLEET tool assumptions to recent data from 2021-2023. Gasoline fuel price was based on the average California gas prices from 2021 and 2022: California Gasoline and Diesel Retail Prices (eia.gov). Electricity rates were based on California residential rates from 2023: California Profile (eia.gov)

[181] Fuel costs were changed from the original AFLEET tool assumptions to recent data from 2021-2023. Gasoline fuel price was based on the average California gas prices from 2021 and 2022: California Gasoline and Diesel Retail Prices (eia.gov). Electricity rates were based on California residential rates from 2023: California Profile (eia.gov)

Table 48. Lifetime Cost of Ownership Outputs- Cab and Chassis

	Diesel	Gasoline PHEV	EV	G.H2 FCV	CNG
Capital Cost	$72,000	$72,000[182]	$100,000	$100,000[183]	$69,000
Depreciation	$63,584	$63,584	$88,311	$88,311	$60,934
Fuel[184]	$370,997	$296,815	$276,445	$727,431	$248,560
Diesel Exhaust Fluid	$4,143	$0	$0	$0	$0
Maintenance and Repair	$261,319	$154,228	$111,404	$111,404	$176,700
Insurance	$38,715	$38,715	$48,470	$48,470	$37,670
License and Registration	$675	$675	$2,053	$2,053	$675
Total Cost of Ownership	$739,433	$554,017	$526,682	$977,669	$524,540

Table 49. Lifetime Cost of Ownership Outputs- Straight Truck

	Diesel	EV	G.H2 FCV	CNG
Capital Cost	$75,000	$185,000	$185,000[185]	$115,000
Depreciation	$59,663	$147,168	$147,168	$91,483
Fuel[186]	$323,253	$166,217	$503,581	$190,503
Diesel Exhaust Fluid	$3,610	$0	$0	$0
Maintenance and Repair	$104,316	$84,780	$84,780	$114,695
Insurance	$120,285	$176,740	$176,740	$140,814
License and Registration	$18,258	$18,258	$18,258	$18,258
Total Cost of Ownership	$629,384	$593,163	$930,527	$555,754

Table 50. Lifetime Cost of Ownership Outputs- Semi-Tractor

	Diesel	EV	G.H2 FCV	CNG
Capital Cost	$130,000	$480,000	$360,000	$170,000
Depreciation	$103,415	$381,841	$286,380	$135,235
Fuel	$938,766	$1,032,959	$3,079,607	$553,245
Diesel Exhaust Fluid	$10,483	$0	$0	$0
Maintenance and Repair	$262,538	$228,133	$228,133	$271,681
Insurance	$198,948	$324,379	$281,374	$213,283
License and Registration	$29,199	$29,199	$29,199	$29,199
Total Cost of Ownership	$1,543,349	$1,996,511	$3,904,694	$1,202,644

182 Assumed to be the same as diesel

183 Assumed the same purchase price as BEV Cab and Chassis.

184 Fuel costs were changed from the original AFLEET tool assumptions to recent data from 2021-2023. Gasoline fuel price was based on the average California gas prices from 2021 and 2022: California Gasoline and Diesel Retail Prices (eia.gov). Electricity rates were based on California residential rates from 2023: California Profile (eia.gov)

185 Assumed the same price as BEV Straight Truck.

186 Fuel costs were changed from the original AFLEET tool assumptions to recent data from 2021-2023. Gasoline fuel price was based on the average California gas prices from 2021 and 2022: California Gasoline and Diesel Retail Prices (eia.gov). Electricity rates were based on California residential rates from 2023: California Profile (eia.gov)

Table 51. Lifetime Cost of Ownership Outputs- Refuse Vehicles

	Diesel	EV	CNG
Capital Cost	$300,000	$500,000	$335,000
Depreciation	$238,650	$397,751	$266,493
Fuel	$1,220,078	$683,646	$761,327
Diesel Exhaust Fluid	$13,624	-	-
Maintenance and Repair	$1,622,045	$1,111,001	$1,735,023
Insurance	$253,732	$311,692	$263,875
License and Registration	$18,258	$18,258	$18,258
Total Cost of Ownership	$3,366,387	$2,522,347	$3,044,976

Table 52. Lifetime Cost of Ownership Outputs- Single Deck Bus

	Diesel	EV	G.H2 FCV	CNG
Capital Cost	$500,000	$900,000	$1,125,000	$540,000
Depreciation	$397,751	$715,951	$894,939	$429,571
Fuel[187]	$923,175	$563,362	$1,852,705	$576,060
Diesel Exhaust Fluid	$10,308	$0	$0	$0
Maintenance and Repair	$1,015,402	$625,940	$1,358,691	$1,015,402
Insurance	$291,952	$460,079	$554,650	$308,764
License and Registration	$18,258	$18,258	$18,258	$18,258
Total Cost of Ownership	$2,656,846	$2,383,590	$4,679,243	$2,348,056

Table 53. Lifetime Cost of Ownership Outputs- Double Deck Bus

	Diesel	EV	CNG
Capital Cost	$500,000	$1,050,000	$540,000
Depreciation	$397,751	$835,276	$429,571
Fuel[188]	$923,175	$563,362	$576,060
Diesel Exhaust Fluid	$10,308	$0	$0
Maintenance and Repair	$1,015,402	$625,940	$1,015,402
Insurance	$291,952	$523,127	$308,764
License and Registration	$18,258	$18,258	$18,258
Total Cost of Ownership	$2,656,846	$2,565,963	$2,348,056

[187] Fuel costs were changed from the original AFLEET tool assumptions to recent data from 2021-2023. Gasoline fuel price was based on the average California gas prices from 2021 and 2022: California Gasoline and Diesel Retail Prices (eia.gov). Electricity rates were based on California residential rates from 2023: California Profile (eia.gov)

[188] Fuel costs were changed from the original AFLEET tool assumptions to recent data from 2021-2023. Gasoline fuel price was based on the average California gas prices from 2021 and 2022: California Gasoline and Diesel Retail Prices (eia.gov). Electricity rates were based on California residential rates from 2023: California Profile (eia.gov)

Table 54. Lifetime Cost of Ownership Outputs- Articulated Bus

	Diesel	EV	G.H2 FCV	CNG
Capital Cost	$500,000	$1,050,000	$1,125,000	$540,000
Depreciation	$397,751	$835,276	$894,939	$429,571
Fuel[189]	$923,175	$563,362	$1,852,705	$576,060
Diesel Exhaust Fluid	$10,308	-	-	-
Maintenance and Repair	$1,015,402	$625,940	$1,358,691	$1,015,402
Insurance	$291,952	$523,127	$554,650	$308,764
License and Registration	$18,258	$18,258	$18,258	$18,258
Total Cost of Ownership	$2,656,846	$2,565,963	$4,679,243	$2,348,056

Table 55. Lifetime Cost of Ownership Outputs- School Bus

	Diesel	EV	CNG
Capital Cost	$100,000	$300,000	$130,000
Depreciation	$79,550	$238,650	$103,415
Fuel[190]	$165,121	$101,640	$103,035
Diesel Exhaust Fluid	$1,844	$0	-
Maintenance and Repair	$316,431	$195,062	$316,431
Insurance	$97,666	$171,111	$108,683
License and Registration	$18,258	$18,258	$18,258
Total Cost of Ownership	$678,870	$724,722	$649,822

Table 56. Lifetime Cost of Ownership Outputs - Shuttle Bus

	Diesel	EV	G.H2 FCV	CNG
Capital Cost	$65,000	$265,000	$265,000[191]	$90,000
Depreciation	$51,708	$210,808	$210,808	$71,595
Fuel[192]	$293,288	$180,534	$725,081	$183,011
Diesel Exhaust Fluid	$3,275	$0	$0	$0
Maintenance and Repair	$676,935	$417,293	$417,293	$676,935
Insurance	$84,813	$158,258	$158,258	$93,994
License and Registration	$18,258	$18,258	$18,258	$18,258
Total Cost of Ownership	$1,128,277	$985,151	$1,529,698	$1,043,793

[189] Fuel costs were changed from the original AFLEET tool assumptions to recent data from 2021-2023. Gasoline fuel price was based on the average California gas prices from 2021 and 2022: [California Gasoline and Diesel Retail Prices (eia.gov)]. Electricity rates were based on California residential rates from 2023: [California Profile (eia.gov)]

[190] Fuel costs were changed from the original AFLEET tool assumptions to recent data from 2021-2023. Gasoline fuel price was based on the average California gas prices from 2021 and 2022: [California Gasoline and Diesel Retail Prices (eia.gov)]. Electricity rates were based on California residential rates from 2023: [California Profile (eia.gov)]

[191] Assumed the same purchase price as BEV Shuttle Bus.

[192] Fuel costs were changed from the original AFLEET tool assumptions to recent data from 2021-2023. Gasoline fuel price was based on the average California gas prices from 2021 and 2022: [California Gasoline and Diesel Retail Prices (eia.gov)]. Electricity rates were based on California residential rates from 2023: [California Profile (eia.gov)]

Table 57. Lifetime Cost of Ownership Outputs- Cutaway[193]

	Diesel	EV	G.H2 FCV	CNG
Capital Cost	$65,000	$265,000	$265,000[194]	$90,000
Depreciation	$51,708	$210,808	$210,808	$71,595
Fuel[195]	$293,288	$180,534	$725,081	$183,011
Diesel Exhaust Fluid	$3,275	$0	$0	$0
Maintenance and Repair	$676,935	$417,293	$417,293	$676,935
Insurance	$84,813	$158,258	$158,258	$93,994
License and Registration	$18,258	$18,258	$18,258	$18,258
Total Cost of Ownership	$1,128,277	$985,151	$1,529,698	$1,043,793

Rail: To estimate the TCO for various rail technologies, the project team used inputs provided through CARB's in-use diesel locomotive regulation economic analysis.[196] To calculate TCO, we incorporated three financial parameters, including the estimated purchase price, projected fuel cost, and anticipated maintenance expenses. These components were considered over an extended timeline of a 15-year period.

Table 58. TCO Calculation for Rail

Locomotive Type	Technology Type	Purchase Price	Fuel Cost	Annual Maintenance Cost	Fuel Economy (fuel per MWhr)	Fuel Cost	Maintenance Cost	Total Cost of Ownership
Passenger Locomotive	**Diesel**	$7,500,000	$5.10 / gallons	$79,000	64.5 gal/MWh	$8,183,223	$1,075,268	$16,758,491
	BEV	$11,000,000	$0.19 / kWh	$71,100	1385 kWh/MWh	$9,302,679	$967,741	$21,270,421
	FCEV	$4,250,000	$16.23 / kg	$79,000	52.97 kg H2/MWh	$22,546,259	$1,075,268	$27,871,527
Freight Locomotive	**Diesel**	$3,100,000	$5.10 / gallons	$79,000	64.5 gal/MWh	$1,572,887	$1,075,268	$5,748,155
	BEV	$6,250,000	$0.19 kWh	$71,100	1385 kWh/MWh	$1,788,057	$967,741	$9,005,798
	FCEV	$13,000,000	$16.23 / kg	$79,000	55.82 kg H2/MWh	$4,566,754	$1,075,268	$18,642,022
Switchers	**Diesel**	$2,700,000	$5.10 / gallons	$79,000	73.7 gal/MWh	$2,337,483	$1,075,268	$6,112,751
	BEV	$4,000,000	$0.19 / kWh	$71,100	1385 kWh/MWh	$2,325,543	$967,741	$7,293,284
	FCEV	$2,875,000	$16.23 / kg	$79,000	63.78 kg H2/MWh	$6,786,491	$1,075,268	$10,736,759

193 Assumed to be the same as Shuttle buses
194 Assumed the same purchase price as BEV Shuttle Bus.
195 Fuel costs were changed from the original AFLEET tool assumptions to recent data from 2021-2023. Gasoline fuel price was based on the average California gas prices from 2021 and 2022: California Gasoline and Diesel Retail Prices (eia.gov). Electricity rates were based on California residential rates from 2023: California Profile (eia.gov)
196 https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/locomotive22/appb.pdf

Appendix D: Survey Questionnaire

<<<Survey Prompt>>>

Thank you for responding to the Southern California Association of Governments' (SCAG) Clean Technology Compendium survey. This survey aims to collect the necessary data to guarantee that the Compendium is as exhaustive and precise as possible.

Please answer each survey question to the best of your ability. **Survey responses should focus on your company or organization's primary product or service offering.** Alternatively, you may complete more than one survey response in cases where multiple types of technology are proposed for inclusion in the SCAG Clean Technology Compendium. These steps will help ensure that each response applies directly to the technology under consideration.

Contact alinder@scag.ca.gov with questions related to this survey or the Clean Technology Compendium.

<<<Multiple Choice Questions>>>

1. Please provide the following information:
   a. Your name ________
   b. Your email address _________
   c. Name of your organization________

2. Which roles does your organization play in furthering a zero-emission transportation system? Select all that apply
   a. Produce zero- or near-zero emission transportation technology
   b. Research and development of zero- or near-zero emission transportation technology
   c. Sell zero- or near-zero emission transportation technology
   d. Produce or sell a product that supports or facilitates zero- or near-zero emission transportation technology
   e. Other _______________ [50-word limit]

Note: *Near-zero emission transportation technology refers to vehicles and related infrastructure that emit extremely low levels of pollutants and may be used as bridging technologies where fully zero emission technologies are not feasible or commercially available;* near zero implies a significant reduction compared to commonly used technologies.

Screen out if None is selected and move to wrap up questions

3. Does your product or service directly reduce Greenhouse Gas (GHG) emissions or facilitate the reduction of GHG emissions regardless of how it is used?
   a. Yes
   b. No

Note: *For example, while public charging infrastructure does not directly reduce emissions, it plays a critical role in facilitating the adoption of electric vehicles, which can significantly reduce emissions and help achieve long-term climate and air quality goals.*

Screen out if no and move to wrap up questions

4. Which of the following categories applies to your zero or near-zero emission technology? Select one.
    a. On-road light-duty vehicle (<8,500 lbs.)
    b. On-road medium-duty vehicle (8,501 – 26,000 lbs.)
    c. On-road heavy-duty vehicle (>26,001 lbs.)
    d. Locomotive
    e. Alternative fueling/charging infrastructure
    f. Alternative fuel provider
    g. Supporting Products (see definition below)
    h. None of the above

Note*: Zero and near-zero emissions supporting products refer to products or systems that facilitate the use of zero- and near-zero emission technologies. This may include hardware or software solutions, or services to deploy, maintain or efficiently operate zero and near zero emission vehicles and their infrastructure. Examples of zero- and near-zero emissions supporting products may include charging management solutions that enable the efficient, equitable and sustainable operation of these technologies. The goal of zero- and near-zero emission supporting products is to provide a comprehensive solution to support the deployment and adoption of clean transportation technologies while reducing or eliminating associated environmental impacts and improving the user experience.*

Screen out if "h (none of the above)" is selected and move to wrap up questions

5. ***(if a – e are selected in question 4)*** Indicate which type of alternative fuel your zero- or near-zero emission technology uses or delivers? Select one.
    a. Electricity
    b. Hydrogen
    c. Other fuels, please indicate

Screen out if 5d – h are selected and move to wrap up questions

6. ***(if 4a is selected)*** Which body style applies to your light-duty vehicle technology? Select one.
    a. Passenger car
    b. Minivan
    c. Pickup Truck
    d. SUV
    e. Utility Van
    f. Other, please indicate______

7. ***(If 4b is selected)*** Which body style applies to your medium-duty vehicle technology? Select one.
    a. SUV
    b. Pickup truck
    c. Cargo van
    d. Passenger van
    e. Step van
    f. Box truck
    g. Cab and chassis
    h. School Bus
    i. Cutaway
    j. Other, please indicate_______

8. ***(If 4c is selected)*** Which body style applies to your heavy-duty vehicle technology? Select one. (if you offer multiple, you will have an opportunity to submit a second entry)
    a. Straight trucks

b. Semi-tractor
c. Refuse trucks
d. Transit bus
e. School bus
f. Shuttle bus
g. Other, please indicate_____

9. ***(If 4e is selected)*** Which category applies to your alternative fuel or charging infrastructure? Select one.
    a. Hydrogen fueling system
    b. Compressed natural gas fueling system
    c. Level 2 charging station
    d. DC fast charging station
    e. Wireless electric vehicle charging system
    f. Pantograph charging system
    g. Other, please indicate________

10. ***(If 9a is selected)*** Which category applies to your hydrogen fueling infrastructure? Select all that applies.
    a. Fast fill (700 bar – H70)
    b. Slow fill (350 bar – H35)
    c. Combined fill
    d. Other, please indicate________

11. ***(If 9a is selected)*** What method does your hydrogen station utilize for hydrogen production?
    a. On-site electrolysis using grid electricity
    b. On-site electrolysis using renewable energy sources (e.g., solar, wind)
    c. On-site steam methane reforming (SMR) from natural gas
    d. Off-site electrolysis with grid electricity, delivered via tube trailers or liquid hydrogen trucks
    e. Off-site electrolysis with renewable energy sources, delivered via tube trailers or liquid hydrogen trucks
    f. Off-site steam methane reforming (SMR) from natural gas, delivered via tube trailers or liquid hydrogen trucks
    g. Off-site hydrogen production from other sources (e.g., biomass, waste, or industrial byproducts), delivered via tube trailers or liquid hydrogen trucks
    h. Other, please indicate________

12. ***(If 9d is selected)*** Which power level applies to your DC fast charging station technology? Select one.
    a. Low power (50 – 100kW
    b. Medium power (>100 – 250kW)
    c. High Power (>250 – 350kW)
    d. Ultra-high power (> 350 kW)
    e. Other, please indicate______

13. ***(If 4f is selected)*** Which of the following best describes the product technology you offer as a provider of zero and near-zero emission supporting solutions?
    a. Hardware
    b. Software
    c. Services, please describe__________
    d. Other, please indicate______

14. ***(If 4f is selected)*** What primary function does your supporting product serve in the zero-emission transportation ecosystem?

a. Optimizing vehicle performance, range, and durability
b. Enhancing charging or refueling speed and efficiency
c. Providing secure and user-friendly payment solutions
d. Improving energy storage capacity and performance
e. Facilitating seamless integration with existing infrastructure
f. Streamlining fleet operations and management
g. Encouraging sustainable manufacturing and recycling practices
h. Increasing user convenience and accessibility
i. Other, please indicate______

15. What phase of product development or deployment applies to your zero or near-zero emissions technology? Select one.
    a. Full-scale commercial availability
    b. Limited commercial availability
    c. Pilot / demonstration phase
    d. Prototype phase
    e. Research and development phase
    f. Conceptual phase
    g. Other, please indicate________

Screen out if d - f and move to wrap up questions

<<<Specific Questions >>>

16. Provide a concise overview of your zero- or near-zero emission technology, including its primary applications and unique features [100-words limit]

17. If your product is still under development (i.e., not commercially available), indicate the estimated timeline for when it will become commercially available? Select one.
    a. Within the next six months
    b. Within the next year
    c. Within the next two years
    d. Within the next five years
    e. Five years or more

18. What is your current capacity to produce this product? Enter the number of units you can deliver per year.

19. What specific challenges or barriers are you facing in broadening the commercial accessibility of your product? Select all that apply.
    a. Supply chain issues
    b. Regulatory hurdles
    c. Manufacturing constraints
    d. Labor constraints
    e. Power grid constraints
    f. Knowledge gaps
    g. Insufficient public incentives
    h. Insufficient support programs
    i. Other, please indicate_______ [200-word limit]

20. What would be the estimated cost of obtaining your technology, including the cost of purchasing your software or acquiring your hardware? [Please include per unit cost and be clear on what's included] [100-word limit]

21. Please provide the best estimate of the annual maintenance cost for your technology, including ongoing maintenance, subscription fees, and any other related expenses. [Please specify the cost per unit] [100-word limit]

22. Does your product include a no-cost warranty?
    a. Yes
    b. No
    c. Other, please indicate______[25-word limit]

23. ***[If 22a is selected]*** What type of no-cost warranty is provided?
    a. Full
    b. Limited
    c. Other, please indicate_____[25-word limit]

24. ***[If 22a is selected]*** What is the duration of the no-cost warranty?
    a. Six months or less
    b. One year or less
    c. Two years or less
    d. Five years or less
    e. Ten years or less
    f. Lifetime warranty
    g. Other, please indicate_____[25-word limit]

25. ***[If 21b is selected]*** Is a warranty offered for purchase? If yes, please describe what is offered.
    a. Yes, please indicate __________________[25-word limit]
    b. No
    c. Other, please indicate______[25-word limit]
26. Please explain whether your technology is designed for compatibility with equipment or vehicles across various modes (e.g., transit buses and commercial vehicles), or if it is specifically intended for use with a particular mode. If this does not apply, please respond with "N/A." [100-word limit]
27. Please describe if your technology is designed to be compatible with equipment or vehicles from different manufacturers, or if it is specifically designed for use with a particular product. If this does not apply, please respond with "N/A." [100-words limit]
28. Could you provide specific details on the redundancy or resource diversity that your product offers? In other words, how can your product adapt to unforeseen events, or system shocks and stressors? If this does not apply, please respond with "N/A." [100 words limit]
29. Does your product contribute to enhancing stability in power systems? If so, how? If this does not apply, please respond with "N/A." [100 words limit]
30. SCAG defines accessibility as providing equal access to mobility, employment and economic opportunity, education, health, and other quality of life opportunities through infrastructure and technologies. Could you describe how your product meets this definition? If this does not apply, please respond with "N/A." [100 words limit]
31. Does your company have any programs in place to support and retain the local workforce? Select all that apply.
    a. Local hire programs
    b. Providing access to training and education
    c. Offering industry-recognized certifications

d. Developing customized training programs, such as pre-employment training
e. Connecting to apprenticeships programs with a mix of instruction and on-the-job training.
f. Supporting employee retention by offering services such as transportation, childcare assistance, and mentoring programs to individuals engaged in training
g. Other, please indicate_______
h. None of the above

<<<Wrap up>>>

32. Is there anything else you would like to tell us? _________________. [100-words limit]

33. Would you like your company's name to be listed as a participant in our survey within the final report?
    a. Yes
    b. No

34. Would you like to select another product to provide information about?
    c. Yes
    d. No

    If the respondent chooses "yes," a new survey should be initiated

Appendix E: Other Clean Technology Adoption Considerations

As discussed in the report, the project team and SCAG initially contemplated a broader set of clean technology specifications that addressed goals such as equity, accessibility, and resiliency. While criteria such as these are important ones, they are difficult to measure categorically. For instance, the ability of disadvantaged communities to access EV charging stations cannot be measured by the qualities of the charging stations themselves. Instead, these outcomes are likely to be determined by contextual factors like grid connectivity, cost, and policies addressing the just distribution of investments. Similarly, the presence or lack of accessibility features for a given clean technology deployment is likely to be determined by a unique set of variables including vendor or client design specifications or accessibility requirements attached to a particular funding source. Goals such as resiliency that are broadly defined and resist easy measurement posed further challenges and were ultimately removed from the list of specifications.

While challenging to measure categorically, these criteria are nevertheless critical ones for SCAG and its member jurisdictions to consider when making policies, plans, or investment decisions. The table that follows provides some of these additional criteria that were excluded from the list of specifications for practical reasons. While not exhaustive, this list of criteria, as illustrated in Table 60, can provide a valuable supplement to the specifications presented earlier in the report. It is recommended that readers prioritize their needs and investigate the characteristics described below as applicable. As noted, some of these criteria were individually discussed within each section of the report.

Table 59. Additional Clean Transportation Technology Adoption Criteria.

Criteria	Description
Physical Accessibility	The measure of physical accessibility refers to whether the technology can be operated and used by individuals with disabilities. This includes, but is not limited to, individuals with mobility impairments, visual impairments, and auditory impairments. Accessibility in technology not only promotes inclusion but also adheres to principles of universal design.
Spatial Accessibility/Equity	Spatial accessibility evaluates whether the technology can be deployed within and primarily benefit disadvantaged communities. It takes into account the geographical distribution of the technology, with a focus on ensuring that marginalized or underserved areas are not left behind in the transition to more sustainable and advanced transportation solutions.
Support for Unbanked Users	This criterion assesses whether the technology provides payment options for users who do not have access to traditional banking services, including debit or credit cards. It ensures that the technology can cater to the financially excluded population.
Safe Systems	This criterion pertains to whether the technology maintains or improves upon the prevailing safety conditions. It's vital that the implementation of new technologies does not compromise user safety.
Public Perception of Safety	The public's perception of safety refers to the degree to which the general public considers the technology to be safe. Acceptance and widespread adoption of new technology often hinge on its perceived safety.
Safety Testing and Standards	This measures whether the technology has passed all applicable safety tests and adheres to industry safety standards. Compliance with established safety standards is crucial to ensuring the technology's safety and reliability. It is recommended that users verify this before making a purchase.
Shared Use Potential	This criterion evaluates whether the technology has the potential for transit and/or shared-use applications, contributing to a more efficient and sustainable use of resources.
Intelligent Transportation Systems	This evaluates whether the technology can contribute to the efficient use of existing transportation systems, such as reducing congestion, improving traffic management, or facilitating better route planning.
Resilience	This measures whether the technology enhances the overall resilience of the transportation and power system, including its ability to withstand and adapt to various disruptions.
State of Good Repair	This refers to whether the technology supports the ongoing maintenance and operation of transportation infrastructure in a condition that allows it to function as intended.

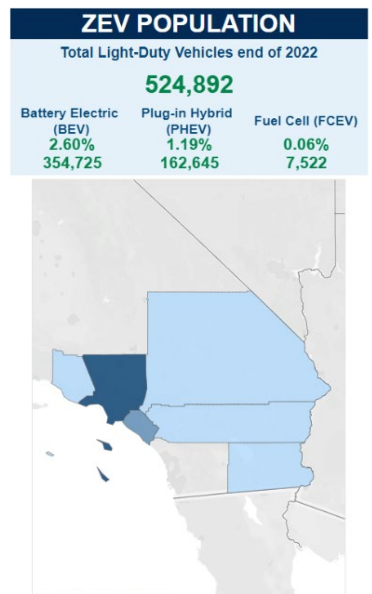
Criteria	Description
Scalability	This criterion evaluates whether the technology can be scaled up or down to suit various use cases or geographical contexts. Scalability is critical for the widespread adoption of the technology.
Versatility	This measures whether the technology supports diverse uses, which can enhance its value and applicability across a range of scenarios.
Reliability	This criterion evaluates whether the technology is generally regarded as reliable. Reliable technologies perform consistently under various conditions, maintain their functionality over time, and seldom malfunction, thereby promoting user trust and satisfaction.
Integration	This criterion measures whether the technology is interoperable and uses prevailing industry standards. Interoperability ensures that the technology can seamlessly function with other systems, enhancing user convenience and facilitating smoother operations across various platforms and devices.
Adaptability	This evaluates whether the technology is seen as reasonably future proof. Future-proof technologies are designed with an eye toward future developments, meaning they can adapt to changes in user needs, technological advances, and regulatory shifts without becoming obsolete.
Commercialization	This criterion is relevant for technologies that are still in development or prototype phases. It evaluates whether the technology has significant commercial potential, meaning it could become a successful product or service in the market once fully developed and launched.
Incentivization	This criterion assesses whether the technology is incentivized by the public sector. Public incentives can accelerate the adoption of new technologies by reducing costs, mitigating risks, and providing supportive regulatory frameworks.
Job Creation	This measures whether the technology is likely to create new jobs in SCAG region. Job creation contributes to economic development and is often a key consideration in public policy and investment decisions.
Locality	This criterion evaluates whether the technology sector or vendor has a significant presence in SCAG region. A strong local presence can contribute to regional economic development, provide local job opportunities, and facilitate coordination with local stakeholders.
Workforce Retention	This criterion assesses whether the technology enables the retention of the existing workforce. Workforce retention refers to the capacity of technology to maintain current jobs, either directly (through jobs in the same industry) or indirectly (through creating demand for jobs in related industries).

Appendix F: Technology Compendium Two-Pagers

Single Occupant Vehicles

The landscape of passenger zero emission vehicles (ZEV) is primarily divided into two categories: Plug-In Electric Vehicles (PEVs) and Hydrogen Fuel Cell Electric Vehicles (FCEVs). Currently PEVs, which include both Battery Electric Vehicles (BEV) and Plug-in Hybrid Electric Vehicles (PHEV), continue to lead the charge in the clean technology revolution, bolstered by continuous improvements in battery technology. On the other hand, FCEVs, although fewer in model diversity, present an alternative for longer journeys where quick refueling is paramount. Several auto manufacturers are investing in this technology to expand their offerings. The production of green hydrogen, primarily through renewable energy-powered electrolysis, is slowly gaining traction. However, the hydrogen refueling infrastructure remains less developed compared to the electric charging network, which impacts market adoption. As of December 2022, consumers in California had a broad range of options with 50 passenger BEV models, 51 PHEV models, and 3 FCEV models commercially available for sale[197]. It should also be noted that while PHEVs are considered a ZEV, they are only truly zero emission when operating solely on battery power. Once the battery is depleted, they operate similarly to a conventional hybrid vehicle, utilizing a gasoline engine. The average electric range of PHEVs has steadily increased from 20.5 miles in 2012 to 38.5 miles as of 2021.[198]

The adoption of passenger ZEVs in the SCAG region has steadily increased over the years. ZEV adoption started gaining momentum around 2010 and was initially concentrated in high populous areas and regions with higher socioeconomic status. In the SCAG region, the majority of ZEVs are found in Los Angeles and Orange counties, with Los Angeles County having more than 50 percent and Orange County having more than 25 percent of the total ZEVs in the region. Prior to 2010, the SCAG region had only 122 ZEVs. Since then, the number has surged to approximately 525,000, representing about 3.9 percent of the total light-duty vehicle fleet in the region by the end of 2022. Sales trends indicate that ZEVs are becoming an increasingly significant portion of the market, composing roughly 25% of light-duty vehicle sales as of the second quarter of 2023. BEVs and PHEVs represent the majority of ZEVs in the region, with FCEVs lagging significantly behind, only representing 0.06 percent of ZEVs in the region. It is worth noting that the majority of the BEVs (88 percent) in the region have battery electric ranges over 200 miles. Given the current adoption rates, the region is making significant progress toward the targets set by the state to require 100% ZEV sales by 2035.



Despite the rapid increase in ZEV adoption, the upfront cost of ZEVs is still higher than their counterpart internal combustion engine (ICE) vehicles. The latest report from Kelley Blue Book[199], reveals that the average cost for a passenger ZEV is $18,000 more than that of an average ICE vehicle. The high price of ZEV, along with limited access to charging and fueling infrastructure, represent significant barriers to the adoption of ZEVs, particularly in low- and moderate-income communities. To counteract these challenges, the SCAG region should employ a comprehensive,

[197] https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics
[198] https://www.iea.org/data-and-statistics/charts/evolution-of-average-range-of-electric-vehicles-by-powertrain-2010-2021
[199] https://mediaroom.kbb.com/2022-05-10-Luxury-Share-Increases-in-April,-Pushing-New-Vehicle-Average-Transaction-Prices-Higher,-according-to-Kelley-Blue-Book

multi-faceted approach that includes both demand and supply side strategies. On the demand side, financial incentives such as rebates, and grants are vital. Not only do they make new ZEVs more affordable for the average consumer, but they are particularly crucial in ensuring that ZEVs are accessible to low- and moderate-income communities. Alongside these incentives, awareness campaigns and education about the benefits of ZEVs can help overcome knowledge gaps that potential buyers may face. Moreover, the region should also actively leverage and promote the pre-owned ZEV market. Pre-owned ZEVs provide a more affordable entry point for low- and moderate-income communities, helping to overcome affordability issues and boost adoption rates. Therefore, it is important for the region to thoughtfully design and implement incentive programs that encourage the purchase of these pre-owned ZEVs. Such incentives could range from direct financial benefits, like grants or rebates, to non-monetary incentives such as extended warranties or battery certifications, aimed specifically at making pre-owned ZEVs an attractive and viable choice for these communities.

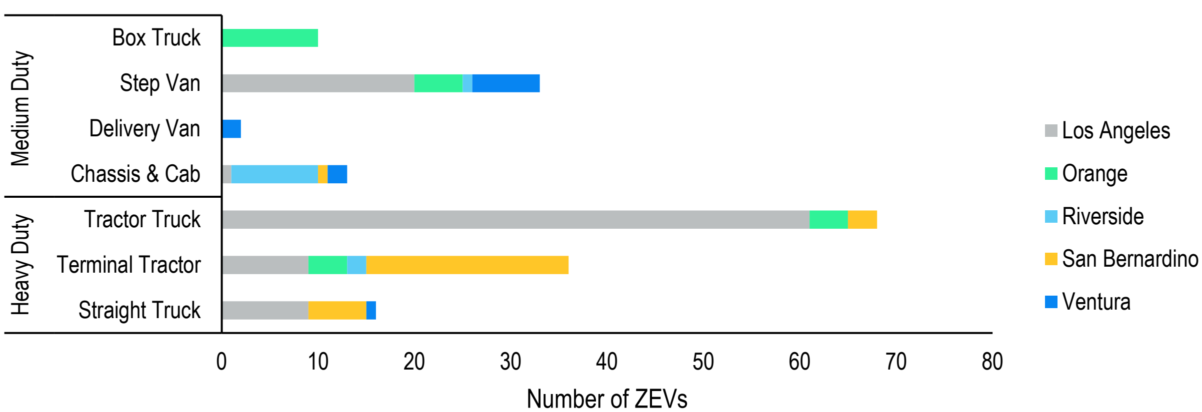
On the supply side, the region should advocate for the development of accessible charging and hydrogen refueling infrastructure. Given that many residents in low- and moderate-income communities may not have access to home charging, public and shared charging infrastructure becomes vital. This can be achieved through partnerships with utilities, local businesses, and real estate developers, as well as leveraging federal and state funding opportunities. In tandem, the region should support building codes that require new constructions and major renovations to be EV-ready, ensuring infrastructure readiness keeps pace with increasing ZEV adoption. To further enhance equity outcomes of this transition, the region could consider establishing a ZEV infrastructure grant program specifically targeted at underserved communities. The program could offer funding to local businesses, nonprofits, and community organizations to install charging or refueling stations in areas that need them the most. The region should also take measures to ensure that the transition to ZEVs is inclusive. This could involve providing workforce development programs focused on ZEV and charging infrastructure maintenance and installation, thereby creating employment opportunities in the clean technology sector for residents of these communities.

Commercial Medium & Heavy-Duty Vehicles

The clean technology landscape for commercial medium and heavy-duty vehicles (MHDV) is currently in a transformative phase, with an increasing shift away from traditional fossil fuel-based technologies toward cleaner, more sustainable alternatives. This shift is being mainly driven by advancements in battery electric, and hydrogen fuel cell technologies that have shown great potential in reducing greenhouse gas emissions (GHG) and improving air quality specifically reducing nitrogen oxides and diesel particulate matter emissions. Several leading manufacturers are now offering electric or hydrogen-powered models for medium and heavy-duty applications, including delivery trucks, semi-tractors, etc. According to the CALSTART's Zero Emission Technology Inventory[200], there are currently 134 models of zero emission MHDVs available in North American market of which 9 of them are FCEVs and the rest are BEVs. The adoption of MHDVs in SCAG region is still in its early stages. Currently, there are only 178 MHDVs (58 heavy duty and 120 medium duty vehicles) in the region, indicating that the use of MHDVs powered by zero-emission technology is not yet widespread. Moreover, the concentration of MHDVs is not evenly distributed across SCAG region. The majority of these vehicles are concentrated in Los Angeles and Orange counties, which are two of the most densely populated and heavily trafficked areas in the region. This concentration of MHD ZEVs in certain areas may be due to the availability of charging infrastructure as well as operational and logistical considerations that make it more financially viable for businesses to adopt MHD ZEVs.

The types of MHD ZEVs currently being used in SCAG region are mainly tractor trucks, terminal tractor and step vans. Tractor trucks, also known as semi-trucks, are primarily used for hauling large quantities of goods by attaching various types of trailers. Terminal tractors, also known as yard trucks, are primarily used in ports, warehouses, and freight terminals for the purpose of quickly moving trailers and containers short distances within these confined areas. Step vans are also typically used for deliveries in urban areas due to their ease of entry and exit, ample cargo space, and maneuverability in tight spaces.

Figure 33. Number of Medium- and Heavy-Duty ZEVs by Vehicle Type and County[201]



[200] https://globaldrivetozero.org/tools/zeti-data-explorer/
[201] https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/medium-and-heavy (Accessed: July 7, 2023)

Despite these advances, challenges remain, including the high upfront costs, lack of available charging and fueling infrastructure, as well as the payload capacity constraints posed by these vehicles. For example, while a diesel semi-tractor is priced around $130,000, the cost of a battery electric semi-tractor is considerably higher, standing at approximately $480,000, making the latter nearly four times as expensive as its diesel counterpart. The lack of widespread and accessible charging and fueling infrastructure also presents a significant challenge to the adoption of zero-emission MHDVs. The current limited availability of charging and refueling stations not only impacts the operational range of these vehicles but also creates uncertainty for fleet operators and drivers, hindering the full-scale transition to cleaner transportation technologies. Payload capacity is also a crucial concern in the transition to zero-emission MHDVs. Due to the weight of the batteries, the battery electric MHDVs often have reduced payload capacity compared to their conventional counterparts, which can limit their functionality in certain industries. As the payload directly correlates to profitability in commercial transport, this reduction can deter businesses from adopting these cleaner, yet potentially less economically efficient, vehicles.

Despite these challenges, the region can play a pivotal role in addressing some of these major barriers that impede the adoption of zero-emission MHDV. Addressing the high upfront cost of zero-emission MHDVs, particularly for owner-operators who may struggle with financial viability, is a critical area where the region can have a significant impact. Firstly, the region should advocate for and support the expansion of federal, state, and local financial incentives that reduce the initial purchase cost of zero-emission MHDVs. These incentives could include grants, tax credits, or rebate programs specifically targeted at owner-operators and small businesses. The region could also partner with financial institutions to develop favorable loan or leasing programs that make it easier for these operators to finance the transition to zero-emission vehicles. Additionally, the region could foster partnerships between owner-operators and larger fleet operators or freight companies to leverage economies of scale in purchasing zero-emission vehicles. By buying in bulk, these groups could negotiate better pricing from manufacturers, making these advanced vehicles more accessible to individual owner-operators.

The region can also play a vital role in accelerating the deployment of zero-emission infrastructure, such as charging stations and hydrogen fueling centers. Leveraging its expertise in regional planning and coordination, SCAG can undertake comprehensive infrastructure planning specifically tailored for MHDVs. This planning process should involve identifying strategic locations for charging and hydrogen refueling infrastructure, factoring in variables such as vehicle routes, parking and dwelling times, proximity to the electrical grid or hydrogen supply, and zoning regulations. In addition to planning, the region can take a proactive role in promoting the construction of charging and refueling stations. Working in collaboration with local jurisdictions, private partners, and utility companies, the region can incentivize infrastructure development through various financial mechanisms, such as grants, low-interest loans, or public-private partnerships. Furthermore, the region can play an instrumental role in streamlining the permitting and approval process for infrastructure installation. By working with local governments to simplify these procedures, SCAG can reduce administrative barriers, making it quicker and easier for businesses and property owners to install charging and refueling infrastructure.

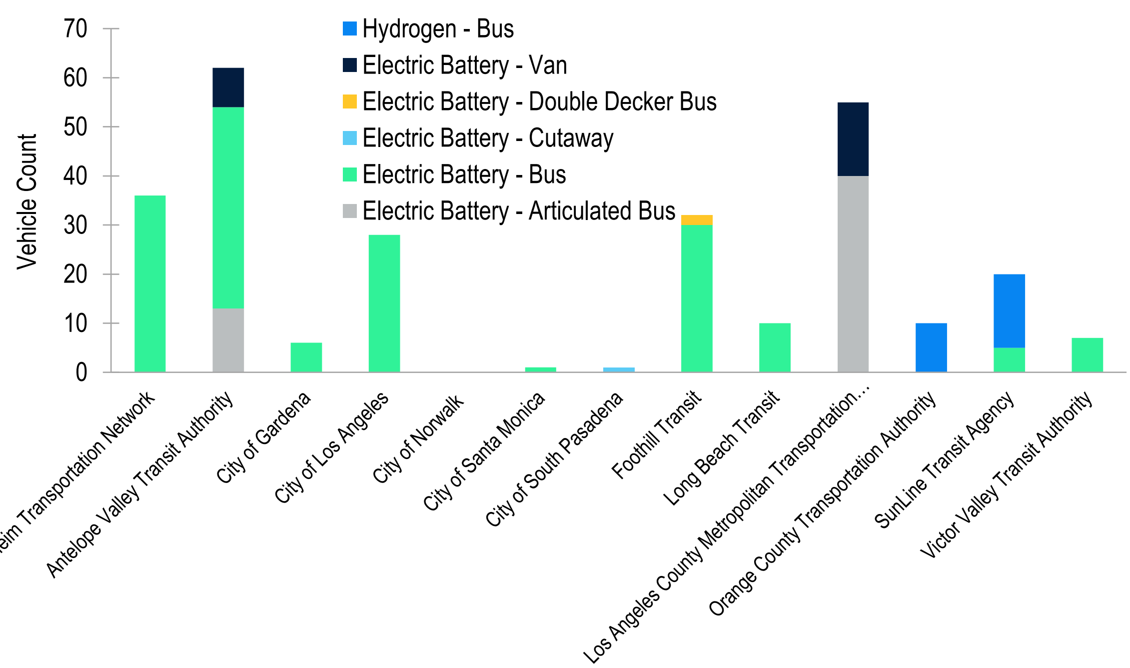
Workforce development and education campaigns are crucial tools that the region can employ to stimulate the transition to zero-emission MHDVs. By partnering with community colleges, trade schools, and universities, the region can aid in the development and expansion of training programs focused on clean transportation technologies. The creation of apprenticeship or internship programs that provide hands-on experience and job placement opportunities in the emerging field of zero-emission transportation could also be facilitated through such collaborations.

Transit Buses

The clean technology landscape for transit buses has evolved significantly over the past few years, experiencing rapid advancements and adoption rates across the globe. The primary clean technology solutions that have gained traction are battery electric buses (BEBs) and fuel cell electric buses (FCEBs). Both technologies are proven to significantly reduce greenhouse gas (GHG) and criteria pollutant emissions compared to traditional diesel- and natural-gas powered buses, thereby playing a crucial role in decarbonizing public transit. Among the two major zero emission transit bus technologies, battery electric buses have become more prevalent, thanks to continued advancements in battery technology that have led to improved energy density, lower costs, and longer lifespans. On the other hand, FCEBs, powered by hydrogen, offer another clean alternative. While FCEBs are currently less widespread than BEBs, they provide a promising solution, particularly for long-range transit applications, due to their quick refueling times and longer-range capabilities. According to the CALSTART's Zero Emission Technology Inventory[202], there are currently more than 25 models of zero emission transit buses available in the North American market of which 23 are BEBs and 2 are FCEBs.

Currently zero emission transit s buses make up the largest number of heavy-duty ZEVs in the SCAG region. When looking at the number of ZE transit vehicles by operator in the SCAG region, LA Metro and the Antelope Valley Transit Authority have the largest fleets, with the latter having the most ZE transit vehicles in the region. The Anaheim Transportation Network, City of Los Angeles, and Foothill Transit also have a considerable number of ZE transit vehicles, although to a lesser extent. Other operators in the region have a much smaller number of ZEBs or none at all (Figure 33).

Figure 34. Zero Emission Transit Vehicles by Operator[203]



202 https://globaldrivetozero.org/tools/zeti-data-explorer/
203 https://www.transit.dot.gov/ntd/data-product/2021-data-tables

Transitioning transit buses in the region to zero-emission technology is not only a crucial strategy for reducing GHG emissions but also a necessary measure with profound implications for public health. Diesel-powered buses emit pollutants, including particulate matter and nitrogen oxides, which contribute to air pollution and associated health issues such as respiratory diseases, heart disease, and premature death. A transition to zero-emission buses would, therefore, result in significant public health improvements, particularly in low-income and disadvantaged communities. These communities are often disproportionately affected by the adverse health effects of air pollution due to their proximity to major transportation corridors and industrial areas. Hence, it is imperative for the region to take a proactive and strategic approach in accelerating the transition of their transit bus fleet to zero emissions. Even though the California Innovative Clean Transit (ICT) regulation has established mandates for transit agencies to make the shift to zero emissions, a complete transition to ZEB is not expected until 2040. To this end, all the regional partners should collaborate to develop a comprehensive, long-term electrification plan - akin to the ZEB Rollout Plans created in response to the ICT regulations. This plan should outline key milestones, pinpoint potential challenges, and propose solutions, taking into consideration factors such as fleet size, route characteristics, bus depot infrastructure, and potential requirements for fast-charging stations or on-route charging facilities.

Establishing partnerships with industry stakeholders, such as bus manufacturers, charging infrastructure providers, utilities, and funding agencies, is crucial for the region. Collaborative efforts between these entities can play a pivotal role in streamlining the transition to clean technology, lowering overall costs, and guaranteeing reliable service. Zero emission infrastructure, and its availability, plays a pivotal role in the transition to ZEB technology. For example, reliable and strategically placed charging and hydrogen fueling stations are critical to successful transition of transit buses in the SCAG region to zero emission technology. Implementing this infrastructure necessitates a robust power grid that can handle the increased energy demand. This is where close coordination with utilities becomes crucial. The transformation of the transit fleet to zero-emission technology will inevitably increase the demand for electricity, thus potentially challenging the local grid's capacity. The region must work together with utility providers to understand the timing and scale of this additional demand, and to identify any grid enhancements required to support this transition.

The transition to zero-emission bus technology is a significant undertaking, made particularly challenging by the higher upfront costs of these clean transit options and their respective infrastructure. This transition would not be possible without substantial support from local, state, and federal funding. To offset initial expenses such as bus procurement and charging infrastructure installation, the regional partners should actively seek federal and state funding opportunities. Launching pilot projects can also provide hands-on experience and highlight potential challenges before a full-scale deployment is undertaken. Furthermore, equipping staff with necessary training on the operation and maintenance of zero-emission buses and related infrastructure is critical. This initiative will enhance internal capabilities and ensure that transit agencies are prepared to manage and optimize the performance of their zero-emission fleets effectively.

Passenger Rail

Adoption of zero-emission technologies in the rail sector is still in its early stages; however, these technologies are relatively mature and have been deployed elsewhere – particularly outside of North America, such as many European and Asian countries – but not yet in the SCAG region. Due to the predictable nature of passenger locomotive operations in terms of routes and schedules, there is a potential opportunity to employ battery-electric technology for shorter routes that allow for convenient charging. Alternatively, fuel cell technology offers more flexibility for passenger rail agencies, enabling them to operate longer routes with faster and less frequent refueling. Caltrans has identified hydrogen locomotives as the most suitable zero-emission (ZE) technology for Amtrak intercity operations[204] and has devised a strategy to transition its rail fleet to 100 percent ZE by 2035. As advancements in zero-emission switch locomotives have shown promise, it is estimated that commercially available zero-emission passenger locomotives will be developed by 2030, building upon these technological successes.

Within SCAG region, zero emission rail have not been fully realized, however a number of agencies have plans to implement these technologies over the coming decade. For example, Metrolink, which serves five of the six counties (all but Imperial County) outlines in its Climate Action Plan that it plans to develop and implement the necessary steps to achieve widespread electrification across its rail fleet fully by 2028. This process will occur in stages, with the Antelope Valley Line expected to be fully electrified by 2025. The plan notes that this will be accomplished by replacing diesel locomotives with electric locomotives. Additional steps described in the plan include the expansion of on-board energy storage systems that can capture and reuse regenerative braking energy. For lines where electrification is not feasible in the short term the plan lays out a program to replace or retrofit older locomotives with more energy efficient models that meet the latest emissions standards.[205] In San Bernardino County, the San Bernardino County Transportation Authority (SBCTA) has laid out plans to debut its hydrogen locomotives in 2024. The project will be funded by the California Transit and Intercity Rail Capital Program and expected to begin testing in late 2023.[206]

The first hydrogen-powered passenger train will debut in 2024, running between San Bernardino

Source: SBCTA

In addition to these initiatives, the California High-Speed Rail (CA HSR) project[207] also aims to connect major urban centers in California, from San Francisco to Los Angeles and eventually extending to Sacramento and San Diego using all-electric trains. Once completed, it will significantly reduce travel times between these cities and serve as a more sustainable transportation alternative to driving or flying. According to CA HSR, this rail will run on electricity supplied entirely from renewable sources.[208] In addition to CA HSR, Brightline West[209] is another anticipated high-speed rail service aiming to connect Southern California with Las Vegas, Nevada. This project will offer a much-needed alternative

[204] Caltrans, Caltrans Intercity Passenger Rail, Our strategy toward zero emission (Draft), October 28, 2022. (weblink: https://ww2.arb.ca.gov/sites/default/files/2020-10/Day%201%20Ext%205%20Caltrans%2020201026.pdf).
[205] https://metrolinktrains.com/globalassets/about/agency/sustainability/climate-action-plan.pdf
[206] https://www.gosbcta.com/wp-content/uploads/2022/12/ZEMU-Technology-Fact-Sheet-ENG-120522.pdf
[207] https://hsr.ca.gov/about/
[208] https://hsr.ca.gov/communications-outreach/info-center/get-the-facts/
[209] https://www.brightlinewest.com/

to the heavily trafficked I-15 corridor, providing faster and more efficient travel options for tourists and business travelers alike. Just like the CA HSR, the Brightline West will be operating all-electric, high-speed trains.

Furthermore, in April 2023, California Air Resources Board (CARB) adopted the In-Use Locomotive Regulation which mandates passenger locomotives manufactured in 2030 and onwards must operate in a zero-emission configuration within California. While this regulation provides a strong policy framework, the region must proactively prepare for the required infrastructure, whether it be hydrogen or battery charging, and focus on technology demonstrations to expedite the adoption of zero-emission solutions in the passenger rail system within the SCAG region.

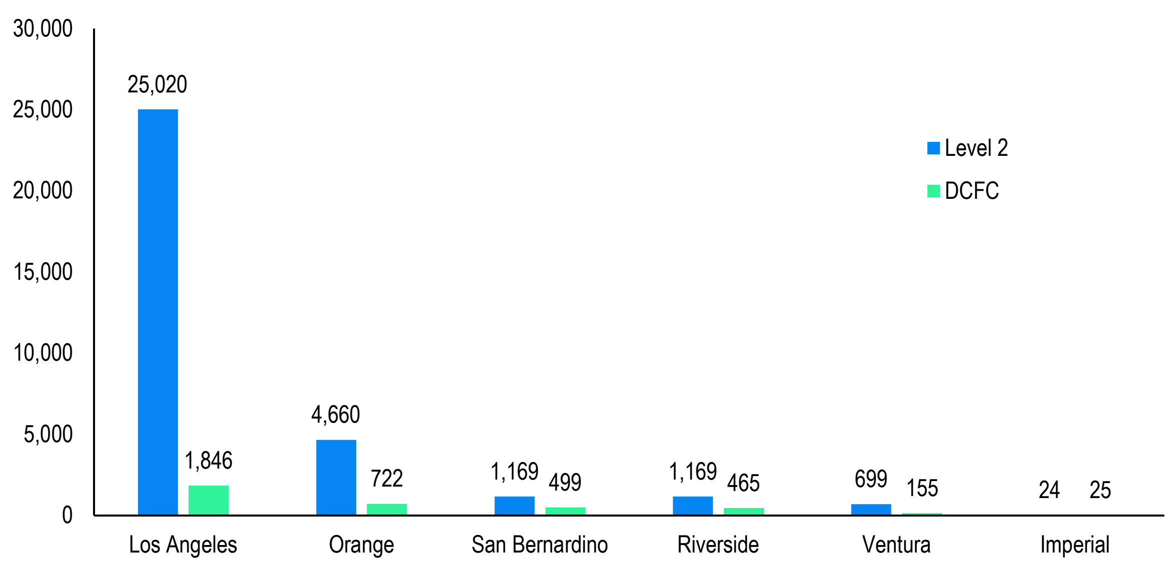
Transitioning a passenger rail system to zero emissions requires a concerted effort and strategic actions at various levels. To achieve a successful transition, the region should *undertake* pilot projects, similar to the initiatives led by the SBCTA, to systematically test and evaluate diverse zero-emission technologies, including hydrogen and battery-electric systems. These pilot projects will provide invaluable insights into the feasibility, performance, and scalability of various clean technologies, enabling informed decision-making and effective implementation strategies. Partnerships with manufacturers of zero-emission rail vehicles are crucial for the region's transition, as exemplified by the Zero Emission Heavy Transport (ZEHTRANS) working group led by CARB. Collaborating with these manufacturers can ensure that the passenger rail system receives state-of-the-art, reliable, and efficient zero-emission locomotives. Additionally, partnerships with charging and fueling infrastructure providers will be essential to establish a robust network of charging or refueling stations to support the operation of electric or hydrogen-powered locomotives. Utilities will also play a critical role in providing the necessary energy supply, grid integration, and charging infrastructure for passenger rail systems, especially considering the significantly high-power needs for charging the battery electric locomotives. Close coordination with utility will ensure a reliable and uninterrupted power source for electric trains or support the deployment of charging stations. Securing funding for demonstrations and implementation is also a vital aspect of the transition process too. The region should actively seek funding opportunities from federal, state, and local sources to support technology demonstrations, infrastructure development, and fleet electrification.

EV Charging Infrastructure

The shift to clean technologies requires access to charging infrastructure. This can be particularly challenging for people who live in apartments or other multi-unit dwellings, where installing personal charging stations (i.e., home charging) might not be possible. Public charging stations are an alternative, but they require investment in infrastructure that may be lacking in low and moderate-income neighborhoods. Even with the significant investments made at the federal and state levels, those investments alone cannot close the gap. According to California Energy Commission's (CEC) AB 2127 report[210], to meet the ambitious goals set by Executive Order N-79-20, nearly 2 million public and shared-private charging facilities will be needed by 2035 to support light-duty vehicles across the state. Within the SCAG region alone, the report indicates the requirement for 1 million of these charging points (by 2035). Notably, out of these, 689,000 chargers should be publicly accessible stations, while the remaining chargers are anticipated to meet the needs of workplaces and multi-unit dwellings.

As of now, according to the CEC's Zero Emission Vehicle and Infrastructure Statistics[211], the region hosts approximately 33,000 Level 2 and 3,700 Direct Current Fast Charging (DCFC) chargers. Los Angeles County leads the region in this regard, holding 76 percent of all Level 2 chargers and 50 percent of all DC fast chargers, reflecting the large population and EV adoption rates in the county. San Bernardino and Riverside counties have comparable numbers of chargers, highlighting their efforts in expanding the charging infrastructure as well. Unfortunately, the more rural Imperial County lags behind, possessing the fewest chargers in the region. This disparity underscores the need for a more equitable distribution of resources to support widespread ZEV adoption. For a detailed visual representation of the charging infrastructure distribution across the SCAG region, please refer to Figure 35 below.

Figure 35. Number of Public EVSE by County



When the current number of chargers deployed in the region are compared with the future projections outlined in the AB 2127 report, it is evident that the existing infrastructure falls significantly short of the projected demand. To address the infrastructure deficit, there is a significant need for an increased pace of charger installation from between 2023

[210] https://www.energy.ca.gov/data-reports/reports/electric-vehicle-charging-infrastructure-assessment-ab-2127
[211] https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics

and 2035. Specifically, each week during this period, around 1,500 chargers for light-duty vehicles should be constructed and commissioned in the SCAG region. This clearly shows why it is important for regional agencies such as SCAG and their regional partners to intensify their efforts in deploying clean fueling and charging infrastructure throughout their jurisdictions.

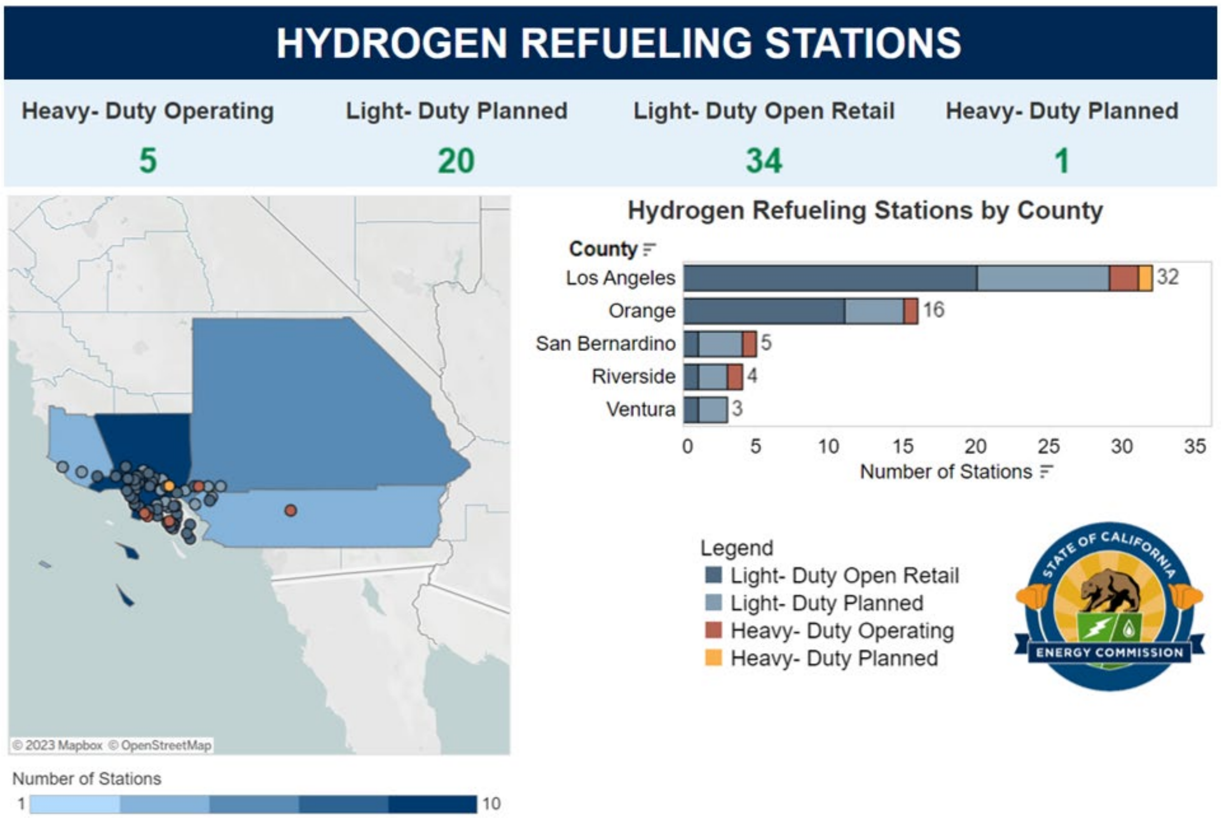
Closing this substantial gap in the SCAG region's charging infrastructure will require a multi-pronged strategy. First and foremost, a significant increase in investment from both the public and private sectors is vital. Infrastructure development should be included as a key component in local planning, as well as incentivized in the private sector through programs such as grants, rebates, or subsidies. Public-private partnerships could be an effective means for accelerating the development of the charging infrastructure. In the context of EV charging infrastructure, such partnerships can expedite the expansion process by leveraging private investment, operational expertise, and technology innovations. Governments can provide incentives such as tax benefits, subsidies, or preferential policies to attract private players, while private companies can contribute with advanced technologies, efficient management practices, and significant capital investment. In addition to the necessary financial investment, the region should also focus on strategic deployment of charging stations. This involves identifying and prioritizing areas where charging infrastructure is lacking, especially in underserved and rural areas like Imperial County. The integration of charging infrastructure with urban planning, such as the inclusion of charging stations in new residential, commercial, and public buildings, will also be critical.

Making necessary adjustments to zoning codes can also accelerate the installation of charging stations in existing buildings by minimizing constraints and restrictions. For example, modifying parking requirements for buildings with EV charging points to be more lenient can act as a motivating factor for property owners to install charging infrastructure. The region shall also consider adopting building codes that surpass state requirements for EV charging infrastructure to ensure new residential, commercial, and public buildings as well as buildings undergoing major renovations are equipped with charging stations, or at the very least, are designed to be 'EV-ready'. Streamlining permitting processes can also play a crucial role in expediting charging infrastructure development. By simplifying the application process, reducing wait times, and perhaps even offering expedited or 'over-the-counter' permit approval for charging stations, local governments can encourage more widespread installation of EV charging infrastructure. Furthermore, the region should prioritize investment in innovative technologies and solutions to enhance the versatility and convenience of the charging infrastructure, ultimately catering to a wider array of EV types and user needs.

Hydrogen Fueling Infrastructure

In terms of hydrogen fueling infrastructure, Southern California is one of the few regions in the world with a significant network of hydrogen fueling stations. SCAG region is gradually increasing its hydrogen fueling infrastructure with a total of 39 fueling stations available as of January 2023. The majority of these stations are concentrated in Los Angeles and Orange County, with only five, four, and three stations located in San Bernardino, Riverside, and Ventura counties, respectively. This lack of infrastructure, and particularly the concentration of fueling stations in high populations centers, speaks to the nascent nature of this technology. While there are currently 34 light-duty retail stations open, 20 additional stations are planned to open soon. For heavy-duty hydrogen fueling stations, there are five currently operating, with one planned to open in the near future (Figure 36).

***Figure 36. Number and Type of Hydrogen Fueling Stations Within the SCAG Region, by County*[212]**



The deployment of hydrogen fueling stations brings with it a distinctive set of difficulties that set it apart from traditional fuel or EV charging infrastructure. To begin with, the processes involved in the production, transportation, and storage of hydrogen fuel are both technically complex and financially demanding. Hydrogen is generally derived from natural gas through a method called steam methane reforming (SMR) or from water through electrolysis, both procedures needing considerable energy inputs. Additionally, due to hydrogen's low energy density and high flammability, its transportation and storage present significant logistical and safety issues. Secondly, the initial investment required for setting up a hydrogen fueling station is considerably high, often acting as a barrier for private sector involvement without substantial financial incentives or subsidies. In addition, there are regulatory complexities to navigate, including

[212] https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/hydrogen-refueling

obtaining necessary permits and compliance with safety regulations, which can be time-consuming and costly. In addition to these barriers, creating a hydrogen infrastructure is a classic 'chicken-and-egg' problem. Consumers are hesitant to buy hydrogen fuel cell vehicles due to the lack of widespread infrastructure, while providers are reluctant to invest heavily in building out infrastructure until there is a large enough fleet of hydrogen vehicles to justify the investment.

To overcome these barriers, the region can adopt a multi-faceted strategy. One key approach is leveraging public-private partnerships (PPPs) to stimulate investment in hydrogen infrastructure. Governments can provide incentives such as subsidies, grants, or favorable regulations to attract private sector involvement, while businesses can contribute their financial resources, technical expertise, and innovative capabilities. The synergy of public regulation and private sector efficiency can accelerate the establishment and operation of hydrogen fueling stations. Streamlining the regulatory process can also be crucial in overcoming these hurdles. Governments can simplify and expedite permitting procedures, provide clear guidelines for compliance with safety regulations, and offer support to navigate through the bureaucratic process. This not only eases the pathway for station developers but also reduces the time and cost associated with bringing a station into operation.

Furthermore, the region can invest in research and development to drive down the costs associated with hydrogen production, transportation, and storage. Technological innovations can make these processes more efficient, safer, and economically viable. The region could also explore alternative, localized production methods, such as on-site electrolysis powered by renewable energy, which could potentially eliminate transportation and storage issues. Finally, education and awareness campaigns can play a significant role in overcoming the 'chicken-and-egg' problem. By informing the public about the benefits of hydrogen fuel cell vehicles, including their fast-refueling times and long ranges, governments can stimulate consumer demand, thus incentivizing providers to invest in infrastructure. Similarly, providing information about the potential profitability of hydrogen fueling stations to potential investors can help to encourage private sector involvement.