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Are Santa Clara County Cities Prepared for a Zero-Emission Light Duty Vehicle Future? A Program Evaluation

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A Program Evaluation

by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

BACKGROUND

This research built on the work of Chi-Pei Fang who explored this issue in *"Ability of the Bay Area Cities to Accommodate Plug-in Electric Vehicles: A Process Evaluation"* (Fang, 2021). Fang recommended that follow-on projects focus on an individual city. This paper moved in that direction, but instead of focusing on a specific city in the California Bay Area, it focused on Santa Clara County (SCC) and the cities within. Additionally, this paper broadened the focus to include all zero-emissions vehicles (ZEVs), a category which not only includes electric vehicles (EVs) but also hydrogen fuel cell electric vehicles (FCEVs).

SCC's efforts to transition to ZEVs were part of a state-wide mandate to cease the sale of new internal combustion engine (ICE) vehicles by 2035. On September 23rd, 2020, Governor Gavin Newsom (D) signed Executive Order (EO) N-79-20:

> ***WHEREAS*** *the climate change crisis is happening now, impacting California in unprecedented ways…we must accelerate our actions to mitigate and adapt to climate change, and more quickly move toward our low-carbon, sustainable and resilient future…100 percent of new passenger cars and trucks will be zero-emission by 2035.* (*Executive Order N-79-20*, *pp 1-2,* 2020)

In addition to prohibiting the sale of non-ZEV passenger cars and trucks, EO N-79-20 also prohibited the sale of new gas-powered off-road vehicles by 2035, and new medium- and heavy-duty gas-powered vehicles by 2045 This research did not examine policies surrounding these other types of vehicles. EO N-79-20 directed the California Air Resources Board (CARB) to "propose regulations requiring increasing volumes of new zero-emission vehicles sold in the state towards the goal of 100 percent in-state sales by 2035" (*Executive Order N-79-20*, p.2, 2020). EO N-79-20 did not prohibit the ownership of ICE vehicles or the sale of used ICE vehicles. It could not therefore be considered a 'ban' on gas-powered cars – but it is a major phase-out of gas vehicle technology.

EO N-79-20 built on previous executive orders signed by Governor Brown: EO B-16-12, which targeted 1.5 million ZEVs on the road by 2025 (E. Brown, 2012), and EO B-48-18, which targeted 5 million ZEVs on the road by 2030 (E. Brown, 2018). California had 635,602 ZEVs on the road in 2020, with about 250,000 additional ZEVs sold in 2021 (California Energy Commission, 2022c, 2022e). If California continued to sell 250,000 ZEVs per year, the state would meet the goal of EO B-16-12, but would fall short of the goal of EO B-48-18 by about 2.3 million vehicles.

Santa Clara Residents Have Voluntarily Adopted ZEVs

The California Energy Commission (CEC) maintained a public database which displayed total annual vehicle sales with statistics on the types and numbers of various ZEVs and traditional ICE vehicles registered across California. A summary of the data is shown in Table 1.

Table 1: New ZEV Registrations in SCC, by Year

Year	Number of New ZEVs
Pre-2010	12
2010	83
2011	1,000
2012	2,411
2013	3,295
2014	9,007
2015	9,821
2016	10,482
2017	12,688
2018	22,311
2019	19,906
2020	15,281
2021	22,826

Source: California Energy Commission, 2022b

All data in this paragraph and Table 1 above came from the CEC's "ZEV Dashboard". Prior to 2010 there were almost no ZEVs registered in SCC. In 2010, all but six ZEVs registered in SCC were Tesla Roadsters. There were 77 Roadsters registered in SCC, with the remaining six ZEVs being battery-electric Ford Rangers. In 2011, Nissan introduced the Nissan LEAF and Chevrolet introduced the Volt, both battery electric vehicles (BEVs). The Nissan LEAF and Chevrolet Volt comprised the majority of newly registered ZEVs, with Tesla selling only 13 additional Tesla Roadsters. 2012 saw the introduction of many new entries in the ZEV market, with Toyota's Plug-in Prius outselling all competitors. Plug-in hybrid electric vehicles (PHEVs), which were initially preferred by consumers, were soon surpassed by BEVs. In 2012 Tesla introduced the Model S. In 2013, the Model S became one of the top-selling ZEVs, with just 16 fewer vehicles than the Nissan Leaf being newly registered in SCC. 2014 marked the beginning of a three-year period of stagnation with new ZEV registrations at or just below 10,000 per year from 2014-2016.

In 2016, FCEVs were introduced, but as of 2021, FCEVs had yet to surpass even 0.5% of vehicles newly registered in SCC. The Tesla Model 3 became widely available for sale in 2018 and this vehicle accounted for the near doubling of ZEVs registered in SCC during that year. In 2019 and 2020, there was a decrease in the number of newly registered ZEVs in SCC. However, the total number of all vehicles newly registered also fell during the same period, possibly as a reflection of decreased demand for vehicles due to COVID-19 lockdowns (Colias, 2021). ZEV registrations rebounded in 2021 and achieved an all-time high of 22,826, slightly edging out 2018's 22,311. Data from 2022 was not available at the time this research was conducted. It remained to be seen whether ZEV adoption will continue to increase, as it has historically done, or whether the number of new registrations would stagnate at around 20,000 per year. All information in this paragraph was drawn from the California Energy Commission's "New ZEV Sales in California" (California Energy Commission, 2022b).

ZEV Fuel Savings & Popularity

Although Californians in 2019 drove less per person than the U.S. average, California is so populous a state that the total miles covered by California drivers was just under 300 billion – the highest state total in the U.S. (U.S. Department of Transportation, 2020). This number illustrates the size of the transportation sector in California, and sheds light on the importance of switching to non-polluting forms of transportation. Fuel savings functioned both as a potential incentive for consumers to switch to ZEVs and also acted as a proxy variable representing a direct reduction in GHG emissions.

Pacific Gas & Electric (PG&E) advertised that with their EV rate plans, BEVs and PHEVs cost approximately $2.14 per gallon-equivalent of electricity to charge. However, translating electricity usage to an equivalent number of miles per gallon (MPG) was difficult, since EVs did not all drive equally far on equal amounts of electricity. EVs also tended to go further per "gallon" of energy than ICE vehicles, so reporting their fuel costs in gallons was unintuitive and could lead consumers to false conclusions. Table 2 is an overview of the fuel cost savings provided by the most popular ZEVs in SCC. The costs to drive were standardized against driving a fixed distance rather than in "gallons" of fuel. This alleviated the potential confusion of translating cost-to-charge an EV versus cost to drive an ICE vehicle. This information was intended as a starting point for future researchers who wished to investigate the cost-savings potential of ZEVs, public administrators who wished to run an awareness campaign promoting the benefits of ZEVs, or members of the public who were curious what it cost to charge and drive a ZEV. Table 2 listed the top ten most-registered ZEVs in SCC and was sorted by the number of registrations per vehicle. This method of sorting served to inform researchers and

SCC policymakers of the consumer preferences of SCC residents, which may help guide their future research or policy decisions.

Table 2: BEVs Consumer Fuel Savings & Registrations in SCC

Make / Model	Battery Size, kWh	Range	Cost to charge	Cost to drive 25 miles	Annual Cost Savings over ICE vehicles	New Registrations In SCC, 2021
Tesla Model 3	62	267	$13.02	$1.22	$2,235	6,270
Tesla Model Y	75	318	$15.75	$1.22	$2,230	5,911
Chevy Bolt	65	259	$13.65	$1.32	$2,245	1,798
Tesla Model S	100	375	$21.00	$1.40	$2,145	658
Nissan Leaf	40	149	$8.40	$1.40	$2,140	652
Jaguar I-Pace	85	234	$17.85	$1.91	$1,891	458
Ford Mach-E	68	247	$14.28	$1.44	$2,125	447
VW ID.4	82	260	$17.22	$1.65	$2,020	408
Hyundai Kona	64	258	$13.44	$1.30	$2,194	172
Kia Niro EV	64	239	$13.44	$1.40	$2,142	142

Sources: California Energy Commission, 2022e; Schmidt, 2021; Tesla, 2022a; Forbes, 2022; Tesla, 2022c; Chevrolet, 2021; Loveday, 2021; Tesla, 2022b; Nissan, 2022a; Jaguar, 2022; Ryan, 2022; Ford, 2022; Stohlman VW, 2021; Hyundai, 2022a; Kia, 2022.

Table 2 indicated that the annual fuel savings of BEVs over ICE vehicles was striking. However, what was not shown on Table 2 was that the average sale price of a BEV was much higher than an otherwise comparable ICE vehicle. The Tesla Model 3, a compact 4-door sedan and the most common BEV newly registered in SCC in 2021, had a manufacturer's suggested retail price (MSRP) of $46,990 (Tesla, 2022a). The Nissan Versa, an ICE vehicle of a similar size and type to a Tesla Model 3, had an MSRP of $14,980 (Nissan, 2022c), a price difference of over $30,000. This price disparity was not unusual. The Tesla Model Y, a compact 4-door crossover and the second-most common BEV in SCC, had an MSRP of $57,940 (Tesla, 2022c). The Hyundai Kona, ICE version, a 4-door compact crossover comparable in size to the Tesla Model Y had an MSRP of $21,300 (Hyundai, 2022b). In 2022, the least expensive BEV in the U.S. market was the Nissan LEAF S, with an MSRP of $27,400 (Nissan, 2022b). The Nissan LEAF S was a compact 4-door hatchback. The Mitsubishi Mirage, which was also a compact 4-

door hatchback, but not a ZEV, had an MSRP of $14,645 in 2022 (Mitsubishi, 2022), meaning the least expensive BEV costs nearly $13,000 more than a comparable ICE vehicle.

Batteries represented 30-40% of the total cost of BEVs (Patterson, 2022b), meaning a significant contributor to the high price of BEVs was the large battery pack required. Whether the price of batteries could be reduced long-term remained to be seen. The price of batteries fell 90% between 2010 and 2020, but sharply increased in 2021 (Patterson, 2022a).

Table 3: PHEVs in Hybrid Mode: Fuel Savings & Registrations in SCC

Make / Model	MPG	Range	Charging & Refuel Costs, Combined	Cost to drive 25 miles	Annual Fuel Cost Savings over ICE vehicles	New Registrations In SCC, 2021
Toyota Prius Prime	56	640	$66.72	$2.60	$1,542	883
Toyota RAV4	41	600	$86.30	$3.59	$1,046	528
Chrysler Pacifica	31	520	$97.94	$4.70	$491	350
BMW X5	22	400	$107.13	$6.69	-$502.81	281
Honda Clarity	49	340	$43.46	$3.19	$1,247.2	278
BMW 330e	30	320	$62.82	$4.90	$395	268
BMW 530e	28	340	$70.76	$5.20	$244	263
Volvo XC90	28	520	$109.40	$5.26	$215	257
Jeep Wrangler	22	370	$101.5	$6.86	-$584	176
BMW X3	26	340	$77.84	$5.72	-$16.76	159

Sources: U.S. Department of Energy, 2022c; Novato Toyota, 2021; U.S. Department of Energy, 2022h; Harley, 2021; U.S. Department of Energy, 2022f; Moloughney, 2021a; U.S. Department of Energy, 2022e; Kane, 2020; U.S. Department of Energy, 2022b; Honda, 2022; U.S. Department of Energy, 2022e; Masters, 2022; U.S. Department of Energy, 2022d; Ceppos, 2021; U.S. Department of Energy, 2022i; Volvo, 2022; U.S. Department of Energy, 2022g; Moloughney, 2021b; U.S. Department of Energy, 2022a; Nedelea, 2020.

Initially, PHEVs did not appear to offer the cost-savings potential of BEVs. However, the disparity in fuel savings was largely explained by the type of vehicle. Larger and more luxury- or performance-oriented vehicles failed to save on annual fuel costs compared to the average ICE vehicle. Vehicles such as the Jeep Wrangler failed to return even average gas mileage, and likely produced more GHG than an average ICE vehicle.

Analysis of PHEVs' fuel cost savings was complicated by the fact that PHEVs did not consistently burn gasoline. All the PHEVs listed in Table 3 had a short range within which they could operate purely in electric mode. When operating in electric mode, the PHEVs in Table 3 used no gasoline and produced no GHG. The vehicles could be taken on an errand and returned home to charge on electricity exactly as a BEV. This allowed drivers to combine the advantages of BEVs and ICE vehicles into one car, getting the reduction in GHG emissions and fuel savings of a BEV while commuting around town, but maintaining the range capabilities of a traditional ICE vehicle when on a longer trip. The amount of fuel consumed when the battery was finally depleted was based on the choice of vehicle, with large vehicles like the Jeep Wrangler performing worse than the 25mpg average, and more compact cars like the Toyota Prius Prime returning significantly above-average mpg. Table 4 is a list of the same vehicles from Table 3 but displayed the range each vehicle could achieve while operating in all-electric mode.

Table 4: PHEVs in All-Electric Mode: Fuel Savings & Registrations in SCC

Make / Model	Battery size	Battery-only range in miles	New Registrations In SCC, 2021
Toyota Prius Prime	8.8 kWh	25	883
Toyota RAV4	18.1 kWh	42	528
Chrysler Pacifica	16 kWh	32	350
BMW X5	17 kWh	31	281
Honda Clarity	17 kWh	48	278
BMW 330e	12 kWh	23	268
BMW 530e	9.1 kWh	21	263
Volvo XC90	11.6 kWh	18	257
Jeep Wrangler	17.3 kWh	22	176
BMW X3	13 kWh	18	159

Sources: Novato Toyota, 2021; U.S. Department of Energy, 2022c; Harley, 2021; U.S. Department of Energy, 2022h; Moloughney, 2021a; U.S. Department of Energy, 2022f; Kane, 2020; U.S. Department of Energy, 2022e; Honda, 2022; U.S. Department of Energy, 2022b; Kane, 2018; U.S. Department of Energy, 2022j; Ceppos, 2021; U.S. Department of Energy, 2022d; Volvo, 2022; Moloughney, 2021b; U.S. Department of Energy, 2022g; Nedelea, 2020; U.S. Department of Energy, 2022a

The U.S. Bureau of Transportation Statistics reported in 2017 that Americans drove an average of 29 miles per day (U.S. Department of Transportation, 2020). Accordingly, many of the PHEVs in Table 4 allowed SCC residents to conduct all or nearly all of their daily driving in all-electric mode. The Toyota RAV4, Chrysler Pacifica, Honda Clarity, and even the relatively large and luxury-market targeted BMW X5 could all travel 30 miles without resorting to running the gasoline engine. Vehicles which ran the gas engine to complete a day of errands or short commuting still produced less GHG emissions than an ICE vehicle. For example, the Jeep

Wrangler was capable of accomplishing 75% of daily commuting without resorting to running the gas engine – although once the battery was depleted, the Jeep Wrangler received 20mpg, 5mpg below the U.S. average (U.S. Department of Energy, 2022g). Consumer choice, as well as daily driving habits, will have a large impact on how effective these vehicles are at reducing future GHG emissions in SCC.

Note: there is a gap in the data where the U.S. Census Bureau tracks daily commutes at the county level in terms of time, but not distance (U.S. Census Bureau, 2021). As California has mandated the electrification of the transportation sector, data on miles traveled versus time spent traveling has become increasingly important.

A benefit of PHEVs over BEVs was the relatively small size of the battery pack. The Tesla Model 3 had a 62kWh battery pack. For a BEV, this was a relatively small battery – the average battery size of the BEVs in Table 2 was 70.5kWh. By contrast, the largest battery in any of the PHEVs in Table 3 was the Toyota RAV4 Prime, with a battery pack size of 18.1kWh – almost 75% less than a Tesla Model 3. The average battery size of the PHEVs listed in Table 3 was 14kWh. This means that the average PHEV required 1/5th as much battery capacity as a BEV. If consumers purchased more PHEVs than BEVs, less extractive mining would be required to produce vehicle batteries. However, PHEVs still produced GHG emissions during operation when driven beyond the limited range of the vehicle's all-electric mode. BEVs, which required larger, more expensive batteries, never produced GHG emissions during operation regardless of how far they were driven.

Table 5: FCEVs Fuel Savings & Registrations in SCC

Make / Model	Tank	Range	Cost to Refuel at $15.80 per kg	Cost to drive 25 miles	Annual Cost Savings over ICE vehicles	New Registrations In SCC, 2021
Toyota Mirai	5.6kg	402	$88.48	$5.50	$93.76	278
Make / Model	Tank	Range	Cost to Refuel at $15.80 per kg	Cost to drive 25 miles	Annual Cost Savings over ICE vehicles	New Registrations In SCC, 2021
Hyundai Nexo	6.3kg	380	$99.54	$6.54	-$429.34	41
Honda Clarity	5.5kg	360	$86.90	$6.04	-$172.36	30

Sources: California Energy Commission, 2022e; Shenhar, 2022; Consumer Reports, 2022; Honda, 2020

The analysis of FCEVs differed from the analysis of BEVs and PHEVs for several reasons. First, while reduced fuel costs translated to reduced GHG emissions for BEVs and PHEVs, the same was not true for FCEVs. FCEVs produced no GHG during operation regardless of the amount of hydrogen used (U.S. Environmental Protection Agency, 2015).

Second, the cost of driving 25 miles on hydrogen was slightly higher than driving an ICE vehicle. The high price of fuel may have acted as a disincentive to consumers shopping for a new vehicle.

Why SCC Must Transition to ZEVs

EO N-79-20 specifically identified a reduction in transportation-related GHG emissions as a key component of achieving the state goal of carbon neutrality and mandated that California prepare to sell no new vehicles other than ZEVs by 2035 (*Executive Order N-79-20*, 2020). The impetus behind this policy decision came from the high degree of GHG emissions from California's transportation sector. In 2019, transportation in California was responsible for 41% of the state's total GHG emissions; no other sector produced so much: industry, 24%; electrical power production, 9%; residential, 8%; agriculture and forestry, 7%; commercial, 6%; and imported electrical power, 5%; (California Air Resources Board, 2019a). Analysis by the Massachusetts Institute of Technology (MIT) indicated that charging vehicles on electricity reduced overall GHG emissions even in states which relied on extremely "dirty" fuel, such as coal. The research also found that the benefit of transitioning from ICE vehicles to electric vehicles (EVs) was greatest in states which had invested in the decarbonization of their electrical power production (Miotti & Trancik, 2021). The next section addressed the importance of decarbonized electrical power production in maximizing the GHG emission reduction potential of EVs.

California's Legal Obligations to Decarbonize Electrical Power Production

Assembly Bill 32 (AB 32), passed in 2006, aimed to reduce and hold future GHG emissions levels to no higher than what was produced in 1990. The state aimed to achieve 1990 emissions levels by 2020, but met this goal four years early, in 2016 (California Air Resources Board, 2018). EO B-55-18, signed by Governor Brown in 2018, set a goal of "statewide carbon neutrality as soon as possible and no later than 2045, with net negative GHG emissions thereafter" (California Energy Commission, 2020b, n.p.). These executive orders focused on state-wide GHG emissions. In 2018, electrical power production specifically was required to "become 100% zero-carbon by 2045" (California Energy Commission, 2020b, n.p.).

The Debate Around Nuclear Power in California

In 2020, nuclear power provided 9.33% of California's total electrical power generation (Nyberg, 2020). 91.4% of that power was provided by California's single nuclear power plant, Diablo Canyon, in Avila Beach, CA. (Clifford, 2021), with the remaining 8.6% being imported from outside the state (Nyberg, 2020). In 2016, PG&E announced plans to close Diablo Canyon by 2025 (Cardwell, 2016). Diablo Canyon produced no GHG emissions, was designed to operate for several decades beyond 2025, and faced no safety concerns (Clifford, 2021). PG&E estimated that decommissioning the plant would take ten years (Pacific Gas & Electric, 2022) and cost $3.8 billion (Cardwell, 2016). PG&E proposed to offset the loss of electrical power production from Diablo Canyon with an investment in renewable energy sources, such as solar (Pacific Gas & Electric, 2018). The history of previous nuclear plant closures indicated that renewable sources of electrical power production often cannot make up for the loss of nuclear power (Cardwell, 2016). When the San Onofre nuclear power plant in San Clemente, California closed in 2012, supporters of the closure stated that closing the plant would provide opportunities for renewable sources of electrical power production to fill the gap (Wald, 2013). Instead, California saw a net increase in GHG emissions as utilities shifted to burning fossil fuel to offset the loss of nuclear power (Cardwell, 2016). In 2020, natural gas produced 37% of California's total electrical power. In that same year, all renewable sources of electrical power combined provided 33.09% of California's electric generation, slightly less than natural gas alone provided. "Renewables" included biomass (2.45% of electrical power production), geothermal (4.89%), small hydroelectric dams (1.39%), solar (13.23%), and wind (11.13%) (Nyberg, 2020, n.p.).

However, California has seen a drop in total electrical power demand. Between 2017 and 2020, the last year for which information was available, California experienced a year-over-year decrease in total system electrical power production. In 2017, California produced 292,083GWh of electricity. In 2020, electrical power production fell 272,576GWh, a decrease of about 6.7% (Nyberg, 2020). The California Department of Energy attributed this decrease to the widespread adoption of "behind-the-meter" solar panels, since their contribution to total energy consumption were not tracked at the state level (Nyberg, 2020, n.p.). In 2006 Governor Schwarzenegger implemented a goal of installing solar panels on one million homes in California, which the state achieved in 2019 (Schwarzenegger, 2022). In January of 2020, the state required all new home construction to include solar panels (Nyberg, 2020). California had an estimated 1.3 million homes with solar panels at the end of 2021 (Associated Press, 2021). These solar panels provided about "10,000 megawatts of electricity – enough to power 3 million homes" (Schwarzenegger, 2022, n.p.).

At the time of this research, whether the decrease in electrical power production reported in California owing to the widespread dissemination of home solar panels would mitigate an increased reliance on fossil fuels for electrical power production as a result of closing Diablo Canyon nuclear power plant remained to be seen.

Environmental Concerns Associated with EV Production

According to the *New York Times*, owing to the process of mining lithium, electric vehicles require 50% more water to produce. Worse, one of the key components of a battery – cobalt – comes primarily from the Democratic Republic of Congo, with workers including children extracting the metal in primitive and dangerous conditions (Tabuchi & Plumer, 2021). Electric car maker Tesla has announced a shift away from cobalt in its battery technology, but at the time of this research the viability of this transition remained to be seen (Zaremba, 2020). The literature review explored whether or not EVs represented a net decrease in GHG emissions when production, including battery and electrical power production, was accounted for.

Private Industry and EV Charging

There were several electric vehicle infrastructure companies operating in 2021 in SCC. One of them was Chargepoint. Chargepoint marketed themselves to business owners who wished to install electric vehicle charging stations on their property. The cost to charge a vehicle was set by the charging station owner and could be provided free (for example, to incentivize shoppers to come to their store), at cost, or sold at a premium as a way to generate income (Chargepoint, 2021). Another was Electrify America (Electrify America, 2021). Volta chargers were attached to small billboards which could be rented out to any relevant business, which allowed Volta to provide electricity to customers at no cost. Volta, like Chargepoint, marketed itself to business owners by detailing how installing charge stations at one's business would bring in more customers (Volta, 2021). EVgo was another private company and they advertised their endorsement by various government agencies including the Bay Area Air Quality Management District and the California Electric Vehicle Infrastructure Project (CAL eVIP), as well as their commitment to "social equity and environmental justice" (EVgo, 2021, n.p.). EVgo also published a white paper collection "Best Practices for Electric Vehicle Market Transformation" which they stated was designed for policymakers and utility companies. PlugShare was a crowdsourced map of electric vehicle charging stations. According to PlugShare, there are 138 EV charging stations in the City of San Jose. PlugShare's parent company Recargo was acquired by EVgo in 2021 (Rubio-Licht, 2021). According to the *Los Angeles Business Journal*, EVgo operated the third-largest network of electric vehicle chargers, behind Chargepoint and Tesla (Rubio-Licht, 2021).

LITERATURE REVIEW

This literature review focused on nine key areas: The first established that climate change was both a significant issue and also that it was anthropogenic, i.e., human-caused. The second and third reviewed efforts at the international and national levels to address climate change to determine if international or national goals were efficacious. The fourth looked at California's state-level efforts to determine whether programs at the state level were effective. The fifth examined efforts below state level, i.e., cities, to determine if cities could address climate change on their own without support from a larger government. Part six reviewed literature on the efficacy of electric vehicles in reducing GHG, including the impact of battery and electrical power production. Part seven addressed the willingness of consumers to bear the increased costs associated with climate change mitigation policies. Part eight examined the different motivating factors influencing consumers to purchase – or not purchase – an EV, aside from mitigating climate change. Part nine addressed consumers' concerns regarding the ownership of EVs.

Is Climate Change a Problem?

A broad and deep consensus was found that climate change is both anthropogenic and of serious concern. The Intergovernmental Panel on Climate Change (IPCC), an organization within the United Nations (UN), reviews "the thousands of scientific papers published [on climate change] each year" (Intergovernmental Panel on Climate Change, 2022, n.p.). In 2022, the IPCC stated that:

> Widespread, pervasive impacts to ecosystems, people, settlements, and infrastructure have resulted from observed increases in the frequency and intensity of climate and weather extremes, including hot extremes on land and in the ocean, heavy precipitation events, drought and fire weather (Pörtner et al., 2022, p. 10).

The literature reinforced the Paris Climate Agreement goal of limiting the global average temperature increase to within 2º C, and ideally to no more than 1.5º C, above pre-industrial levels (Hoegh-Guldberg et al., 2019; Schleussner et al., 2018; Chen & Sun, 2018; Akashi et al., 2014; Markolf et al., 2020; Williams et al., 2012). Extensive literature also confirmed that anthropogenic GHG emissions are a significant factor in climate change (Wolski et al., 2020; Iizumi et al., 2018; Sylla et al., 2015) and that climate change had "already had adverse impacts on human systems, including on water security and food production, health and well-being, and cities, settlements, and infrastructure" (Pörtner et al., 2022, p. 11).

International goals

The literature indicated that adherence to international goals was inherently political. Nejat et al. (2015) found that "ten countries, including China, the U.S., India, Russia, Japan, Germany, South Korea, Canada, Iran, and the U.K, account for two-thirds of global CO2 emissions" and that "developing nations, including China, India, and Iran, still encounter with [*sic*] considerable growth in GHG emissions and energy consumption, which are mostly related to the absence of strong, efficient policies (Nejat et al., 2015, p. 843)". Also built into the Paris Climate Agreements was the concept of "common but differentiated responsibilities and respective capabilities", or CBDR-RC (Voigt & Ferreira, 2016, p. 285). A BBC report not available in peer-reviewed literature indicated that China and India used CBDR-RC in 2021 as a justification to weaken an agreement to phase out coal as a source of electrical power production. The two nations stated that "various countries' efforts to meet the 1.5C target should be seen in the context of their efforts to eradicate poverty"; the agreement was changed from a "phase out" of coal, to a "phase down" (Khadka, 2021, n.p.). However, the literature indicated that India's reliance upon coal for electrical power production was increasing, not decreasing (Oskarsson et al., 2021)

The literature identified a debate over who was responsible for reducing GHG emissions. The Chinese government stated that countries which consumed goods, e.g. the U.S., should bear the burden for the GHG emissions of the country which produced those goods, e.g., China (Feng et al., 2017). Gross (2020) found that nations which could afford to shift the production of goods abroad could claim a reduction in national-level GHG emissions, but that doing so would not decrease net global GHG emissions.

Oberthür & Groen (2018) found that the Paris Climate Agreement suffered from "downscaled ambition" and is "insufficient by itself and needs to be strengthened quickly (p. 708)". This reinforces research cited above which indicated that even a global average temperature increase of 1.5° C carried the risk of extreme weather disruption to critical aspects of society, such as food production and water supply.

Saiger (2020) found that governments were "reluctant" to pursue climate goals. The research indicated that domestic judicial systems were a key component of enforcing internationally-agreed-upon laws and treaties. This topic was outside the scope of this research, but indicated that international treaties alone did not guarantee climate policy compliance.

National goals

The United States has not consistently adhered to international climate agreement goals (Markolf et al., 2020; Gross, 2020). Gerrard & Welton (2014) found that climate change, which the researchers state had been politically "unmentionable" prior to 2012, became one of President Barack Obama's top priorities during his second term in office. However, the literature indicated that the extent to which climate change mitigation was a priority for presidents varied greatly between administrations. For example, the “price” of one ton of CO2 emissions was set at $53 under President Barack Obama, fell to $1 under President Donald Trump, and could rise as high as $125 under President Joe Biden (Voosen, 2021). The U.S. rejected joining the Kyoto protocol (a U.N. effort to address climate change in 1992) during the President George W. Bush administration, but signed on to the Paris Climate Accord under President Obama, only to exit the Paris agreement under President Trump (Kronlund, 2021).

Kronlund (2021) found that as of 2021, the last significant piece of legislation focusing on climate change passed by the U.S. Congress was *The American Clean Energy and Security Act of 2009*, indicating no significant legislation had passed Congress in over a decade. Kronlund (2021) attributes “the lack of a bipartisan view on how to proceed (p. 107)” as the main factor inhibiting the passage of a new law, with “increased polarization (p. 107)”, the “two-year election cycle in the House of Representatives (p. 107)”, and “constant campaign efforts (p. 107)” as exacerbating factors.

The U.S. Congress has passed significant legislation targeting emissions, although not specifically GHG emissions: the Clean Air Act of 1963, along with its subsequent amendments, has caused “average concentrations of air pollutants such as particulate matter and ozone [to] have fallen by, in many cases, 85 to 90 percent (Fowlie et al., 2020, p. 7).

On balance, the literature review indicated that the federal government is capable of enacting powerful climate change policy, but that those efforts were hampered by competing executive and legislative priorities, as well as by the politicized nature of climate change policy.

California’s Progress Towards Carbon Neutrality

California had 12% of the US population in 2020, with 37.53 million people (U.S. Census Bureau, 2020a; U.S. Census Bureau, 2020o), a significant increase since 1990, when the state's population was 27.5 million people (U.S. Census Bureau, 1992). In 2012, California's goal was to reduce GHG emissions to 20% of 1990 levels by 2050. At the time this goal was established, California was the 12th-largest emitter of GHG in the world (Williams et al., 2012). In 2017, California Assembly Bill (AB) 398 increased this goal to a GHG emissions reduction of 40% that of 1990 levels (Manzagol, 2018).

Brookings completed an overview of California's experience with the 2006 Global Warming Solutions Act, or AB32. They highlight some of the challenges, for example economists and policymakers prefer to use market-based tools such as a carbon tax or cap and trade, but social justice advocates point out that these policies allow companies to continue polluting, and while cap and trade can reduce net GHG emissions, poorer residents can be unfairly victimized by specific, local, pollution sources (Fowlie et al., 2020; A. Brown, 2020). The authors cite addressing local pollution as a strategy for building broader political support for climate-focused policies – but ultimately, AB32 was unable to promote a policy which both satisfied local environmental justice advocates while simultaneously promoting state-wide GHG emission reduction, and a second bill (AB617) was passed to address social equity concerns (Fowlie et al., 2020). California ultimately implemented a successful cap-and-trade policy which saw a decrease both in emission and unemployment. Rabe (2017) indicated that California's cap-and-trade policy, while imperfect, is an effective tool to reduce GHG emissions without hampering economic development.

Williams et al. (2012) determined that California would have to switch to nearly 100% carbon-neutral energy in order to meet the state's 2050 emissions goal, and that 26% of that energy would have to come from nuclear power. Akashi et al. (2014) reinforced the necessity of some nuclear power being retained. The researchers found that decarbonizing electrical power production without nuclear or carbon capture is prohibitively expensive. Perry (2016) found that nuclear power accounted for 60% of carbon-free electrical power production in the U.S.

California can negotiate with auto manufacturers to raise mile-per-gallon requirements higher than what the US Environmental Protection Agency would otherwise require (Zycher, 2019), and they are the only state in the U.S. which is so authorized (Fowlie et al., 2020). California received this authority in order to address unusually poor air quality in California's cities. Seven of the ten U.S. cities with the poorest air quality were in California (California Air Resources Board, 2019b). This authority was rescinded under the Trump administration and later restored by the Biden administration (Guillén, 2022). Although only California can set higher standards than the EPA, states can choose between adopting the EPA standard or the California standard, and thirteen other states – New York, Massachusetts, Vermont, Maine, Pennsylvania, Connecticut, Rhode Island, Washington, Oregon, New Jersey, Maryland, Delaware, and Colorado, as well as the District of Columbia - have adopted the California standard (California Air Resources Board, 2019b). California and the thirteen states listed represent 40% of the vehicle market in the United States (Guillén, 2022).

Have City-level Goals Proven Effective Without State Support?

Markolf et al., 2020 and Muro, 2020 found that cities struggled to set meaningful climate policy on their own. The work they have done "is – at best – a start. As of 2017, only 45 of the largest 100 cities had any serious climate pledge at all, and many of those pledges are more aspirational than realistic…13 [of the 45 cities] don't appear to have any available emissions tracking in place" (Muro, 2020, n.p.). The literature indicated that cities must have the support of larger government entities to be effective, i.e., state or federal governments.

Evidence for the Efficacy of Electric Vehicles in Reducing GHG Emissions

The transportation sector accounted for 24% of all global CO_2 emission from fuel combustion in 2019 (Hou et al., 2021), highlighting the importance of transitioning from vehicles which burn gasoline to vehicles which run on cleaner alternative fuels such as electricity. Williams et al. (2012) found that in order to hit California's GHG reduction goals, transitioning from ICE vehicles to EVs is essential. Without switching to EVs, Williams et al. (2012) projected that California will achieve at best a 50% reduction of 1990 emissions levels. Electric vehicles have been shown to dramatically reduce GHG emissions (H. Lin et al., 2021). Liu et al. (2020) found that GHG emissions data lags behind real GHG emissions by several years. However, this lag was not a barrier to modeling the projected decrease in GHG emissions as a result of switching from ICE vehicles to EVs.

The literature clearly indicated that the operation of EVs resulted in a reduction of GHG emissions. The literature was mixed on whether EVs remained a strong option to reduce net GHG emissions once electrical power production and battery manufacturing were included in the analysis.

Regarding battery production, the literature varied widely depending on the assumptions used by the researchers. Vitta (2021) found that, owing to more stringent emissions standards and the wider availability of clean fuel, CO_2 emissions from ICE vehicles declined by 62% worldwide between 2007 and 2021. Vitta (2021) estimated that owing to the energy-heavy process of battery manufacturing, global CO_2 emissions would actually double if mass adoption of BEVs became a reality. Given advances in cleaner-burning types of gasoline, Vitta (2021) advocated for the adoption of PHEVs, which required much smaller batteries than BEVs and also benefited from the advances in cleaner-burning types of gasoline.

In contrast, Wolfram et al. (2021) found that electric cars significantly reduced CO_2 emissions as compared to ICE vehicles, even when battery production was included in the analysis. The difference between the two reports was in their assumptions of future technological developments – Vitta (2021) did not assume any improvements in the manufacture of batteries, and assumed that batteries would have to be discarded after a 10-year lifecycle. Wolfram et al. (2021) assumed batteries would become easier to make and that batteries could be recycled. Wolfram et al. (2021) stated that the "higher emissions [of EVs] from material production and vehicle assembly are relatively small and could be more than offset by increased material efficiency efforts including more ambitious material recycling and reuse of components" (Wolfram et al., 2021, p. 6).

Researching battery recycling options in the Chinese auto market, Luo (2021), stated that the first generation of EVs have approached the end of their lifecycle. SCC, which saw EV adoption beginning in 2011, was in in a similar position. Luo (2021) stated that consumer preference was one of the largest incentives for EV companies to recycle batteries, and recommended that consumers be made aware of the harmful effects of unrecycled batteries. This research was highly relevant to SCC, where EVs have also approached the end of their lifecycle. The question of battery recycling will only become more pressing as EV adoption increases.

Regarding GHG emissions from electrical power production, the literature clearly indicated that the method of generating electrical power was an important factor on whether EVs could decarbonize overall transportation. Nanaki & Koroneos (2013); Canals Casals et al. (2016); and Kim et al. (2020); all found that reductions of GHG emissions were strongest in regions which decarbonized their electrical production. Michaelides (2020) provided a good overview of the topic.

Michaelides (2020) found that while EVs themselves do not produce any GHG emissions, the energy required to charge them can remain a significant source of pollution. The research found that the environmental benefits of EV "depends to a large extent on the methods of electricity production: if the electricity is supplied by non-carbon energy sources – nuclear, hydroelectric, solar, wind, biomass and waste products – there is significant CO_2 avoidance" (Michaelides, 2020, p. 5). Michaelides (2020) found that the U.S. as a whole, which in 2019 generated 31.4% of its energy from coal, could see a decrease in transportation-sector CO_2 of anywhere between 22-53%. The range of 22-53% was dependent on the efficiency estimates of the EVs adopted. This confirmed data, produced by MIT and cited above in the Background section of this research, which found that the source of energy production had a dramatic impact on net GHG emissions as a result of driving EVs. For reference, California produced 0.17% of its energy from coal in 2019 (California Energy Commission, 2020a).

Michaelides (2020) also found that charging requirements for EVs, depending on consumer charging behavior, may be impossible to meet: if 40,000 EVs owners within one metropolitan area attempted to use DC fast charging during a lunch break, the energy demand between noon and 2pm would be significant enough – 3,210 megawatts – to cause city-wide brownouts.

Do Americans Support Green Policies When Costs are Made Explicit?

Noel & Sovacool (2016) found that Denmark accomplished the majority of their GHG emission reduction through steps which required no effort from citizens, such as the use of high taxes on gasoline and large investments in renewable energy sources such as wind. However, when it came to measures which required Danes to take an active role, such as the purchase of an

EV, the research noted that Danes were reluctant to take on the additional inconvenience that owning an EV entailed.

The literature indicated a similar phenomenon in the United States. Krosnick & MacInnis (2013) noted that large numbers of U.S. citizens supported government action to promote environmentally friendly laws and policies – e.g., 84% of U.S. citizens in 2006 supported government policies providing incentives and tax breaks for “the building of cars that use less gasoline” (Krosnick & MacInnis, 2013, p. 28); in 2006 & 2007, “86% and 87% of respondents, respectively, said the federal government should limit utilities’ emissions” (Krosnick & MacInnis, 2013, p. 28). The researchers cited several other examples of the high support respondents demonstrated on similar polling questions.

However, Krosnick & MacInnis (2013) found that when cost was made explicit, support for the theoretical programs decreased dramatically. Respondents were asked “if they would vote for or against a law that would reduce air pollution by 85% by 2050 but cost each household an extra $75 per year on average” (Krosnick & MacInnis, 2013, p. 33). At $75 per year, 66% of respondents stated that they would support the law. At $150 per year, 58% of respondents supported the measure. And at $250 per year, the support rate dropped to 41%. This consumer reluctance to bear additional financial hardship to support the environment must be considered when examining the high cost of many ZEVs as compared to traditional ICE vehicles.

Miniard & Attari (2021) conducted a review of public opinion on the state of Indiana’s efforts to shift from coal to renewables for electrical power production. They found that while “a majority” (Miniard & Attari, 2021, p. 1) of Indianians wished to decarbonize their sources of electricity, concerns over climate change were not a factor. Instead, the pro-decarbonization residents were motivated by “themes of protecting the environment and public health, reducing pollution, [and] improving the economy (p. 1)" while detractors were concerned with "economic and employment concerns, fear, lack of familiarity, doubting the feasibility of renewable resources, and concerns about fairness (p. 1)".

Consumer Motivations for EV Purchase Aside from Climate Change

Regarding the adoption of EVs specifically, the literature indicated that far from being related strictly to environmental concerns, EV ownership is related to a consumer's lifestyle. Lane et al. (2018) indicated that purchasing a PHEV or BEV may be motivated by "lifestyle choices, including financial management, activity and fitness, and having a strong sense of community" (Lane et al., 2018, p. 2).

Range Concerns (Also Known as "Range Anxiety"):

The literature regarding range & charging concerns for EVs is broad and well-developed. Recurring themes indicate that the range capabilities of EVs, as well as ready access to charging, remain serious concerns for consumers. Access to charging was identified as a factor by Noel & Sovacool (2016); Neubauer & Wood (2014); Sankaran et al. (2020); and Lane et al. (2018). Neubauer & Wood (2014) found that access to charging at places of work can significantly increase the utility of EVs for drivers, and plentiful public charging benefits both low-mileage and high-mileage drivers. However, Zhang et al. (2015) found that Californians drive an average of 7.8 miles per trip and 31.8 miles per day, implying that EVs are already sufficient to meet the majority of consumers' actual driving requirements. Consumer concerns regarding charging and mileage may be perceived rather than actual. This was supported by Rauh et al. (2015) which found that experience owning an EV decreased consumer anxiety regarding range, and Lane et al. (2018) which found that "direct previous experience with alternative-fueled vehicles, such as a conventional hybrid…tends to encourage interest in [plug-in electric vehicles] (p. 2)". A meta-analysis conducted by Danielis et al. (2020) indicated that the importance given to an EV's range by consumers had not decreased between 2013 and 2018, despite "the many changes that occurred in the last years concerning BEVS' uptake in the market, growing consumers' direct and indirect experience with electric cars, vehicles' increased range, and growing diffusion of the charging infrastructure (p. 1)".

Rauh et al. (2015) found that EV drivers typically leave a large "buffer" of around 20% of their vehicle's range to compensate for range concerns. If this is true, then EVs may need to target an advertised range even higher than ICE vehicles to truly ameliorate consumers' concerns. Lane et al. (2018) found that "the absence of range anxiety for PHEV is a major factor influencing potential [EV] buyers (p. 1)". There is a gap in the literature examining what range capability consumers prefer with regards to both EVs and ICE vehicles.

METHODOLOGY

Figure 1: Methodology Logic Model

Program Evaluation			
Problem: GHG Emissions	Solution: ZEV	Implementation	Evaluation

Phase 1 focused on the problem of GHG emissions in the consumer transportation sector. Phase 2 identified how California is addressing this issue through the use of ZEVs. Phase 3 collected data on policies and programs designed to support the sale of ZEVs. Phase 4 analyzed whether or not the policies and programs successfully supported the sale of ZEVs in Santa Clara County. The primary lens of analysis was effectiveness - whether cities in SCC are on-track to meet the goal, i.e., are city programs sufficient to ensure a successful transition to a marketplace where the only new vehicles available for sale will be ZEVs.

Sources of Data

The CEC provided data on the number and type of ZEVs sold state-wide, by county, or by zip-code since 2010. Data on the number of public charging stations, along with information on any other ZEV-promoting programs, came from city websites and local newspapers. Information on the number of privately-owned publicly available charging stations came from publicly available data provided by PlugShare and Tesla Motors.

Sample Size

There are 15 cities in Santa Clara County: Campbell, Cupertino, Gilroy, Los Altos, Los Altos Hills, Los Gatos, Milpitas, Monte Sereno, Morgan Hill, Mountain View, Palo Alto, San Jose, Santa Clara, Saratoga, and Sunnyvale. SCC had a population of 1.9 million people in 2020 (U.S. Census Bureau, 2020).

Data Collection and IRB Exclusion

Program data was collected from open city websites within SCC. Relevant contextual data was collected from open state and federal websites. This paper made use of academic (peer-reviewed) articles from San Jose State University's library databases. It also included data from journalistic outlets, think tanks, and companies. No personally identifiable information was collected, and no interviews were conducted. The study qualified for an IRB exclusion.

Data Collection: Which Programs are SCC Cities Using to Incentivize ZEV Adoption?

City programs designed to support ZEV adoption fell into several categories. Table 6 is a list of all programs designed to encourage ZEV adoption at the city level.

FINDINGS

Table 6: Programs to Encourage and Support ZEV adoption by City

City	Permits for Charging Stations	City-Owned Chargers	Grants for Charging Stations	Grants for ZEV Purchases	Grants to Upgrade Electrical Panel	Free Parking in City-Owned Garages	Hydrogen Fueling Station
Campbell	Yes	Yes	-	-	-	-	Yes
Cupertino	Yes	Yes	-	-	-	-	Yes
Gilroy	Yes	-	-	-	-	-	-
Los Altos	Yes	Yes	-	-	-	-	Yes
Los Gatos	Yes	Yes	-	-	-	-	Yes
Los Altos Hills	-	-	-	-	-	-	-
Milpitas	Yes	-	-	-	-	-	-
Monte Sereno	Yes	Yes	-	-	-	-	-
Morgan Hill	Yes	-	-	-	-	-	-
Mountain View	-	Yes	-	-	-	-	Yes
Palo Alto	Yes	Yes	Yes	-	-	-	Yes
San Jose	Yes	Yes	Yes	-	-	Yes	Yes
Santa Clara	-	Yes	Yes	Yes	Yes	-	-
Saratoga	-	-	-	-	-	-	-
Sunnyvale	Yes	-	-	-	-	-	Yes

Sources: City of Campbell, 2022; Schena, 2015; California Fuel Cell Partnership, 2022; City of Cupertino, 2022; City of Cupertino, 2022; California Fuel Cell Partnership, 2022; City of Gilroy, 2020; City of Los Altos, 2020; City of Los Altos, 2013; California Fuel Cell Partnership, 2022; City of Los Gatos, 2021; City of Los Gatos, 2022; California Fuel Cell Partnership, 2022; City of Milpitas, 2022; City of Monte Sereno, 2022; City of Monte Sereno, 2019; City of Morgan Hill, 2022; City of Mountain View, 2022; California Fuel Cell Partnership, 2022; City of Palo Alto, 2018; City of Palo Alto, 2022; California Electric Vehicle Infrastructure Program, 2022; California Fuel Cell Partnership, 2022; City of San Jose, 2021; City of San Jose, 2022a; California Electric Vehicle Infrastructure Program, 2022; City of San Jose, 2022a; California Fuel Cell Partnership, 2022; City of Sunnyvale, 2020; Santa Clara County, 2022; California Electric Vehicle Infrastructure Program, 2022; Silicon Valley Power, 2021; California Fuel Cell Partnership, 2022.

The most commonly-pursued program to support the adoption of ZEVs in SCC was the development of permitting processes for the installation of residential and commercial EV charging stations. The cities of Los Altos Hills, Mountain View, Santa Clara, and Saratoga did not have permitting procedures listed online. However, the existence of charging stations in each of those cities implied that a permitting procedure did exists. The second-most commonly-pursued program was the installation of city-owned EV charging stations – nine cities had at least one city-owned publicly-available charging station. Three cities had grant programs to encourage the construction of privately-owned charging stations. One city (Santa Clara) provided grants towards the purchase of a ZEV and the installation of a more robust home electrical panel to support that vehicle. Finally, San Jose provided free parking in city-owned garages to ZEV owners. Eight cities had a hydrogen fueling station either in operation or undergoing the permitting and construction process.

County-Wide ZEV Adoption Remains Below Target Rate Despite City-Level Programs

Table 7: Annual ZEV New Registrations in SCC by Type

Year	BEVs	PHEVs	FCEV	Total
Pre-2010	12	0	0	12
2010	83	0	0	83
2011	838	162	0	1,000
2012	870	1,541	0	2,411
2013	3,740	2,200	0	5,940
2014	5,281	3,726	0	9,007
2015	6,584	3,237	0	9,821
2016	6,477	3,882	123	10,359
2017	7,364	5,061	263	12,688
2018	15,434	6,461	416	22,311
2019	19,906	5,460	333	25,366
2020	11,961	3,168	152	15,129
2021	18,082	4,415	349	22,846

Source: California Energy Commission, 2022b

Table 8: Cumulative ZEV Registration in SCC by Type & Percentage of Total Vehicles

Year	BEV	PHEV	FCEV	Total ZEVs	Total Vehicles	ZEV as a % of total vehicles
2010	93	0	0	93	1,132,294	0.01%
2011	732	129	0	861	1,133,618	0.08%
2012	1,291	1,220	0	2,511	1,140,932	0.22%
2013	4,556	3,260	0	7,816	1,178,520	0.66%
2014	9,052	7,104	0	16,156	1,204,964	1.32%
2015	14,778	10,034	0	24,812	1,222,380	1.99%
2016	20,270	13,294	95	33,659	1,261,508	2.56%
2017	26,276	17,738	434	44,448	1,402,093	3.07%
2018	36,743	22,697	805	60,245	1,399,036	4.13%
2019	45,581	24,705	1,058	71,334	1,390,964	4.88%
2020	49,385	23,707	1,033	74,125	1,336,130	5.26%
2021	*2021 data not available at time this research was conducted*					

Source: California Energy Commission, 2022c

ZEV registrations in SCC were about 50% below the rate required to ensure a smooth transition to an all-ZEV new-vehicle marketplace in 2035. According to Table 8, 95% of vehicles registered SCC at the time this research was conducted were still traditional ICE vehicles. The annual adoption rate across SCC was about 20,000 new ZEVs per year. To determine if this adoption rate was adequate, the research had to determine an appropriate target rate:

In 2017, U.S. consumers tended to purchase a new car slightly less than once every eight years, with the average age of a vehicle on the road being just over 11 years (Gillies, 2017). (The difference between the two statistics was likely accounted for by the difference between the 'new' and 'used' vehicle market. The vehicles sold on the 'used' market, even if they tended to trade hands every eight years, contributed to the increase in the average age of vehicles on the road.)

If the average owner of a car made a vehicle purchase every eight years, then that meant about 12.5% of vehicle owners were in the market for a new purchase in any given year. Data from Table 8 indicated that there were 1,336,330 vehicles registered in SCC in 2021. Twelve and a half percent of that total meant that in any given year, there were about 167,041 SCC residents in the market for a vehicle. National data on the sale of new versus used cars indicated that about 74% of those consumers were in the market for a used car (Carlier, 2021), which meant the number of SCC residents in the market to purchase a new car in any given year was about 43,430. According to CEC data, there were 22,846 ZEVs sold in 2021 – a gap of 20,584 vehicles.

To determine the number of ZEV sales required in 2035 required a projection of vehicle ownership growth between when this research was conducted (2022) and when EO N-79-20 would take effect (2035). The total number of light-duty vehicles registered in SCC grew by about 20,000 vehicles per year over the previous ten years. Assuming this growth continued, there would be 1,596,300 vehicles registered in SCC by 2035, and about 51,880 residents per year would be in the market for a new vehicle. In order to meet the purchasing needs of 51,880 residents between now and 2035, the adoption rate of ZEVs would have to increase by 227%.

In conclusion, the overall adoption rate of ZEVs across SCC was not on track to ensure a smooth transition to an all-ZEV marketplace by 2035. The rate of adoption would have to double, and continue to grow as vehicle ownership in SCC continues to rise.

Permits for EV Charging Stations Were the Single Most Effective City-Level Program

Two methods were considered to determine the necessary quantity of charging stations for electric vehicles. The first method assumed the ratio of EV charging stations to EVs would have to be about equal to the ratio of gas stations to ICE vehicles. According to the California Department of Energy, there are between 250-399 gas stations in SCC (California Department of Energy, 2020). As of 2020, SCC had 1.26 million ICE vehicles(California Energy Commission, 2022c). This sets a gas station to vehicle ratio of between 1:3,000-5,000 as a potential baseline for the number of charging stations required. However, BEVs and PHEVs did not charge as quickly as ICE vehicles could be filled with fuel. U.S. Combined Federal Regulations (CFR) limited the flow rate of gasoline to 10 gallons per minute (*40 CFR § 80.22 - Controls and Prohibitions.*, n.d.). Consuming an average of 500 gallons per year, this means Americans spent approximately 500 minutes, or 8 hours and 20 minutes, at the pump every year. (In reality, Americans spent more time at the pump than this. According to a report from the National Association of Convenience Stores, 48% of gas shoppers went inside the convenience stores often attached to the gas station (National Association of Convenience Stores, 2018). However, this research focused only on recharging and did not further examine other aspects of consumer behavior, such as shopping. An average of the mileage and charging times of the BEVs listed in Table 6 indicated that BEVs required an average of 681 hours at a level 2 charger to drive 12,500 miles – just over 28 days of level 2 charging per year. This significantly complicated the baseline assumption of 1: 3,157-5,040 charging stations per vehicle. Assuming residents did not use any home or level 3 charging, BEVs required 82 times as many charging stations as ICE vehicles required gas stations. Using these assumptions increased the required charger-to-vehicle ratio to 1:38-61. The ideal ratio is going to be somewhere between the extreme high end of 1:38-61, which assumed EV owners did not charge at home or utilize DC fast charging, and 1:3,157-5,040 on the extreme low end, which used gas stations as a rough approximation of the number of charging stations EVs will require.

The second method of modeling future requirements for charging infrastructure assumed the current ratio of charging stations to EVs was appropriate, and modeled requirements for the future growth of charging stations based on expectations of the rate of EV adoption. This paper primarily used this method for projecting future demand.

Table 9: Availability of EV Chargers by City Compared to City Populations

City	City-Owned Public Charging Stations	Privately-owned Public Level 2 Charging Stations	Privately-owned Public Level 3 Chargers	Tesla Level 2 Chargers	Tesla Level 3 Chargers	Total	Population	Ratio of Stations to Residents
Campbell	2	13	1	0	0	16	42,221	1:2,639
Cupertino	5	9	3	2	2	21	60,381	1:2,875
Gilroy	0	5	9	1	2	17	59,520	1:3,501
Los Altos	3	4	8	1	1	17	31,625	1:1,860
Los Gatos	9	7	1	3	1	21	33,529	1:1,597
Los Altos Hills	1	2	1	0	0	4	8,489	1:2,122
Milpitas	0	17	4	0	2	23	80,273	1:3,648
Monte Sereno	1	0	0	0	0	1	3,843	1:3,341
Morgan Hill	2	5	1	1	1	10	45,483	1:4,548
Mountain View	3	24	4	2	1	34	82,376	1:2,574
Palo Alto	10	35	5	5	2	57	65,572	1:1,150
San Jose	10	106	22	8	5	151	1,013,240	1:6,710
Santa Clara	16	35	4	3	0	58	127,647	1:2,200
Saratoga	0	10	3	0	0	13	31,051	1:2,388
Sunnyvale	0	28	3	0	2	33	155,805	1:4,721

Sources: Schena, 2015; Campbell, 2021; PlugShare, 2022; Tesla, 2022d; City of Cupertino, 2022; PlugShare, 2022; Tesla, 2022d; U.S. Census Bureau, 2020b; PlugShare, 2022; Tesla, 2022d; U.S. Census Bureau, 2020c; City of Los Altos, 2013; PlugShare, 2022; Tesla, 2022d; U.S. Census Bureau, 2020d; City of Los Gatos, 2022; PlugShare, 2022; Tesla, 2022d; U.S. Census Bureau, 2020f; PlugShare, 2022; Tesla, 2022d; U.S. Census Bureau, 2020e; PlugShare, 2022; Tesla, 2022d; U.S. Census Bureau, 2020g; City of Monte Sereno, 2019; PlugShare, 2022; Tesla, 2022d; Bay Area Census, 2010; PlugShare, 2022; U.S. Census Bureau, 2020h; City of Mountain View, 2022; PlugShare, 2022; Tesla, 2022d; City of Palo Alto, 2022; PlugShare, 2022; Tesla, 2022d; U.S. Census Bureau, 2020i; City of San Jose, 2022b; PlugShare, 2022; Tesla, 2022d; U.S. Census Bureau, 2020j; Santa Clara County, 2022; PlugShare, 2022; Tesla, 2022d; U.S. Census Bureau, 2020k; PlugShare, 2022; Tesla, 2022d; U.S. Census Bureau, 2020m; Tesla, 2022d; U.S. Census Bureau, 2020n

EV charging stations were unevenly distributed across SCC's cities, ranging from one charging station in Monte Sereno to 151 in San Jose. However, comparing the number of charging stations to population indicated that most cities in SCC had an average of one charging station for every 3,000 residents. San Jose was a statistical outlier with one charging station for every 6,710 residents. Removing San Jose produced an overall county average of one charging station for every 2,797 residents. The vast majority of charging stations were privately-owned.

These charging stations were likely being installed in accordance with the market demand for charging in specific cities, with cities where the adoption rate of EVs is high (or where significant numbers of travelers from outside the city were expected) installing high numbers of chargers. Some cities, such as Monte Sereno, were likely benefitting from the charging stations installed nearby in adjacent cities. For example, Monte Sereno residents have access to several nearby charging options in Los Gatos. Monte Sereno EV owners may also have made more extensive use of home EV charging.

Significant flexibility in the number of chargers was to be expected as city markets reacted to the adoption rate of EVs and the specific charging behavior of city residents. For example, in the city of Palo Alto, one in every six households owned an EV – the "highest adoption rate in the country" (City of Palo Alto, 2022, n.p.). Palo Alto had a correspondingly high number of publicly available charging stations.

There were three cities in SCC with grants or rebate programs for the construction of charging stations. When the number of charging stations was controlled against either population or rates of EV ownership, two of those cities (Palo Alto & Santa Clara) had significantly more charging stations than average. This indicated that grants and rebates for charging stations were effective in encouraging charging station construction. However, the third city (San Jose) had significantly fewer charging stations than average. It may be that grants and rebates stood in for a more important statistical variable, such as median or average income levels.

Table 10: Availability of EV Chargers by Zip Code Compared to ZEV Adoption

City	Zip Codes	Total Number of Charging Stations	Total Number of EVs	Ratio of Charging Stations to EVs
Campbell	95008	16	1,854	1:116
Cupertino	95014	21	5,541	1:263
Gilroy	95020	17	7,031	1:413
Los Altos	94022, 94024	17	11,273	1:633
Los Gatos	95030, 95032, 95033	21	3,734	1:178
Los Altos Hills	94022, 94024	4	4,332	1:1,083
Milpitas	95035	23	2,867	1:124
Monte Sereno	N/A	N/A	N/A	N/A
Morgan Hill	95037	10	2,238	1:234
Mountain View	94040, 94041, 94043	34	3,096	1:91
Palo Alto	94301, 94303, 94304, 94305, 94306	57	5,364	1:94
San Jose	95101, 95110-95113, 95116-95148	151	30,505	1:202
Santa Clara	95050, 95051, 95054	58	4,163	1:72
Saratoga	95070	13	3,012	1:213
Sunnyvale	94085, 94086, 94087, 94089	33	5,976	1:181

Sources: U.S. Postal Service, 2022; Table 9; California Energy Commission, 2022b

The CEC did not report the number of ZEVs sold by city. However, they did provide data on the number of ZEVs sold by zip code. By collating the zip codes assigned to each city, an estimate of the number of ZEVs (excluding FCEVs) registered in each city could be assessed. Comparing the number of EVs registered in each city against the number of charging stations available in each city allowed a determination of the optimum number of charging stations required for city infrastructure to be capable of supporting BEVs and PHEVs. Charging stations to registered EVs ranged from 1:72 on the high end, such as in the City of Santa Clara, to 1:1,083 on the low end, such as in San Jose. San Jose was again a statistical outlier, with a low quantity of charging stations compared both to the populace as a whole and EV-owners specifically. The average number of charging stations to registered EVs in SCC was 1:280. This indicated that the required number of charging stations was far closers to the high end of the range (estimated at 1:38-61) than to the low end of 1:3,000-5,000.

Using 1:280 as the ratio of charging stations to EVs, and assuming growth in the FCEV segment of the market remains low, city planners should anticipate that SCC will require about 1,140 charging stations across the county to meet the needs of the over 1.5 million ZEVs on the road under N-79-20. Assuming consumers continued to purchase a new vehicle about once every eight years, city administrators can assume the turnover for vehicles will not result in 100% ZEVs on the road until at least 2043, eight years after the implementation of N-79-20. City administrators must anticipate a need for 665 additional charging stations across SCC, but have until 2043 to meet this demand. This model assumed little or no growth in the adoption rate of hydrogen fuel-cell vehicles and assumes that 80% of EV charging will occur at home (Valderrama, 2019).

All Other City-Level Programs Had Little Impact on ZEV Adoption

Only one city, Santa Clara, had a program in place to provide a rebate for the purchase of a ZEV. The program covered only BEVs and PHEVs and did not include FCEVs. It was a low-income program which was not available to all residents. Using population data from Table 9 and ZEV ownership data from Table 10 indicated that the City of Santa Clara had significantly fewer ZEVs than other cities when controlled for population – one ZEV for every 30 residents, compared to the average across SCC's cities of one ZEV for every 17 residents. The findings were the same for the city of Santa Clara's program which provided grant funding to upgrade a home electrical panel – the overall adoption rate in Santa Clara City remained low.

San Jose had a policy of providing free parking to ZEVs in city-owned garages. The city of San Jose did not publish information on the number of ZEV owners who used this program, their consumer satisfaction, or the extent to which this program influenced their decision to purchase a ZEV. San Jose had a relatively low adoption rate of ZEVs, with one ZEV for about every 33 residents, compared to the SCC average of one ZEV for about every 17 residents. Based on the rate of ZEV adoption within the city, free parking did not strongly incentivize the purchase of ZEVs.

Availability of Hydrogen Fueling Stations Remained Limited

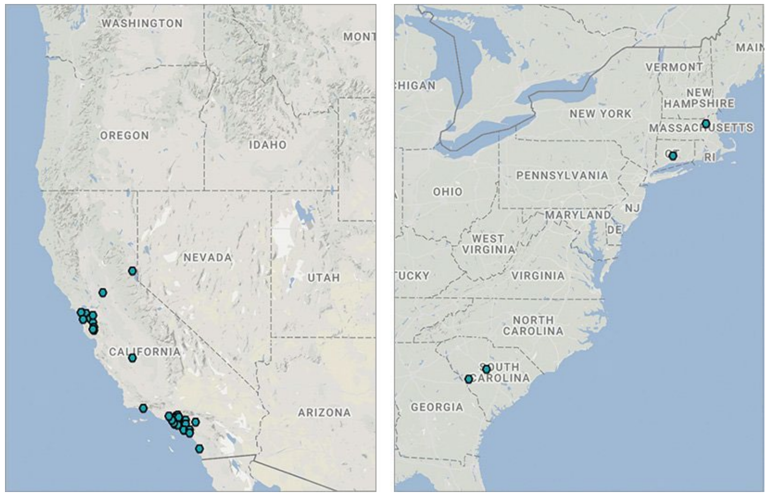
Table 11: Comprehensive List of All Hydrogen Stations in SCC as of March, 2022

City	Stations	Status
Campbell	2	Online
Cupertino	1	Under Construction
Gilroy	0	-
Los Altos	1	Pending Permit Approval
Milpitas	0	-
Monte Sereno	0	-
Morgan Hill	0	-
Mountain View	1	Offline
Palo Alto	1	Online
San Jose	4	1 online; 2 under construction; 1 permitting
Santa Clara City	0	-
Saratoga	1	Online
Sunnyvale	1	Online

Sources: California Fuel Cell Partnership, 2022

In 2022, there were six operational hydrogen fueling stations in SCC, and on 21 March 2022, all but one was out of fuel (California Fuel Cell Partnership, 2022). The lack of refueling stations extended beyond SCC. Figure 1 is a map of all publicly available hydrogen fueling stations that were available in the U.S. in 2018.

Figure 2. All Hydrogen Fuel Stations Nationwide, 2018



Source: U.S. Department of Energy, 2018

Equally concerning was the lack of infrastructure outside of the greater San Francisco Bay Area. Figure 1 indicated that hydrogen fueling stations existed almost exclusively in the San Francisco and Los Angeles regions of the state, with almost no stations anywhere outside of California. California Fuel Cell Partnership (CFCP) data for March of 2022 indicated that there was only one hydrogen fueling station between San Francisco and Los Angeles, meaning FCEV owners driving between those two major metropolitan centers relied on the operation and fuel availability of a single hydrogen fuel station. Fuel stations existed in Sacramento, CA and there was a single station in Truckee, CA, near Lake Tahoe. For practical purposes, FCEV owners were limited to driving in the San Francisco Bay Area, Los Angeles, Sacramento, and Lake Tahoe. Travel between San Francisco and Los Angeles depended on the operation of a single hydrogen fuel station. Travel to Lake Tahoe was likewise dependent on a single hydrogen fueling station.

ANALYSIS

PHEVs Low Adoption Rates Present City Administrators with an Opportunity

Overall, SCC consumers' adoption rate of PHEVs was low compared to BEVs. However, this provides an opportunity for city administrators who wish to advertise the benefits of these vehicles. PHEVs were available at a lower cost than BEVs, which made them more attainable to consumers. The batteries required were smaller, which reduces pressure on the construction of charging stations, the demand for electrical power production, and the national supply of lithium-ion batteries. There is very little holding this sector back from experiencing strong growth, and the research indicated that PHEVs will be an essential component of the 2035 ZEV target.

BEVs May Not Be the Answer for Equity in the ZEV Marketplace

Lane et al. (2018) indicated that consumers who wished to purchase a PHEV and consumers who wished to purchase a BEV were motivated by different goals: potential PHEV owners likely compared the costs and environmental concerns between ICE vehicles and PHEVs, whereas potential BEV purchasers were motivated "more on emotive, ideological concepts around the image and environmental benefits (p. 9)" of all-electric vehicles. Lane et al. (2018) cited additional factors which increased the likelihood of a consumer purchasing a BEV, such as an interest in high-tech devices. Given that image and lifestyle were strong factors in a BEV purchase, there is little reason for policymakers to subsidize the purchase of these vehicles. The lower cost and increased range of a PHEV, along with their ability to run purely on electricity during local commutes, meant PHEVs were ideal targets of equity initiatives designed to ensure that all SCC residents had fair access to the ZEV marketplace.

City-Owned Charging Stations Have Decreased in Importance Relative to Commercially-Owned Charging Stations

Analysis of Table 6 indicated that most, but not all, cities had a policy of installing city-owned chargers. Efforts by city administrators to install city-owned charging stations have decreased in importance due to the large number of privately-owned publicly-available charging stations as shown in Table 9. While cities may have felt compelled to operate charging stations during the early years of EV adoption, the charging station market is now robust and direct city ownership or construction of charging stations may no longer be necessary.

Grants and rebates refunding the cost of installing charging stations was a more effective policy than the direct construction of city-owned charging stations. Grants and rebates encouraged the installation of charging stations while allowing residents, businesses, and institutions such as schools the flexibility to install charging stations where they found them to be most necessary. As was discussed in the Background section on private industry and EV charging stations, there were many private companies offering charging station solutions in SCC in 2022. Allowing private citizens to determine the optimum charging locations and the quantity of charging required for their community (for example, customers patronizing a specific business or parents of children in specific school districts) would remove the significant analytic overhead which would otherwise be required of city planners.

City-Level Grants Toward the Purchase of a ZEV May Become Important as N-79-20 Moves Closer to Implementation

City of Santa Clara's program providing low-income residents with a grant for the purchase of an EV did not significantly alter the rate of ZEV adoption in that city. In fact, Santa Clara City's ZEV adoption rate was significantly below county-wide ZEV average adoption rates. However, programs of this nature will likely become important when EO N-79-20 takes effect. At the time of this research, all SCC residents could choose to purchase a new ICE vehicle or a ZEV. It was possible that many low-income residents chose to purchase a practical, low-cost ICE vehicle instead of a PHEV or BEV, regardless of the grant. When EO N-79-20 takes effect, purchasing such a vehicle will no longer be possible. In order to avoid an equity concern where low-income residents cannot afford to purchase a new ZEV, implementing grant programs such as the one in City of Santa Clara will likely become extremely important. However, such programs may not increase ZEV adoption until EO N-79-20 takes effect. City of Santa Clara did not publish statistics on how many residents used their low-income grant program. Inferences about the effectiveness of the program were solely drawn from the city-wide adoption rate of ZEVs.

Increasing the Availability of Hydrogen Fueling Stations Could Improve FCEV Adoption

The small number of hydrogen fueling stations likely acted as a strong disincentive to consumers who might otherwise have purchased a FCEV. City administrators should continue to allow the construction of additional hydrogen fueling stations, and should consider networking with governments outside their jurisdiction in order to increase the number of refueling stations across California and beyond. Even if consumers have plentiful fueling stations in Santa Clara County, they are unlikely to purchase an FCEV if the Bay Area is the only area in which they can drive with confidence.

FCEVs have several advantages over EVs – FCEVs do not require charging, can be refueled in minutes, and do not require the production of lithium-ion batteries. They also decrease the projected demand for electrical power production, as they do not charge on electricity. Increasing the number of refueling stations, and therefore increasing the adoption rate of FCEVs, will reduce pressure on the battery-manufacturing supply line, reduce the possibility that vehicle manufacturers will be unable to supply an all-ZEV marketplace, and reduce the demand for electrical power production.

Decreased Reliance on Personal Vehicles Could Improve the Effectiveness of EO N-79-20

An alternative to increasing ZEV adoption is decreasing the need of SCC residents to own their own vehicles. If the total number of residents who owned a car decreased, this would ease pressure on the ZEV market and decrease GHG emissions. Investment in public transportation – bus, bike, light rail, and pedestrian transit – would likely be beneficial in helping the county meet the goal of EO N-79-20. In 2018, the most recent year for which data was available, SCC residents who drove to work spent 28 minutes driving one-way. The average time spent commuting by SCC residents who rode public transportation was twice that – 57 minutes one-way (Metropolitan Transportation Commission, 2020). This indicated that there was great room for development in the area of public transportation. A full review of the practical, fiscal, and political feasibility of increasing public transportation was outside the scope of this research, but any development which reduced the need of residents to own a vehicle will benefit California's zero-emission objectives.

Policymakers Should Monitor Equity Concerns Regarding the Price of Used Vehicles

EO N-79-20 allowed for the sale of used ICE vehicles, which will provide significant consumer flexibility in 2035. Although allowing the sale of used cars under EO N-79-20 may have been necessary, it is important to note that there will be policy trade-offs. For example, the goal of achieving net zero GHG emissions will be slowed by the presence of a robust used-vehicle market. For another, the price of used vehicles is likely to dramatically increase. If consumers are constrained financially or by market availability into driving older vehicles, they will not have access to up-to-date safety features which they might otherwise have if they had been allowed to purchase a new ICE vehicle. There are likely to be significant equity concerns involved with SCC's poorest residents being "trapped" in older, more polluting, less safe vehicles. It is also quite possible that the supply of ZEVs will not be able to match consumer demand, forcing the price of both used ICE vehicles and new ZEVs higher as consumers compete for purchases.

Policymakers Should Consider Modifying EO N-79-20's Definition of ZEVs

California law considered all of the vehicles listed in Table 3 to be ZEVs regardless of the amount of GHG emissions they produced. As Table 3 indicated, ZEVs such as the Jeep Wrangler, BMW X5, and BMW X3 return lower miles per gallon than an average U.S. vehicle, and likely produce higher than average GHG emissions. Policymakers should restrict the definition of ZEV to exclude low-MPG vehicles, or expand the definition of ZEV to include those ICE vehicles which have above a certain MPG rating. For example, the 2022 Toyota Corolla was rated at 34 MPG (U.S. Department of Energy, 2022k) and had an MSRP of $20,175 (Toyota, 2022). Such vehicles could reduce California's net GHG emissions while alleviating equity concerns about the affordability of ZEVs.

Smog Mitigation May Be a More Compelling Message than Climate Change

The literature review indicated that residents of Indiana were motivated by concerns regarding air quality, but not necessarily motivated by concerns over climate change. Policymakers messaging the benefits of ZEVs may see increased support among residents by communicating the benefits of ZEVs in reducing smog, rather than in their potential for mitigating climate change. Residents are likely to find this message compelling, since California has seven of the ten cities with the worst air pollution in the U.S.

Policymakers Should Be Aware that Demand for Electrical Power Production is Likely to Increase Dramatically as EV Adoption Increases

By 2030, the widespread adoption of electric vehicles was estimated as likely to cause "a significant new load onto the electrical grid" (California Energy Commission, 2021). The CEC estimated that daytime and nighttime electrical power demand were likely to increase by 20% and 25%, respectively (California Energy Commission, 2021). Key components of managing this increase in the demand for electrical power were balancing charge times to avoid overwhelming the grid in any given period, and matching peak electrical power demand with peak production.

The report suggested various strategies to balance the load across the 24-hour spectrum. For example, if more residents are capable of charging at home, the daytime use of DC fast chargers, a significant source of the model's peak load, could be mitigated (California Energy Commission, 2021). Additionally, PG&E's time-of-use charging, where residents were charged varying rates for electricity depending on the time of day, encouraged the initiation of EV charging at midnight. The CEC stated that this incentive would cause a large spike of electrical power demand exactly at midnight as millions of potential EVs began charging simultaneously.

Adjusting PG&E's time-of-use (TOU) rates to take advantage of increased solar panel electrical power production and to disincentivize simultaneous initiation of charging will likely be mandatory to keep total grid load below peak delivery capacity.

City administrators should also be aware of the potential for increases in the cost of electricity. The CEC projected an increased demand both during the day (while EV owners charged at work) and at night (when EV owners charged at the end of the day). Increased demand for electrical power production is likely to raise the prices of electricity, especially if

California continues to pursue a strategy of electrical power production which deemphasized fossil fuels and nuclear energy as sources of electrical power production.

CONCLUSION

Of all the programs designed to increase consumer adoption of ZEVs, the most important was establishing a clear permitting process for electrical charging stations. Allowing the private market to meet the needs of SCC's EV owners has resulted in the development of a robust network of charging stations across SCC. This program was even more important than the installation of city-owned charging stations. City officials should be aware that the number of privately-owned charging stations, adequate for the number of EVs currently registered in SCC, will have to rise correspondingly as the number of EVs in SCC increases. Other programs, such as city-level grants for the purchase of an EV or providing free parking, were not found to shift consumer behavior.

The adoption rate of ZEVs was about half of what EO N-79-20 required. This is actually quite positive, as EO N-79-20 was over a decade away at the time of this research. Cities that wished to increase the rate of ZEV adoption should consider a public messaging campaign which focused on the benefits of ZEVs for reducing smog and other visible air pollutants. City administrators should also consider a messaging campaign focused on the benefits of PHEVs over BEVs, which reduce GHG emissions compared to ICE vehicles, but were lower-cost and more flexible than BEVs.

The lack of hydrogen refueling infrastructure significantly hampered the ability of consumers to consider FCEVs as a serious option for any other purpose other than local transportation. FCEVs were an option only for SCC residents who did not feel the need to use their FCEV to travel anywhere outside of the Bay Area, Los Angeles, Sacramento, or Lake Tahoe. SCC cities have pursued strategies to increase the number of local refueling stations. However, cities should be aware that until the number of refueling stations increases dramatically - not only within SCC but also across California - FCEVs will not be adopted by SCC residents in any large number. A policy of advocating to state-level officials for an increase in state-wide infrastructure, including fuel production, should be investigated by researchers and pursued by local public administrators.

Recommendations to Future Researchers

Future researchers could consider studying the market impact on used vehicles if the supply of ZEVs is unable to meet the demand. Future researchers could also study the viability of a carve-out from N-79-20 for consumers under a certain income threshold, or for ICE vehicles which can drive over a certain number of miles per gallon, or both. A study of the ability of SCC to support medium and heavy-duty ZEVs would also be appropriate, as would a political analysis of the feasibility of increasing public transportation as a means to decrease demand for vehicle ownership overall.

Limitations

This study examined only light-duty consumer vehicles. However, California has many medium- and heavy-duty vehicles, such as are used in construction and shipping, which are also subject to EO N-79-20. These vehicles deserved their own separate analysis, which was not conducted in this study.

In addition to providing more public transportation options to reduce demand for personally-owned vehicles (POVs), cities in SCC could consider modifying zoning regulations to encourage more urban density. Increased population density, such as is found in well-developed downtown areas, significantly decreases individual reliance on personal vehicles, and increases the efficiency of public transportation, as well as decreases overall energy use beyond the transportation sector (Owen, 2009). Zoning regulations are relevant to the goal of reducing transportation-sector GHG emissions but were outside the scope of this research.

This research assumed the adoption rate of FCEV vehicles would remain low. If hydrogen infrastructure can be expanded dramatically, that assumption will change. FCEVs have many benefits over both BEVs and PHEVs. They do not require the use of lithium-ion batteries, they refuel in minutes rather than hours, and they have no GHG emissions. It may well be that FCEVs are a superior technology hampered only by lack of infrastructure.

APPENDIX

How Were the Estimates in Tables 2-5 Generated?

The tables were constructed using the Bay Area average price of gasoline of $5.69 as reported by the Mercury News, March 2022 [note: this data was collected during the nationwide increase in gas prices seen during high inflation and the initial stages of the Ukrainian invasion. This increased the cost of fuel by approximately 13% at the time of this paper's publication, which increased the advantage of ZEVs as compared to traditional ICE vehicles. At the time of publishing this paper, it remained unclear whether gas prices would continue to increase, stabilize at the new rate, or decrease.] (S. Lin, 2022). Mile per gallon estimates came from a Department of Transportation report stating that the average fuel economy in the U.S. in 2020 was 25.4 miles per gallon (U.S. Department of Transportation, 2020). Therefore, the assumption was that it costed the average consumer in the Bay Area $5.69 to drive 25 miles. In 2021, California residents drove approximately 12,500 miles per year (Covington, 2022). Tables 2-5 therefore assumed Californians drove 12,500 miles per year, divided by 25 MPG, multiplied by $5.69 per gallon, for an annual fuel cost of $2,845. The tables compared the cost of charging a ZEV which drove the same distance using PG&E's EV rate of $0.21 per kWh. The price of hydrogen was not available online, so data was collected from the six operational hydrogen fueling stations in SCC on 15 March 2022. The average price of hydrogen across those six stations, found to be $15.80 per kilogram, was used for the cost estimates in Table 5.

Battery Size Standards in Tables 2-4

The BEVs and PHEVs listed in Tables 2-4 often came with the option to upgrade the size of the battery, which increased both the cost and range of BEVs and PHEVs. To keep comparisons consistent, the standard battery size available to each BEV or PHEV was used in this research.

GLOSSARY

BEV: battery-electric vehicle which only runs on electricity, such as a Tesla or Nissan Leaf.

CARB: California Air Resources Board, charged with "protecting the public from the harmful effects of air pollution and developing programs and actions to fight climate change" (California Air Resources Board, 2022, n.p.). CARB is a department within the CalEPA.

CalEPA: California Environmental Protection Agency.

CEC: California Energy Commission. California's "primary energy policy and planning agency" (California Energy Commission, 2022a, n.p.).

DC Fast Charging: "direct current (DC) electricity at 480 volts to recharge an all-battery electric vehicle to 80 percent capacity in about 30 minutes, though the time required depends on the size of the vehicle battery and the power level of the charger." (California Energy Commission, 2022d, n.p.)

EV: electric vehicle, which can refer either to BEVs or PHEVs interchangeably.

FCEV: fuel-cell electric vehicle, a vehicle which is powered by refilling a hydrogen fuel cell.

Fuel cell: In this context, a fuel cell is a hydrogen fuel tank (gas tank) which must be replenished regularly from non-residential refueling stations in a manner similar to traditional gas stations.

GHG: greenhouse gas

ICE: internal-combustion engine, i.e., a traditional gas-powered vehicle.

IPCC: Intergovernmental Panel on Climate Change, the United Nations' organization dedicated review of climate change science and peer-reviewed literature.

Level 1 Charger: "use alternating current electricity at 120 volts to provide about 5 miles or less of range per hour of charging." (California Energy Commission, 2022d, n.p.)

Level 2 Charger: “alternating current electricity to charge a plug-in electric vehicle at 208 to 240 volts and can provide about 14 to 35 miles of range per hour of charging.” (California Energy Commission, 2022d, n.p.)

Level 3 Charger: See DC Fast Charging

MTC: Metropolitan Transportation Commission, the “transportation planning, financing, and coordinating agency for the nine-county San Francisco Bay Area” (Metropolitan Transportation Commission, 2021, n.p.).

PHEV: plug-in hybrid-electric vehicle, i.e., a gas-powered car with a small, rechargeable battery which can drive in full electric mode for a short time and be recharged without running the gas motor.

PG&E: Pacific Gas & Electric, a utility company covering much of northern California, including SCC.

POV: Personally-owned vehicle

SCC: Santa Clara County.

Tesla Supercharger: Tesla’s brand-name version of DC fast charging. See DC Fast Charging.

ZEV: zero-emissions vehicles – BEVs, PHEVs, and FCEVs only. Hybrid-electric vehicles which cannot recharge the battery at a charging station are excluded from this category.

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