California Energy Commission

City & County of San Francisco Alternative Fuel Vehicle Readiness Plan

Prepared for: **California Energy Commission**

Prepared by: **City and County of San Francisco Department of the Environment and EV Alliance**

California Energy Commission

Edmund G. Brown Jr., Governor

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The Technical Advisory Committee includes representatives of CALSTART, Clean Energy Fuels, Pacific Gas and Electric Company, San Francisco Municipal Transportation Authority, the San Francisco Public Utilities Commission, the San Francisco General Services Administration (Fleet Services), Propel Fuels, the San Francisco Department of Environment, Recology, and Veritable Vegetable.

The goals of the AFV readiness planning process are to accelerate adoption of AFVs and promote the deployment and use of alternative fuel infrastructure in the City and County of San Francisco and immediately surrounding areas.

PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007), created the Alternative and Renewable Fuel and Vehicle Technology Program (ARFVT Program). The statute, subsequently amended by Assembly Bill 109 (Núñez; Chapter 313, Statutes of 2008), authorizes the California Energy Commission to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. The Energy Commission has an annual program budget of about $100 million and provides financial support for projects that:

- Develop and improve alternative and renewable low-carbon fuels.
- Enhance alternative and renewable fuels for existing and developing engine technologies.
- Produce alternative and renewable low-carbon fuels in California.
- Decrease, on a full-fuel-cycle basis, the overall impact and carbon footprint of alternative and renewable fuels, and increase sustainability.
- Expand fuel infrastructure, fueling stations, and equipment.
- Improve light, medium, and heavy-duty vehicle technologies.
- Retrofit medium and heavy-duty on-road and non-road vehicle fleets.
- Expand infrastructure connected with existing fleets, public transit, and transportation corridors.
- Establish workforce training programs, conduct public education and promotion, and create technology centers.

The California Energy Commission provided funding opportunities under the ARFVT Program to produce a comprehensive Alternative Fuel Vehicle Readiness Plan for the City and County of San Francisco.

ABSTRACT

This Alternative Fuel Vehicle (AFV) Readiness Plan for the City and County of San Francisco is intended to guide the development of the City's AFV readiness policies and infrastructure. The development and deployment of AFVs ready infrastructure, policies, and incentives are intended to encourage local residents and fleet managers to utilize AFVs with reduced emissions of greenhouse gases and toxic air contaminants. Key benefits of adopting Alternative Fuel Vehicles include improvement in local air quality, reduction of greenhouse gas emissions that impact climate change, increased use of renewable energy and sustainable biofuels, more efficient use of existing grid energy via off-peak Plug-in Electric Vehicle charging and energy storage, and increased energy security through reduction in the use of petroleum fuels.

Keywords: California Energy Commission, Plug-In Vehicle, AFV Readiness Plan, City and County of San Francisco.

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Executive Summary

The objectives of the Alternative Fuel Vehicle Readiness Plan for the City and County of San Francisco are to assess the various types of alternative fuels and fueling infrastructure currently available and to provide recommendations regarding potential policies and practices to promote accelerated alternative vehicle adoption and use. Recommendations are provided to the City and County of San Francisco regarding options for effective use of each alternative fuel type, and assessments of their advantages and limitations.

The report begins with a summary of recommendations, organized by fuel type, for decision makers seeking an overview of plan findings. Chapter 2 reviews the national, state, and local policy context that has shaped the City of San Francisco's alternative vehicles ecosystem, and provides an introduction to the various vehicle types.

Subsequent chapters address each specific alternative vehicle type and associated fuel pathways and infrastructure. Chapter 3 addresses Plug-in Electric Vehicles and includes a discussion of the emissions reduction potential of vehicles powered by renewable electricity available through CleanPowerSF. Chapter 4 explores the potential benefits and challenges of hydrogen Fuel Cell Electric Vehicles, and Chapter 5 reviews the potential advantages and impacts of biofuel vehicles given the expanding array of biofuel production pathways. Finally, Chapter 6 addresses Natural Gas Vehicles, including their lifecycle emissions impacts, and the potential of Renewable Natural Gas.

CHAPTER 1: Overview and Key Recommendations

1.1 Overview

Alternative Fuel Vehicles (AFVs) and infrastructure have enormous potential to help meet San Francisco's goals for greenhouse gas (GHG) emissions reductions, and to improve the quality of life for residents of the City. The *San Francisco Alternative Fuel Vehicle Readiness Plan* is a blueprint to guide public and private action in the transition toward vehicles powered by renewable energy. This plan, funded by the California Energy Commission ("Energy Commission"), is intended to align local action with city and state policy goals for emissions reduction, the shift to cleaner and fewer vehicles, and reduced petroleum consumption.

State policy goals call for reduction of GHGs 80 percent below 1990 levels by 2050 and a reduction in petroleum use of 50 percent by 2030. The City and County of San Francisco's ("the City's") goals align with California Assembly Bill 32 mandates, and the City has identified key targets for reductions across all key sectors. In the transportation sector, the City aims to reduce car and truck emissions by 35 percent from 1990 levels by 2030, to reduce automobile trips to just 20 percent of total trips by 2030, and to transition taxi fleets and key public transportation services to Zero Emissions Vehicles (ZEVs).[1] Accomplishment of these aligned city and state goals will provide economic, public health, and mobility benefits to San Francisco residents as more vehicles are powered by renewable energy, toxic air contaminants are reduced, and consumers benefit from reduced costs associated with clean vehicles and innovative "mobility-as-a-service" platforms.

AFVs encompass numerous fuel types, including electricity, hydrogen, biofuels, and natural gas. The environmental attributes of these fuel types vary depending on the type of feedstock used for fuel production. For example, electricity to power Plug-In Electric Vehicles (PEVs) and to formulate hydrogen for Fuel Cell Electric Vehicles (FCEVs) can in turn be produced by renewable energy sources including hydropower, solar, wind, biomass, and geothermal energy, or by natural gas, including both fossil-based and renewable natural gas (RNG). Likewise, sources for ethanol or diesel-powered vehicles can be derived from a wide array of recently decayed organic matter, from corn to switchgrass to woodchips to fats, oil, or grease (FOG), each with their own lifecycle carbon impacts. As San Francisco moves forward in sourcing more of its fuel from renewable and low-carbon sources, the key metric that will guide stakeholders is the Carbon Intensity (CI) of fuels. This metric is used by the California Air Resources Board (ARB) and other regulatory bodies to assess the relative CI of various fuels, and thus their

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[1] *San Francisco Climate Action Strategy, 2013 Update*. San Francisco Department of the Environment, 2013. Available online at: http://sfenvironment.org/sites/default/files/engagement_files/sfe_cc_ClimateActionStrategyUpdate2013.pdf

relative heat-trapping impact on the climate system. The measurement of CI in turn utilizes carbon dioxide equivalent values (CO2e), to convert various gases, such as methane or oxides of nitrogen, into a common measure for purposes of climate impact assessment.

Given the increasing diversity of vehicles, fuels, and feedstocks in the transportation system, understanding which combination of vehicles, fuels, and infrastructure will best meet city goals and mobility needs is a complex and dynamic undertaking. There is no single best AFV solution for all use cases over time. Today's optimum solution will not necessarily remain the best solution even in the relatively near future, given the potential for dynamic and disruptive developments in fuel pricing, technology cost reduction (e.g., batteries), and technology breakthroughs (e.g., the recent commercialization of renewable diesel and RNG). Despite some uncertainty about specific capabilities and pricing of alternative fuels and vehicles over the next ten years and beyond, however, cleaner vehicles and fuels are available in greater variety and lower cost now than ever before, and higher-performance AFV products are being introduced on a continuous basis. Therefore, City leaders can be confident that the accelerated development of lower-emissions fuel sources and infrastructure will be rewarded with increasingly robust AFV model choices at steadily improving price and performance levels.

The urgency of accelerating progress on clean transportation is clear. The known impacts of climate change, including drought, storms, floods, extreme temperature events, and accelerated sea level rise all directly threaten the long-term livability of San Francisco and the Bay Area region. These impacts will be exacerbated without a dramatic reduction in use of fossil fuels. Moreover, nations, states, and cities around the world are looking to California, and the Bay Area in particular, for solutions to the climate crisis. With transportation-related emissions constituting almost half of all GHG emissions in the City and the region, accelerating the shift to clean transportation solutions offers a unique opportunity for San Francisco to further its global leadership on environmental sustainability.[2]

1.2 The San Francisco AFV Readiness Plan in State, Regional, and Local Context

The San Francisco AFV Readiness Plan is one in a series of regional readiness plans being developed throughout the state to accelerate the shift from conventional vehicles to lower-carbon AFVs. This AFV Readiness Plan in turn builds on several important state, regional, and local planning efforts. At the state level, California's ZEV Action Plan calls for sufficient fueling infrastructure to support 1 million electric drive vehicles by 2020 and 1.5 million by 2025, replacing 1.5 billion gallons of petroleum fuels.[3] At the regional level, the Bay Area Plug-in Electric Vehicle Readiness Plan, produced in 2012-13 by the Bay Area Air Quality Management District (BAAQMD) and ICF on behalf of the Greater Bay Area EV Strategic Council, called on cities in the region to increase the deployment of public charging infrastructure and enact building codes and other PEV friendly policies to lower the cost and streamline the installation

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[2] *San Francisco Climate Action Strategy, 2013 Update.*

[3] *San Francisco Climate Action Strategy, 2013 Update.*

of charging stations.[4] Finally, San Francisco's own *Transportation Plan 2030* calls for the City to advance its carbon reduction goals by:

1) *Reducing Vehicle Miles Travelled (VMT)*
2) *Shifting to less carbon dioxide (CO2) intensive travel modes, such as walking, biking, and transit*
3) *For remaining trips that require private or shared cars, trucks, and other motorized travel, switching to ZEVs, specifically PEVs.*

San Francisco's overall transportation policy objective is to reduce use of single-occupancy vehicles in San Francisco, regardless of fuel source. However, the scope of the AFV Readiness Study does not include measures to promote "mode shift" from motor vehicles to transit, walking, or biking. Rather, the focus of this Plan is to identify strategies for reducing environmental impacts by switching to ZEVs for those *remaining trips that require private or shared cars, trucks, and other motorized travel.*

Although San Francisco has made remarkable headway in shifting to AFVs, much work remains to be done. Among other achievements, the City is using renewable diesel in its truck and bus fleets. Further, for over 100 years the City has delivered carbon-free electricity from its Hetch Hetchy power system to municipal facilities and other customers. Managed by the San Francisco Public Utilities Commission (SFPUC), this electricity powers not only buildings throughout the City but San Francisco's public transportation system. Managed by the San Francisco Municipal Transportation Agency (SFMTA), the City's light rail, street cars, trolley buses, and historic cable cars represent the largest electric public transportation system in the country. In addition, San Francisco has incorporated PEVs into its municipal light-duty vehicle fleet which benefit from this GHG free electricity supply and in 2015 integrated 100 percent into renewable diesel into its entire diesel fleet.

In 2016, San Francisco launched its new Community Choice Aggregation program, CleanPowerSF, extending the opportunity for residents and businesses to power their daily lives with 100 percent renewable electricity, including their VMT. The City is now the default electricity provider and has secured renewable energy procurement contracts for in state wind resources to meet the programs initial demand. By early 2020, CleanPowerSF aims to have over 300,000 utility accounts enrolled in the program which is a *game changer* in achieving GHG emission reductions from the transportation sector.

To take additional steps toward sustainable, low-carbon mobility, however, the City will need to access additional state, federal, and private sector support. Accordingly, a key goal of the AFV Readiness Plan is to identify near-term projects (focusing on the 2017-2020 timeframe) that are most likely to attract funding, and set in motion the necessary steps to further qualify and prepare those projects to win competitive grants and financing. To prioritize projects for

[4] *Bay Area PEV Readiness Plan.* Bay Area Air Quality Management District, 2012. Available online at: http://www.baaqmd.gov/?sc_itemid=F6C4214F-CD70-4725-A186-B02FA38B8544.

potential funding, the Technical Advisory Committee proposed that local AFV projects be guided by these principles:

- ***Environmental and community benefit:*** Proposed AFV policies and programs should be focused on those technologies that have the greatest potential for reducing GHG emissions and criteria air pollutants[5] at a reasonable economic cost.
- ***Readiness for mass adoption:*** Policies and programs should initially focus on AFVs with the highest potential for mass adoption in the 2016-2020 period. Criteria should include model choice, price/performance, and fuel availability and convenience.

Given the framework provided above, recommendations are grouped by alternative fuel type, taking into account electric, hydrogen, biofuels, and natural gas.

Recommendations provided below have been vetted by the Technical Advisory Committee, but are not formally adopted policies of the City and County of San Francisco. To spur broader consideration of these measures within City government and the public at large, the AFV Readiness Plan will be broadly distributed, and select projects, programs, and policy recommendations will be advanced by relevant departments within the City, and by consortia of public and private stakeholders.

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[5] Criteria air pollutants refer to six common air pollutants regulated by the U.S. EPAin accordance with the Clean Air Act using the National Ambient Air Quality Standards (NAAQS).

1.3 Key Recommendations

1.3.1 Plug-in Electric Vehicles and Charging Infrastructure

Recommendation	Next Steps
1. Develop strategic partnerships to drive new funding for EV Service Equipment (EVSE) deployment and PEV programs.	▪ Building on strategies in the San Francisco AFV Readiness Plan and 2016 U.S. Department of Transportation (U.S. DOT) Smart City Challenge/Vulcan proposal, pursue partnerships that attract funding from regional, state, federal, and private sources. ▪ Leverage San Francisco's status as a Clean Cities Coalition, U.S. DOE Climate Action Champion, U.S. DOT Smart City Challenge finalist, and its membership in the Pacific Coast Collaborative and Carbon Neutral Cities Alliance. ▪ Leverage and/or create new partnerships with key Bay Area local governments to achieve statewide ZEV program goals. ▪ Partner with CleanPowerSF to create local incentive programs that accelerate deployment of PEVs and EVSE. ▪ Leverage partnerships with regional, state, and federal agencies, including the Metropolitan Transportation Commission (MTC), BAAQMD, the Association of Bay Area Governments (ABAG), U.S DOE and U.S DOT, Energy Commission, ARB, and CalTrans. ▪ Leverage existing programs and best practices to accelerate EVSE and PEV adoption including U.S. DOE's Workplace Charging Challenge and EV Everywhere programs and California PEV Collaborative's (e.g., Veloz) best practices guides.

Recommendation	Next Steps
2. Collaborate with industry stakeholders to accelerate deployment of electric light, medium and heavy-duty vehicles.	▪ Explore partnerships with Original Equipment Manufacturers (OEMs) and other stakeholders including but not limited to delivery companies, vanpool and commuter shuttle providers, Transportation Network Companies (TNCs); and car sharing firms based on the project descriptions included in the City's 2016 USDOT Smart City Challenge/Vulcan proposal. ▪ Work with internal stakeholders (e.g., SFMTA, SFPUC) to scope and develop pilot projects that support PEV deployment paired with charging solutions in taxi fleets, hourly rental car services, TNCs, vanpool/commuter shuttles, and car share services. ▪ Leverage California Vehicle Rebate Program (CVRP), as well as federal, state, and regional grant funds. ▪ Create projects that pair a consumer demand pipeline with supply side product solutions (e.g., aggregated procurements). ▪ Conduct consumer awareness and training events for medium-duty fleets operating in San Francisco. ▪ Assist medium-duty fleets operators in pursuing funding opportunities for vehicles and charging equipment through the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) and future ARB solicitations. ▪ Coordinate with Pacific Gas & Electric (PG&E) to match EVSE investments with site hosts, including workplaces and Multi-Unit Dwellings (MUDs).
3. Develop project proposals that seek state support for the installation of publicly available EVSE at higher utilization locations	▪ Conduct assessment to identify optimal locations for new and or expanded publicly available charging (e.g., Level 2 and DC Fast Charge). ▪ Identify public/private partnership opportunities to support project development in or near high-utilization public and private sector locations, including areas with high concentrations of MUDs, workplaces, retail centers, etc. ▪ Work with internal stakeholders (e.g., SFMTA, SFPUC, ADM) to identify funding opportunities[6] and develop procurement solicitations.

Recommendation	Next Steps
4. Support strategy for accelerated adoption of PEVs and EVSE at San Francisco International Airport (SFO), Port of San Francisco (SF Port), and other City Departments	▪ Partner with enterprise departments and the City Administrator's office (ADM; municipal fleet) to identify policies, technologies, timelines, and funding opportunities to electrify equipment and vehicles. ▪ Work with ADM's office to evaluate potential to reach 100 percent PEV light duty sedan procurement by 2020.
5. Develop consensus among Bay Area municipalities on transformative fleet procurement goals and pursue collaborative procurement strategies.	▪ Lead convening of regional local governments to develop transformative fleet procurement goals (e.g., 100 percent annual procurement of light duty fleet PEVs by 2020). ▪ Based on outcome of West Coast Mayor's Fleet Request for Information, coordinate engagement of local government and other regional stakeholders in collaborative procurement effort to reduce the cost of fleet PEV acquisition and complexity of financing options.
6. Support ARB's California Sustainable Freight Plan and MTC's Bay Area Goods Movement Plan.	▪ Explore local actions including policy support and/or development, and pilot programs that work to electrify the movement of goods in San Francisco to eliminate diesel emissions and truck congestion.

[6] For more information on Energy Commission EVSE investment programs, see the Investment Plan Update for the Alternative and Renewable Fuel and Vehicle Technology Program website at: http://www.energy.ca.gov/altfuels/2015-ALT-01/index.html.

Recommendation	Next Steps
7. Maximize deployment of electric buses in the San Francisco Unified School District, commuter and shuttle service applications.	▪ Provide technical assistance to stakeholders (e.g., School District, AC Transit, private sector companies) in assessing the feasibility of integrating electric buses into their fleet vehicle contracts. ▪ Collaborate with partners like the Business Council on Climate Change and local tour operators to support information dissemination on the viability of electric buses. Work to understand perceived and actual constraints and develop solutions to remove barriers. ▪ Develop vehicle-grid integration (VGI) pilot projects to understand the utility coordination requirements and other technical aspects required to build the business case for electric buses operating in San Francisco. ▪ Assess feasibility of developing group procurement initiatives to lower the cost and complexity of acquiring electric buses. ▪ Leverage ARB, Energy Commission, and BAAQMD funds to enable deployment of necessary depot-based and on-route fast charging to support electric bus charging requirements.
8. Create zero emission freight delivery zone/corridor pilot project	▪ Work with stakeholders to assess feasibility of creating zero emission freight delivery zones/corridors. Key partners include but are not limited to neighboring local governments, SFMTA, San Francisco County Transportation Agency (SFCTA), MTC, and the Ports of Oakland, San Francisco, and Richmond.
9. Accelerate deployment of medium duty electric trucks through "Mobility-as-a-Service" Platform	▪ Evaluate the feasibility of OEMs establishing "Mobility as a Service (MaaS) platform, leveraging state funding via HVIP. ▪ Assess opportunities for MaaS platform to create flexible, low-cost, short-term leases; pilot financing model as a strategy to deploy medium-duty electric trucks in fleets operating in San Francisco. ▪ Leverage ARB, Energy Commission, and BAAQMD funds to enable deployment of necessary depot-based and on-route fast charging.

Recommendation	Next Steps
10. Accelerate adoption of electric scooters and bikes for personal use and shared business models.	▪ Partner with internal and external stakeholders, including SFMTA, bike coalitions, community based organizations and affinity groups to conduct outreach and education. Organize ride and drive events to accelerate personal adoption of these vehicle alternatives. ▪ Work with regional agencies (e.g., MTC, BAAQMD) to pilot incentives for electric bike and scooter adoption. ▪ Support development of public and/or private business models that integrate these electric alternatives to vehicles to provide first/last mile transportation solutions.
11. Build a San Francisco PEV awareness campaign	▪ Increase awareness of existing incentives for PEVs and charging infrastructure among car owners ▪ Work with car rental, car share and ride share companies to highlight PEV options in their fleets and among their network of drivers. ▪ Partner with automobile dealerships in and supplying to San Francisco to position PEVs and available incentives.
12. Develop grid integration road map and strategies that influence charging patterns to optimize use of renewable energy and shape load.	▪ Develop City of San Francisco grid integration roadmap that models locational demand for charging infrastructure and opportunities/constraints on the utility grid. ▪ Coordinate with local utilities to develop pilot programs that incentivize driver-charging patterns to provide ancillary grid services. ▪ Pursue state, federal, and other funding sources.
13. Build load for existing utility renewable electricity supply programs to power PEVs in San Francisco.	▪ Work with SFPUC to develop strategies that engage developers, property owners, and managers in enrolling in CleanPowerSF or becoming a SFPUC Enterprise customer. ▪ Work with PG&E to engage property owners in PG&E's EVSE and PEV rebate programs.

Recommendation	Next Steps
14. Establish citywide MUD goal for EVSE.	▪ Define MUD charging deployment goals with input from Energy Commission-funded MUD study ▪ Develop outreach plan that includes online information connecting property owners/managers to resources, develop and hold educational workshops. ▪ Support actions to extend SB 2565 to include tenant-installed PEV charging in rent controlled units. ▪ Identify Energy Commission funding to support MUD EVSE pilot projects that integrate Distributed Energy Resources (DERs) including solar photovoltaics (PV) and energy storage.
15. Identify barriers and facilitate solutions that assist private sector MUD EVSE operators in co-locating EVSE with other DER solutions	▪ Work with internal and external stakeholders, including local utilities, to develop solutions that accelerate deployment of EVSE paired with other DER solutions (e.g., rooftop PV and/or energy storage).
16. Align building codes	▪ Address state and local barriers to charging infrastructure deployment in building codes and other policies. ▪ Streamline permitting for EVSE installations in single-family homes and MUDs per state requirements.
17. Evaluate traffic congestion data and develop proposals for congestion pricing in priority areas of the City to improve air quality and accelerate market transformation of PEVs.	▪ Collaborate with SFMTA and SFCTA to assess data and key planning process and policy steps that lead to 1. Congestion pricing zones with preferential pricing/access for PEVs. 2. Preferential street parking zones for PEVs and PEV car share vehicles, and explore other fee exemptions. 3. High Occupancy Vehicle (HOV) lane expansion in combination with transit lanes.
18. Develop financial incentives to support PEV adoption and fuel displacement.	▪ Analyze methods for pricing in environmental costs of owning, parking, fueling and operating Internal Combustion Engine (ICE) vehicles in San Francisco to discourage their use where economical alternatives exist. ▪ Identify ways to reduce the costs of owning, parking, charging and operating PEVs in San Francisco, especially in tandem with clean transit improvements.

Recommendation	Next Steps
19. Evaluate feasibility of establishing public right-of-way or curbside charging in San Francisco.	▪ Understand regulatory obstacles to public right of way street charging and develop plan to address barriers and opportunities. ▪ Work with SFPUC and PG&E to identify obstacles and opportunities to provide curbside power. ▪ Work with SFPUC, SFMTA, and other relevant city departments to understand opportunities and restraints for the City.
20. Provide zero cost EVSE retrofit for single family home owners	▪ Work with SFPUC and PG&E to develop incentive programs (e.g., innovative EV rate plan) made available to customers. ▪ Develop approved City service provider (e.g., installer) pipeline, creating workforce development opportunities. SFPUC provided charger with Demand Response capabilities installed by service provider. ▪ Develop on-bill repayment mechanism for electrical upgrade requirements and/or promote existing solutions such as Property Assessed Clean Energy (PACE) financing.
21. Provide zero-cost EVSE retrofit for commercial customers.	▪ Work with SFPUC and PG&E to develop incentive program (e.g., innovative EV rate plan and incentives) made available to commercial customers enrolled in CleanPowerSF. ▪ Develop approved City service provider (e.g., installer) pipeline, creating workforce development opportunities. SFPUC provided charger with Demand Response capabilities installed by service provider. ▪ Develop on-bill repayment mechanism for electrical upgrade requirements and/or promote existing financing solutions such as PACE.
22. Develop convenience incentives	▪ Work with internal and external stakeholders to evaluate feasibility and development of programs that improve convenience of owning, operating and parking PEVs as compared to ICE vehicles (e.g., priority HOV lanes, parking access, restricted air quality zones).

1.3.2 Fuel Cell Electric Vehicles and Hydrogen Infrastructure

Recommendation	Next Steps
1. Assess potential of FCEVs to meet the City's municipal fleet GHG reduction goals	▪ Assess FCEV deployment opportunities in the context of the City of San Francisco vehicle fleet.
2. Determine station needs and identify hydrogen fueling sites	▪ Complete planning process for FCEV fueling needs, currently underway with the UC Berkeley Transportation Sustainability Research Center in partnership with the San Francisco Department of Environment. ▪ Support applications for Energy Commission funding for hydrogen stations from local station developers (building on the applications submitted in 2016)
3. Streamline permitting and inspection processes for implementation of hydrogen fueling stations.	▪ Coordinate among relevant City departments to identify best practices and streamline permitting and inspection processes for implementation of hydrogen fueling stations.
4. Coordinate/deliver training on hydrogen fueling safety, code, and standards for all relevant City agencies	▪ Coordinate and deliver training on hydrogen fuel safety, codes, and standards for all relevant City agencies, including public safety.
5. Increase community awareness of FCEVs and hydrogen fueling.	▪ Conduct outreach and awareness campaign to local communities with existing or planning hydrogen fueling stations.
6. Develop and implement group procurement of FCEVs.	▪ Develop and implement a group procurement program that reduces the cost and complexity of FCEVs to the community and local fleets.

Recommendation	Next Steps
7. Evaluate traffic congestion data and develop proposals for congestion pricing in priority areas of the City to improve air quality and accelerate market transformation of FCEVs.	▪ Collaborate with SFMTA and SFCTA to assess data and key planning process and policy steps that lead to •Congestion pricing zones with preferential pricing/access for FCEVs. •Preferential street-parking zones for FCEVs and FCEV car share vehicles; block parking exemption. •HOV lane expansion in combination with transit lanes.
8. Consider City requirement for 100 percent renewable hydrogen fuel at all hydrogen stations	▪ Work with local utilities, station developers and fuel providers to assess feasibility of 100 percent renewable fuel requirements for hydrogen stations in San Francisco.
9. Assess feasibility of local production of renewable hydrogen	▪ Assess potential for locally produce renewable hydrogen in collaboration with internal and external stakeholders with industrial operations.
10. Collaborate with FCEV OEMs to accelerate deployment of medium- and heavy-duty options.	▪ Accelerate adoption of medium and heavy-duty options in public and private fleets by pursuing funding through HVIP and potential funding ARB Medium-and Heavy-Duty vehicle solicitations.

1.3.3 Natural Gas Vehicles and Infrastructure

Recommendation	Next Steps
1. Ensure that the City's existing fleet of CNG cars, trucks, and vans have access to the lowest Carbon Intensity (CI) natural gas available.	▪ Work with fleet and enterprise departments to identify lower CI natural gas supplies for the City's existing fleet of CNG vehicles.

Recommendation	Next Steps
2. Periodically update natural gas procurement goals to identify lowest CI fuels practically obtainable and to refine sustainable feedstock sourcing policy for City vehicles.	▪ Identify policy process to ensure that the City's AFV procurement and fueling policies are consistent with the most recent regulations or validation criteria on the economic and environmental Life Cycle Assessment (LCA) of available alternative fuel and vehicle technologies. ▪ Require procurement of RNG for all relevant City CNG fleet vehicles based on results of LCA.
3. Identify local supplier of RNG with low CI and explore partnership to replace fossil-based natural gas in public/private fleets traveling in San Francisco	▪ Initiate dialogue on RNG supply options with appropriate city leaders, likely to include the Mayor's Office, ADM, Department of Environment, SFMTA and others as appropriate. ▪ Based on recommendations of key stakeholders, develop RNG supply plan and policy approach.
4. Consider development of regulatory guidance requiring that CNG sold in the City be replaced by RNG	▪ See above.

1.3.4 Biofuel Vehicles

Recommendation	**Next Steps**
1. Conduct outreach and education about renewable diesel to maximize deployment in public and private fleets	▪ Continue to monitor success of renewable diesel in San Francisco's municipal fleet. Provide technical assistance, outreach, and education to public and private sector fleets to maximize implementation of renewable diesel, including SF Port and SFO tenants, Business Council on Climate Change members, medium duty delivery and shuttle fleets, bus fleets, school districts, public safety agencies, small businesses, and other diesel users. ▪ Provide technical assistance to stakeholders) that opt to integrate renewable diesel into their fleet vehicle contracts.
2. Periodically update renewable diesel procurement goals to identify lowest CI fuels practically obtainable and to refine sustainable feedstock sourcing policy for City fleet vehicles	▪ Identify policy process to ensure that the City's AFV procurement and fueling policies are consistent with the most recent regulations or validation criteria on the economic and environmental LCA of available alternative fuel and vehicle technologies.
3. Periodically review opportunities for development of local biomethane fuel sources.	▪ Develop feasibility study and cost-benefit analysis of local sourcing opportunities to produce biofuels from anaerobic or landfill sources.

CHAPTER 2: Policy and Market Context for Alternative Fuel and Vehicle Planning

2.1 Introduction

The City and County of San Francisco is at the center of a clean transportation ecosystem, with national, state, regional, and local policies changing rapidly in response to the urgent need to reduce the GHG impact of fossil fuel based transportation. According to the most recent data available, the transportation sector emits 36 percent of the total GHGs in California and approximately 83 percent of smog-forming oxides of nitrogen (NOx).[7] With a state population of nearly 39 million, California hosts nearly 26 million light duty passenger vehicles and almost 1 million medium and heavy-duty vehicles (MDVs and HDVs). Given the climate change crisis and persistent non-attainment of federal air quality standards in large areas of the state, California has adopted increasingly robust measures to accelerate GHG emissions reduction. These goals and mandates have been accompanied by increasing funding from the state's Cap and Trade revenues, formally known as the Greenhouse Gas Reduction Fund (GGRF), to accelerate the shift to clean, renewable fuels in both the energy and transportation sectors. However, the state is only at the very beginning of the necessary de-carbonization of the transportation sector, with PEVs at just over 1% penetration of the existing stock of light duty vehicles, and deployments just beginning in the medium and heavy-duty vehicle segments.

Illustrating the scale of the de-carbonization challenge, the following chart describes key state and federal goals that are helping to benchmark San Francisco's action on AFV ecosystem development.

Table 2-1: GHG, Fuel, and Air Quality Goals and Milestones Relevant to California

Policy Basis	Objectives	Goals and Milestones
AB 32	GHG Reduction	Reduce GHG emissions to 1990 levels by 2020
Executive Order S-3-05	GHG Reduction	Reduce GHG emissions to 80 percent below 1990 levels by 2050
Low Carbon Fuel Standard	GHG Reduction	Reduce CI of transportation fuels in California by 10 percent from 1990 levels by 2020
State Alternative Fuels Plan	Petroleum Reduction	Reduce petroleum fuel use to 15 percent below 2003 levels by 2020

[7] *2016 Edition: California GHG Emissions Summary.* California Air Resources Board, 2014, June 2016 Update, accessed October 12, 2016 at: https://www.arb.ca.gov/cc/inventory/pubs/reports/2000_2014/ghg_inventory_trends_00-14_20160617.pdf

Policy Basis	Objectives	Goals and Milestones
Bioenergy Action Plan	In-State Biofuels Production	Produce in California 20 percent of biofuels used in state by 2010, 40 percent by 2020, and 75 percent by 2050
Energy Policy Act of 2005; Energy Independence & Security Act of 2007	Renewable Fuel Standard (RFS)	36 billion gallons of renewable fuel by 2022 (nationally)
Clean Air Act	Air Quality	80 percent reduction in NO_X by 2023
Executive Order B-16-2012	ZEV Mandate	Accommodate 1 million electric vehicles by 2020 and 1.5 million by 2025*

Source: The Energy Commission 2015-16 Alternative Fuel Program Investment Plan

Meeting these ambitious goals for GHG emissions reduction in the transportation sector will require accelerated retirement of older high-polluting vehicles and their replacement with ZEV and near-zero emission technologies. To enable that transition, the state has developed a comprehensive suite of incentives, programs, and policies described below.

2.2 Policy Leadership of California

California formed the ARB in 1967 to drive air quality improvement. An independently governed department within the California Environmental Protection Agency, ARB sets regulatory standards for air quality within California. Because ARB was formed prior to the federal Clean Air Act, the state was granted unique authority to establish emissions standards that are more rigorous than federal standards. The strict vehicle emissions standards established by ARB have been adopted by a coalition of states known as the "CARB states," including Arizona, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New Mexico, New York, Oregon, Pennsylvania, Rhode Island, Vermont, Washington, and the District of Columbia. ARB has also led the nation through emissions-related initiatives such as the ZEV Mandate, the establishment of the Low Carbon Fuel Standard (LCFS), and other vehicle policy initiatives now in their early stages of development, such as the Zero Emission Bus standard and low-carbon freight strategies. Due to California progress on emissions, the United States Environmental Protection Agency (U.S. EPA) has committed to adopting ARB standards for vehicles manufactured after the year 2016.

2.2.1 Vehicle Emissions, Fuel Standards and the ZEV Mandate

In 2012, California implemented Executive Order B-16-2012, known as the ZEV Mandate. The ZEV Mandate requires that by 2025, at least 15 percent of new car sales conform to the ZEV emissions performance criteria created by ARB, which can be met by both PEVs and FCEVs. The

ZEV mandate establishes minimum thresholds for the production of qualified ZEVs, and establishes a structure of financial penalties and credit trading for manufacturers that fail to meet required thresholds, while rewarding OEMs that exceed the requirements.

California has implemented a number of additional measures to reduce GHG emissions by promoting broader AFV adoption. Most important among these initiatives is the Global Warming Solutions Act of 2006, known as AB 32 (Núñez, Chapter 488, Statutes of 2006), which capped economy-wide California GHG emissions at 1990 levels by 2020. In August 2016, Senate Bill 32 was adopted requiring aggressive targets for reducing emissions by 40 percent from 1990 levels by 2030. In addition to AB 32 and SB 32, California Executive Orders S-3-05 and B-16-2012 called for reductions in GHG emissions to 80 percent below 1990 levels by 2050. Finally, via SB 350, Governor Brown established the goal to increase the proportion of electricity derived from renewable sources from 33 percent to 50 percent by 2030.

2.2.2 Creation of the Air Quality Improvement Program and the Alternative and Renewable Fuel and Vehicle Technology Program

AB 118 created the Air Quality Improvement Program (AQIP), administered by the ARB, and at the same time created the *Alternative and Renewable Fuel and Vehicle Technology Program* (ARFVTP), managed by the Energy Commission. The ARFVTP is focused primarily on *GHG reduction* within the transportation sector, while the AQIP is primarily responsible for reducing specific transportation-related *criteria air pollutants,* such as NOx (the primary contributors to smog), and diesel-related Particulate Matter (PM), which is implicated in asthma and lung disease. The two ARB and Energy Commission managed programs have jointly contributed funds toward clean vehicle rebates. The Energy Commission has also invested in light-duty PEV charging infrastructure; regional PEV, FCEV, and AFV planning; in-state manufacturing; and the development and demonstration of advanced hybrid and fully electric truck and bus models. The AQIP has provided deployment incentives for these vehicles through HVIP, as well as loans to assist fleets in diesel modernization projects. The AQIP also provides grants for demonstration and testing of emission reduction technologies, with projects addressing railroads, port vessels, and other applications. Cumulative funding from the AQIP is summarized below.

Table 2-2: AQIP Project Allocations by Year

AQIP Project	Project Allocations by Fiscal Year (million)								
	2008 -09	2009 -10	2010 -11	2011 -12	2012 -13	2013 -14	2014 -15	2015 -16	Total
Truck Loan Assistance	$30				$4	$20	$10	$18	**$82**
CVRP[2]		$4	$7	$16	$36	$40	$10	$3	**$116**[2]
HVIP[2]		$20	$23	$11		$5	$5		**$64**[2]
Low NOx Engine Incentives								$2	**$2**
Agricultural Equipment Trade Up in the San Joaquin Valley								$0.5	**$0.5**
Advanced Technology Demonstration/Vehicle Testing		$1.9	$1.7	$1.6	$1				**$6**
Lawn and Garden Equipment Replacement		$1.6	$1						**$3**
Off-Road Hybrid Equipment Pilot			$2						**$2**
Zero-Emission Agricultural Utility Equipment		$0.1							**$0.1**
TOTAL	**$30**	**$28**	**$35**	**$29**	**$42**	**$65**	**$25**	**$23**	**$276**

Proposed Fiscal Year 2016-17 Funding Plan for Low Carbon Transportation and Fuels Investments and the Air Quality Improvement Program. California Air Resources Board; May 20, 2016, pg. 8. Available at: https://www.arb.ca.gov/msprog/aqip/fundplan/proposed_fy16-17_fundingplan_full.pdf

The Energy Commission and ARB have invested approximately $1 billion in California's AFV ecosystem from 2010-2015, spanning a broad range of strategies from research and development (R&D) to manufacturing, vehicle incentives, regional planning, and market development. The California Vehicle Rebate Program (CVRP) has provided several hundred million dollars in direct-to-consumer incentives in the form of purchase rebates for PEVs and FCEVs.

Assembly Bill 8 (Perea, 2013) extended the timeframe of the original AB 118 legislation by authorizing more than $2 billion through the year 2024 ($100 million per year) for clean transportation programs, including the ARFVTP. The Energy Commission and ARB have invested broadly across vehicle and fuel types in the AFV spectrum. In addition to $67M allocated to light-duty PEVs and infrastructure, the Energy Commission has invested over $150M in biofuels and gasoline fuel substitutes, $84M in hydrogen vehicles and infrastructure, and more than $77M in CNG.

The 2016-17 ARFVTP Investment Plan proposes approximately $20M out of the $100M annual budget to be focused on PEVs and PEV infrastructure deployment, supplemented by AQIP funds focused on fleet applications, CVRP rebates for consumers, and HVIP for medium and heavy-duty AFV rebates (with larger rebates available for PEVs and FCEVs). This diversity of investment reflects the state's ongoing "all of the above" strategy including hydrogen, natural gas, and biofuels, as well as ZEVs. Tables 2-3 and 2-4 indicate recent funding commitments.

Table 2-3: Cumulative Energy Commission Investments in Alternative Fuel Ecosystem

Category	Funded Activity	Cum. Awards ($M)	# of Projects or Units
Alternative Fuel Production	Biomethane Production	$50.9	16 Projects
	Gasoline Substitutes Production	$27.2	14 Projects
	Diesel Substitutes Production	$57.4	20 Projects
Alternative Fuel Infrastructure	EV Charging Infrastructure	$40.7	7,490 Charging Stations
	Hydrogen Refueling Infrastructure	$96.0	49 Fueling Stations
	E85 Fueling Infrastructure	$13.7	158 Fueling Stations
	Upstream Biodiesel Infrastructure	$4.0	4 Infrastructure Sites
	Natural Gas Fueling Infrastructure	$21.0	65 Fueling Stations
Alternative Fuel and Advanced Technology Vehicles	Natural Gas Vehicle Deployment	$56.6	2,809 Vehicles
	Propane Vehicle Deployment	$6.0	514 Trucks
	Light-Duty PEV Deployment	$25.1	10,700 Cars
	Med- & Heavy-Duty PEV Deployment	$4.0	150 Trucks
	Med. & Heavy-Duty Vehicle Demos.	$93.7	44 Demonstrations
Related Needs and Opportunities	Manufacturing	$57.0	22 Manufacturing Projects
	Emerging Opportunities	-	-
	Workforce Training & Development	$27.7	83 Recipients
	Fuel Standards & Equip. Certification	$3.9	1 Project
	Sustainability Studies	$2.1	2 Projects
	Regional Alt. Fuel Planning	$7.6	34 Regional Plans
	Centers for Alternative Fuels	$5.8	5 Centers
	Technical Assistance & Evaluation	$5.6	n/a
Total		$606.0	

Source: Energy Commission, 2016-17 Investment Plan Update for the Alternative & Renewable Fuel & Vehicle Technology Program, p. 2. Accessed October 12, 2016.

Table 2-4: California 2015-16 Alternative Fuel Program Investment Plan

<table>
<tr><th>Category</th><th>Funded Activity</th><th>2014-2015</th><th>2015-2016</th><th>2016-2017 (Proposed)</th></tr>
<tr><td>Alternative Fuel Production</td><td>Biofuel Production and Supply</td><td>$20</td><td>$20</td><td>$20</td></tr>
<tr><td rowspan="3">Alternative Fuel Infrastructure</td><td>Electric Charging Infrastructure</td><td>$15</td><td>$17</td><td>$17</td></tr>
<tr><td>Hydrogen Refueling Infrastructure</td><td>$20</td><td>$20</td><td>$20</td></tr>
<tr><td>Natural Gas Fueling Infrastructure</td><td>$1.5</td><td>$5</td><td>$2.5</td></tr>
<tr><td rowspan="3">Alternative Fuel and Advanced Technology Vehicles</td><td>Natural Gas Vehicle Incentives</td><td>$10</td><td>$10</td><td>$10</td></tr>
<tr><td>Light-Duty Electric Vehicle Deployment</td><td>$5</td><td>-</td><td>-</td></tr>
<tr><td>Medium- & Heavy-Duty Vehicle Technology Demonstration & Scale-Up</td><td>$15</td><td rowspan="2">$20</td><td rowspan="2">$23</td></tr>
<tr><td rowspan="5">Related Needs and Opportunities</td><td>Manufacturing</td><td>$5</td></tr>
<tr><td>Emerging Opportunities</td><td>$6</td><td>$3</td><td>$4</td></tr>
<tr><td>Workforce Training and Development Agreements</td><td>$2.5</td><td>$3</td><td>$2.5</td></tr>
<tr><td>Regional Alternative Fuel Readiness and Planning</td><td>-</td><td>$2</td><td>$2</td></tr>
<tr><td>Centers for Alternative Fuels and Advanced Vehicle Technology</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Total</td><td></td><td>$100</td><td>$100</td><td>$100</td></tr>
</table>

Source: California Energy Commission, *2016-17 Investment Plan Update for the Alternative & Renewable Fuel & Vehicle Technology Program,* page 5, Accessed October 12, 2016 at: http://www.energy.ca.gov/2015publications/Energy Commission-600-2015-014/CEC-600-2015-014-CMF.pdf

2.3 San Francisco Clean Transportation Policies and Goals

The City and County of San Francisco has a broad array of policies and programs to reduce emissions and promote transportation fueled by renewable sources, summarized below.

2.3.1 GHG Emissions Goals: San Francisco's Climate Action Plan

The City and County of San Francisco has an overarching climate action goal known as Ordinance 81-08, which pledges the City to reduce GHG emissions 80 percent below 1990 levels by 2050, in alignment with the state's climate action targets. San Francisco has in turn developed a Climate Action Strategy to provide the necessary framework for achieving this goal. The Climate Action Strategy addresses all sectors of the City's economy, including transportation, in alignment with San Francisco's long-standing commitment to both local emissions reduction and global leadership in all dimensions of environmental sustainability.[8] The City's 2013 Climate Action Strategy Update tracks progress against goals and includes a comprehensive set of actions by which the City is advancing its key interim GHG emission reduction goals, which calls for emissions reductions of 44 percent below 1990 levels by 2030. Complementary transportation related goals identified in the 2013 Climate Action Strategy Update include the following:

1. Shift 50 percent of trips to non-automobile transportation methods by 2017 and 80 percent by 2030.[9]
2. Grow public transportation options and expand alternative transit infrastructure
3. Expand access to clean vehicles and fuels, including:
   a. Move Bay Area Rapid Transit (BART) to 100 percent renewable electricity.
   b. Move the taxi fleet and Muni buses to 100 percent renewable fuels.

Table 2-5 demonstrates the shifts required to reduce automobiles as a mode choice to the 20 percent target for 2050, set in the City's Climate Action Strategy. This substantial reduction in auto-based travel will also enable important co-benefits, including reductions in traffic injuries, reduced noise and congestion, and the reclamation of public right of way and parking areas for people, parks, recreation, and open space.

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[8] *San Francisco Climate Action Strategy, 2013 Update*. San Francisco Department of the Environment, 2013. Available online at: http://sfenvironment.org/sites/default/files/engagement_files/sfe_cc_ClimateActionStrategyUpdate2013.pdf

[9] Note that the San Francisco Climate Action Strategy describes the goal date for the shift to 80 percent of trips to non-automobile as 2030 on page vii and 2050 on page 32.

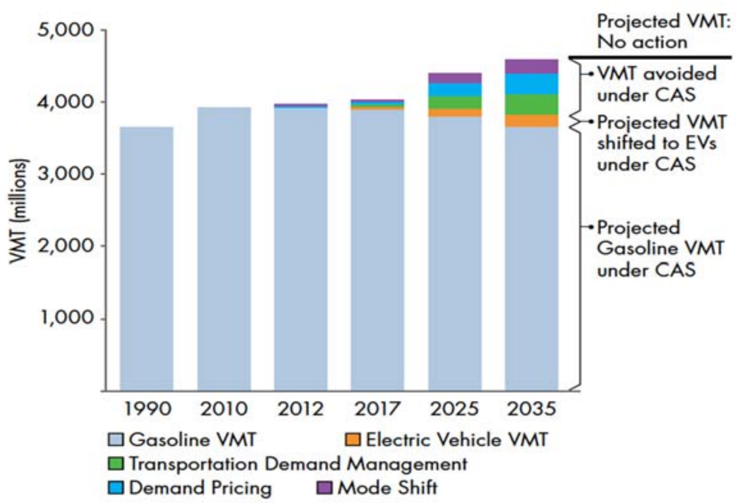
Table 2-5: San Francisco Transportation Mode Choice – 2010 vs. 2050 Goal

	2010	2050
Automobile	62%	20%
Public Transit	17%	40%
Bicycle	3.5%	40%
Walking	17.5%	
TOTAL	100%	100%

Source: San Francisco Climate Action Strategy, 2013 Update, 2013. p. 32.

The initiatives articulated in the Climate Action Strategy are also intended to reduce VMT to close to 1990 levels by 2035. The cumulative decrease in VMT is shown below and attributed to various Transportation Demand Management (TDM) measures and demand pricing (tolling), among other measures. The introduction of new electric buses and vans, and PEVs suitable for taxi and carshare operations, suggest an important role for PEVs in the broader effort to shift away from private single-occupancy vehicle utilization.

Figure 2-1: Projected VMT Reductions from the San Francisco Climate Action Strategy



Source: San Francisco Climate Action Strategy, 2013 Update, 2013.

2.3.2 San Francisco Municipal Transportation Agency Goals

In addition to the high-level goals articulated in the Climate Action Strategy, the development of the City of San Francisco's transportation system is guided by the SFMTA Strategic Plan for the five-year period of 2013-2018.[10] Although the SFMTA plan addresses a wide range of issues beyond the scope of this study, the most relevant goals are identified in the table below.

Table 2-6: SFMTA's Strategic Goals and AFV-Related Objectives

Strategic Goal	Emissions Related Objectives	Emissions-Related Key Performance Indicators (KPIs)
Make transit, walking, bicycling, taxi, ridesharing, and carsharing the preferred means of travel	Increase use of all non-private auto modes	FY 2018 mode split goal: • Private auto: 50 percent • Non-private auto modes: 50 percent
Improve the environment and quality of life in San Francisco	Reduce the Agency's and the transportation system's resource consumption, emissions, waste, and noise	Reduce emissions 25 percent below 1990 levels by 2017 for the transportation system

Source: SFMTA Strategic Plan, Fiscal Year 2013 - Fiscal Year 2014.

The 2018 goal to reduce non-private auto trips to 50 percent of all auto trips further highlights the opportunity to leverage rider preferences for electric propulsion and accelerate deployment of PEVs in taxi, car share, and ride hailing fleets.

2.3.3 San Francisco Transportation Plan Goals

The San Francisco *Municipal* Transportation Authority (SFMTA) has operational responsibility for San Francisco's light rail, bus, and cable car systems, while the San Francisco *County* Transportation Authority (SFCTA) is principally a planning and regulatory agency. The SFCTA is responsible for long-range transportation planning for the City and analyzes, designs, and funds improvements for the City's roadway and public transportation networks. The SFCTA also administers and oversees the delivery of the Proposition K half-cent local transportation sales tax program. It also serves as the designated Congestion Management Agency for San Francisco under state law, and acts as the San Francisco Program Manager for grants from the Transportation Fund for Clean Air. The SFCTA develops the City's most comprehensive transportation planning document, known as the San Francisco Transportation Plan (SFTP)[11], which "positions San Francisco to meet the city's transportation system goals."[12] In its transportation planning process, SFCTA has taken into consideration existing policy

[10] *SFMTA Strategic Plan, Fiscal Year 2013 – Fiscal Year 2014.* San Francisco Municipal Transportation Agency. Available online at https://www.sfmta.com/sites/default/files/pdfs/FYpercent202013%20-%20FY%202018%t20SFMTA%20Strategic%20Plan.pdf.

[11] *San Francisco Transportation Plan 2040.* San Francisco County Transportation Authority, December 2013. http://www.sfcta.org/sites/default/files/content/Planning/SFTP2/FinalReport/SFTP_final_report_low-res.pdf

[12] Ibid. pg. 7.

documents, including the Climate Action Strategy and SFMTA plans. The SFTP has four goals through 2040:

1. Develop world-class infrastructure
2. Enhance livability
3. Promote a healthy environment
4. Retain economic competitiveness

The SFTP focuses its third goal, "Promote a healthy environment," on the challenge of reducing emissions on an aggregate level (not merely on a per capita basis). Given the City's increasing economic and population growth rates, and related increases in VMT, this is a daunting challenge, which will require a strong policy response. As stated in the SFTP:

> *We found this goal is only possibly attainable with a robust combination of aggressive local and regional vehicle pricing, widespread use of electric vehicles, and major new infrastructure (including a new BART tube across the Bay at a cost of $10 billion).*[13]

While advocating for BART and other transit system expansions, SFTP also notes that demand side strategies to reduce automobile travel are more feasible and effective at curtailing GHG than supply side public transit investments. This policy approach is consistent with the AFV Readiness Plan recommendation to advance ongoing planning for zero emissions corridors and zones in the City and across the region.

2.3.4 The San Francisco Clean Air Plan – Zero Emissions 2020[14]

The Clean Air Plan, implemented in 2004, identifies a goal of achieving 100 percent zero emissions in the SFMTA revenue fleet (Muni buses and rail vehicles) as a goal for 2020. Produced jointly by the SFMTA and San Francisco's Department of Environment, the City's Clean Air Plan aligns with the San Francisco Climate Action Strategy goal to expand access to clean vehicles and fuels, with an emphasis on City-operated fleets amenable to direct City control.

2.3.5. Existing Policies to Reduce Transportation Emissions and Promote AFV Use in San Francisco

The 2013 Climate Action Strategy notes that "substantial shifts in personal travel choices away from the personal automobile with the simultaneous replacement of petroleum-based fuels with low-carbon fuels and vehicles will be essential if San Francisco is to meet its GHG emissions reduction goals over the next 20 years."[15] Accordingly, the plan highlights investment in public transit, bicycling, and walking infrastructure as well as an accelerated shift to non-fossil fuels.

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[13] Ibid. pg. 19.
[14] *San Francisco Municipal Transportation Agency Fiscal Year 2013 Departmental Climate Action Plan.* San Francisco Municipal Transportation Agency. Available online at: http://sfenvironment.org/sites/default/files/fliers/files/sfe_cc_2014_mta_cap_fy1213.pdf
[15] *San Francisco Climate Action Strategy, 2013 Update.* San Francisco Department of the Environment, 2013. p. 32. http://sfenvironment.org/sites/default/files/engagement_files/sfe_cc_ClimateActionStrategyUpdate2013.pdf

Consistent with other local climate action plans, the San Francisco plan distinguishes between state policies that will help advance climate action goals and policies that must be designed and implemented locally. According to the City's climate blueprint, if all local policies identified in the 2013 Climate Action Strategy are fully implemented, 2030 emissions from the transportation sector are expected to be 508,000 metric tons (mT) lower than 2010 levels. In addition, state policies alone are projected to further reduce transportation emissions in the City by 806,959 mT in 2030. The following table identifies the diverse program elements driving the projected reductions.

Table 2-7: GHG Reduction by 2030 via Local Transportation Policy Measures (vs. 2010 baseline)

Policies Identified in the 2013 San Francisco Climate Action Strategy	
Measure	**Reduction**
Investing in expanded transit, bicycle, walking, and vehicle sharing networks	72,000 mT
Expansion of clean vehicles and utilization of clean fuels via:	
1. Switch to 100 percent renewable electricity by Caltrain and BART	89,000 mT
2. Shift to PEVs in personal automobile fleet and to electric taxis	59,000 mT
3. Switching Muni to 100 percent carbon-free fuels	69,000 mT
SUBTOTAL reduction via alternative fuels and vehicles:	218,000 mT
TOTAL Transportation Sector Reductions by 2030	**290,000 mT**

Source: San Francisco Climate Action Strategy, 2013 Update. p. 32.

Table 2-7 illustrates that 25 percent of the reduction targeted for 2030 is to be achieved through a shift from private cars to transit, bicycle, pedestrian and vehicle sharing. However, the balance of planned reductions requires the substitution of 100 percent renewable fuels for existing fossil fuels (including in electricity generation), and a shift to PEVs.

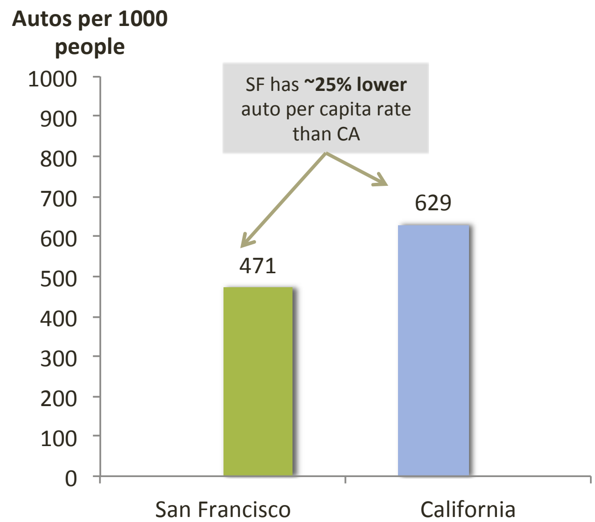
2.4 Vehicle Overview –San Francisco

The AFV population in the San Francisco, especially PEVs, has already achieved significant size and is rapidly growing. The following overview summarizes current data on AFVs in the City. Supplementary information will also be presented on each AFV type in Chapters 3-6.

2.4.1 San Francisco Vehicle Ownership and Registration Overview

San Francisco has a lower rate of vehicle ownership per capita than California as a whole, reflecting the City's many "Transit First" policy initiatives.

Figure 2-2: San Francisco Auto Ownership Rates vs. Statewide Average



Source: US Department of Energy, accessed online on October 2, 2016 at: http://energy.gov/eere/vehicles/fact-573-june-1-2009-vehicles-capita-state

San Francisco has a total of 471,388 registered motor vehicles as of 2015. Of these, 83 percent are automobiles and 11 percent are trucks.

Table 2-8: Total Vehicles Registered in the City of San Francisco

Vehicle type	Number	Percent of Total
Autos	407,656	83%
Trucks	54,768	11%
Motorcycles	23,342	5%
Trailers	8,337	2%
TOTAL	**494,103**	**100%**

Source: San Francisco DMV, 2015. Available online: https://www.dmv.ca.gov/portal/wcm/connect/add5eb07-c676-40b4-98b5-8011b059260a/est_fees_pd_by_county.pdf?MOD=AJPERES

2.4.2 Private Fleets Domiciled in San Francisco

Private fleet deployments in San Francisco have substantial GHG impacts. Accordingly, the City has an interest in accelerating the transition from existing fossil-fueled fleets to cleaner AFVs. Currently, relatively few fleets are domiciled in the City compared to the number that enters the City on a daily basis. This is due to high local land costs and the shrinking availability of property affordable for light industrial uses. Reliable data on fleet populations domiciled in San Francisco vs. fleet traffic in San Francisco is not readily available. However, the table below illustrates the range of larger fleet populations, based on the proprietary FleetSeek database.

However, FleetSleek only provides data on fleets by location of the physical headquarters of the company, as data on satellite fleet depot populations is typically highly dynamic. In the case of San Francisco companies, it is well-known that PG&E, McKesson, and Recology fleets are *not* operating within City boundaries in the numbers indicated below. However, the other fleets shown are deployed in approximately the numbers shown.

Table 2-9: Private Fleets of SF based Companies

PG&E Corp (1138 = CNG)	8043
Recology, Inc. (385 in SF: 13 LNG, 372 B20+)	1580
McKesson Corp.	790
San Francisco Chronicle	190
McKesson Corp.	104
Crane Pest Control	60
Otis Elevator Co.	50
Frank & Grossman Landscape Contractors	36
Ranger Pipelines, Inc.	34
Decorative Plant Service, Inc.	30
Civic Center Towing	29
Abbett Electric Corp.	26
McMillan Electric Co.	23
Veritable Vegetable, Inc.	23
Anderson Rowe & Buckley, Inc.	20

Source: Fleetseek, 2016.

2.4.3 Trucks in California and San Francisco

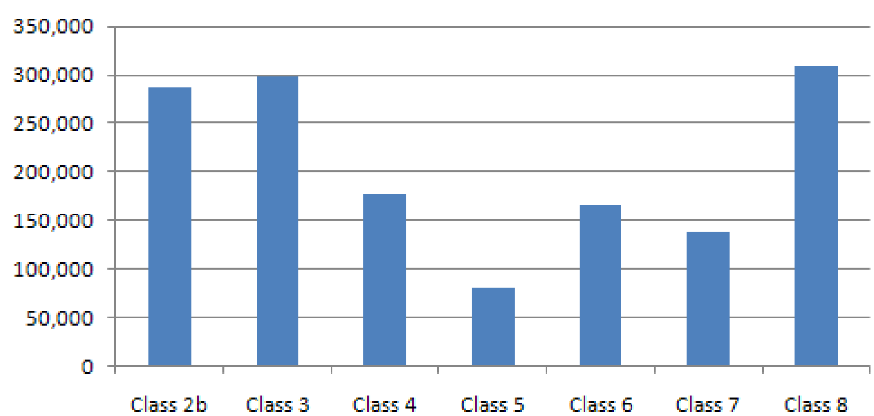
There are more than 900,000 medium and heavy duty vehicles in use in California, and approximately 55,000 trucks of all classes registered in San Francisco. The truck segment includes diverse vehicle types, including long haul tractors, refuse hauling trucks, package delivery vans, medium-duty work trucks, and shuttles, buses, and commercial grade vans. In 2012, these trucks comprised about 3.7 percent of the total vehicle population in California, yet consumed more than 20 percent of the total fuel, and were responsible for approximately 23 percent of transportation-related GHG emissions and 30 percent of total NOx emissions. Replacing the average truck with a zero emission vehicle offers nearly six times the GHG benefit compared with replacing a typical light duty. Accordingly, substantial state funding has been focused on reducing the GHG and air quality impact of trucks by advancing cleaner medium and heavy duty technologies across multiple engine and fuel types, including natural gas, electric and hybrid drive, biofuels such as renewable diesel, and FCEV drivetrains. State resources for demonstration and deployment of these advanced vehicle technologies were referenced in the ARB and Energy Commission funding charts shown in Tables 2-3 and 2-4 above.

In addition to existing state funding, targeted regional incentives are being provided by Air Quality Management Districts through a funding mechanism known as AB 2766. The AB 2766 Subvention Program (initiated in 1991) levies a $6 fee per each motor vehicle registration to enable cities and counties to meet requirements of federal and state Clean Air Acts, and to implement transportation emission reduction measures consistent with local Air Quality Management Plans. These funds, in combination with HVIP, provide opportunities for public and private fleet operators in San Francisco to acquire cleaner vehicles at significant discounts. For example, the state HVIP program offers rebates of up to $110,000 per medium duty truck (up to a maximum of 90 percent of the purchase price), with the largest rebates provided to Battery Electric Vehicles (BEVs). In addition, the BAAQMD offers additional incentives for charging infrastructure, and for PEV fleet vehicles for public fleets. These are typically offered on a first-come first-served basis within each funding year. As discussed in both the Electric Vehicle and Biofuels Chapters of this Plan, maximizing the use of both state and regional incentives will be an important success factor in driving accelerated adoption of cleaner medium and heavy duty vehicles in San Francisco.

2.4.3.1 Distribution in California

Medium duty vehicles in Class 3-6, and heavy duty vehicles in Class 7-8 (tractor trailers) have low fuel economy and high emissions factors compared with light duty vehicles (Class 1-2). Therefore, targeting incentives to accelerate replacement of larger and older diesel trucks and buses can help maximize return on investment in clean vehicles. The distribution of trucks by class in California is indicated in the figure below.

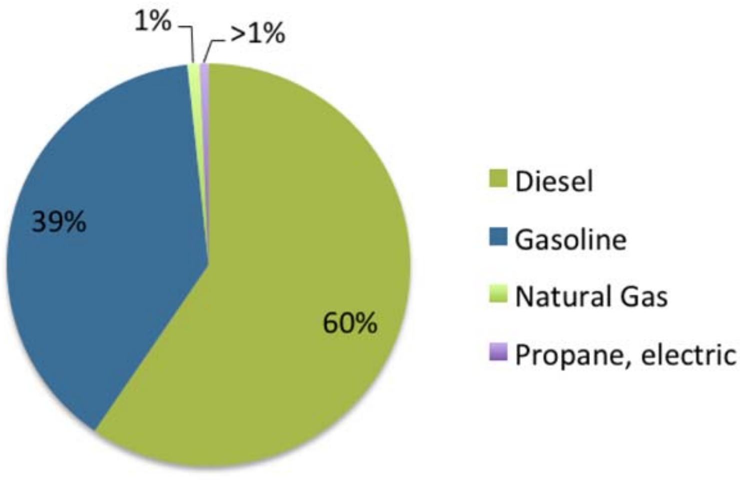
Figure 2-3: Trucks in California by Class, 2010



Source: Jennings, Geoff and Brotherton, Tom; *Vehicle and Technologies Characterization and Baseline.* CalHEAT Truck Research Center, 2011.

There are approximately 1.5M commercial trucks in California, approximately 600,000 of which are diesel. Although there are at least 75,000 units of each class, the largest number of trucks is in the heaviest duty (Class 8) and lighter-duty segments. Notably, while more diesel fuel is used by the truck fleet (Figure 2-4), there is a larger quantity of gasoline-burning trucks deployed, reflecting the prevalence of light-duty pick-up trucks (Class 2-3) in the overall truck segment mix.

Figure 2-4: Truck Fuel Use in Total Quantity (2010)



Source: Jennings, Geoff and Brotherton, Tom; *Vehicle and Technologies Characterization and Baseline.* CalHEAT Truck Research Center, 2011.

2.4.3.2 Trucks in San Francisco

Approximately 55,000 trucks were registered in the San Francisco as of December 2015. This is supplemented by an influx of about 4,000 trucks that travel to the City each day (Table 2-10). The distribution of vehicles by gross vehicle weight rating (GVWR) class in the City is indicated below.

Table 2-10: Domiciled and Non-Domiciled Vehicles Entering San Francisco

Federal Highway Classification						
GVWR	**Class**	**Axle**	**SF Domiciled**	**Transit (daily)**	**Total Transit & Domiciled by Class**	**Total by GVWR**
Light Duty	2	2	10,774	230	11,004	23,127
	3	2	11,196	926	12,123	
Medium Duty	4	2	6,675	552	7,227	17,100
	5	2	3,015	249	3,264	
	6	3	6,247	362	6,608	
Heavy duty	7	4	5,223	19	5,242	18,556
	8	4+	11,638	1,676	13,314	
Total			**54,768**	**4,014**	**58,782**	**58,782**

Source: Registration data provided by DMV at https://www.dmv.ca.gov/portal/dmv/detail/pubs/media_center/statistics. Accessed June 8, 2016.

Notes on methodology: "Domiciled" vehicle classifications are calculated by applying the ratio of trucks by class registered in California to the number of trucks registered in the City. "Non-domiciled" vehicles are calculated by summing daily averages of truck traffic on the three major city access points: Bay Bridge, Golden Gate Bridge, and the 101 north of the 280 cutoff, then dividing by 2. This calculation assumes the following: 1) An equivalent number of trucks enter and leave the city each day, so dividing the total truck traffic on all three entry points by two approximates the amount of non-domiciled vehicles in the city; 2) The majority of non-domiciled truck traffic enters and leaves the city on one of these three routes; 3) An unknown number of vehicles domiciled in SF leave the city on a daily basis – therefore, for purposes of analysis, we assume that number to be no more than 4 percent. 4) Note that vehicles transiting the City are categorized by number of axles, not by class. To estimate class and GVWR, the proportion of two-axle trucks by class registered in the state of California was applied to the total number of two axle non-domiciled vehicles entering SF (paralleling the calculation method for domiciled vehicles).

2.4.3.3 Future Trends in City Truck Growth

The increasing density of development in the City, as well as increasing affluence, e-commerce utilization, and consumer demand for rapid delivery are among the many factors driving increasing truck traffic in the City. However, truck traffic is not evenly distributed throughout the City. A 2011 analysis by Caltrans predicts that while traffic on 101 is expected to increase from between 33 percent and 66 percent by 2030, traffic on the Bay Bridge is expected to increase less than 10 percent (Figure 2-5). However, the level of truck traffic growth is problematic in virtually all neighborhoods and travel corridors, and underscores the urgency of a comprehensive approach to the challenge. Viable mitigation strategies include: 1) accelerating the shift to PEVs wherever feasible; 2) accelerating use of the cleanest and quietest engines and the lowest-carbon fuels in cases where electric drive options are not yet available; 3) facilitating consolidated delivery patterns; and, 4) exploring development of low-carbon zones, demand pricing, or time of use restrictions to reduce congestion, emissions, and noise. These strategies are discussed in more detail later in this Plan.

Figure 2-5: Predicted Truck Traffic Increase by Location, 2011-2040

Source: California Department of Transportation, "San Francisco Bay Area Freight Mobility Study" p. 30.

2.5 Alternative Fuel Vehicle Type Overview and Citywide Inventory

The following section provides a brief overview of Citywide deployment of each AFV type in statewide context. Environmental and economic attributes of each vehicle type are explained in further detail in subsequent chapters.

2.5.1 Plug-in Electric Vehicles

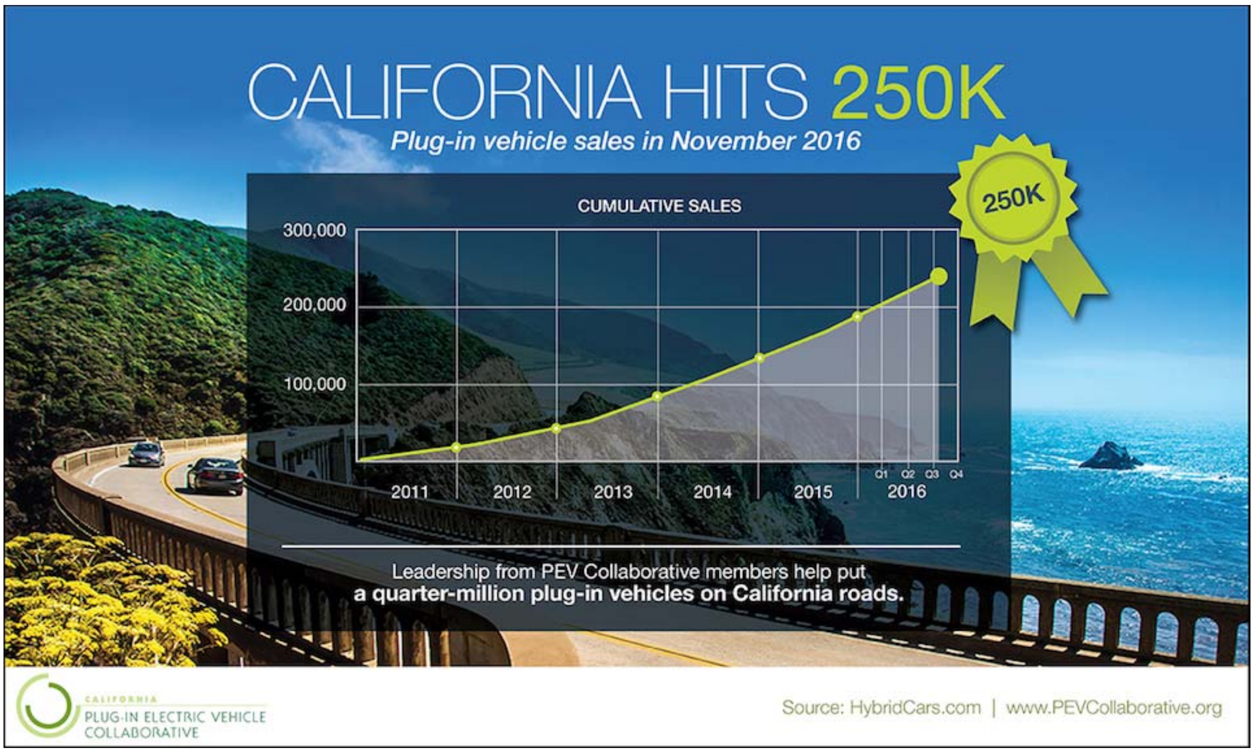
PEVs are powered exclusively or in part by electricity stored on-vehicle in a battery system. PEVs are available in two primary forms, BEVs, which exclusively utilize power from their battery system, and PHEVs, which supplement battery power with energy generated from an ICE fueled by gasoline.

While BEVs are considered by ARB to be ZEVs, the "zero emissions" label is somewhat misleading. If they are running on a typical mix of California grid power, most electric drive vehicles consume electrons fed into the grid from a range of generation sources that typically include natural gas as well as renewable energy sources. Specific GHG intensities for a given vehicle in a specific location vary considerably based on both the time of fueling and the utility providing the electricity. By fueling at night, drivers are more likely to increase the proportion of wind energy used to fuel their vehicles, and if refueling in the mid-day are likely to consume solar power. In addition, some utility programs, including San Francisco's CleanPowerSF, provide access to a 100 percent renewable energy. While electrons are "fungible" once they enter the grid, additional renewable power procurement reduces the average CI of electricity used in the grid mix.

2.5.1.1 PEVs in California

California is a driving force in PEV adoption nationally, and the Bay Area plus Los Angeles leads the state. In comparison with the nation as a whole, California adoption comprises almost half of PEV sales to date and 53 percent of PEV sales in 2016, as illustrated below.

Figure 2-6: California Share of US PEV Cumulative Sales



Source: PEV Collaborative. Accessed January 18, 2017
http://www.pevcollaborative.org/sites/all/themes/pev/files/250K%20PEVC%20Graphic_FINAL.jpg

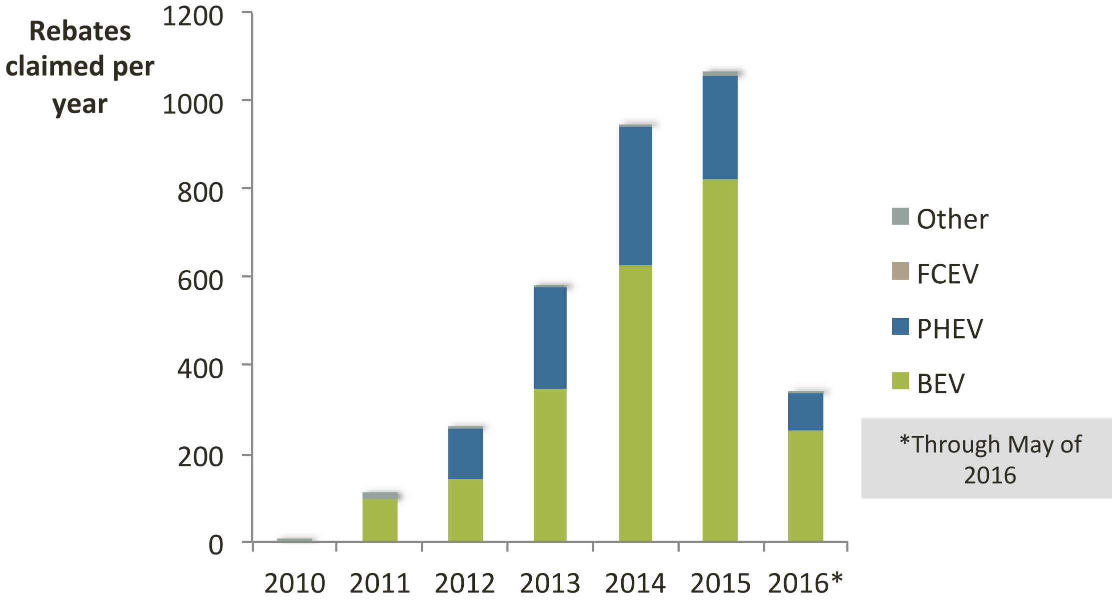
2.5.1.2 Estimated PEVs in San Francisco

The CVRP tracks vehicle owners who take advantage of rebates by county. In San Francisco, 3,408 Clean Vehicle Rebates have been redeemed for PEVs since the inception of the program through mid-2016.[16] However, CVRP rebate numbers undercount actual PEVs registered in the City for two reasons. For the first 14 months of availability, the Chevrolet Volt was ineligible for the rebate. At least 1,861 Volts were sold statewide during this period, and an unknown

[16] California Clean Vehicle Rebate Project. Available online at: https://cleanvehiclerebate.org/eng/cvrp-rebate-map

number of these were likely sold in San Francisco. Additionally, some PEV owners have been ineligible for the rebate due to income, while others have neglected to file a rebate application. For these reasons, the rebate level illustrated below has been adjusted by the recommended "participation rate" of 64 percent for San Francisco, arriving at a PEV estimate of 5,325.

Figure 2-7: Number of Clean Vehicle Rebates Claimed in SF per Year by Type



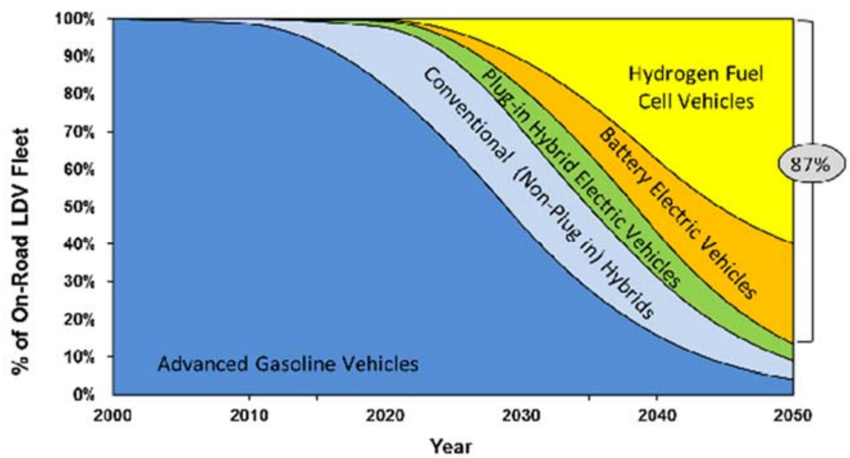
Source: Center for Sustainable Energy (2016). California Air Resources Board Clean Vehicle Rebate Project, Rebate Statistics. Data last updated May 2016. Retrieved 6/6/2016 from https://cleanvehiclerebate.org/rebate-statistic

2.5.2 Hydrogen Fuel Cell Electric Vehicles (FCEVs)

The engine of a FCEV is electric. As a result, there are zero emissions at the tailpipe. FCEVs are currently powered by either hydrogen formulated with natural gas, or hydrogen formulated using renewable sources of biomethane gas, which are extracted from landfill emissions or in other industrial contexts where the gas would otherwise be flared or vented back into the atmosphere. Hydrogen can also be created by electrolysis powered by electricity, in which case the CI of the resulting hydrogen fuel varies depending on the CI of the energy used in the electrolysis process. When compared with PEVs using grid power, FCEVs with natural gas formulated hydrogen have significantly higher CI. However, hydrogen production with renewable feedstocks can produce lower CI ratings, including negative CI valuations if powered entirely by specific formulations of biomethane.

As of June 2016, only one clean vehicle rebate for FCEVs has been claimed in the City of San Francisco. However, given the historic scale of state investment in FCEVs, policy-makers at ARB and the Energy Commission expect growing FCEV consumer uptake. Rapid refueling capability is one of the key advantages of FCEVs over PEVs. As hydrogen refueling infrastructure expands statewide and beyond, some analysts consider hydrogen to be especially promising in the medium and heavy-duty vehicle sector, although viable hydrogen trucks have been slow to appear in the marketplace. Early projections developed by ARB in 2011, in the context of the Advanced Clean Car Program, included a robust 50 percent FCEV penetration estimate for 2050. More recent ARB assessments have dialed back this projection, but ARB remains bullish on the long-term outlook for FCEVs.

Figure 2-8: Initial State Expectations for FCEV Market Growth by 2050



Source: Advanced Clean Cars: Initial Statement of Reasons, ARB December 2011

By contrast with the initial ARB outlook, more recent sales projections from auto manufacturers are relatively modest, showing FCEV sales in the single digit thousands per each FCEV model over the coming five years. Given the relatively large number of PEVs on the market today (more than 30 different models in 2016 and likely reaching over 40 by 2017), it appears that PEVs are at least five years ahead of FCEVs on the pathway to mass-market adoption. Additionally, medium and heavy-duty PEV options are expanding rapidly, while new FCEV models have been slow to emerge in all vehicle segments, in large part due to the very limited FCEV fueling infrastructure outside California.

2.5.3 Biofuels

Biofuels are fuels produced directly or indirectly from biological materials or any source of organic carbon that is renewed rapidly as part of the carbon cycle. Biofuels are distinguished from fossil fuel feedstocks in part by the age of the organic materials involved in their production. As their name indicates, fossil fuels are derived from fossilized biological sources living eons ago, while biofuels are produced from recently living organic material, including plant materials, FOG, and animal and human waste.

The State of California views increased biofuel production and use as a critical strategy for reducing carbon emissions from the transportation sector and achieving AB 32 and SB 32 goals. Plant and waste-derived biofuels are typically blended with petroleum-based gasoline or diesel to meet the state's LCFS goals, but they can also be sold as stand-alone fuels, potentially in proportions of up to 100 percent biofuel. The designation B20 biodiesel denotes a blend of 20 percent biofuel and 80 percent conventional petroleum fuel, while B80 is 80 percent biofuel based, and 20 percent conventional. B100 (100 percent biofuel) can be used in some vehicles with minimal modification, though most manufacturers do not warranty their vehicles' use with B100.

Growth in the production and utilization of biofuels is being spurred by regulations and incentive funds through a combination of federal and state incentives and mandates, including: the federal Renewable Fuel Standard, the LCFS, a federal blender's tax credit for biodiesel and renewable diesel sales, and Energy Commission grants for development of biofuel production plants. First-generation biofuels have depended primarily on food-based feedstocks such as corn and soy. Taking into account the fossil fuel inputs and CI of these crops, GHG benefits for some first-generation biofuels have been limited at best. Advanced second- and third-generation biofuels include both liquid fuels and renewable or low-carbon biogas. These advanced biofuels are sometimes called "drop-in fuels" as they utilize a wide array of urban and agricultural waste streams with very low CI values, and they can be blended (as a "blendstock") or used as stand-alone fuels with minimal or no modifications of the engines and vehicles.

The California biofuels industry is growing rapidly, especially in market demand for biodiesel and renewable diesel. However, scaling in-state production of biofuels to a meaningful proportion of conventional fuels has been challenging because of feedstock limitations on waste-based oils and greases (among fully renewable sources), as well as agricultural limitations imposed by California's long-term drought. Finally, biogas production is challenged by regulations related to the injection of biogas into existing distribution pipelines, which is needed to enable economic distribution. Despite the challenges of scaling biofuels to meet potential statewide demand, the City of San Francisco has been in the forefront of municipalities converting to renewable diesel for its entire diesel fleet, and will also be exploring the potential to convert the City's CNG fleet to RNG. As discussed further in the biofuels chapter, most of the biofuels currently sourced for use in San Francisco and the Bay Area is produced from renewable feedstocks sourced on a global basis and produced in locations in Europe, Asia, and the U.S. Midwest.

2.5.4 Natural Gas Vehicles

2.5.4.1 Natural Gas Vehicles

Natural gas derived from fossil fuels (sometimes called "fossil gas" to distinguish from RNG) can provide a superior alternative to conventional diesel fuel when considering a variety of criteria air pollutants, especially particulates. However, this fuel pathway has recently come under greater scrutiny from state regulators and research institutions. Recent studies on methane leakage rates in the fuel pathway demonstrate that "well to wheels" leakage may be much higher than previously reported (as much as 3 percent or more vs. a previously assumed 1.3 percent.) If these studies are confirmed, and leakage rates system-wide are not rapidly reduced, it may be determined that fossil-based natural gas provides no GHG emissions advantage (or even a net disadvantage) relative to diesel fuel. As a signal of the seriousness of this issue, ARB and the Energy Commission noted in their 2014 *Integrated Energy Policy Report* (IEPR) that recent methane leakage studies have:

> *"…raised questions about the potential benefits of natural gas due to uncertainties about methane leakage along the natural gas distribution and transmission pipeline systems and upstream at the production wells and gas collection systems. Many research efforts are underway to reduce uncertainties regarding how much methane is being emitted from the natural gas system and where leaks are located. Continued engagement and research support on this issue will be critical as the state continues to initiate solutions to transform its heavy-duty vehicle sector." (2014 IEPR, pp. 3-4.)*

Concerns about methane leakage and the net GHG benefit of fossil natural gas are increasing interest in RNG. RNG can be sourced from a variety of biogas feedstocks, including anaerobic digestion of FOG, dairy biogas, and landfill gas. These RNG sources can have very low or even negative CI values. When available in sufficient quantity, RNG could provide a pathway to rapidly decarbonizing heavy-duty trucking. It could also be locally produced to strengthen regional economies and to enhance energy security. Accordingly, increasing state and regional RNG production and expanding RNG distribution and consumption is one of the key strategies that will be discussed in the Natural Gas section of this Plan.

2.5.4.2 Natural Gas Vehicles in City of San Francisco Fleet

As of 2016, the City of San Francisco has a sizeable fleet of Compressed Natural Gas (CNG) vehicles: 440 in total. As shown in Table 2-11 below, the City's Enterprise Division (including the SFO, SFMTA, SFPUC, and SF Port) has the most CNG vehicles, including 245 light duty vehicles and 4 medium/heavy duty vehicles. This is followed by General Government, which has a total of 170 CNG vehicles, 162 light duty and 8 medium/heavy duty. Finally, the Safety Departments have the fewest, with a total of 20, of which 19 are light duty and one is medium/heavy duty.

Table 2-11: Number of CNG Vehicles by City and County of San Francisco Division

Department	Light Duty	Medium/ Heavy Duty	Total
Enterprise	245	4	249
General Government	162	8	170
Safety	19	1	20
Total	**427**	**13**	**440**

Source: 2016 City of San Francisco Vehicle Inventory

The medium and heavy duty CNG vehicle city fleet is small, and primarily composed of pickup trucks. As can be seen in Table 2-12, 11 out of the total 13 medium/heavy duty vehicles are trucks. The General Government division has the most vehicles.

Table 2-12: Number of CNG Medium and Heavy Duty Vehicles by City and County of San Francisco Division

Department	Buses	Trucks	Vans	Total
Enterprise		4		**4**
General Government		7	1	**8**
Safety	1			**1**
Grand Total	**1**	**11**	**1**	**13**

Source: 2016 City of San Francisco Vehicle Inventory

In contrast with the medium and heavy duty vehicles, the Enterprise division has the most light duty CNG vehicles, with 245 of a total of 427 (Table 2-13 below). Most of these are pickups (151), though General Government also has 81 cars and 48 vans. Looking at the city light duty fleets as a whole, 30 percent of light duty are cars, 43 percent are pickup trucks, and 27 percent are vans. Notably, the Safety Division's small fleet of 19 vehicles is composed entirely of cars and vans.

Table 2-13: Number of CNG Light Duty Vehicles by City and County of San Francisco Division

Department	Cars	Pickups	Vans	Total
Enterprise	32	151	62	245
General Government	81	33	48	162
Safety	15		4	19
Grand Total	**130***	**184**	**114**	**427**

Source: 2016 City of San Francisco Vehicle Inventory, *Including one vehicle in the "Other" category.

2.5.5 AFV Fueling Infrastructure

The table below provides an overview of the existing fueling infrastructure for different AFV types. More details will be provided in subsequent chapters.

Table 2-14: State and Local AFV and Public Infrastructure: Cumulative 2010 – 2016

Domain	Fuel Type	California 2010	California 2016	San Francisco 2016
AFV Infra-structure	EV Charging	~2,523 charge stations	3,082 Level 2 stations 435 DC fast charge stations	150 Level 2 8 DC fast charge stations
	Biofuel: E85	45 fueling stations	117 fueling stations	1 station
	Natural Gas	213 fueling stations	363 stations	5 stations
	Renewable Diesel	N/A	3 stations	1 station
	Hydrogen	7 fueling stations	33 fueling stations	2 fueling stations proposed
Alternative Fuel Vehicles	Electric Vehicles	75	211,328	5,325
	Natural Gas Vehicles	~9,995 light duty ~10,892 medium/ heavy duty	~13,872 light duty ~15,115 medium/ heavy duty	466+ light duty 40+ medium/ heavy duty
	FCEVs	~8	232	1

Source: US Department of Energy, Alternative Fuels Data Center; Accessed September 6, 2016 at http://www.afdc.energy.gov/data_download

Infrastructure analysis notes: Charging station data sourced from U.S. DOE Alternative Fuels Data Center. Accessed June 20, 2016 at http://www.afdc.energy.gov/data_download/. Vehicle notes: PEV and FCEV data is triangulated from the Clean Vehicle Rebate Project and adjusted by the percentage guidelines for participation rates to compensate for undercounting from early Chevrolet Volt ineligibility and for vehicle purchases for which rebates were not claimed. Accessed September 6, 2016 at https://cleanvehiclerebate.org/eng; participation rates accessed September 6, 2016 at https://cleanvehiclerebate.org/sites/default/files/docs/nav/transportation/cvrp/survey-results/2015-10%20CVRP%20Participation.pdf.

2010 and 2016 natural gas vehicle data adjusted from a 2013 CA inventory (p. 15 at http://www.energy.ca.gov/2015publications/CEC-500-2015-091/CEC-500-2015-091-D.pdf) using averaged 2012-2016 CNG vehicle stock growth rate of 5.6 percent from the US Energy Information Administration. Available online at http://www.eia.gov/forecasts/aeo/data/browser/#/?id=49-AEO2015&cases=ref2015&sourcekey=0.

San Francisco natural gas vehicle counts are calculated from comprehensive city inventory and major private regional fleets listed in the proprietary FleetSeek database. The list of private fleets is not exhaustive, and vehicle counts should be considered a minimum. Schroeder, Alex. Statewide natural gas vehicle counts sourced from "2015 Natural Gas Vehicle Roadmap (DRAFT)". Prepared for the California Energy Commission by National Renewable Energy Laboratory; July 2015. Accessed June 23, 2016 at http://www.energy.ca.gov/2015publications/CEC-500-2015-091/CEC-500-2015-091-D.pdf.

2.6 AFV Environmental Impacts and Market Trends

2.6.1 Emissions Comparison of AFV Types

The need to reduce GHG emissions is a key policy driver for the transition from fossil-fueled vehicles to AFVs. As such, reliable data on the relative emissions impacts of different fuel and vehicle types is essential. To comprehensively assess the impact of AFVs, both the fuel type and the vehicle model are relevant. The impact of each fuel pathway is assessed via a "source to tank" measure, which assesses all the energy inputs into the fuel from production to the point of delivery to the vehicle. Vehicle-specific efficiency is assessed via measurement of the efficiency of converting the fuel into motive power, known as the "tank to wheels" measure. Together, these two measurements determine the comprehensive "source to wheels" impact. For fossil fuels, this measurement is often referred to as "well to wheels."

Assessment of the GHG impact of a fuel production pathway is expressed in terms of the CI of gasoline and diesel fuel and their substitutes, with a standard value for conventionally produced gasoline used as a reference baseline. Although GHG emissions from the use of fuels are primarily in the form of CO_2, other GHG emissions associated with the complete life cycle of fuels can also include methane, oxides of nitrogen (N_2O), and other GHG contributors. To provide a true "apples to apples" measure across all fuel types, the overall GHG contribution from all steps of the fuel production life cycle— including production, transport, and use—is divided by the fuel's energy content (in megajoules). Thus, CI is expressed in terms of grams of CO_2 equivalent per megajoule (gCO_2e/MJ). This LCA includes direct emissions associated with producing, transporting, and using the fuels, as well as significant indirect effects on GHG emissions, such as potential changes in land use to enable the production of biofuel crops.

Using the comprehensive life-cycle approach to CI on a source-to-wheels basis, it is possible to compare all alternative fuels to standard gasoline and diesel fuel. In the following charts, the CI of the most prevalent alternative fuels is highlighted in comparison to conventional gasoline and diesel. In the fuel-specific chapters that follow, additional detail will be provided about the many varieties of alternative fuel inputs or feedstocks, each with their own carbon profile and scalability. Currently, the largest and most rapidly scalable reductions in GHGs and fossil fuel use in the transportation sector are enabled by reliance on very low carbon renewable electricity to power BEVs or PHEVs. Due to superior efficiency in translating energy into motive power, PEVs are considered more energy efficient and thus environmentally superior to hydrogen produced with electricity of the same CI.

CI values for RNG depend on the specific source of the waste gas. Depending on feedstock characteristics, CI values for RNG can range from very low (e.g. a CI value of 11 as assigned by ARB) or can be assessed as a "negative" value. With 100 (or nearly 100) as the value typically assigned to gasoline as the reference standard, a value of 11 represents just 11 percent of the CI (in gCO2e/MJ) relative to gasoline. A negative CI value indicates that fewer GHG are emitted due to the combustion of the biogas in a vehicle than if the biogas was vented directly into the atmosphere (or flared as waste heat). Accordingly, there is significant environmental benefit in harvesting waste biogas that is otherwise being produced by processes inherent to activity in other sectors of the economy, such as dairy farming, as well as anaerobic digestion of waste FOG from restaurants, homes, and commercial establishments. The complex fuel supply chains and production processes associated with each of these alternatives will be further assessed in this Plan, as they have significant implications for the City of San Francisco's strategy for decarbonized transportation.

In the charts below, CI values are provided across a range of alternative fuel feedstocks. For comparative purposes, this chart reflects the CI of the current PG&E grid mix. Superior environmental results are obtained for City-owned fleet vehicles because of the 100 percent renewable electricity supply available in San Francisco through both the SFPUC Hetch Hetchy power supply to City government accounts, as well as CleanPowerSF's 100% renewable "SuperGreen" product. Solar panels configured for direct linkage to car charging on homes or commercial buildings could also alter the CI for electricity used to power PEVs, depending on the percentage of electrons that are 100% renewably sourced in a particular car charging location.

The landfill biogas assessed in this chart is indicated to have a very low (but still positive) CI value, whereas other biogas feedstocks have been rated as having a negative value, depending on specific biogas sources.

Table 2-15: Full Fuel Cycle Comparison of Alternative Fuels to Standard Gasoline

Fuel / Feedstock	Carbon Intensity (gCO2e/MJ)	CO2e Reduction from Gasoline
Gasoline, conventional	***95.86***	***N/A***
Ethanol, conventional CA average	95.66	0
Ethanol, CA corn	80.70; decreasing to 70.70 in 2016	16% to 26%
Ethanol, Low CI Corn	73.21	24%
Ethanol, Sugarcane	73.40; decreasing to 67.38 by 2020	23% to 30%
Renewable Gasoline	25.00[a]	74%
LNG	83.13	13%
CNG	67.70 [b]	29%
Biogas, landfill	11.56	88%
Electricity, marginal [c]	30.80; decreasing to 26.32 by 2020	68%
Hydrogen [d]	39.42	59%

Source: ARB LCFS lookup table and CCR sections 95480-95490. [a] Estimated carbon intensity based on stakeholder consultation, as noted in *California's Low Carbon Fuel Standard: Compliance Outlook for 2020,* June 2013, ICF International. pp. 11-12. [b]North American NG delivered via pipeline; liquefied in CA using liquefaction with 80percent efficiency. [c]Includes the energy economy ratio (EER) of 3.4 for electric vehicles. [d]Includes the EER of 2.5 for Fuel Cell Electric Vehicles.

Table 2-16: Full Fuel Cycle Comparison of Alternative Fuels to Standard Diesel

Carbon Intensity Values for Fuels that Substitute for Diesel		
Fuel / Feedstock	**Carbon Intensity (gCO2e/MJ)**	**CO2e Reduction from Diesel**
Diesel, conventional	94.71	N/A
Biodiesel – waste oil conversion	15.84	83%
Biodiesel – Midwest soybeans	83.25	12%
Renewable Diesel – average scenario[a]	29.49	69%
CNG	67.70 [b]	29%
LNG	83.13	12%
Electricity, marginal [c]	30.80	67%
Hydrogen [d]	39.42	58%

Source: ARB LCFS lookup table and CCR sections 95480-95490. [a]Based on conversion of tallow, average of high energy and low energy scenario. [b]North American NG delivered via pipeline; liquefied in CA using liquefaction with 80 percent efficiency. [c]Includes the energy economy ratio (EER) of 3.4 for electric vehicles. [d]Includes the EER of 2.5 for FCEVs.

As summarized above, BEV emissions are estimated by ARB to be nearly 75 percent lower than the average conventional gasoline-powered vehicle, and 55 percent lower than the average conventional hybrid vehicle. Plug-in Hybrid Electric (PHEV) emissions (in the case of PHEVs with a 20-mile all-electric range) reduce GHGs by 60 percent compared to a conventional vehicle, and 30 percent compared to a conventional hybrid.[17] PHEVs with longer all-electric range (AER), such as the Chevy Volt with 40+ miles of AER, can be expected to have relatively superior emissions performance, assuming a greater percentage of all-electric vehicle miles actually travelled. As noted above, the PEV emissions advantage will increase over time due to progressively cleaner electrons available on the grid and at home and commercial charging sites, and larger batteries enabling greater substitution of fossil-fueled miles by electrically powered miles on PHEVs. By 2020, California's grid is expected to produce 40 percent lower emissions than the grid in 2008, because of increased renewable generation. Grid power carbon emissions are expected to be reduced from the 2009 average of 447 grams/CO2 per kWh to 261 grams/C02 per kWh by 2020.[18]

2.6.2 Long Term Adoption Trends

2.6.2.1 Long Term Adoption Trends

Long-term adoption trends for AFVs are difficult to predict, as they involve multiple variables, including the pace of future technology developments, macroeconomic conditions, relative fuel prices, state and federal incentives and regulations, fueling infrastructure investment, and

[17] *Taking Charge: Establishing California Leadership in the Plug-in Electric Vehicle Marketplace;* The California Plug-in Electric Vehicle Collaborative, December 2010, p. 17.

[18] Ibid, p. 17.

consumer preference. Within the AFV spectrum, PEVs have been in the marketplace for more than five years, and many manufacturers have announced future vehicle and battery plans, making it easier to develop predictions for PEVs relative to FCEVs and bio-fueled vehicles.

According to the United States Department of Energy (U.S. DOE) and leading manufacturers, battery technology and cost breakthroughs will enable multiple OEMs to produce 200-mile range vehicles by 2020 priced in the low to mid $30,000 range after incentives.[19] This projection has been verified by recent announcements by Tesla (for their late 2017 Model 3) and General Motors (for their late 2016 Bolt), both expected to be priced in the mid-$30,000 range with over 200 miles of all-electric range. With nearly 400,000 pre-orders for the Model 3 alone, these models and others in this price/performance band are likely to make a material difference in overall PEV market penetration in the 2017-2020 timeframe, setting the stage for further economies of production and lower prices in the early 2020s.

Across the industry, the U.S. DOE expects price parity of conventional ICE vehicles and PEVs by the early 2020s. Price parity as set by the OEMs could make PEVs even less expensive than ICEs if state and federal incentives continue. Further, expected improvements in battery performance (weight to energy ratios and kWh/$) are likely to make 350-mile range batteries relatively commonplace at the high end of the market, at prices comparable to today's shorter range batteries. Some OEMs, including Porsche and Audi, have announced 300-380 mile range vehicles for delivery around 2020. Further, if gas prices resume their historic climb back to $4.00/gallon and beyond, the cost differential in fueling PEVs vs. ICEs will again become prominent in buying considerations. PEVs can typically be fueled today for approximately $1 per gasoline gallon equivalent (GGE), or less than a third of the current operating cost of equivalent ICE vehicles. This cost advantage may help PEVs to maintain an ongoing edge over FCEVs and other AFVs despite the fueling time advantage of liquid and gaseous fuels.

Finally, the time-to-fill advantage of liquid and gaseous fuels may erode by the early 2020s as super-fast electric fueling becomes more widespread. Currently, Tesla provides the fastest electric vehicle charging, with a charge output rate of 145 kW—or 450 Volts at 335 Amps. The company's vehicles can receive the electrons at a rate of up to 120 kW, or about twice the power output of all other electric cars currently available. This enables an 80 percent recharge of a typical Tesla 85 kW battery in approximately 35 minutes. However, Porsche, in partnership with Audi and VW, have announced a system about twice as fast, which would enable an 80 percent recharge in just 15 minutes for their line of electric vehicles due around 2020. Research is also ongoing on even faster charger technologies likely to make their way into the market by 2025, with a goal of five-minute recharge times.[20] Currently, some E-bus manufacturers (including Bay Area based Proterra) have deployed such super-fast chargers, proving that the

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[19] *How Affordable 200-mile Electric Cars Change the Fleet Equation.* Fleetcarma, June 2016. Accessed October 17, 2016 at: http://www.fleetcarma.com/affordable-200-mile-electric-cars-change-fleet-equation/

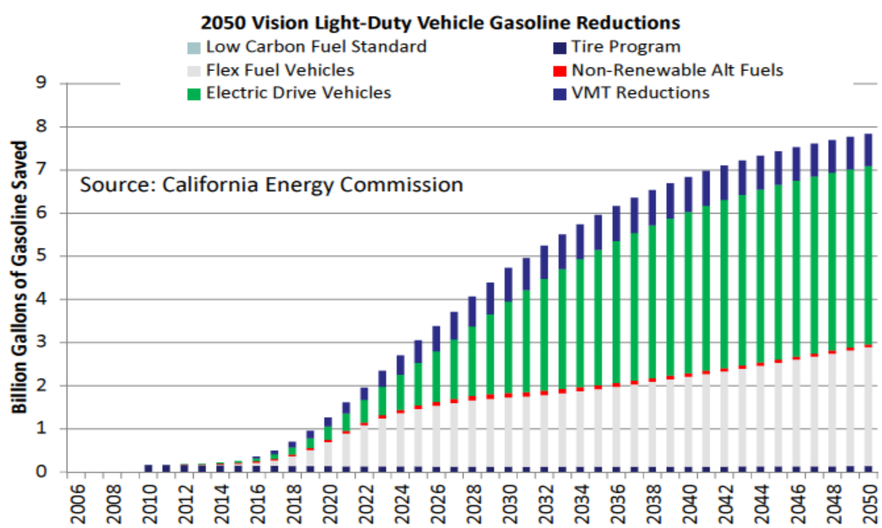
[20] Frederic Lambert, "Porsche's Ultra Fast Charging Network for the Mission E Will Also Work With Tesla," *Electrek,* September 2016, available online at*:* https://electrek.co/2016/10/03/porsches-ultra-fast-charging-infrastructure-for-the-mission-e-will-also-work-with-tesla-says-ceo/

technology can work. The key to these technologies for light-duty use will be cost reduction through streamlined designs, economies of scale, and the provision of appropriate power supplies in public locations.

2.6.2.2 State Expectations for AFV Market Growth

In their *2050 Alternative Fuels Vision,* ARB and the Energy Commission illustrated one strategic pathway to achieve the 80% GHG reductions required by AB 32, illustrating that the preponderance of savings are projected to come from electric drive vehicles. Figure 2-9 does not distinguish between FCEVs and PEVs, but shows the important contribution (nearly 40 percent of planned GHG reductions) that is expected to come from a dramatic increase in biofuels utilized by flex-fueled vehicles. Both biofuels and electric drive will have dominant roles in the fuel mix in California's future, as fossil fuels for use in transportation must be nearly entirely replaced by mid-century to meet AB 32 mandates.

Figure 2-9: ARB 2050 Vision Light Duty Vehicle Gasoline Reductions



Source: Data from *State Alternative Fuels Plan,* December 2007. California Energy Commission, accessed June 2016 at : http://www.energy.ca.gov/2007publications/CEC-600-2007-011/CEC-600-2007-011-CMF.PDF

On a statewide basis, it is noteworthy that reduction in VMT, while viewed as a highly desirable policy goal for a variety of reasons, is not anticipated to save much fuel even after the full implementation of SB 375 "smart growth" and transportation demand management reforms. With its already high density and strong transit services, San Francisco proposes to achieve much deeper VMT reductions locally, per the Climate Action and transportation policy mandates reviewed in earlier.

State-level policy action relative to PEV incentives, biofuel production, and AFV infrastructure will likely have the strongest impacts on consumer uptake of AFVs. However, local action by the City and regional stakeholders can have a powerful impact on AFV uptake and modal choice, as referenced above. The strongest local impact on increased AFV use will likely be produced from further expansion of public charging and fueling infrastructure, including expanding access to

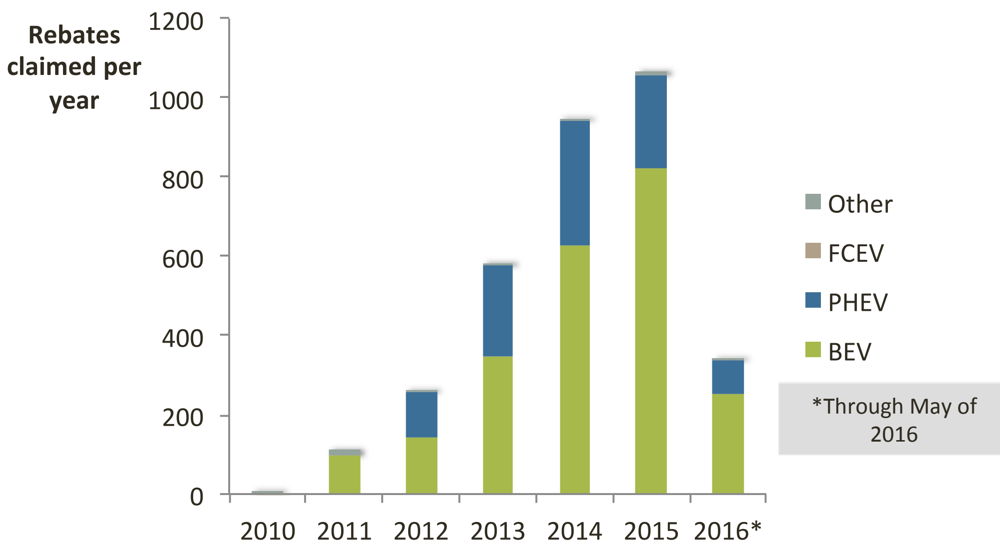
100 percent renewable electricity and very low carbon biofuel supplies (e.g., biogas from landfills for CNG vehicles and renewable diesel for trucks). Another key leverage point will be potential establishment of congestion pricing mechanisms or zero emissions zones that advantage the movement of clean vehicles relative to other vehicles, and encourage modal shift from private cars to other transportation choices, including walking, biking, shared vehicles, and transit. Only with a comprehensive effort addressing all facets of transportation planning will the City and County of San Francisco and California accomplish its emissions reduction goals.

CHAPTER 3: Plug-in Electric Vehicles and Infrastructure

PEVs powered by renewable electricity have high potential to make a significant impact on the City of San Francisco's emissions goals. To realize that potential, this chapter of the AFV Readiness Plan will present policy options and funding opportunities that can further support PEV uptake.

To date, San Francisco residents have strongly embraced PEV ownership, with sales in the City outpacing that of the state as a whole. As noted in Chapter 2, residents of the City are estimated to have purchased more than 5,000 PEVs as of June 2016, with an approximate split of 70 percent BEVs to 30 percent PHEVs, as shown below:

Figure 3-1: Number of Clean Vehicle Rebates Claimed in SF Per Year by Type[21]



Source: Clean Fuel Vehicle Rebate Program website, Center for Sustainable Energy, Accessed June 2016.

However, overall state and national PEV adoption has been slower than many original market forecasts, and there is clearly room for accelerated uptake in San Francisco as well. Surveys indicate that key barriers to higher adoption have been primarily: 1) high initial purchase prices, especially of the more desirable longer range models; 2) persistent range anxiety, especially for drivers of first-generation BEVs with all-electric ranges of 100 miles or less; 3) high costs and "hassle factor" in the deployment of residential charging infrastructure, especially for renters and residents of MUDs; 4) limited availability and consistency in public charging infrastructure deployment, especially fast charging on inter-city corridors and particularly for non-Tesla

[21] Center for Sustainable Energy (2016). California Air Resources Board Clean Vehicle Rebate Project, Rebate Statistics. Data last updated [last update date shown in spreadsheet]. Retrieved 6/6/2016 from https://cleanvehiclerebate.org/rebate-statistic

owners. Finally, deployment of electric buses and electric trucks has been slow because of a combination of high upfront cost and modest product availability during the early market development period of 2009-2015.

Fortunately, many of these key barriers are coming down rapidly, such that PEV uptake in the City, the region, and the state is poised for a dramatic increase in the 2017-2020 period and beyond. Currently, the outlook for PEV product innovation and price/performance improvement is stronger than ever before, with virtually all major OEMs planning to introduce compelling products in the 2017-2020 period. This new generation of PEVs will bring higher all-electric range to the mainstream market, along with increasingly rapid charging rates and expanding public charging infrastructure. Continuing state and private investments in the PEV ecosystem are also paying dividends in the form of new inter-city charging corridors that enable fast charging in both of the current fast charging standards. Further, California investor-owned utility investments of nearly $1 billion in charging infrastructure are expected to come online in 2017, along with $850 million dollars in settlement funds from the VW fraud case. Together, these investment streams are likely to result in a substantial increase in the availability of both public charging and charging in MUDs.

To reinforce these positive underlying trends, Section 3.7 of this Chapter includes a series of Recommended Actions proposed for consideration by City stakeholders with potential to further advantage PEVs relative to fossil-fueled vehicles, boost the deployment of public and residential charging, and position the City of San Francisco and the Bay Area as a showcase of electrified transportation that will attract substantial new investments to further accelerate PEV adoption and use.

3.1 PEV Adoption Trends

3.1.1 Total Cost of Ownership for PEVs vs. Conventional Vehicles

In the light-duty segment, the total cost of ownership (TCO) for BEVs can be significantly less than either ICE or PHEV alternatives. However, if vehicles are purchased new at prices close to their manufacturer's suggested retail price, then annual VMT must be high enough to rapidly amortize the higher up-front investment. According to analyses by PEV rental fleet operators such as EverCar, the break-even point for TCO advantage on new PEVs is reached when BEVs are used for at least 12,000 miles a year, and the operating cost advantage becomes highly compelling at 20,000 miles per year or more. For drivers or fleet operators willing to buy on the used market, the break-even point can be achieved at much lower mileage levels.

The reason why BEVs can excel in reducing TCO relative to ICE vehicles is that BEV fuel costs can be as low as 10% to 20% of ICEs (depending on the gas/electricity price differential). Further, BEVs have fewer parts than ICEs, and maintenance costs are much lower. For example, BEV exhaust systems are non-existent, cooling systems greatly simplified, and complex clutches and transmissions replaced with streamlined units. Although PHEVs can share with BEVs some of the cost advantage of fueling by electricity, depending on the proportion of miles driven in all-electric mode, their operating complexity is at least equivalent to conventional hybrids and thus maintenance costs are likely to be similar.

The table below assesses the relative operating cost differential between a typical BEV and an ICE vehicle in a small sedan format, with a Nissan Leaf as the comparison vehicle. Note that in this example, six years and 18,000 miles per year is the identified usage pattern, and over the six-year hypothetical use period, average fuel costs of $3.50 per gallon and off-peak electricity rates of .056/kWh are used for comparative purposes. Of course, the example provided below can only be illustrative of one particular scenario for fleet replacement. Different results will be obtained with different projections for mileage, fuel and energy costs, and residual values, as well as different purchase prices. Since all buying decisions are highly context dependent, use of fleet cost calculators, such as those available through the DOE's Clean Cities website, is highly recommended to assess other options for AFV fleet procurement and operations (see http://www.afdc.energy.gov/tools for calculator options).

Table 3-1: Operating Cost Comparison of ICE vs. BEV

	Internal Combustion (ICE)	**Battery Electric Vehicle (BEV)**	**Battery Electric Vehicle (BEV)**
Operating Cost Comparison ICE vs. BEV	TYPE: 5 passenger RANGE: 400 mi. with 16 Gallon tank GASOLINE: $3.50 Gallon FUEL COST/TANK: $56.00/ 400 m	TYPE: Nissan LEAF ~ 1kWh = 4 mi. driving distance RANGE: 96 mi. w/ 24kWh battery ELECTRICITY: $0.056 / kWh (off-peak PG&E summer rate with "E9B" Plan)	TERM: 6 Yrs. USAGE: 18,000 mi. / Year TOTAL Mileage: 108,000
Fuel	**Gasoline (ICE)**	**Electric (BEV)**	**Fuel Cost Savings**
Cost (per mile)	**$0.140** Avg. 25 miles per gallon – reg. gas Cost per mi.: $56/400 miles = 14 cents/mile	**$0.014** Electricity cost of 5.6 cents per kWh. 1kWh = 4 Mi. of driving distance = 1.4 cents per mile	**10x less**
Lifetime Costs (6 yrs./108k miles)	$15,120	$1,512	**$13,608 savings in 6 Yrs.**

	Internal Combustion (ICE)	Battery Electric Vehicle (BEV)	Battery Electric Vehicle (BEV)
Maintenance	**Gasoline (ICE)**	**Electric (BEV)**	**Maintenance Savings**
Est. routine service and engine wear Lifetime Costs (6	~$6,000	~$2,000	**$4,000 savings in 6 Yrs.**
Ownership	**Gasoline (ICE)**	**Electric (BEV)**	**Ownership Savings**
Est. Insurance (6 Yrs./108K mi.)	~$6,000	~$5,000	**$1,000 savings in 6 Yrs.**
Est. DMV Smog (6 Yrs. /108K mi.)	~$400	~$0	**$400 savings in 6 Yrs.**
TOTALS	**~$27,520**	**~$8,512**	**~$19,008/6 Yrs.**

Source: *Electrifying Your Business.* Business Council on Climate Change and Bay Area Council. Accessed October 10, 2016 at http://www.bc3sfbay.org/uploads/5/3/3/9/5339154/electrify_your_business.pdf.

Note that the example in the table above projects a somewhat more PEV-favorable ratio of fossil fuel to electric pricing than exists in 2016, with the result that the BEV operating cost advantage is projected at $19,008 over six years, given annual mileage of 18,000/year. In this example, operating cost savings for BEVs can be achieved despite a $15,000 or greater price differential between a light-duty BEV and the equivalent ICE vehicle. However, it is important to keep in mind that initial costs for charging infrastructure must also be factored into the initial purchase price of PEVs by consumers and fleet managers. For fleet managers, there may be grant funds available to support charging infrastructure investment, and some charging infrastructure providers offer favorable financing agreements to reduce or eliminate up-front capital expenditures.

As always, interest rates and leasing terms matter greatly in the fleet cost/value matrix. The example above does not address net present value issues given potentially higher up-front costs for PEVs, but online calculators can enable this function. Fleets may find that their usual ratio of operating versus capital budgets may also need to be adjusted to consider higher up-front costs and lower operating costs as they transition to a predominantly electric fleet.

To navigate this complex terrain, it is recommended that fleet managers consult their local Clean Cities Coalition, which can help provide access to information resources and fleet managers with experience making the EV transition. (See https://cleancities.energy.gov/coalitions/san-francisco for more information on City specific resources.)

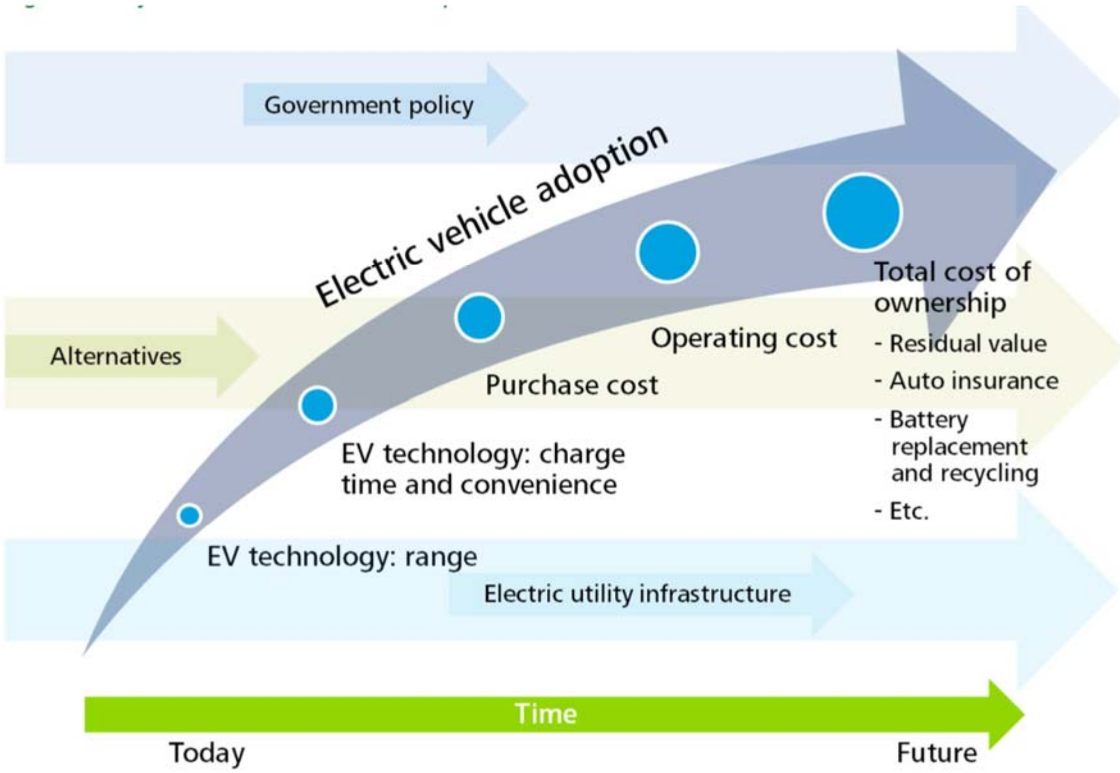
3.1.2 Outlook for PEV Product Diversity and Price/Performance

Although initial purchase prices of PEVs remain a primary concern for consumers, trend lines are positive. At their market launch in 2009-2010, “entry-level” PEVs initially carried Manufacturers Suggested Retail Price ranging from $29,000 to $40,000. Price adjustments in subsequent years have lowered prices, so that 2017 “entry-level” PEVs have reached just $23,000 for a Mitsubishi i-Miev, $29,000 for a Nissan Leaf, and $33,000 for a Chevy Volt PHEV. Federal and state tax credits are generally available to further reduce these costs by up to $7,500, complemented by an additional rebate of $1,500 to $5,000 for the CVRP. Further, regionally specific incentives, such as those available to public fleet buyers in the Bay Area (via BAAQMD), can reduce prices for vehicles like the Nissan Leaf to as low as $15,000.

For those fleet or individual buyers who may not have the tax liability to take all of the available tax credit, a lease arrangement can enable the application of rebates to the lease transaction. Excellent values are also available on the used vehicle market. For example, three-year-old Nissan Leafs with relatively low mileage and ~65 mile electric range can be purchased for well under $10,000.

Consumer acceptance of BEVs appears to be closely correlated to both range and price, as illustrated in the graphic below from a 2011 study of PEV consumer attitudes by Deloitte and Touche. Although PEVs already lead on operating cost, TCO is a complex calculation that is challenging to perform accurately for many consumers given uncertainties about PEV residual values, battery replacement requirements, and future trends in fuel pricing. Therefore, consumers tend to be far more influenced by up-front purchase price despite the substantial operating cost advantage of PEVs.

Figure 3-2: Factors Influencing PEV Purchases



Source: Deloitte Global Consumer Auto Survey, 2011, p. 21. Accessed September 5, 2016 at: https://www2.deloitte.com/us/en/pages/manufacturing/articles/unplugged-electric-vehicle-realities-vesrus-consumer-expectations.html

Despite early challenges to PEV adoption, as consumers determine that PEV prices, range, and style are within their "sweet spot," the results are dramatic. Within a few weeks of the debut of the 2017 Tesla Model 3, retailing for a base price of approximately $35,000 with 220+ miles of all-electric range, nearly 400,000 consumers responded with advance deposits. Automotive industry analysts took note of this watershed event, with many declaring that the era of mass adoption of PEVs is upon us. The late 2016 debut of the Chevy Bolt, winner of the 2016 Motor Trend Car of the Year award, will provide another key benchmark for consumer embrace of longer-range, mid-priced BEVs. Another key marker in the maturation of the PEV market is the plethora of new PEV models that have been announced by automakers between 2017 and 2020, including new models in key categories such as SUVs, cross-overs, and minivans, as well as economy and luxury sedans in both BEV and PHEV configurations. (Plug-in America's PEV tracking website provides an overview of the many new products in the pipeline, at http://www.pluginamerica.org/vehicles.)

Prices of new vehicles are expected to continue to decline. The DOE projects price-parity on initial purchase with ICE vehicles by 2022. This projection assumes that battery prices will drop from the current range of approximately $200-$350 per kWh of capacity to approximately $100-150/kWh or even less. Ongoing advances in lightweight design, power electronics, and other inputs are expected to increase efficiency, performance, and range, further driving PEV uptake among consumers and fleets.

3.2 PEV Charging Infrastructure

PEVs are powered entirely by electricity in the case of BEVs, and by a combination of electricity and fossil-based gasoline in the case of PHEVs. The equipment that delivers electricity from the grid or generation source to the vehicle is known in the industry as electric vehicle supply equipment (EVSE) or electric vehicle charging stations. A wide array of EVSE exists and can supply electricity at different voltages and currents, depending on use case. Three predominant categories of EVSE exist, known as Level 1, Level 2, and Direct Current Fast Charge (DCFC), sometimes also called Level 3.

Table 3-2: Categories of EVSE

Type	Voltage	Common Use Case	Standard
Level 1	120V AC (common household plug)	Home charging	SAE J1772
Level 2	240V AC (requiring 40Amp circuit)	Home or workplace charging	SAE J1772
Level 3/ DC Fast Charging	480V Direct Current	En-route charging	SAE J1772 Combined Charging System
			CHAdeMo
			Tesla Supercharger

Source: *Developing Infrastructure to Charge Plug-In Electric Vehicles*. Alternative Fuels Data Center. Accessed October 4, 2016 at http://www.afdc.energy.gov/fuels/electricity_infrastructure.html.

To avoid confusion, it is important to clarify the terminology used to define PEV charging infrastructure. A “charge point” or “charge port” is defined as a single charging connector that connects to just one vehicle. A “charging station” is defined as a charging device, wall mounted or on a pedestal, that typically has one or two (or potentially more) individual charging ports. Stations with more than one charging port can charge multiple vehicles concurrently. Thus, it is more accurate to use the term “charge point” or “port” rather than “charging station” to define the total capacity of a network. To identify charging station sites that function more like traditional gasoline stations, with multiple pedestals and charge ports, the term “charging plaza” is sometimes used.

3.2.1 Comparing Charging Rates

To provide a simplified method of comparing charging rates across vehicles and chargers, it is helpful to use the metric of “range per hour of charging” (RPH), which designates the distance a PEV can travel for each hour it is charging. Level 1 chargers typically provide RPH of 3 - 5 miles, Level 2 stations can provide RPH of approximately 25 miles, while DCFC stations with 24kW charge rates can provide about100 miles of RPH, and 50kW DCFC charging stations provide about 200 miles of RPH, and 100-120kW stations provide about 300 miles RPH.

While RPH provides a guideline, the exact amount of range a charging station can deliver per hour depends on a number of factors, including the power capacity of the car's on-board charger, the state of charge of the vehicle when it begins charging, the temperature of the battery, and the efficiency of a particular vehicle in translating electricity into motive power.

From a policy perspective, deployment of charging infrastructure involves significant tradeoffs between cost and charging speed. DCFC equipment costs much more than the slower Level 2 systems, as noted in the chart below. Further, costs are highly variable based on local site conditions, and average costs are only meaningful across a large sample size. Local costs at a specific site can easily vary by as much as 300 percent depending on distance to the power supply, need for trenching, electrical capacity upgrade requirements, labor costs, and other factors.

Table 3-3: Charging Station Types, Rates and Installation Costs

<table>
<tr><th rowspan="2">Charger Type</th><th rowspan="2">Charge</th><th colspan="3">Time to Charge Vehicles at Various States of Charge</th><th rowspan="2">Charger Hardware Costs[1]</th><th rowspan="2">Installation Costs[2]</th><th rowspan="2">Typical Range of Total Costs</th><th rowspan="2">Average Total Costs</th></tr>
<tr><th>Volt 16 kWh</th><th>Leaf 24 kWh</th><th>Tesla 60 kWh</th></tr>
<tr><td rowspan="2">Level 1 1.4 kW 120V</td><td>Half</td><td>6 hrs</td><td>8.5 hrs</td><td>19 hrs</td><td rowspan="2">$300 - $500</td><td rowspan="2">$300 - $500</td><td rowspan="2">$600 – $1000</td><td rowspan="2">$900</td></tr>
<tr><td>Full</td><td>11 hrs</td><td>17 hrs</td><td>38 hrs</td></tr>
<tr><td rowspan="2">Level 2 7.5 kW 240V</td><td>Half</td><td>1 hrs</td><td>1.5 hrs</td><td>3.5 hrs</td><td rowspan="2">$500 - $1500 home
$2000 – $6000 commercial</td><td rowspan="2">$500 - $2500/home
$3,000 – $5,000 commercial</td><td rowspan="2">$1500 – $4,000/home
$4,000 - $11,000 commercial</td><td rowspan="2">$2200/ home
$8000/ commercial</td></tr>
<tr><td>Full</td><td>2 hrs</td><td>3 hrs</td><td>7 hrs</td></tr>
<tr><td rowspan="2">DC Fast 50 kW 480V</td><td>Half</td><td>10 min</td><td>15 min</td><td>35 min</td><td rowspan="4">$25,000 $55,000</td><td rowspan="4">$15,000 - $30,000</td><td rowspan="4">$40,000 $85,000</td><td rowspan="4">$65,000</td></tr>
<tr><td>Full</td><td>20 min</td><td>30 min</td><td>70 min</td></tr>
<tr><td rowspan="2">DC Fast 150 kW 480 volts</td><td>Half</td><td>5 min</td><td>8 min</td><td>17 min</td></tr>
<tr><td>Full</td><td>10 min</td><td>16 min</td><td>35 min</td></tr>
</table>

Source: *Ready Set Charge Fleets*. Bay Area Climate Collaborative, Metropolitan Transportation Commission Alameda, and the County General Services Agency, May 2015; EV Alliance analysis.

Note: The approximate all-electric range associated with the first generation of these vehicles is: Chevy Volt ~40 mi.; Nissan Leaf ~70 miles; Tesla Model S 60 ~230 miles.

[1]Hardware costs are trending downward quickly

[2]For hard-to serve installations, costs can vary upwards to double or triple the indicated amounts1 Higher-cost units have multi-car capabilities

3.2.2 Matching PEV Charging Types to User Needs

PEV drivers have diverse needs that require diverse charging solutions. In the home context, many PEV owners (especially PHEV drivers with smaller capacity batteries) find Level 1 charging to be adequate, while workplace and fleet charging may require Level 2 equipment to facilitate charging of several vehicles during the work day. Inter-regional charging and on-route charging of commercial vehicles is best facilitated by DCFC, with higher-rate 100-150 kW equipment the preferred choice to keep up with steadily increasing battery size and charging speeds enabled by manufacturers.

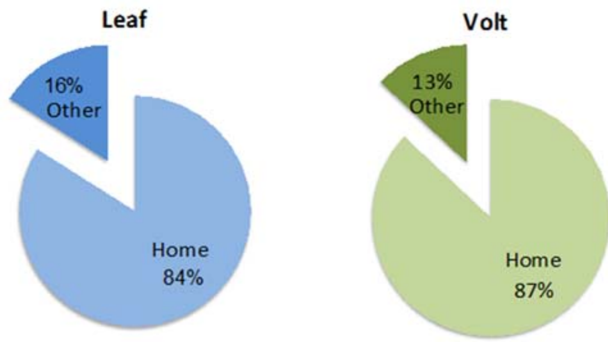
To address the diverse charging needs of PEV drivers from a system-wide perspective, planners have introduced the concept of the “charging pyramid.” As illustrated below, the base of the pyramid is residential charging, where approximately 85% of all charging sessions occur. Workplace charging, fleet charging, public “destination” and “inter-regional” charging make up the balance of approximately 15% of the total demand for charging.

Figure 3-3: Charging Pyramid

Source: New York State Energy Research and Development Authority (NYSERDA). Accessed 11/11/16 at https://www.nyserda.ny.gov/Researchers-and-Policymakers/Electric-Vehicles/Info/Charging-Station-Hosts

The most extensive study of PEV charging completed to date, by the Idaho National Laboratories in conjunction with the DOE’s EV Project, found that BEV (Nissan Leaf) and PHEV (Chevrolet Volt) customers charged at home approximately 85% of the time, while PHEV drivers plugged in nearly 1.5 times per day vs. only about once per day for BEV drivers.[22]

Figure 3-4: Charging Patterns of Vehicle Owners



Source: Plugged-In: How Americans Charge Their Electric Vehicles. Idaho National Laboratory. September, 2015.

For the City of San Francisco, national norms for residential and workplace charging are helpful indicators of PEV driver behavior generally, but they may need to be adjusted to local circumstances. Given the cost and complexity of installing charging stations in MUDs with limited off-street parking, many PEV buyers need to rely on public charging to a much greater extent than the typical suburban dweller with a single family home and garage. Further, public investment will likely be required to encourage more MUD owners to provide PEV charging infrastructure, given the high up-front installation costs and potentially short tenure of any specific PEV-driving tenant.

3.2.3 The Importance of Public Charging

An abundance of workplace and public charging is vital to accelerating PEV adoption and providing equal access to charging for drivers that may confront steep barriers to the installation of residential charging. Further, robust inter-city corridor charging helps resolves range anxiety and supports broader use of BEVs as a realistic “one-car solution” for all driving needs. However, even when the availability of public charging is increased, most PEV charging will still be conducted at home. In a somewhat counter-intuitive development, studies have found that the propensity of drivers to charge at public charging stations actually declined as station density increased because drivers felt more confident that they could make it all the way back to their home-based charging station. With more options to recharge, drivers feel less compelled to “top off” as frequently. Given this phenomenon, planners should be cautious not to read a utilization plateau or decline in *charging sessions per charging port* as a sign that additional infrastructure is not needed or serves no purpose. This is especially true in the case of charger placement in “destination” locations that may be relatively remote. Strategically

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22. *Plugged In: How Americans Charge Their Electric Vehicles -- Findings from the largest plug-in electric vehicle infrastructure demonstration in the world*; Idaho National Laboratory, 2015, avt.inl.gov/sites/default/files/pdf/arra/SummaryReport.pdf, pp. 1-2

placed stations in outlying areas help enable anxiety-free charging on a regional basis, even if that particular station might see relatively rare utilization.

3.2.3.1. PEV Charging Infrastructure and Vehicle Sales Growth

Fortunately, San Francisco has made significant strides in increasing public charging over the last six years, growing the public network from nearly zero to 150 public Level 2 charging sites and eight public DC Fast Chargers as of September, 2016.[23]

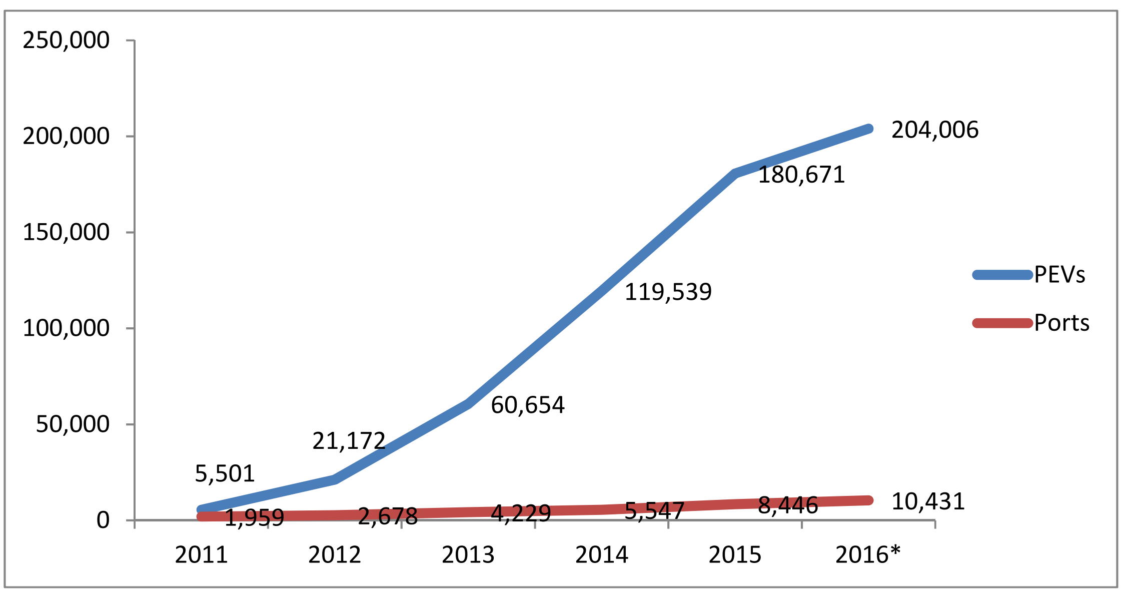
Table 3-4: California and San Francisco Public PEV Charging

California Public Charging Sites	San Francisco Public Charging Sites
3,082 Level 2 Sites (avg. 2.9 ports/site) 435 DCFC Sites	150 Level 2 Sites (avg. 3 ports/site) 8 DCFS Sites

Source: US Department of Energy, Alternative Fuels Data Center; Accessed September 6, 2016 at http://www.afdc.energy.gov/data_download

However, the ratio of chargers to PEVs has not kept pace with growth in PEV deployment, as the graphs below indicate.

Figure 3-5: Growth of PEVs vs. Public Charge Points in California (Sept. 2016)



[23] Data collected from the US Department of Energy's Alternative Fuels Data Center, accessed September 6, 2016, http://www.afdc.energy.gov/data_download/ Note: some opening dates estimated. Excludes private charging.

Sources: Clean Vehicle Rebate Project. accessed July 5, 2016 https://cleanvehiclerebate.org/eng/rebate-statistics.; US Department of Energy, Alternative Fuels Data Center; Accessed September 6, 2016 at http://www.afdc.energy.gov/data_download

* As of May, 2016

Notes: As not all of the electric vehicle charging stations had opening dates listed in the DOE database, the proportion of charging locations opening annually with dates was applied to the total number of sites to approximate total sites opening each year.. This analysis includes Level 1, Level 2, and DC Fast Chargers that are publicly accessible. Residential charging stations and stations serving only private fleets are excluded. EV analysis adjusted from rebate numbers by participation rates to approximate total vehicle registrations based on guidelines in: Williams, B., Anderson, J., Santulli, C., and Arreola, G. (2015), "Clean Vehicle Rebate Project Participation Rates: The First Five Years (March 2010 – March 2015)," Center for Sustainable Energy, San Diego CA, October 2015.

As seen in Figure 3-5 above, the growth of PEVs registered in the state far outpaced the growth of PEV charging infrastructure in the period from 2012 to 2014. In the period from 2012 to 2015, the cumulative number of PEVs in California has grown nearly ten times more than publicly available charging infrastructure.

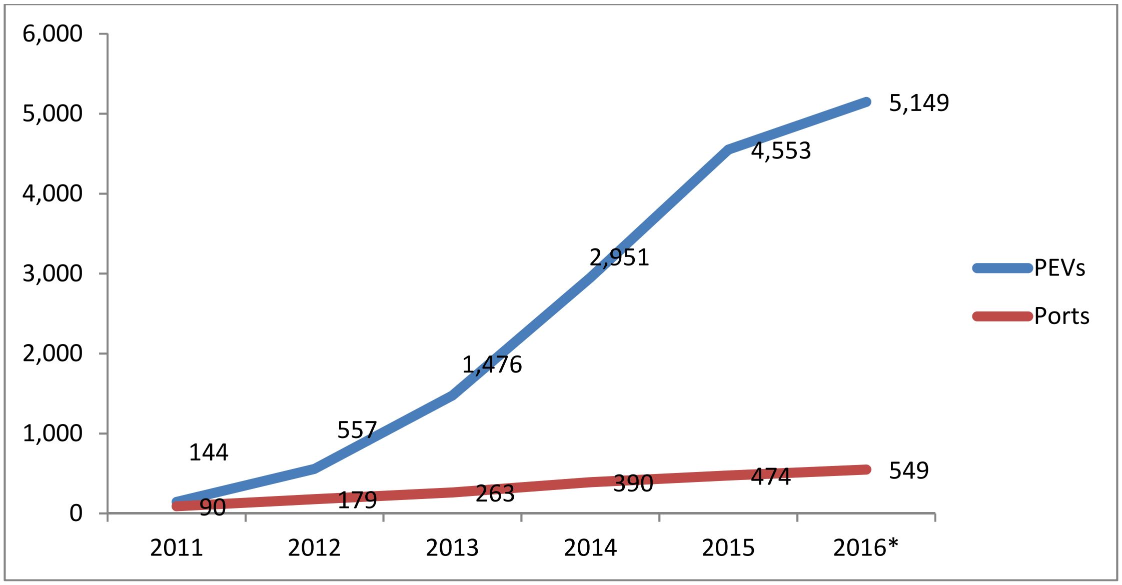
Table 3-5: Growth Rates of PEVs and Charge Points in California

	2012	**2013**	**2014**	**2015**	***Cumulative***
PEVs	285%	186%	97%	51%	*3200%*
Public ports	37%	58%	31%	52%	*330%*

Sources: Clean Vehicle Rebate Project. accessed July 5, 2016 https://cleanvehiclerebate.org/eng/rebate-statistics.; US Department of Energy, Alternative Fuels Data Center; Accessed September 6, 2016 at http://www.afdc.energy.gov/data_download

In San Francisco, growth in PEVs has also significantly outpaced growth in EVSE, with the public EVSE to PEV ratio growing from approximately one in five in 2012 to one in ten in 2016.

Figure 3-6: Growth Rate in San Francisco PEVs vs. PEV Charging Ports (2011-2016)



Sources: Clean Vehicle Rebate Project. accessed July 5, 2016 https://cleanvehiclerebate.org/eng/rebate-statistics.; US Department of Energy, Alternative Fuels Data Center; Accessed September 6, 2016 at http://www.afdc.energy.gov/data_download. Note that the analysis above was conducted via the same methodology as California EVSE statistics presented in the preceding figure.

In 2011, San Francisco had approximately 150 EVs and approximately 90 publicly accessible individual charge points. By the end of 2015, the city was home to approximately 4,500 PEVs (the city gained an additional approximately 600 in the first 7 months of 2016) and approximately 475 publicly accessible charge points (including Level 1, Level 2, and DCFC.) From 2011 to the end of 2015, PEVs registered in the City increased by approximately 3,000%, while EVSE growth was approximately 430%.

Table 3-6: Relative Growth Rates of PEVs vs. Charge Points in San Francisco

	2012	2013	2014	2015	Cumulative
PEV sales	286%	165%	100%	54%	~3050%
Public ports	100%	47%	48%	22%	~430%

Sources: Clean Vehicle Rebate Project. accessed July 5, 2016 https://cleanvehiclerebate.org/eng/rebate-statistics.;

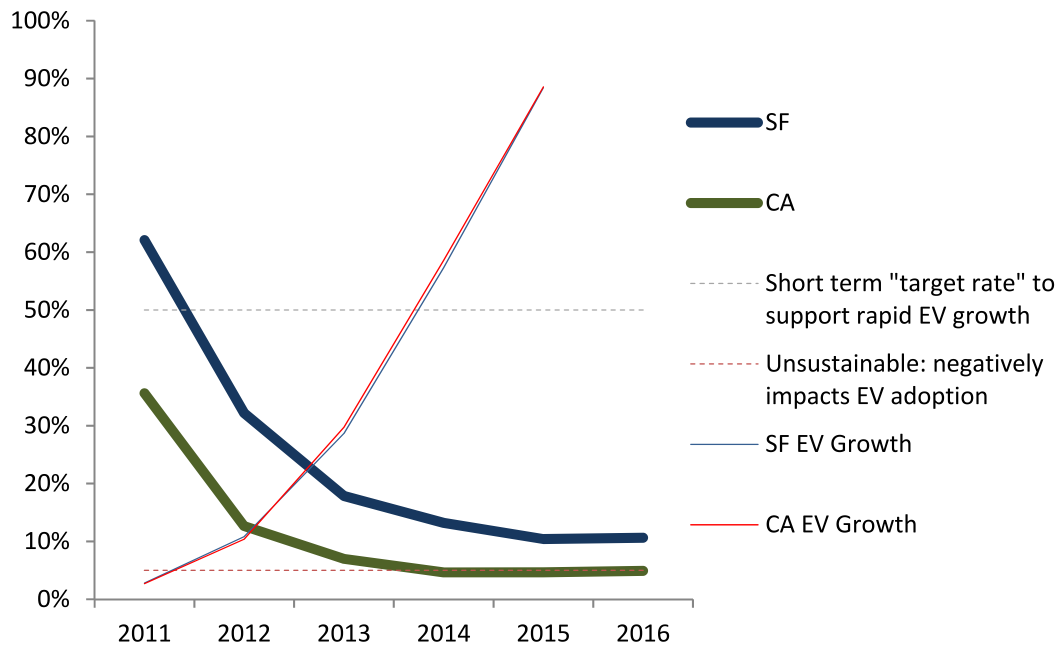
US Department of Energy, Alternative Fuels Data Center; Accessed September 6, 2016 at http://www.afdc.energy.gov/data_download

3.2.3.2 Attach Rates

The differential growth of PEVs versus charging infrastructure is further illustrated by an examination of the cumulative "attach rates," a term that refers to the ratio of publicly accessible charging ports to total PEVs. While there is no widely adopted standard for optimal attach rates, ChargePoint, the market leading charging provider in California, has identified 15 percent or below as an inflection point at which station hosts in a local area experience frequent complaints about insufficient charging infrastructure. ChargePoint has proposed a 50 percent attach rate as optimum, a goal also endorsed by Nissan.[24]

As illustrated in Figure 3-7 below, San Francisco's public charging attach rate was initially above the 50 percent target rate, but fell below that rate after 2011, with the rate continuing to decline in the years since then. As of June 2016, San Francisco had an 11 percent attach rate, above that of the rest of the state, but progressively falling behind the growth rate in PEV deployment.

Figure 3-7: Cumulative PEV to Charger Port Ratio ("Attach Rate") for San Francisco and California



[25]

Sources: Clean Vehicle Rebate Project. accessed July 5, 2016 https://cleanvehiclerebate.org/eng/rebate-statistics.; US Department of Energy, Alternative Fuels Data Center; Accessed September 6, 2016 at http://www.afdc.energy.gov/data_download

Given the importance of public PEV charging to PEV market acceleration, a key priority for San Francisco will be to increase the attach rate in the public charging domain.

Attach rates have also been a focus of planning at the regional level. The BAAQMD, in cooperation with the Bay Area PEV Strategic Council, contracted with the consulting firm of ICF International to prepare a Bay Area Regional EV Readiness Plan, published in 2014. To identify an optimum attach rate, ICF drew on studies from the Electric Power Research Institute (EPRI), which has defined a "benefits tested scenario" to determine the level of charging needed to achieve a high level of electric VMT (eVMT) in a given region. In EPRI's scenario-based analysis,

[24] "Long Term Vehicle Charging Plans," Presented to the California Energy Commission April 2014, ChargePoint. Accessed July 5, 2016, http://www.energy.ca.gov/2014_energypolicy/documents/2014-04-10_workshop/presentations/08_ChargePoint_CEC_Planning.pdf.

[25] 2016 refers to attach rates through June 2016; SF and CA PEV growth rates are shown as a percentage of 2016 cumulative PEV sales, approximating 5,150 PEVs in SF and 204,000 PEVs in CA

significantly more public PEV charging stations will be required in the Bay Area to relieve range anxiety, and to increase PHEV all-electric miles travelled, especially given that many PHEVs (such as the Plug-in Prius) have as few as 15-20 miles of all-electric range. Note that this analysis considers Level 1 and Level 2 charging interchangeable.

Table 3-7: Public Level 1 and 2 EVSE Needed to Support Forecasted Bay Area PEV Growth

Year	Vehicle Forecasts		Level 1 and Level 2 EVSE Incremental Need		
			Estimates		EPRI-defined Optimum to Maximize eVMT Growth
	PHEV	BEV	Low	High	
2015	17,600	18,100	7,900	14,200	4,370
2020	70,000	44,700	13,960	30,960	16,730
2025	148,000	98,900	20,789	45,190	35,550

Source: Bay Area Regional PEV Readiness Plan Summary, 2012, pp. 29.

The proposed 2020 goal of 16,730 charging points within the Bay Area compares to a current inventory of approximately 3,000 in the region. The cost of adding more than 10,000 chargers regionally is difficult to estimate without determining the split between Level 1 and Level 2 chargers. However, even a very low-cost deployment (with dual port Level 2 chargers plus some Level 1 chargers at workplaces) would likely require at least $4,000 - 5,000 per port including hardware and installation costs, or a total of $40 to $50 million to reach the level required to optimize eVMT, given 2020 PEV adoption estimates. Achieving this level of investment will likely require new local, regional, and state funding beyond what is currently programmed.

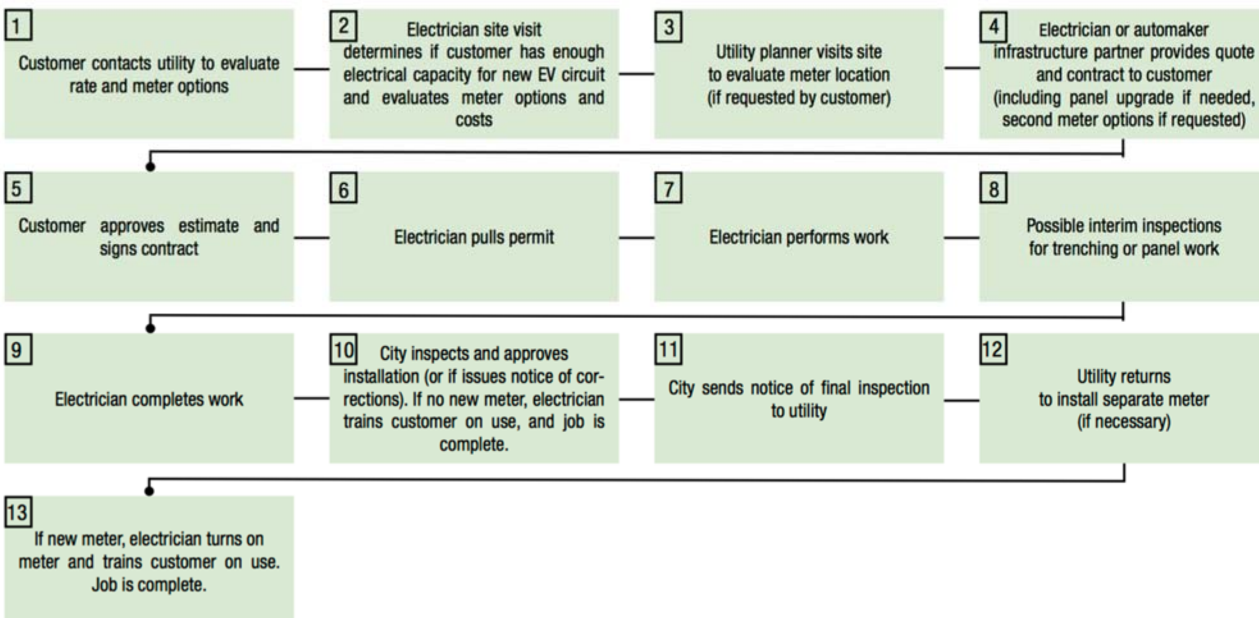
3.2.4 Residential Charging in San Francisco

Charging at home for owners of single-family housing with attached garages is relatively straightforward. If the home is relatively new, the electrical panel is likely to be proximate to the garage, and a Level 2 or Level 1 charging solution can typically be readily installed. However, in the City of San Francisco, as in other dense urban areas where multi-unit housing predominates, charging at home is often far more challenging. Accessing even a Level 1 outlet in an apartment building can pose a myriad of challenges ranging from safety (overheated electrical outlets, cord tripping, theft, etc.) to complexities regarding metering and payment for electricity. Likewise, finding sites and deploying suitable public charging outlets on streets or in parking lots proximate to residential areas is very challenging. Finally, parking (with or without charging) in San Francisco is available only at a substantial premium, and property owners are reluctant to reserve a space exclusively for PEVs while they constitute only a modest proportion of all vehicles in the City.

Because of the high cost potentially associated with Level 2 residential charging, many PEV drivers in the City and elsewhere are opting for Level 1 charging at home. Level 1 charging can be accomplished with the portable charging equipment that comes with a new PEV and existing outlets—although some older homes may require a new, grounded and dedicated 30 amp 110 outlet, at a cost of a few hundred dollars. In the MUD context, a string of Level 1 outlets can be somewhat less expensive than a Level 2 solution. However, if individual metering capabilities or a J1772 connection device are included, the cost for Level 1 can be in the same range as the Level 2 solution.

All charging station installations require an electrical permit. This can be procured via the online permit system at the City's Department of Building Inspection and is typically available at a cost of approximately $150 or more depending on the nature and size of the building and the charging system. An onsite inspection will also be required to sign off on the work. In some cases, the combination of permitting, inspection, and utility "hand-offs" can result in significant delays before a charger installation is complete. The following chart indicates the steps required in many charging station installation scenarios.

Figure 3-8: Residential Charging Installation Process



Source: Ready Set Charge California: A Guide to EV-Ready Communities, 2013, p. 34. Available at:

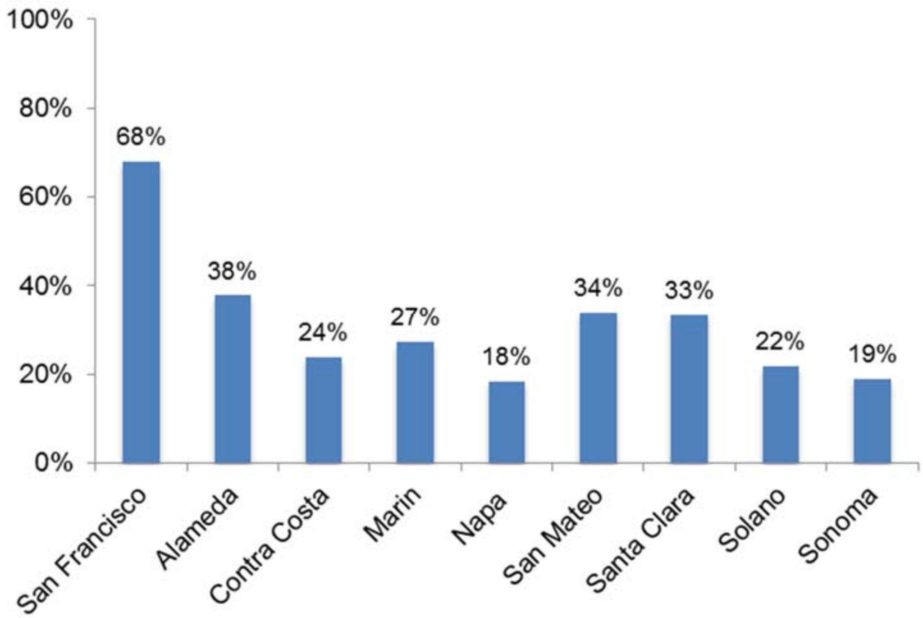
http://www.rmi.org/Content/Files/Readysetcharge.pdf

The City already has online permitting and reasonable fees for charging stations. Beyond these fundamentals, key policy strategies to lower costs and streamline residential charging over time include: 1) a focused initiative to increase MUD charging, and; 2) a PEV Ready building code that requires PEV charging station pre-wiring for all new residential and commercial buildings as well as major remodels. Both of these initiatives are underway in San Francisco and are described in more detail below.

3.2.5 Charging in Multi-Unit Buildings

San Francisco has the highest proportion of MUDs to residential housing of any County in the region, with more than 200,000 total units being MUD out of approximately 380,000 total residential units.

Figure 3-9: Bay Area MUD Units as a Proportion of Total Residential Units



Source: American Fact Finder: US Census. Accessed June 2, 2016 at:http://factfinder2.census.gov/faces/nav/jsf/pages/index.xhtml

Depending on local circumstances, MUD residents and building owners seeking to install charging stations may be challenged by any combination of the following problems.

Table 3-8: Challenges Facing EVSE Installation at Multi-Unit Developments

Physical Challenges	Availability of capacity in the electrical panel Availability of space for additional meters in the meter rooms Distances between utility meters, parking spaces, and unit electrical panels
Cost of Installation & Operation	Restrictive facility configurations (master meter, remote parking, etc.) Cost allocation to residents (based on usage, equipment, parking, shared service areas) Inability to take advantage of off-peaking charging rates Homeowners Association fee structures
Codes, Covenants, & Legalities	Differences in ownership Differences between actors who make the investment versus those that reap benefit Agreements between property owners and residents / renters Deeded parking spaces assigned to individual residents

Source**:** *Bay Area and Monterey Bay Area Plug-in Electric Vehicle Readiness Plan:* Background and Analysis, Bay Area Air Quality Management District and ICF, December 2012, p. 28

3.2.5.1 Challenges and Potential Solutions for MUD PEV Charging

Finding solutions for existing MUDs requires a wide range of strategies. Key challenges and potential solutions are outlined below.

- **High installation costs and limited parking:** MUD installation siting challenges and high costs are two key initial barriers to broader MUD charging deployment. Cost factors depend on the age, condition, and physical layout of the building and can range from $5,000 to $20,000 or more per dual port charger, depending on configuration, electrical capacity upgrades needed, and other factors. MUD garages and lots in the City are crowded and most spaces are assigned or deeded. Finding practically feasible spaces for chargers may require re-shuffling of designated parking or other use-policy changes. Where deeded parking spaces exist, Home Owner Associations (HOAs) may require that residents pay the full cost of initial installations. California Assembly Bill (AB) 2565 mandates that tenants be allowed to install PEV charging at their own expense. However, in apartments, some cost-sharing may be feasible if building owners exercise their right to exact a surcharge on energy used at the site, or to charge a monthly lease fee for equipment that is retained by the apartment owner and re-assigned to future PEV driving tenants.

- **Electricity cost reduction through load management and off-peak charging:** PG&E and CleanPowerSF, the City's new Community Choice energy provider, both feature EV-specific charging rates defined by Time of Use tariffs. Also, PEV drivers who wish to drive on 100 percent renewable power can do so through the CleanPowerSF "SuperGreen" product for a modest additional cost of approximately two cents per kilowatt hour (Table 3-8).

Table 3-9: CleanPowerSF PEV Rate Schedule

EV (PG&E Equivalent EV)		
Summer: May 1 – October 31		
	Generation	**Schedule**
Peak	$0.2035 /kWh	2pm – 9pm M–F; 3pm – 7pm Sat, Sun, and holidays*
Part Peak	$0.08562 /kWh	7am – 2pm & 9pm – 11pm M–F* (except holidays**)
Off Peak	$0.03106 /kWh	All other hours
Winter: November 1 – April 30		
	Generation	**Schedule**
Peak	$0.06099 /kWh	2pm – 9pm M–F; 3pm – 7pm Sat, Sun, and holidays*
Part Peak	$0.02908 /kWh	7am – 2pm & 9pm – 11pm M–F* (except holidays**)
Off Peak	$0.03303 /kWh	All other hours

Source: CleanPowerSF website, accessed November 12, 2016 at http://sfwater.org/index.aspx?page=993.

Accessing PEV specific rates may require a new meter and utility service. Although most MUDs have meters clustered in a central location, in some cases there may not be space to add another meter. In these circumstances, building owners or managers may choose to establish a flat monthly fee for energy use based on average utilization at the common area meter.

- **Load Management Technologies and MUD Billing Management:** Alternative load management technologies for multi-unit scenarios are also available from companies such as EverCharge, which specializes in PEV charge management for MUDs. EverCharge provides a "powershare" hardware device that can shift the electrical load among a number of charging devices to ensure that existing electrical panels are not overloaded. Many charger companies, including market leaders ChargePoint and EVGo, have billing solutions that apportion energy costs to EVSEs among different tenants and management.

- **Limited electrical capacity:** Level 2 chargers typically require a minimum of a 40 amp circuit. Upgrading capacity can be costly and may trigger requirements to bring the property up to current building code. In these circumstances, power-sharing technology to enable multiple chargers to charge sequentially (rather than simultaneously) may reduce the burden, as referenced above. Another low-cost option is to utilize existing or new 110 volt outlets and the vehicle's portable Level 1 charging cord. Level 1 charging may be adequate for overnight charging of PEV owners that drive less than 50 electric miles per day. If common area power is used in car ports, some building owners use low cost devices such as the "Kill-a-watt" energy meter, which is available for less than $20, to track energy use and reimburse the HOA. Note that extended use of a 110 volt charger typically requires a dedicated 30 amp circuit and grounded outlet.

- **Owner Issues: Cost of capital and utility interconnection:** To the extent that MUD building owners, rather than tenants, are asked to invest capital in an EVSE installation, there are a number of structural changes that can impede owner embrace of the project. If the owner is not motivated strictly by the environmental benefit or perceived competitive value in the marketplace of the "green amenity," then the EVSE investment must be greater than other opportunities, given the timeframe for return on investment, and the perceived "hassle" of PEV charging. EVSE installations can take a long time (three to nine months is typical) to move through planning, permitting, electrical upgrade, and physical construction, even though the installation of the charging unit itself can often be done in a single day. In a scenario in which multiple charging stations may be installed, a "utility-side-of-the-meter" transformer upgrade may also be required. These upgrades may require 8-12 months after all planning documents are submitted and approved by both the City and the utility. In some circumstances, the upgrade may take longer than the would-be PEV user's residency in the building.

- **Operating Costs:** Even when the EVSE itself is provided at no cost to the building owner (as in the case of a state-funded grant program), other cost issues can impede owner uptake. For example, if the PEV-equipped space displaces other tenant parking, there may be lost revenue for the rental of the space. In San Francisco, spaces may rent from $150 per to $300 per month or more depending on building location. Electricity, maintenance, and repair costs are also involved. Cost recovery strategies can involve new policies to install charging stations in common areas serviced by the same master meter that covers other common services such as lighting, and the cost of the amenity can be borne by rent or HOA fee increases in future years. An alternative approach is to establish charger use rates with payment via credit card to enable cost recovery on EVSE installation, energy use, and maintenance.

- **Limitations of the "Free Chargers" Model:** An early strategy to incentivize greater deployment of PEV chargers in the City was pilot tested by the *MultiCharge SF Project* in the 2011-12 timeframe. This collaboration of the Energy Commission-funded ChargePoint America program and the City of San Francisco sought to place up to 100 EVSE in MUDs in the City. Installation services were provided by ABM and outreach was conducted by the consulting firm, EV Charging Pros. This time-limited initiative provided free installation and hardware to multi-unit property owners. However, uptake on the offer was viewed by program managers as disappointing, as significantly less than 50% of the property owners who considered the program ultimately determined that benefits outweighed potential liabilities. In addition, some property managers elected to de-activate the charging units when residents did not adopt PEVs, or after PEV-using residents moved. This left some property managers with liability for the annual EVSE network operation fee required by ChargePoint, as well as potential liabilities for vandalism, maintenance, and repair. Lessons learned by program managers included: 1) the need for enhanced building owner incentives; and 2) the need for turn-key solutions to operating costs, operations, and maintenance.

In spite of these challenges, PEV charger installation in MUDs had tremendous benefits. Once the option of PEV ownership with home-based charging is available for MUD residents, chargers in MUDs can have a higher rate of utilization than single-family homes, given the potential for shared use of EVSE. Assuming parking spots are not linked to specific tenants, the diversity of possible users leads to a lower likelihood that the charger will become a stranded asset if the original PEV owner moves.

Given the potential impact on PEV adoption, a comprehensive strategy to address charging challenges is needed for MUDs. To create a strong policy and planning foundation for charging in MUDs, the City has secured Energy Commission grant funding to develop and deploy revised green building codes requiring that new buildings and major remodels (both commercial and residential) are equipped with adequate electrical capacity and stub-outs for Level 2 PEV charging equipment.

3.2.5.2 Modifying San Francisco Building Codes to Enhance PEV Charging Infrastructure

Given the challenges facing expansion of local charging networks, City policy makers are eager to reduce the costs of future charging installations in both residential and commercial buildings. To this end, the City accessed CEC grant resources to develop revisions to the building code that will require new electrical "stub-outs" for PEV charging, including conduit and a junction box with appropriate capacity to meet building-specific charging needs. Although the code will not require the installation of PEV charging stations as such, in most locations, the preponderance of PEV charging station cost is in the electrical capacity upgrade and site preparation, rather than in the procurement and final placement of the charging station itself. As such, the planned building code upgrades will significantly lower the cost barrier to PEV charging. The planned code change will close a loophole in the statewide CalGreen building code that limited the previous charging requirements to MUDs with 16 or more units, while exempting entirely all residential buildings with fewer than 16 units.

3.2.5.3 Integration of MUD Charging with Solar and Energy Storage

As noted above, the provision of free chargers and installation alone does not address all owner concerns regarding the opportunity cost of dedicating a space exclusively for PEV use, charger maintenance and repair, potential liability for hazards or injury, future upgrade costs, and the potential for stranded assets. Given these obstacles to charger adoption by property owners, some entrepreneurs are providing new turn-key approaches that provide enhanced revenue and benefits by combining PEV charging with other clean energy solutions. One such example is Powertree, a San Francisco based company focused entirely on the MUD market. Powertree is implementing a large-scale MUD program in the City, focused on buildings of 10 to 50 units in size, featuring concurrent installation of EVSE, solar panels, and energy storage. The Powertree solution includes three revenue streams to building owners: 1) parking rental fees; 2) a share of the net-metered solar installation; and, 3) PEV charging revenue. Further, the building owner gains a valuable capital improvement for the building in the form of the combined value of PEV chargers, solar panels, and energy storage. When combined with a bankable revenue stream from the new energy assets, these distributed energy resources will increase the building's property valuation. Powertree is currently installing its integrated solution in approximately 71 San Francisco buildings, representing 1,571 residential units, with at least 3,000 residents. The 70-plus charging ports included in this deployment will represent an expansion of nearly 50 percent over the existing stock of publicly accessible PEV chargers in the City. Additional investments by PG&E in combination with the pending VW settlement are likely to further enable expansion of MUD charging capacity in San Francisco in the 2017 to 2020 period.

3.2.5.4 Combining MUD Electrification with Expanded Car Sharing

The benefits of electrification can be further enhanced via potential co-location of electric car-sharing pods in MUDs. To date, car share companies have been challenged to expand their operations in San Francisco due in large part to the lack of available off-street or on-street parking. However, the electrification of MUD parking provides a dual opportunity to substitute PEVs for ICE vehicles, <u>and</u> to replace a portion of individually owned vehicles with shared mobility solutions that have the significant co-benefits of lower cost and freeing up more urban space for non-parking uses.

Potential incentives and resources to support accelerated MUD charging include:

1. Prioritized access to rebates from the City of San Francisco and California Solar Initiative solar programs to further incentivize co-location of solar and EVSE.
2. Accelerated approval (or other incentives) in the planning and permitting process for new developments and major remodels that include EVSE, solar, and/or energy storage (with

specifics to be determined in dialogue with the Planning Department and the Department of Building Inspection).

3. Public/private partnership approaches to attract regional, state, and federal grants for "super-green MUDs" that provide 100 percent renewable power, energy storage, PEV charging, and PEV car share.

3.2.5.5 The NRG/EVGo "Make-Ready" Program of PEV Charging Readiness

Another ambitious initiative to address the MUD market has been advanced through the NRG EVGo, "make-ready" program, formally known as the "Ready for EV" program. This program was originally established when NRG, the large national energy provider, owned and operated the NRG EVGo program. Resulting from a settlement against NRG's predecessor for failing to fulfill electricity contracts during 2001, NRG's EVGo was ordered to invest $100 million in charging stations. In 2016, EVGo became an independent company, and the status of the Ready for EV program is being renegotiated with the state.

Following settlement of a legal dispute with the California Public Utilities Commission (CPUC), NRG entered into an agreement with the CPUC to develop 10,000 Ready-for-EV sites at both workplaces and MUDs. The program involves a two-step process that first engages property owner participation, followed by voluntary enrollment by PEV drivers. Property owners that wish to promote their buildings as "Ready for EV" can apply to EVGo and have their site inspected. If EVGo indicates that they can prepare the site for charging within cost parameters for the program, then the company will build out the necessary electrical capacity, including a PEV charging station stub-out. In return, building owners commit to reserve their building exclusively for future installation of EVGo network charging stations over the following 18-month period. During that period, if a PEV driver is interested in signing up for an EVGo PEV subscription plan, then EVGo will authorize the installation of a charging station. Both the installation and the charger are free to the property owner. There is also limited provision for revenue sharing of the subsequent charging fees. Following an 18 month "lock-up" period, the property owner can install a charging station from any other vendor, without limitation or payment to EVGo.

The EVGo program includes a monthly fee for program participation by PEV drivers, plus an hourly charge that varies based on the speed of the vehicle's own on-board charging system. Current program guidelines call for PEV-equipped spaces to be reserved for the exclusive use of a single tenant, and would not be available for visitors or other tenants. This enables enrolled tenants to have 24/7 access to their own dedicated EVSE-equipped space. However, the significant disadvantage of this configuration is that more charging equipment is required to serve other tenants in the building compared to a shared-access model. Further, if the resident PEV owner moves, the property owner may have a stranded asset if the PEV equipment is not conveniently located for other tenants to take advantage of that charging location. Some larger property management companies, such as Sequoia Properties, have signed up for the program. However, overall program engagement has been slower than EVGo and other stakeholders have expected, and the program may be restructured in the future.

3.2.5.6 Property Owner-operated Charging Systems

The EVGo and Powertree models are considered EV Service Provider approaches, in which the EV Service Provider sets the prices, terms, and conditions of charger utilization, and takes full responsibility for maintenance, repair, and operation. In contrast to this model, there are many other EVSE manufacturers which provide equipment that enables MUD property owners to set their own access protocols and prices, enabling either individual tenant assignment, shared use, or hybrid models that may shift over time. In some cases, equipment for these solutions can be financed out of the revenue gained from use of the charging stations over time.

As noted earlier, some of these equipment providers also include forms of energy load management hardware and software that can enable chargers to share an electrical circuit, and thereby reduce electrical capacity upgrade costs that might otherwise be required. Some of the leading charging manufacturers and service providers active in the MUD space include ChargePoint, Clipper Creek, eMotorwerks (Juicebox), PlugShare, Car Charging Group, Leviton, Schneider, and Aerovironment.

3.2.5.7 The Need for New Investment Strategies to Address the Persistent MUD Access Gap

As the examples above indicate, entrepreneurs have been creative in devising a variety of business models to meet the unique requirements of MUD charging. However, the return on investment for MUD charging at this early stage of PEV market penetration is low, and the "chicken and egg" problem of promoting PEV sales in the absence of charging deployment (and vice versa) remains as a persistent market failure in the MUD context. This reality was formally acknowledged by the CPUC when, in 2016, it approved pilot programs offering investor-owned utilities the right to develop PEV infrastructure with rate-payer funds (a.k.a. "rate-based infrastructure.") However, these investor-owned utility pilot programs will take considerable time to ramp up, and as of late 2016, a PG&E pilot program has yet to be approved. In any case, even with robust utility participation, MUD charging programs will likely require ongoing public investments and a wide variety of strategies to drive the needed scale of deployment. Given the significant challenges involved, it is recommended that the City invest in promising new strategies that can be pilot-tested for potential scale-up with a combination of Air Quality Management District, Energy Commission, utility, and private investment funds.

Tackling the MUD challenge with new strategies is crucial for accelerating PEV adoption not only within the City but also on a regional and statewide basis. A few statistics tell the story.

- Through 2015, over 93 percent of PEVs (both BEV and PHEV) have been sold to drivers that own a single-family home in California, and only 4 percent have been sold to either condominium or apartment residents (per CVRP data).
- The US Census indicates that 42 percent of Californians reside in rental apartments.
- When surveyed by the UCLA Luskin Center, 65 percent of <u>prospective</u> early adopters were MUD residents. But the same surveys indicate that up to 81percent of MUD

residents viewed the current lack of at home/near home charging as a serious impediment to the purchase of a plug-in vehicle.[26]

By overlaying the interest level of MUD residents with income data on renters in the PEV purchase demographic, it can be inferred that if MUD charging was not a barrier to adoption, the deployment of PEVs could double on a statewide basis, and potentially triple in cities like San Francisco where MUD dwellers make up nearly two thirds of the population. While San Francisco has a very large proportion of higher income residents in MUDs than many other cities, it is important to note that the income floor for PEV purchase is constantly trending downward as prices on both new and used PEVs are reduced. (For example, relatively low-mileage Nissan Leafs are available for under $10,000, and used Chevy Volts for under $20,000.) Thus, any investments made now in MUD charging will drive increasing adoption and emissions impact over time as more and more households in the City are able to purchase, lease, rent, or share a PEV with attractive pricing and performance.

3.2.5.8 Structuring Incentives to Increase MUD Owner Commitment to Electrification

The foregoing discussion of MUD deployment models makes it clear that there are a number of promising options to address MUD property owner constraints, ranging from full turnkey solutions, to free "make-ready" electrical capacity upgrades, to customized strategies from charging supply providers, and others. These solutions enable property owners to set their own pricing and (in many cases) to finance 100 percent of system costs from future charging revenue. Common to all of these approaches, however, is the need for site host identification, site qualification, engineering, and site host approval of the relevant PEV charging solution. Thus, *financing the up-front site assessment and enrollment cost* for MUD properties is perhaps the most significant challenge to growth within the urban PEV ecosystem.

Of course, funders cannot afford to pay for site host outreach and engagement without ensuring a reasonable return on investment in the form of deployed charging stations with a likelihood of robust utilization over time. Currently, return on investment OI on deployed chargers in MUDs is so limited that EV Service Providers are not incentivized to fully engage the market. Further, the current funding model, which requires deep-pocketed private investors with very patient capital, limits the range of solution providers operating in the marketplace. Thus, MUD property owners typically encounter just one or two "one size fits most" EVSE providers, who tend to promote their particular product or service regardless of how well that solution fits a specific site host. This situation can lead to poor outcomes, including stranded assets due to low utilization, over-charging of PEV drivers, and dissatisfied customers.

To address these challenges, the City and other stakeholders must work collaboratively to bring charging solutions to the MUD segment that will drive broad adoption. With a combination of

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[26] *Southern California Plug-in Electric Vehicle Readiness Plan, Chapters for Building Owners,* UCLA Luskin Center and Southern California Association of Governments (SCAG), December 2012. http://www.scag.ca.gov/Documents/SCAG_PEV_Plan-Buildings_and_Retail_Owners.pdf, p. 35.

private construction financing and public funding for initial qualification and acquisition of MUD charging sites, PEV adoption could be greatly accelerated. What is at stake is enabling PEV ownership as a viable possibility for the two thirds of San Franciscans, and the 42% of Californians, who currently reside in MUDs.

3.3. PEV Potential in Fleets

3.3.1 PEVs in City of San Francisco Public Fleet

3.3.1.1 Policy Basis

Clean fleet policy within San Francisco is guided by the City's overarching climate action goal known as Ordinance 81-08, which pledges the City to reduce GHG emissions 80 percent from 1990 levels by 2050, in alignment with the state's climate action targets. As noted in Chapter 2 of this Plan, the 2013 *Climate Action Strategy Update* prepared by the San Francisco Department of Environment tracks progress against goals and affirms a key interim GHG goal, which is *to reduce emissions 44 percent below 1990 levels by 2030*.

Each major department within the City is responsible for its own departmental Climate Action Plan by which it will achieve these goals, as well as its own fleet procurement goals and practices. For example, SFMTA, SFO, SFPUC, the public safety agencies, and the General Services Agency within the Department of Administrative Services all have their own differentiated responsibility for fleet vehicle procurement and maintenance, and for clean fleet practices.

In addition to the City's GHG reduction goal, the City's Clean Air Plan, implemented in 2004, identifies a *100 percent zero emissions City fleet* as a goal for 2020. Produced jointly by the San Francisco Municipal Transportation Agency (SFMTA) and San Francisco's Department of Environment, the City's Clean Air Plan aligns with the San Francisco Climate Action Strategy goal to expand access to clean vehicles and fuels. Because the City recognizes that there are not yet viable zero emission vehicle types in every vehicle category needed to meet the City's critical needs, a process is in place to grant waivers for "non-ZEV" fleet procurements. This process is managed by the Clean Fleet and Fuels Coordinator within the Fleet Management Division of the City and County of San Francisco, in alignment with the City's Healthy Air and Clean Transportation Ordinance (HACTO). Relevant sections of the Ordinance pertaining to fleet management policies are included in Appendix A.

3.3.1.2 Implementation of the Healthy Air and Clean Transportation Ordinance (HACTO)

HACTO is part of the City's Environmental Code and includes three elements of policy guidance for AFV and clean fleet management:

- Transit First
- Fleet Replacement Using the Cleanest Vehicles Possible
- Fleet Reduction

HACTO affirms the City's *Transit First Policy,* by which all City employees are expected to utilize transit rather than single-occupancy vehicles wherever feasible. The *Fleet Replacement*

Policy affirms that City departments must utilize the cleanest vehicle possible, with exemptions that reflect the unique operational requirements of entities such as Muni and the public safety agencies. The mechanism for managing the Replacement Policy is the *Vehicle Selector List,* managed by the Fleet Management Division. This list includes the cleanest vehicles in each relevant vehicle category, and applies to light-duty vehicles of 8,500 pounds or less GVWR). Departments that do not select the cleanest vehicle available must submit a waiver request which is approved or denied by the Clean Fleet and Fuels Coordinator. Finally, the *Fleet Reduction Policy* states that departments should seek to minimize fleet size through transit first approaches and optimized fleet management practices. For example, a new City-wide telematics system introduced in 2016 will help identify underutilized vehicles, serve as a guide to rightsizing the overall fleet, and promote enhanced economies of operation.

3.3.1.3 PEVs in San Francisco's Municipal Fleets

The City of San Francisco has a total of 61 on-road PEVs in its fleets. The majority of these (51) are in the General Government department, with five vehicles respectively in the Enterprise and Safety departments. The City's fleet also includes an assortment of electric carts, off-road vehicles, and other miscellaneous, which are used for a variety of purposes, including in-airport transit.

Figure 3-6: Number of PEVs in City of San Francisco Fleets

	On-road				Other (carts, off road, etc.)	Grand total
	Cars	SUV	Vans	Total On-road		
Enterprise	5			**5**	70	**75**
General Gov	47	3	1	**51**	28	**79**
Safety		5		**5**	1	**6**
Grand Total	**52**	**8**	**1**	**61**	**99**	**160**

Source: City and County of San Francisco Fleet Inventory Report, June 2016

3.3.1.4 Preliminary Analysis of Opportunities for Accelerated Electrification of the City Fleet

As part of the City's 2016 application to the DOT's Smart Cities program and to Vulcan Ventures for PEV initiatives, the City contracted with the Electrification Coalition, a national PEV consultancy, to undertake a "Rapid Fleet Assessment." This assessment identified opportunities for cost-effective replacement of existing fleet vehicles with PEVs, and for potential fleet downsizing. Although this assessment was not considered definitive, it proposed a potential baseline TCO to benchmark existing fleet economics, and to determine cost-effective options for accelerated PEV deployment. The results are illustrative of the potential for additional PEV procurement and fleet downsizing in coming years, based on these parameters.

- The assessment focused exclusively on sedans, SUVs, and Minivans, not larger vehicles such as trucks, buses, or off-road vehicles.
- All vehicles 7 or more years old were regarded as potential candidates for replacement
- PHEV replacements for ICEs were viewed as potentially economically viable if the incumbent vehicle was utilized for more than 8,000 miles per year and/or had more than 70,000 miles of lifetime VMT
- BEV replacements for ICEs were considered viable if the incumbent vehicle was being driven less than 8,000 miles per year and had accumulated greater than 70,000 miles of lifetime VMT
- Candidates for replacement by a BEV in a "BEV Pool" configuration included conventional vehicles with less than 8,000 miles per year, and less than 70,000 miles of VMT

The original dataset of light-duty vehicles assessed by the Electrification Coalition included 7,495 vehicles total (including 300 police vehicles). However, 717 vehicles lacked enough data to calculate TCO and were excluded. Following application of the screening criteria above, **885 sedans, minivans, and SUVs were viewed as replacement candidates.** A TCO analysis of this cohort revealed substantial variations in cost per mile, with conventional hybrid electric vehicles being the most efficient at .54 cents per mile, and minivans the least efficient at $1.07 per mile. The table below indicates vehicles that could be targeted for replacement within each vehicle category.

Table 3-10: Analysis of Light-Duty Vehicles for Replacement by PEVs in the City Fleet

Vehicle Type	Vehicles	Vehicle Age (avg.)	12-- -month VMT (avg.)	Lifetime VMT (avg.)	< 8k VMT/yr	> 70k total VMT	TCO Baseline
Sedan–C	95	10.5	4.262	42,950	83	16	$0.91
Sedan–M	117	14.0	5,166	88,546	139	120	$0.68
Sedan–F	171	14.2	7,152	122,319	115	150	$0.69
Sedan–HEV	293	6.3	5,884	36,843	229	39	$0.54
SUV	41	10.9	7,076	83,057	26	22	$0.75
SUV–HEV	21	6.9	5,902	44,500	14	5	$0.78
Minivan	87	10.5	4,818	52,900	72	23	$1.07
TOTAL	**885**	**10.5**	**5,762**	**68,256**	**678**	**375**	**$0.73**

Legend: C=Compact, M=Medium, F=Full sized; HEV = Conventional hybrid-electric vehicle.
Source: Ben Prochazka and Ryan Daley, Electrification Coalition presentation for the San Francisco Smart City Challenge proposal to Vulcan Ventures, May 2016.

Among the 885 vehicles identified above, 228 vehicles were identified as ideal "BEV replacement candidates" based on their very low annual VMT of less than 3,000 miles per year on average. The fleet consultants suggested that the City consider replacing these vehicles with a "BEV Pool" that could potentially meet City staff needs with less than 200 vehicles.

In another slicing of the data, consultants suggested that "near-term" replacement candidates be prioritized based on the older age of the incumbent vehicles and the potential for replacing fossil miles with electric miles through either BEV substitution or PHEV substitution where longer range is required. Note that the estimated proportion of eVMT for PHEVs in the proposed fleet procurement is 75 percent.

Table 3-11: Operating Cost for Proposed PEVs in City Fleet Applications

	# Vehicles	Vehicle Age (avg.)	Annual VMT (avg.)	Annual VMT (Total)	Lifetime VMT (avg.)	TCO* (avg.)	MPG (avg.)	Est.% E-VMT	Est. Electric VMT
PHEV	128	12.4	1,637,286	12,791	131,489	$0.59	21.3	75%	1,258,099
BEV	482	13.5	1,604,516	3,323	74,311	$0.96	17.9	100%	1,601,516
TOTAL	**610**	**13.0**	**3,238,802**	**5,310**	**103,900**	**$0.77**	**19.6**		**2,829,480**

Source: Electrification Coalition presentation for Smart City Challenge, May 2016.

If the City were to replace the 610 vehicles identified above with the proposed cohort of 128 PHEVs and 482 BEVs, the Electrification Coalition analysis suggests that the following environmental benefits would be achieved.

Table 3-12: Potential Environmental Benefits of Proposed PEV Fleet Replacement for 610 Replacement Candidate Vehicles Identified in the SF Smart City Fleet Survey

Annual Impacts	Baseline	New Vehicles			% Change
		PHEV	BEV	TOTAL	
G–VMT	3,238,802	409,322	-	**409,322**	-87%
E–VMT	-	1,227,965	1,601,516	**2,829,480**	-
Gasoline (gal.)	165,359	9,746	-	**9,746**	-94%
Electricity (GGE)	-	11,585	14,048	**25,633**	-
MPGe	19.6	76.8	114	**91.5**	+367%
GHG (MTCO_2e)	1,837	290	220	**510**	-72%
GHG (g/mile)	567	266	1	**267**	-53%

Source: Electrification Coalition presentation for Smart City Challenge, May 2016.

Notes: GHG emissions are based on well-to-wheels analysis and reflect an average of 469 g/KWh of CO2e across the western region. This analysis understates actual benefits because San Francisco power is potentially 100% renewable if sourced from CleanPowerSF.

In addition to the vehicles identified above, there are approximately 1,750 light-duty pickups in the fleet, some of which may be suitable for replacement by a PEV in a different form factor. In addition to the pick-up inventory, the City fleet has approximately 2,700 trucks in total (including approximately 950 medium and heavy duty vehicles), some of which may be replaceable by PEVs as new models enter the market with equivalent capabilities and TCO. Finally, 276 non-pursuit police vehicles were included in the analysis above. These vehicles averaged 15 years old with operating costs of $0.75 per mile, and they account for more than 300 of the replacement candidates. Additional analysis will be required to determine which of these may be replaceable by PEVs now in the market.

As noted above, the City's Clean Air Plan identifies a *100 percent zero emissions City fleet* as a goal for 2020, and the City's HACTO ordinance mandates replacement of vehicles by the cleanest possible replacement vehicle type. To ensure that these policy goals are implemented at the most rapid feasible pace, it is recommended that the City's fleet management team identify all potential financing strategies that could realize the TCO savings identified above within the City's budget constraints. Fleet consultants focused on financing strategy may help to identify new public and private funding streams and innovative strategies that could enable accelerated fleet replacement.[27]

3.3.1.5 PEV Strategies at San Francisco International Airport

SFO adopted its own Clean Vehicle Policy in February 2000.[28] The policy encourages the replacement of gasoline and diesel vehicles with cleaner fuels and vehicles. As in the City generally, the policy calls for use of the cleanest vehicles possible, with the caveat that some vehicle types are not available in electric versions. The Airport indicates that ground transportation sectors are operating virtually 100 percent with alternative fuels and vehicle types, including hybrid, electric, or CNG. Relevant vehicles include on-Airport shuttle buses, hotel shuttles, off-Airport parking courtesy shuttles, shared-ride vans, San Francisco city taxis. Aircraft ground service equipment (on-road and off-road) is addressed through separate policies described below.

The Airport has equipped each public garage with networked chargers, with most charging stations offering both Level 2 charging along with 110V outlets. As of 2016, SFO has 106 public parking stalls with access to electric outlets, plus 20 electrified employee spaces, with PEV enabled stalls shown on the map below. Although the Airport qualified for a DCFC grant with the BAAQMD, cost issues related to electrical capacity and siting constraints have thus far precluded installation of Fast Chargers at SFO.

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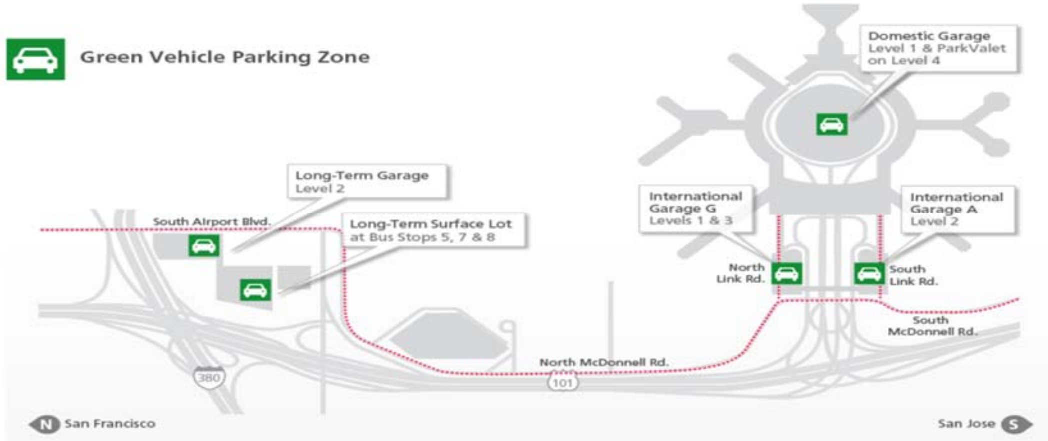
[27] One example is Gladstein, Neandross & Associates, which works with the City and County of Los Angeles and other large cities. Additional information is available at www.gladstein.org/gna-services/fleet-planning-analysis/

[28] *SFO Clean Vehicle Fact Sheet.* Accessed June, 2016, at: http://media.flysfo.com/sfo-clean-vehicle-policy_0.pdf

Figure 3-10: PEV Charging Facilities at SFO



Source: SFO Airport Website, accessed July 20, 2016 at: www.flysfo.com/to-from/parking/plugin-electric-car

SFO's Clean Vehicle Policy extends to airfield vehicles. The move to electrify aircraft Ground Service Equipment started over a decade ago. Now, approximately 300 BEVs are in service. Approximately 40 percent of the off-road aircraft service vehicle fleet uses 100 percent renewable power from SFPUC. Terminals 2 and 3E feature Airport-supplied electric chargers for all Ground Service Equipment needs. The Airport has also developed the AirTrain automated people mover to replace diesel-powered rental car shuttle buses linking the Airport's terminals, short-term parking garages, and Rental Car Center.

As part of ongoing City fleet policies and initiatives, airport vehicle operations (along with other City fleet operations) are regularly assessed for potential opportunities for accelerated electrification based on emerging PEV technologies and funding streams. These include, but are not limited to HVIP rebates and ARB Medium- and Heavy-Duty Demonstration programs. Areas of greatest potential at the Airport include possible electrification of some of the 300 diesel highway coaches now serving the Airport (involving many private operators), along with the 30 CNG transit buses, the 140 CNG minibuses, and the 300 vans running on CNG. Relevant PEV products newly emerging in these vehicle types in 2017 and beyond include robust, longer-range 22 to 45 foot commercial buses from BYD, Nohm, Proterra, Flyer, and others. These products, when combined with generous HVIP incentive, payments of up to $100,000 or more per vehicle, can provide opportunities for replacing CNG and diesel with all-electric buses at purchase prices that are competitive with diesel and CNG, with significant potential TCO savings.

3.3.1.6 San Francisco MTA Electrification and Clean Fleet Strategies

Following the directive of the San Francisco Board of Supervisors that each City Department must reduce 1990 emissions 20 percent by 2012, the SFMTA met its reduction target two years early, in June 2010. In the years since that milestone, Muni has continued to advance clean fleet implementation and emissions reduction. Initial success was accomplished through purchasing hybrid electric buses and using biodiesel, creating the cleanest multi-modal transit fleet in California. Further progress has been made by sourcing of carbon-free electricity from the SFPUC, which now powers 500 electric transit vehicles and over 26 facilities. Fuel use has decreased in the non-revenue vehicle fleet as well, due to fleet consolidation and hybridization, as reported in SFMTA's Departmental Climate Action Plan.[29]

In addition to its bus and train operating responsibilities, SFMTA is responsible for all modes of transportation within the City and County of San Francisco, including taxi and traffic and parking management. The SFMTA's 1,951 fleet vehicles include five transit modes (motor coaches, trolley coaches, light rail, historic streetcars, and cable cars), parking control vehicles, pooled staff cars, and maintenance support vehicles. As of 2016, 50 percent of the transit fleet is zero emission. Hybrid buses make up 38 percent of the motor coach fleet. A pilot program has been developed to transition 260 parking enforcement carts to PEV operation. The SFMTA also regulates a fleet of 1,891 privately owned taxis and paratransit vans. Fully 86 percent of the taxi fleet is hybrid electric--although PHEVs and BEVs are not yet widely deployed. Opportunities for BEV and PHEV taxi replacement are described further below.

SFTMA has been actively assessing both hydrogen fuel cell electric buses (FCEBs) as well as battery electric buses (E-Buses) that can operate without an overhead catenary system. However, to date, neither the FCEBs nor the E-Buses have been able to meet Muni's stringent operating requirements, which include navigating steep grades under heavy loads. Testing will continue as new products emerge on the marketplace with the capability to replace existing CNG or biodiesel buses.

3.3.2 PEVs in Private Fleets

3.3.2.1 Taxis

In February 2012, Mayor Lee, Lieutenant Governor Newsom, the SFMTA, the Department of the Environment, and San Francisco taxi industry leaders jointly announced that the City's taxis exceeded their 2008 goal of reducing per-vehicle GHG emission by 20 percent from 1990 levels by 2012.[30] In 1990, the average San Francisco taxi emitted 59 tons of GHG emissions per year vs. 30 tons just 12 years later, a 49 percent reduction. The fleet is now the cleanest in the U.S. and a global model for rapid emissions reduction. The City's taxi fleet included 821 vehicles in 1990 and has grown to 1,432 today, of which 89 are CNG, and 1,229 are hybrid electric. San Francisco has almost doubled the size of its taxi fleet while achieving a 10 percent total reduction in GHG emissions. Phasing in hybrid and CNG taxis into the taxi fleet has resulted in 35,139 metric tons of GHG reduction (the equivalent of taking 6,890 passenger cars off the road every year) and saved taxi drivers an estimated $11 million in fuel costs annually. Taxi drivers also report that

[29] San Francisco Municipal Transportation Agency, *FY 2013 Departmental Climate Action Plan Fact Sheet,* p. 3. http://sfenvironment.org/sites/default/files/fliers/files/sfe_cc_2014_mta_cap_fy1213.pdf

[30] The Green Taxi Ordinance was passed in 2008 and originally published as Police Code Section 1135.3. The SFMTA re-enacted the requirement as Transportation Code, Division II, Sections 1106(m) (emissions reductions) and 1114(e)(9)(A) (annual reporting requirement).

hybrids save on brake repairs due to the regenerative braking function. Although they are somewhat more costly up-front, the fuel savings significantly reduce TCO when compared to an ICE vehicle.

The SFMTA, in partnership with the Department of the Environment, encouraged clean taxi procurement by providing a Clean Air Taxi Grant incentive. Grants of $2,000 provided jointly by BAAQMD and the SFCTA were issued to purchasers on a first come-first served basis. A total of $518,670 in grant funds was dispersed to help purchase 251 hybrid vehicles.[31]

In June 2007, the Taxi Commission passed resolution 2007-21, which called for the SF taxi industry to reduce GHG emissions by 20 percent from 1990 levels and 50 percent from current levels by 2012, as well as to work to offset remaining emissions with investments in renewable energy or energy efficiency by 2015, and to move to a Zero Emissions taxi by 2020.[32]

As of 2016, there have not yet been cost-efficient BEVs available that can meet the demanding, all-day driving requirements for City cab operators. However, the introduction of the Chevy Bolt could be a game changer. Coming to market in late 2016, the Bolt will be available to fleet operators for close to $30,000 after incentives, with over 200 miles of range along with DCFC capabilities. In addition, the more expensive Tesla Model 3, likely to list in the high $30,000 range, will be available in late 2017 with somewhat more range (depending on battery options), and slightly faster recharging when connected to a Tesla Supercharger.

While it may be premature to determine if these specific vehicles will meet the price/performance requirements of City taxi companies, the introduction of these BEV models will be an important milestone on the way to the "viable Zero Emissions taxi" that the Taxi Commission has committed to deploy by 2020. Accordingly, the San Francisco Department of Environment, SFMTA, and the Taxi Commission will continue to coordinate closely on the PEV taxi opportunity, with the intention of accelerating electric taxi deployment as soon as viable models come to market.

3.3.2.2 Fleet Electrification for Transportation Network Companies (TNCs)

When former Mayor Newsom and the Board of Supervisors enacted the City's clean taxi policies in 2008, firms such as Uber, Lyft, GetAround, ZipCar, and other Ride Hailingand Car Sharing services did not exist or were in their infancy. As of 2016, however, a broad range of TNCs and Ride Sourcing enterprises, and a growing list of new on-demand transportation services, are rapidly gaining market share in the City.[33]

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[31] "San Francisco Taxis Surpass Emissions Goal", Office of the Mayor, City of San Francisco (website accessed June 2016), http://www.sfmayor.org/?page=684

[32] *Clean Air Taxi Background History,* SFMT. Accessed September 12, 2016 at: https://www.sfmta.com/sites/default/files/pdfs/CAT-BkgrndHistory.pdf

[33] *Robyn Purchia,* "Are Uber and Lyft putting San Francisco's health at risk?," SF Examiner, November 25, 2015, http://www.sfexaminer.com/are-uber-and-lyft-putting-san-franciscos-health-at-risk/

Many of these companies have rapidly evolving business models that have complex potential impacts on net emissions, compared to the "base case" mobility system that existed prior to the rise of TNCs and Ride Sourcing. Unfortunately, there is no readily accessible and definitive data on emissions from Uber or Lyft fleets, which are the largest TNC operators in the City. Given that more definitive data and studies of TNCs are ongoing, this AFV Plan will not make recommendations regarding regulations pertaining to TNC or Ride Sourcing operators as such. However, the Plan will note opportunities whereby the substitution of cleaner vehicles for existing TNC vehicles could provide emissions benefits based on a simple vehicle-for-vehicle replacement or upgrade strategy, regardless of the broader policy environment within which TNCs are operating.

Currently, TNCs are under no special City, state, or regional regulatory mandate with regard to clean vehicle operation. The CPUC (which regulates taxi and TNC operations statewide) would need additional state legislative authority to set emissions regulations for TNCs, according to CPUC testimony.[34] This assessment is also affirmed by Tim Papandreou, former Chief Innovation Officer at the SFMTA, which has indicated that the City does not have clear authority to regulate TNCs, nor adequate data to guide regulations.

Setting aside potential regulatory imperatives, both Uber and Lyft as well as other TNC operators have expressed interest in fleet electrification. Following the $500 million dollar GM investment in Lyft, drivers for Lyft will soon be able to rent General Motors PEVs for operating within the Lyft program. This program, named Express Drive, is similar to Lyft's partnership with Hertz, in which drivers in San Francisco and other locations can rent a vehicle on a weekly basis to drive for Lyft. However, the GM fleet will feature both the 2017 Chevrolet Bolt BEV and the 2016 Chevrolet Volt PHEV. Rental costs will differ depending on how much a person drives, but Lyft will cover the cost of rental for individuals who drive for more than 30 hours a week, essentially making vehicle usage free. Uber has a similar program with Hertz and Enterprise, but has not yet announced plans for a PEV option. The GM-Lyft partnership has also been announced as a prelude to deployment of an autonomous vehicle fleet that would likely be comprised of electric drive vehicles.[35]

Figure 3-11: 2017 Chevrolet Bolt BEV – Soon to be Available for Rent by SF Lyft Drivers

34 Ibid.

35 Tracey Lien, "Lyft and GM to rent electric vehicles to ride-hailing drivers," LA Times, July 12, 2016.

Source: CBS – SF Bay Area, “GM, Lyft to Test Fleet of Self-Driving Electric Taxis,” May 6, 2016, http://www.sfmayor.org/?page=684

3.3.2.3. Vanpools and the San Francisco Commuter Shuttle Program

According to the SFCTA, commuter shuttles in San Francisco transport 8,500 people daily, and load and unload at up to 125 designated locations in the City. Currently, these shuttle routes are served by fossil fueled vehicles. However, many of the routes could be served by PEVs (E-Vans and E-Buses), particularly if the routes were equipped with appropriate en-route Fast Charging. For those routes which may not be economically served by electric shuttles, use of renewable diesel or RNG could drive significant emissions reductions, including both GHG and criteria pollutants. Accordingly, developing an ultra-low emissions commuter shuttle transition strategy is a key recommendation of this plan. (See *Recommendation 1.6: Develop an E-Mobility Demonstration to include taxi, Car Share, Ride Hail, and commuter Vanpool companies where feasible and appropriate.*)

Notable new entrants in the world of commuter vanpools include Chariot, which crowdsources new commute routes in the City using a sophisticated mobile app, and Green Commuter, a LA-based electric vanpool operator now becoming established in the Bay Area. Green Commuter will be deploying new Tesla Model X and BYD model e3 EVs, which meet minimum capacity requirements for federal transportation subsidies for vanpools. The Green Commuter program design includes a novel element whereby the PEV utilized by the vanpool driver can be entered into a car share program at the employer worksite during the day, to be used by either the employer (as an extension of its own fleet), by employees for brief errands, or by broader car sharing network members by agreement with Green Commuter and the employer. Green Commuter has backup vehicles in the event of a breakdown or failure to return the vehicle in a timely manner.

Thanks to public agency and employer subsidies for commuter vanpools, PEVs in the Green Commuter program can be deployed to employer sites at little or no upfront cost to the employer, and ridesharing costs for the employee are typically much less than comparable costs for their own vehicle, with faster transit times than fixed route transit services. Additional perks for the driver include the possibility of keeping the PEV for personal use during the weekend. Deployment of the Green Commuter program at scale in a larger metro region depends on appropriately situated PEV charging. Because of the longer range batteries in the Model X (up to 280 miles of range) or BYD e3 (about 180 miles), it is possible to recharge the vehicle at just one end of most commutes. In the Green Commuter model, chargers are located at or near the employer site, at a park and ride lot, or another public site where charging privileges have been established for Green Commuter.

The SFMTA and SFCTA have recognized the potential for expanded commuter vanpools as a means to reduce both emissions and congestion. In 2016, the agencies launched a study assessing the feasibility of expanding existing employer vanpool programs based on a hub model with a limited number of pick up locations. The SFMTA and SFCTA are encouraging interested people to provide input into potential hub stop locations that will be evaluated as part of the study. As the assessment process advances, the potential GHG impact of expanding the city's commuter vanpools and utilizing electric vanpools will be assessed.

3.3.2.4 Accelerating Commercial and Consumer PEV Deployment via "Mobility-as-a-Service"

The Mobility-as-a-Service platform model makes vehicles available on flexible short-term leases, potentially on an hourly, daily, weekly, or monthly basis. In addition, the MaaS concept typically includes turn-key service and could potentially address charging infrastructure. Equipped with PEVs, MaaS platforms have the potential to introduce both fleet operators and consumers to the "electric experience." Further, the MaaS model has the potential to accelerate the use of PEVs in every kind of Ride Hailing application, from TNCs to conventional taxis and livery services. Finally, by utilizing the MaaS model as a platform for pilot testing and flexible leasing of E-Trucks and E-Buses, the MaaS approach has the potential to become a true "E-Mobility Accelerator," driving PEV adoption in both the light, medium, and heavy duty segments, and thereby accelerating the commercial scale-up of new E-Truck and E-Bus models that can rapidly reduce both GHG and criteria pollutants.

3.3.3 PEV Freight Applications

The new California Sustainable Freight Plan, developed by ARB and multiple state agencies, calls for 100,000 electric trucks to be deployed across the state by 2020.[36] This ambitious goal will likely be associated with substantially increased funding, as evidenced by the initial ARB proposal for a $500 million dollar allocation for Low Carbon Transportation in the 2016-17 California state budget.[37] Both the California Sustainable Freight Action Plan (finalized in July 2016), and the San Francisco Bay Area Goods Movement Plan[38] (released in February 2016), call for electrification of trucking and the establishment of low-emissions freight corridors and "zero emissions last mile" delivery strategies. San Francisco has already begun the complex planning and assessment process required to develop a potential congestion zone in the downtown core. The congestion zone concept has the potential to establish differential pricing policies that would advantage E-trucks and E-Bus in providing local goods and passenger movement in high-density neighborhoods now heavily impacted by diesel emissions and congestion. The PEV Readiness Plan recommends ongoing support of these planning efforts.

3.3.4 PEV Charging and Analytics in Fleets

3.3.4.1 Using Fleet Analytics to Optimize PEV Deployment

New PEVs in all vehicle classes, as well as cleaner conventional vehicles powered by fuels such as renewable diesel and RNG, are being introduced with increasing frequency. This requires fleet

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[36] *California Sustainable Freight Action Plan (draft*). Freight Action Plan's interagency website, accessed September 2, 2016 at: http://www.casustainablefreight.org.

[37] The California Air Resource Board 2016-17 proposal for Low Carbon Transportation Investments and the Air Quality Improvement Program (AQIP) Funding Plans serve as a blueprint for expending AQIP funds, describes the projects ARB intends to fund, and sets funding targets for each project. Details on approved (June 2016) allocations are available at http://www.arb.ca.gov/msprog/aqip/fundplan/fundplan.htm#2016-17

[38] *The San Francisco Bay Area Goods Movement Plan*. Metropolitan Transportation Commission, 2016. Accessed September, 2016 at http://mtc.ca.gov/our-work/plans-projects/economic-vitality/san-francisco-bay-area-goods-movement-plan

managers to re-consider AFV and PEV options on at least an annual basis. In the PEV domain, the new model introduction curve is beginning to accelerate rapidly as virtually all manufacturers in all segments begin the process of electrifying entire model lines. As of late 2016, available PEV models now include examples from nearly every class and type of vehicle, from high-performance motorcycles (Vectrix, Zero, et al.) to medium-duty cargo vans (Nohm, BYD), to heavy duty Class 8 tractors (Navistar, Nikola), to SUVs, cross-overs, pickups, vans, compacts, sports cars, luxury cars, and all-electric off-road vehicles and equipment. Given the rapidly evolving AFV and PEV market, fleet operators are advised to obtain the latest information on vehicle options and new technology demonstrations from organizations such as Plug-in America[39], which tracks all classes of EVs, and CalSTART[40], which focuses on medium and heavy duty vehicle development and demonstration across all the alternative fuel vehicle types.

Given the dynamism in the PEV and AFV marketplace generally, annual fleet planning "tune-ups" are essential to ensure rapid deployment of the most cost-efficient and environmentally sound AFV strategies. In addition to the constant introduction of new technologies, new fuels, and new price/performance data, fleet management strategies are evolving to drive more effective shared use of vehicles across departments and functions, and to enable fleet right-sizing with more sophisticated routing, telematics, service strategies, and other state-of-the-art fleet management practices.

Appropriate metrics are essential to drive the most economical and ecologically sustainable approach to low-carbon mobility. The goal for fleet managers should not be simply to raise the absolute numbers of PEVs procured, or even to increase the proportion of PEVs relative to conventional vehicles. Rather, the goal should be to ensure that mobility needs are satisfied with a minimum level of VMT and associated emissions. Regrettably, one-time grants and special incentives have in some cases led fleets to adopt PEVs in circumstances where they are not being deployed in the most efficient manner. Given that the CO2e generated through the manufacturing of a vehicle (known as "embedded carbon") is approximately half of the lifetime emissions of a vehicle, when fleets purchase a new PEV, it is essential to maximize displacement of VMT from fossil sources in order to make environmentally effective use of that investment, and "come out ahead" in a comprehensive carbon accounting framework.

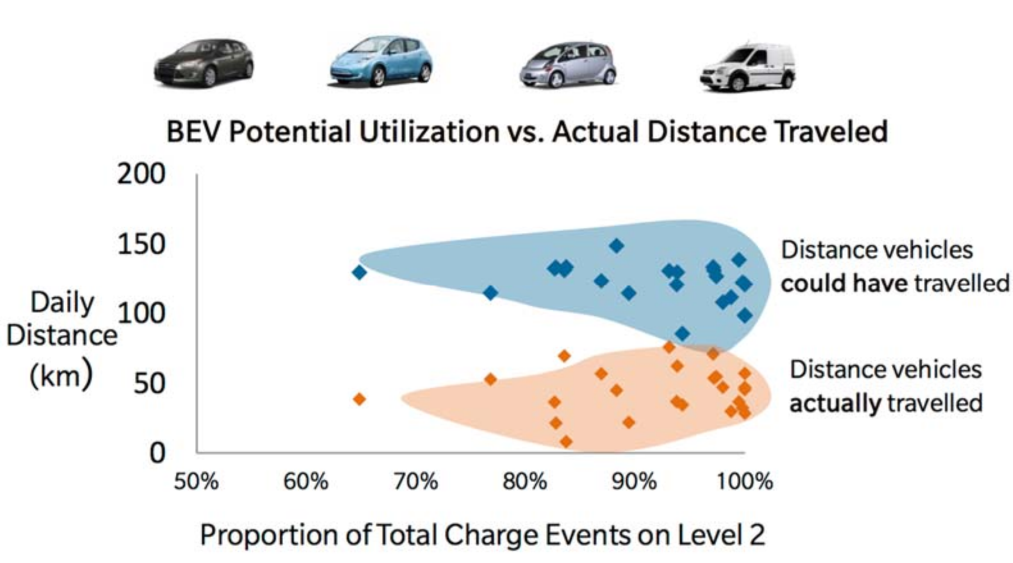
3.3.4.2 Impact of Charging Infrastructure on eVMT in Fleet Contexts

The potential return on investment for fleet electrification can depend significantly on the siting, right-sizing, and efficient use of charging infrastructure. Key variables that can increase PEV utilization and range include optimizing charging type and locations to maximize vehicle availability and eVMT. Developing and enforcing a clear "plug-in policy" whereby drivers plug in their vehicles once they reach their location or return to the fleet depot is an obvious requirement for sustaining high PEV availability. Regularly assessing potential new charging locations and strategies to determine en-route charging options is also needed to maximize

39 Plug in America. Accessed November 1, 2016 at: http://www.pluginamerica.org/
40 CalStart: Accessed November 1, 2016 at: http://www.calstart.org

utilization on longer routes. The chart below illustrates how different utilization rates can be enabled by strategic charging station siting.

Figure 3-12: Impact of Charging Patterns on BEV Utilization

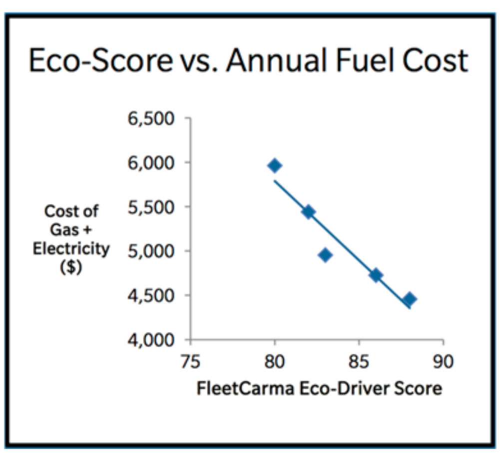


Source: Handbook to Improve Electric Vehicle Utilization in Your Fleet, FleetCarma, 2016, p. 4. Available online at:

http://www.fleetcarma.com/docs/Handbook-to-Increase-Electric-Vehicle-Utilization-in-Your-Fleet.pdf

Driver behavior affects range significantly in both BEVs and PHEVs. The following chart utilizes real-world data from a fleet that deploys Chevy Volts utilized by different drivers. The "Eco-Score" is a metric that correlates fuel and mileage data with driver behavior to arrive at a measurement of miles travelled per kWh of electricity, which can be converted to GGE to permit comparable scoring across BEVs, PHEVs, and ICE vehicles.

Figure 3-13: Impact of Driver Behavior on Fuel Cost



Source: Handbook to Improve Electric Vehicle Utilization in Your Fleet, FleetCarma, 2016, p. 4. Available online at:

http://www.fleetcarma.com/docs/Handbook-to-Increase-Electric-Vehicle-Utilization-in-Your-Fleet.pdf

E-Bus operators have also reported wide variation in efficient driving habits. According to the Antelope Valley Transit Authority, which is deploying the largest fleet of E-Buses in California, variation in driver behavior has resulted in a 2 fold differential range (miles per kWh) in the least efficient vs. the most efficient drivers. For all E-fleet operators, it is essential that training programs be developed that maximize efficient operator techniques specific to particular PEV model types.

3.3.4.3 Fleet Charging Strategies

Fleet vehicle charging options span the full range from Level 1, Level 2, and DCFC options. As with any commercial charging arrangements, fleet managers need to be cognizant of utility surcharges known as demand charges, as well as utility time-of-use rates, to select an optimum configuration for their needs. At depot sites where light-duty vehicles are likely to be stationary for 12 hours or more, Level 1 charging options may be most appropriate. For vehicles needing the fastest turnaround, as in demanding applications such as shuttle, taxi, or vanpool services, DCFC may be a priority need. It is important to note that it can be mutually advantageous for the general public and fleet operators to co-locate fleet charging where practical. Many fleet vehicles are gone most of the day and it may be feasible for visitors to occupy charging stalls at some locations, while contributing fees to defray EVSE costs.

3.4 Strategies for Accelerating Electrification

3.4.1 Accelerating Electrification Among Fleets

Fleet operators operating vehicles in the City are a key stakeholder group whose participation is needed to drive the sustainable mobility transition across the region. Fleets operating in San Francisco include vehicle operators of all types, including light, medium, and heavy duty vehicles, E-Bus, truck, and specialty vehicle operators such as refuse haulers and utilities. For fleet operators, the PEV use case is already compelling for many applications.

3.4.1.1 Local Government PEV Fleet Demonstration Project

Through the MTC funded E-Fleet Project, developed by the Bay Area Climate Collaborative with Alameda County, a total of 90 PEVs and 90 Level 2 chargers were deployed across ten Bay Area local government agencies. Partners included San Francisco (which received 14), Alameda County (26), Concord (10), Fremont (2), Marin Municipal Water District (1), Oakland (3), San Jose (3), Santa Rosa (4), Sonoma County (22), and Sonoma County Water Agency (5). The evaluator's program assessment found that PEVs substantially reduced operating costs on a per-mile basis. However, many suggestions for fine-tuning deployment locations and vehicle applications were identified to maximize eVMT and return on investment.[41]

[41] *Climate Initiatives Program: Evaluation Summary Report,* Metropolitan Transportation Commission, Prepared by: ICF International, July 2015. pp. 42-43.

3.4.1.2 Recommended Steps to Accelerate Clean Fleet Transitions

Given the expanding range of choices in the domains of AFVs and low-carbon mobility generally, it is important that fleets utilize analytic tools and strategies that enable "apples to apples" comparisons across fuel types. Specifically, it is recommended that fleet managers:

- **Develop fuel efficiency targets** which are convertible to common energy and emissions factors (e.g., megajoules of energy per mile and grams of CO2e per mile)
- **Analyze vehicle performance** of conventional vehicles vs. AFVs with regard to specific duty cycles, taking into account vehicle operating range, charging needs, and likely annual mileage to arrive at a comprehensive life cycle assessment (LCA) of operating costs
- **Develop a comprehensive green fleet plan** that includes goals, milestones, staff responsibilities, commitments from top management, and monitoring and implementation strategies
- **Include attention to training and behavioral strategies** in successfully transitioning to an electric fleet, as driving technique variations ("lead foot vs. hyper-miler") can account for a 2x or more difference in fuel economy among drivers on the same route
- **Assess opportunities for joint procurement** with other public and private fleet operators. The state Department of General Services has already created a common joint procurement mechanism, and the San Francisco and East Bay Clean Cities Coalitions have current information on clean fleet procurement options.

3.4.2 Accelerating Private PEV Adoption

3.4.2.1 Ride and Drive Campaigns

Ride and Drive campaigns can be highly effective in driving PEV adoption. In 2015, the EV Alliance and Bay Area Climate Collaborative partnered with MTC and the Bay Area EV Strategic Council to develop *Experience Electric – The Better Ride*. This large-scale regional ride-and-drive campaign produced 21 events in eight Bay Area counties, resulting in an 11 percent conversion to sales for individuals that participated in a PEV test ride. At the free events, attendees were able to test drive PEVs in a casual environment, free from sales pressure. Expert "EV Owner/Ambassadors" were available to answer participants' questions about available models, home charging, rebates, tax incentives, and related issues. This approach, combined with the aggregation of PEV models in one location, has proven effective in driving PEV sales across the country. An ongoing Ride and Drive campaign is a key element in the proposed regional strategy for accelerated regional PEV market development discussed later in this Chapter. Funding for Ride and Drives are available through Energy Commission PEV Plan Implementation funds, and potentially through the planned VW settlement or other industry investments.

3.4.2.2 Preferential Access for PEVs in HOV Lanes and "Green Lanes"

Preferential access for PEVs in HOV lanes has proven to be a strong incentive for to consumers procure PEVs. Vehicles with "white stickers" from the California DMV routinely sell for substantially more than vehicles without these stickers. In addition to state preferential access policies for PEVs in HOV lanes, there may be additional opportunities for regional prioritization of PEV mobility. Bay Area transportation agencies, led by the MTC, are currently developing a 550-mile network of *Bay Area Express Lanes* that combine HOV prioritization with dynamic tolling. The Express Lanes Network will increase freeway capacity by encouraging free flow in the HOV lane, providing new funding for system-wide improvements, and limiting access to Express Lanes by subjecting single occupancy vehicles to real-time, dynamic tolling to ensure that minimum Express Lane speeds are maintained. The development of the tolling and monitoring system will provide opportunities for regional and local transportation agencies to experiment with differential tolling for BEVs as a further incentive for PEV adoption.

Planned for completion in 2035, MTC will operate 270 miles of the 550-mile Bay Area Express Lanes network. MTC will convert 150 miles of existing carpool lanes to Express Lanes and add 120 miles of new lanes. In 2015, MTC began construction on its first Express Lane project with the conversion of the carpool lanes on I-680 between Walnut Creek and San Ramon. MTC's next projects are on I-880 in Alameda County, I-680 between Walnut Creek and Martinez, and I-80 in Solano County. Lanes are currently open on I-580 in Dublin, Pleasanton and Livermore, I-680 southbound from Pleasanton to Milpitas, and on State Route 237 between Milpitas and San Jose. As shown in the map and color-coded chart below, approach lanes to the San Francisco, Oakland Bay Bridge are among the Express Lanes slated for future development.

As part of the ongoing planning for Express Lane expansion, SFCTA, the Department of Environment, and sister agencies could engage with MTC planners and other Congestion Management Agency to assess the feasibility of creating differential tolling levels for EVs in the HOV lanes. This would not amount to "free access" to HOV lanes (which as demonstrated in the existing Caltrans white sticker program can quickly lead to unacceptable levels of congestion in the HOV lane). Rather, differential tolling would be dynamically priced to ensure continued free flow in the HOV lane while providing a sufficient discount to incentivize accelerated PEV adoption. At some point, HOV lane access by single-occupancy vehicles could potentially be restricted only to BEVs, thus further incentivizing BEV utilization.

While HOV lanes have been considered a "finite resource" in the region to this date, future feasibility studies could assess the potential to establish lanes that combine HOV and PEV preferential access policies with an integrated approach known as Green Lanes. As PEV deployment increases, Green Lanes could be expanded to include one or two freeway lanes, which would raise additional revenue for transportation improvements (especially public transit), while further incentivizing PEV utilization.

3.5 Vehicle Grid Integration Opportunities

The administration of Governor Brown, as well as the CPUC, Energy Commission, and the California Independent System Operator (CAISO), have all identified the development of a commercial VGI ecosystem as a key strategy for enabling the state's goal of achieving 80 percent market share for PEVs by 2050, and deploying 1.5 million PEVs by 2025. Accordingly, the agencies named above collaborated with PEV industry stakeholders to develop a *Vehicle-Grid-Integration*

(VGI) Roadmap, published in February 2014, that lays out a series of tasks for development of a commercial VGI ecosystem in California. The definition of VGI developed by the CAISO is as follows:

> *The term vehicle-grid integration or VGI, as used in this roadmap, encompasses the ways PEVs can provide grid services. To that end, PEVs must have capabilities to manage charging or support two-way interaction between vehicles and the grid. Managed charging refers to the technical capability to modulate the electric charging of the vehicle through delay, throttling to draw more or less electricity, or switching load on or off. Two-way interaction refers to the controlled absorption and discharge of power between the grid and a vehicle battery or a building and a vehicle battery.*
>
> *VGI is enabled through technology tools and products that provide reliable and dependable vehicle charging services to PEV owners, and potentially additional revenue opportunities, while reducing risks and creating cost savings opportunities for grid operators. Such tools might include technologies such as inverters, controls or chargers, or programs and products, such as time of use tariffs or bundled charging packages.*[42]

The practical benefits of VGI for PEV ecosystem development are significant, especially in the fleet domain. VGI encompasses the concept of "smart charging" or "managed charging," whereby utilities provide signals to PEV drivers and fleets to modulate charging in response to grid conditions. In smart charging scenarios now being pilot-tested by PG&E and other utilities, PEV drivers are being paid a premium to initiate charging when there is an oversupply of generation capacity (which most often occurs with solar generation peaks in the early afternoon and wind generation peaks at night), or to modulate charging down or off when demand peaks, typically in the four pm to nine pm timeframe, depending on seasonal and locational variations. In a smart charging program, PEV drivers still have control over their desired battery state of charge by providing user-defined preferences, such as "I need my battery at an 80 percent state of charge by five pm tonight." However, by providing flexibility to automatically modulate charging at other times, PEV owners can be eligible for payments from the utility or grid operator.

Existing consumer vehicles are not typically equipped for two-way energy flow from the vehicle to the grid (V2G). Therefore, most VGI services are limited to uni-directional power modulation from the grid to the vehicle, known as V1G. However, an increasing number of E-Trucks and E-Buses are now entering the market that (along with VGI compliant PEV Charging stations) make it possible to provide Vehicle-to-Grid energy flow. V2G capabilities have been extensively tested by research institutions and industry groups for nearly a decade. Prominent VGI pioneers include the University of Delaware, EPRI, the Department of Defense, the National Renewable Energy Laboratories, the CAISO, other regional grid operators, Energy Commission, and

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[42] *California Vehicle-Grid integration (VGi) Roadmap: Enabling vehicle-based grid services,* California Independent System Operator, February 2014, p. 3. http://www.caiso.com/documents/vehicle-gridintegrationroadmap.pdf

numerous utilities, auto OEMs, charging companies, and other stakeholders. In dozens of research projects, the capacity for PEVs to create economic value for utilities and PEV drivers has been demonstrated.

One of the core benefits that PEVs can provide when configured in a two-way V2G configuration is known as "Frequency Regulation," which are small shifts in power levels (known as "regulation up" or "regulation down") that the grid requires on second-by-second basis to maintain a frequency balance (at 60 hertz) between energy demand and supply on the grid. Historically, this balance has been maintained by other generation resources, such as fossil natural gas or hydropower plants. However, it has been demonstrated that PEVs as well as stationary battery storage devices are well-suited to provide this very short-duration and relatively shallow and infrequent cycling of battery resources to provide either up- or down-regulation (charging or discharging of the battery) as needed to balance the grid. When appropriately managed in the context of larger aggregations of PEVs, this relatively shallow and infrequent pattern of battery cycling has been shown to have a minimal impact on battery life, with economic benefit outweighing degradation impact.

However, VGI energy services can only achieve commercial viability when vehicles are aggregated into a controllable network of a certain minimum size. In the case of the CAISO, the minimum size required for wholesale market participation has been 500kW of controllable battery capacity per sub-Load Aggregation Point (sub-LAP), which is a location on the grid associated with a particular substation and a specific Locational Marginal Price for electricity. A sufficient VGI aggregation could be achieved by as few as 75 E-Trucks or E-Buses parked in a depot setting (with at least 100KwH batteries per vehicle), or approximately 150 light-duty BEVs (with 75 kWh batteries), depending on many variables regarding vehicle availability to the grid, location, fleet duty cycles, etc. Vehicles in a VGI aggregation can also be combined with fixed battery storage arrays to provide the necessary CAISO minimum for participation of storage resources on the wholesale market.

According to Energy Commission-sponsored studies and other technical papers referenced in the *California VGI Roadmap,* the value of V2G services, including but not limited to Frequency Regulation, can be as much as $1,000 per vehicle per year or more. This assumes that PEVs participating in a VGI aggregation are parked in a location with a V2G compliant charger, and that they have two-way energy flow capability. The promise of larger revenue flows, while still somewhat speculative, is so large that it may be sufficient to fully fund the cost of the PEV battery itself over the life a PEV without substantially degrading battery life. As V2G capable PEVs become deployed in the millions of units, as projected for California in the 2020s, they could serve in the aggregate to fill the existing valleys of electricity supply and reduce the peaks of demand, also known as the "duck curve." In this scenario, PEVs providing grid services could enable payments to drivers and fleet managers worth hundreds of millions of dollars per year in the aggregate, as reduced grid costs and other benefits are monetized in a fully developed commercial VGI ecosystem.

Most industry observers believe it will be several more years before PEV OEMs equip light-duty vehicles with full V2G capabilities, although Japanese manufacturers (including Nissan, Honda, and Mitsubishi) have already incorporated V2G power capabilities in PEVs for sale in their domestic market. In addition, the Toyota Mirai FCEV has a "Vehicle to Home" feature that enables back-up power to be provided by the vehicle to the home in the event of a grid outage. The Japanese have led the way in V2G commercial deployment in large part because V2G capabilities can be used to provide back-up power to homes, buildings, and appliances in an emergency scenario such as an earthquake. This capability was demonstrated in the context of the Fukushima disaster, when Nissan Leafs and other PEVs provided backup power for streetlights and buildings for several days while the grid was down.

Beyond the Japanese light duty vehicle context, manufacturers of medium and heavy duty E-Trucks and E-Buses are also building in V2G capabilities in their current vehicles, because the revenue opportunities and operational flexibility afforded by V2G-enabled vehicles has near-term commercial potential and operational benefits for fleet managers needing "exportable power" for appliances and other services.

Given the potential for VGI services to add value for PEV drivers, the AFV Readiness Plan recommends that the City of San Francisco join with other regional stakeholder to develop a VGI strategy and state funding for local demonstration projects that could yield meaningful benefits to PEV drivers and fleet operators.

3.6 PEV Funding Opportunities

3.6.1 Regional Funding Sources

3.6.1.1 Energy Commission Funding

Energy Commission grant opportunities for PEV infrastructure are issued annually based on priorities developed for each state fiscal year (July 1 through June 30th). Specific guidelines are not typically announced in advance, but are presented in each solicitation as it is published. Solicitations in the 2015-2016 grant cycle focused on inter-regional Fast Charge corridors, while 2014-15 grants focused on workplace and destination sites. It is expected than an MUD-focused solicitation will likely be issued as part of the FY 2016-17 cycle. Stakeholders in the City will be most likely to succeed in these solicitations by identifying target sites in advance, partnering with previously successful organizations, and developing local incentives and policies that complement state investments and demonstrate strong local match.

3.6.1.2 BAAQMD Funding

Air District grants in the Bay Area and elsewhere are typically available for a time-limited period (usually less than a year), on a first-come, first-served basis until funding is exhausted, after which there is typically a pause until additional funding is available, usually with new terms and conditions. In the Bay Area, the most recent PEV charging station rebate program, known as Cycle 2 of the *Charge!* Program, provided incentives for installation of charging stations along transportation corridors, and in workplaces, MUDs, and destination sites. The program's intention is to provide charging infrastructure to support the nine-county regional PEV deployment goal of 110,000 PEVs by 2020 and 247,000 PEVs by 2025. The *Charge!* program was funded through the Transportation Fund for Clean Air Regional Fund. An initial allocation of $5 million was awarded to qualifying *Charge!* projects on a first-come, first-served basis. Increased funding was available for projects that included onsite wind or solar power generation. The program closed on January 15, 2016, but similar programs are likely to be available again in future years.[43]

3.6.1.3 MTC

The MTC has also developed PEV ecosystem investment strategies as part of its Climate Initiatives Program, aligned with requirements of Senate Bill 375 (SB 375), which requires regional transportation and planning agencies to reduce per-capita GHG. In 2009, MTC programmed $80 million in five funding categories: TDM, Safe Routes to School, bicycle projects, PEVs, and other project types (e.g., Shore Power). Evaluation of the various strategies was done on a "snapshot" basis in 2014, without addressing the GHG savings potential of PEVs over time. Thus, evaluators cautioned that the cost effectiveness metrics for PEVs should not be considered to be a definitive measure of efficiency in GHG reduction relative to other strategies. That said, the relative funding and GHG scoring of the program is noted in the chart below.

[43] For more information, and to sign up for future program alerts, see the BAAQMD PEV program website at http://www.baaqmd.gov/grant-funding/businesses-and-fleets/charge.

Table 3-13: MTC Climate Investment Investments in PEVs vs. Other GHG Strategies

Project Title	Type	GHG emission annual reduction (tons)	Total project costs (as of Dec 2014)	Total MTC funding	Cost Effectiveness ($/ton CO2e reduced)
Connect, Redwood City! [a]	TDM	1,945	$921,386	$1,487,000	$416
Shore Power	Other	534	$9,070,000	$3,000,000	$849
Cold In Place Recycling [b]	Other	493	-$1,221,290	$2,000,000	-$2,477
goBerkeley	TDM	317	$3,100,000	$2,000,000	$9,792
Bay Area School Transportation Collaborative	SRTS	297	$996,447	$867,000	$3,355
Regional Safe Routes To School (5 counties)	SRTS	210	$10,801,000	$15,000,000	$17,124
BikeMobile	Bicycle	201	$565,000	$500,000	$2,811
Local Government EV Fleet	EV	172	$2,879,694	$2,445,000	$1,679
Bike-Sharing Pilot Program	Bicycle	79	$7,000,000	$4,300,000	$17,643
Green Ways to School	SRTS	57	$427,046	$383,000	$7,491
Dynamic Rideshare Programs Demonstrated in Three Counties	TDM	10	$1,750,000	$2,400,000	$86,292
San Francisco Integrated Public/Private Partnership TDM Program	TDM	5	$858,000	$750,000	$171,600
Tribal Community Sustainable Transportation Pilot	EV	3	$409,676	$376,000	$12,274
eFleet: Car Sharing Electrified	EV	0.9	$847,090	$570,000	$100,745
Enhanced Automatic Vehicle Locator System	Other	NQ [c]	$1,483,015	$600,000	N/A
SRTS Education and Encouragement School Route Maps	SRTS	NQ [c]	$249,685	$335,000	N/A
Innovative Bicycle Detection Systems	Bicycle	NQ [d]	$1,710,000	$1,500,000	N/A
"Experience Electric" Campaign	EV	NQ [c]	$845,000	$925,000	N/A
Smart Driving Pilot	Other	NQ [c]	$400,000	$400,000	N/A
Total		**5,165**	**$43,091,749**	**$39,838,000**	

Note (a): GHG reduction and cost effectiveness reflect mid-point of upper and lower bound estimates.
Note (b): Negative figures indicate cost *savings*. The Cold in Place Recycling project resulted in a net cost savings because the process used had a lower cost than traditional paving methods.
Note (c): Not quantified. Project resulted in small GHG reductions but they could not be accurately measured.
Note (d): Not quantified. Project was not completed.

Source: *Climate Initiatives Program: Evaluation Summary Report,* Metropolitan Transportation Commission, Prepared by: ICF International, July 2015, p. 2.

The MTC investment of $80 million in the Climate Initiatives Program was part of a larger commitment by the agency to invest approximately $120 million in the 2010 through 2022 period. Following the initial $80 million allocation, the MTC has projected investment of an equivalent amount between 2022 and 2035, for a total of nearly $240 million for GHG reducing projects. These investments (largely sourced from federal Congestion Management and Air Quality fund) are intended to achieve a reduction of at least 6.5 percent in regional transportation GHGs per capita, as part of the overall regional commitment to a reduction of 16 percent GHG per capita by 2035. To summarize, the first three rounds of MTC investment include the following tranches:

- **First Round: $80 million** authorized in 2010 (focused on non-PEV projects)
- **Second Round: $20 million** over four years starting in 2014, which included PEV procurement for public agencies and charging infrastructure grants awarded in conjunction with BAAQMD, as well as the Experience Electric campaign. These are summarized in Table 3-12 above.
- **Third Round: $22 million** over five years starting in 2017. These funds are not yet allocated but may include EVSE, TDM strategies such as car sharing and vanpools, and

other GHG-reducing projects yet to be identified.[44]

3.6.1.5 The City's Transportation Expenditure Plan

A new Transportation Expenditure Plan failed by a slim margin to achieve the necessary 2/3 majority vote on the November 2016 ballot. The proposed 0.75% City sales tax increase was expected to yield new revenues of $100 million per year for transportation improvements across all modes and service types. A new expenditure plan may be developed in future years that would create opportunities for bringing additional PEVs and AFVs into City and Muni fleets, and provide support for other AFV initiatives in the future. An inter-agency process involving San Francisco Department of Environment, SFMTA, SFCTA, and other key stakeholders will be required to determine which elements of PEV and Alt Fuel Vehicle ecosystem development (including both vehicles and fueling infrastructure) could be resourced through a future Transportation Expenditure Plan.

3.6.1.6 Potential for Future Regional Level Climate Action Funding

A new regional-level funding mechanism pioneered by the recent Measure AA for Baylands restoration may also be politically feasible as a means to provide additional support for regional low-carbon transportation strategies. On June 7, 2016, voters across the nine Bay Area counties voted to approve the *Clean and Healthy Bay Ballot Measure,* which will generate approximately $25 million per year, totaling $500 million over 20 years, to fund projects to protect and restore San Francisco Bay. The vote for Measure AA surpassed the required two thirds majority for tax measures by achieving 69 percent support across the region.

Measure AA is entirely focused on climate *adaptation* (through wetlands restoration), rather than *mitigation* through emissions reduction. However, the relatively narrow focus of Measure AA raises the prospect that a *complementary measure* could be developed focused on direct emissions reduction, potentially with *clean mobility powered by clean energy* as a key strategy. Enabling state legislation, similar to the statute creating the Bay Restoration Authority, would likely be needed to chart a legal path for development and governance of a regional funding measure focused on GHG mitigation.

Given the significant funding that could potentially be raised through a complementary climate-related ballot measure, the City may wish to partner with a coalition of organizations that will be exploring a regional emissions mitigation measure modeled on the success of Measure AA.

3.6.2 VGI Grant Opportunities

Because of the many potential benefits provided by "grid-enabled vehicles" and VGI services, the Energy Commission and ARB, utilizing the Electric Program Investment Charge (EPIC) funding mechanism, have invested nearly $30 million in VGI demonstration projects in recent years. These include projects in every major utility territory, including several projects in the greater

[44] Plan Bay Area 2040 - MTC Climate Initiatives Program Fact Sheet, accessed October 12 2016 at http://planbayarea.org/file10306.html

San Francisco Bay Area. Building on this foundation, a VGI-related grant solicitation was held in late 2016, and another may be funded in the 2019- 2020 timeframe. To compete effectively in future solicitations, it is recommended that the City explore a collaborative effort with other jurisdictions and industry stakeholders as appropriate to develop a VGI strategy and program that would enable relevant fleets to demonstrate participation in the grid services market, and enable payments to PEV drivers for smart charging and VGI services. Project elements could include development of:

- **a VGI-enabled microgrid** that would include V2G capable vehicles, additional V1G fleet vehicles configured for smart charging, and integration of stationary energy storage and distributed generation (largely PV) to enable emergency operations centers to meet emergency and disaster resilience needs
- **"Smart charging" and demand response (DR) program integration with local utilities**
- **Integration with the CAISO wholesale grid service markets** via linkage of V2G enabled PEVs with stationary storage aggregations of 500kW (meeting CAISO requirements for market participation)

Key outcome goals of a successful VGI project could include:

- Integrating key elements of a functioning VGI commercial ecosystem in California with scalable business processes that can accelerate commercial V2G initiatives
- Establishing a commercial value proposition that is attractive to fleet operators
- Demonstrating the key role of VGI-enabled vehicles and microgrids in meeting regional disaster recovery and resilience needs, with a focus on emergency operations centers.

Project Partners could include locally based research institutions such as Lawrence Berkeley National Labs and technical leaders in the EV and EVSE industry.

3.7 Key Recommendations for PEV Deployment

The following recommendations define high-level actions that public and private fleet managers, as well as AFV stakeholders generally, can take to assess the potential role of PEVs in advancing their organization's economic and environmental goals.

Recommendation	Next Steps
1. Develop strategic partnerships to drive new funding for EVSE deployment and PEV programs.	▪ Building on strategies in the San Francisco AFV Readiness Plan and 2016 U.S. DOT Smart City Challenge/Vulcan proposal, pursue partnerships that attract funding from regional, state, federal, and private sources. ▪ Leverage San Francisco's status as a Clean Cities Coalition, U.S. DOE Climate Action Champion, U.S. DOT Smart City Challenge finalist, and its membership in the Pacific Coast Collaborative and Carbon Neutral Cities Alliance.

Recommendation	Next Steps
	▪ Leverage and/or create new partnerships with key Bay Area local governments to achieve statewide ZEV program goals. ▪ Partner with CleanPowerSF to create local incentive programs that accelerate deployment of PEVs and EVSE. ▪ Leverage partnerships with regional, state, and federal agencies, including the MTC, BAAQMD, ABAG, U.S. DOE and U.S. DOT, Energy Commission, ARB, and CalTrans. ▪ Leverage existing programs and best practices to accelerate EVSE and PEV adoption including U.S. DOE's Workplace Charging Challenge and EV Everywhere programs and California PEV Collaborative's (e.g., Veloz) best practices guides.

Recommendation	Next Steps
2. Collaborate with industry stakeholders to accelerate deployment of electric light, medium and heavy-duty vehicles.	▪ Explore partnerships with OEMs and other stakeholders including but not limited to delivery companies, vanpool and commuter shuttle providers, TNCs; and car sharing firms based on the project descriptions included in the City's 2016 U.S. DOT Smart City Challenge/Vulcan proposal. ▪ Work with internal stakeholders (e.g., SFMTA, SFPUC) to scope and develop pilot projects that support PEV deployment paired with charging solutions in taxi fleets, hourly rental car services, TNCs, vanpool/commuter shuttles, and car share services. ▪ Leverage CVRP, as well as federal, state, and regional grant funds. ▪ Create projects that pair a consumer demand pipeline with supply side product solutions (e.g., aggregated procurements). ▪ Conduct consumer awareness and training events for medium-duty fleets operating in San Francisco. ▪ Assist medium-duty fleets operators in pursuing funding opportunities for vehicles and charging equipment through the HVIP and future ARB solicitations. ▪ Coordinate with PG&E to match EVSE investments with site hosts, including workplaces and MUDs.
3. Develop project proposals that seek state support for the installation of publicly available EVSE at higher utilization locations	▪ Conduct assessment to identify optimal locations for new and or expanded publicly available charging (e.g., Level 2 and DCFC). ▪ Identify public/private partnership opportunities to support project development in or near high-utilization public and private sector locations, including areas with high concentrations of MUDs, workplaces, retail centers, etc. ▪ Work with internal stakeholders (e.g., SFMTA, SFPUC, ADM) to identify funding opportunities[45] and develop procurement solicitations.

[45] For more information on Energy Commission EVSE investment programs, see the Investment Plan Update for the Alternative and Renewable Fuel and Vehicle Technology Program website at: http://www.energy.ca.gov/altfuels/2015-ALT-01/index.html.

Recommendation	Next Steps
4. Support strategy for accelerated adoption of PEVs and EVSE at SFO, Port of San Francisco, and other City Departments	▪ Partner with enterprise departments and the City Administrator's office (ADM; municipal fleet) to identify policies, technologies, timelines, and funding opportunities to electrify equipment and vehicles. ▪ Work with ADM's office to evaluate potential to reach 100 percent PEV light duty sedan procurement by 2020.
5. Develop consensus among Bay Area municipalities on transformative fleet procurement goals and pursue collaborative procurement strategies.	▪ Lead convening of regional local governments to develop transformative fleet procurement goals (e.g., 100 percent annual procurement of light duty fleet PEVs by 2020). ▪ Based on outcome of West Coast Mayor's Fleet Request for Information, coordinate engagement of local government and other regional stakeholders in collaborative procurement effort to reduce the cost of fleet PEV acquisition and complexity of financing options.
6. Support ARB's California Sustainable Freight Plan and MTC's Bay Area Goods Movement Plan.	▪ Explore local actions including policy support and/or development, and pilot programs that work to electrify the movement of goods in San Francisco to eliminate diesel emissions and truck congestion.

Recommendation	Next Steps
7. Maximize deployment of electric buses in the San Francisco Unified School District (SFUSD), commuter and shuttle service applications.	▪ Provide technical assistance to stakeholders (e.g., SFUSD, AC Transit, private sector companies) in assessing the feasibility of integrating electric buses into their fleet vehicle contracts. ▪ Collaborate with partners like the Business Council on Climate Change and local tour operators to support information dissemination on the viability of electric buses. Work to understand perceived and actual constraints and develop solutions to remove barriers. ▪ Develop vehicle-grid integration (VGI) pilot projects to understand the utility coordination requirements and other technical aspects required to build the business case for electric buses operating in San Francisco. ▪ Assess feasibility of developing group procurement initiatives to lower the cost and complexity of acquiring electric buses. ▪ Leverage ARB, Energy Commission, and BAAQMD funds to enable deployment of necessary depot-based and on-route fast charging to support electric bus charging requirements.
8. Create zero emission freight delivery zone/corridor pilot project	▪ Work with stakeholders to assess feasibility of creating zero emission freight delivery zones/corridors. Key partners include but are not limited to neighboring local governments, SFMTA, SFCTA, MTC, and the Ports of Oakland, San Francisco, and Richmond.
9. Accelerate deployment of medium duty electric trucks through "Mobility-as-a-Service" Platform	▪ Evaluate the feasibility of OEMs establishing a MaaS platform, leveraging state funding via HVIP. ▪ Assess opportunities for MaaS platform to create flexible, low-cost, short-term leases; pilot financing model as a strategy to deploy medium-duty electric trucks in fleets operating in San Francisco. ▪ Leverage ARB, Energy Commission, and BAAQMD funds to enable deployment of necessary depot-based and on-route fast charging.

Recommendation	Next Steps
10. Accelerate adoption of electric scooters and bikes for personal use and shared business models.	▪ Partner with internal and external stakeholders, including SFMTA, bike coalitions, community based organizations and affinity groups to conduct outreach and education. Organize ride and drive events to accelerate personal adoption of these vehicle alternatives. ▪ Work with regional agencies (e.g., MTC, BAAQMD) to pilot incentives for electric bike and scooter adoption. ▪ Support development of public and/or private business models that integrate these electric alternatives to vehicles to provide first/last mile transportation solutions.
11. Build a San Francisco PEV awareness campaign	▪ Increase awareness of existing incentives for PEVs and charging infrastructure among car owners ▪ Work with car rental, car share and ride share companies to highlight PEV options in their fleets and among their network of drivers. ▪ Partner with automobile dealerships in and supplying to San Francisco to position PEVs and available incentives.
12. Develop grid integration road map and strategies that influence charging patterns to optimize use of renewable energy and shape load.	▪ Develop City of San Francisco grid integration roadmap that models locational demand for charging infrastructure and opportunities/constraints on the utility grid. ▪ Coordinate with local utilities to develop pilot programs that incentivize driver-charging patterns to provide ancillary grid services. ▪ Pursue state, federal, and other funding sources.
13. Build load for existing utility renewable electricity supply programs to power PEVs in San Francisco.	▪ Work with SFPUC to develop strategies that engage developers, property owners, and managers in enrolling in CleanPowerSF or becoming a SFPUC Enterprise customer. ▪ Work with PG&E to engage property owners in PG&E's EVSE and PEV rebate programs.

Recommendation	Next Steps
14. Establish citywide MUD goal for EVSE.	▪ Define MUD charging deployment goals with input from Energy Commission-funded MUD study ▪ Develop outreach plan that includes online information connecting property owners/managers to resources, develop and hold educational workshops. ▪ Support actions to extend SB 2565 to include tenant-installed PEV charging in rent controlled units. ▪ Identify Energy Commission funding to support MUD EVSE pilot projects that integrate Distributed Energy Resources (DERs) including solar photovoltaics (PV) and energy storage.
15. Identify barriers and facilitate solutions that assist private sector MUD EVSE operators in co-locating EVSE with other DER solutions	▪ Work with internal and external stakeholders, including local utilities, to develop solutions that accelerate deployment of EVSE paired with other DER solutions (e.g., rooftop PV and/or energy storage).
16. Align building codes	▪ Address state and local barriers to charging infrastructure deployment in building codes and other policies. ▪ Streamline permitting for EVSE installations in single-family homes and MUDs per state requirements.
17. Evaluate traffic congestion data and develop proposals for congestion pricing in priority areas of the City to improve air quality and accelerate market transformation of PEVs.	▪ Collaborate with SFMTA and SFCTA to assess data and key planning process and policy steps that lead to 4. Congestion pricing zones with preferential pricing/access for PEVs. 5. Preferential street parking zones for PEVs and PEV car share vehicles, and explore other fee exemptions. 6. HOV lane expansion in combination with transit lanes.
18. Develop financial incentives to support PEV adoption and fuel displacement.	▪ Analyze methods for pricing in environmental costs of owning, parking, fueling and operating ICE vehicles in San Francisco to discourage their use where economical alternatives exist. ▪ Identify ways to reduce the costs of owning, parking, charging and operating PEVs in San Francisco, especially in tandem with clean transit improvements.

Recommendation	Next Steps
19. Evaluate feasibility of establishing public right-of-way or curbside charging in San Francisco.	▪ Understand regulatory obstacles to public right of way street charging and develop plan to address barriers and opportunities. ▪ Work with SFPUC and PG&E to identify obstacles and opportunities to provide curbside power. ▪ Work with SFPUC, SFMTA, and other relevant city departments to understand opportunities and restraints for the City.
20. Provide zero cost EVSE retrofit for single family home owners	▪ Work with SFPUC and PG&E to develop incentive programs (e.g., innovative EV rate plan) made available to customers. ▪ Develop approved City service provider (e.g., installer) pipeline, creating workforce development opportunities. SFPUC provided charger with Demand Response capabilities installed by service provider. ▪ Develop on-bill repayment mechanism for electrical upgrade requirements and/or promote existing solutions such as Property Assessed Clean Energy (PACE) financing.
21. Provide zero-cost EVSE retrofit for commercial customers.	▪ Work with SFPUC and PG&E to develop incentive program (e.g., innovative EV rate plan and incentives) made available to commercial customers enrolled in CleanPowerSF. ▪ Develop approved City service provider (e.g., installer) pipeline, creating workforce development opportunities. SFPUC provided charger with Demand Response capabilities installed by service provider. ▪ Develop on-bill repayment mechanism for electrical upgrade requirements and/or promote existing financing solutions such as PACE.
22. Develop convenience incentives	▪ Work with internal and external stakeholders to evaluate feasibility and development of programs that improve convenience of owning, operating and parking PEVs as compared to ICE vehicles (e.g., priority HOV lanes, parking access, restricted air quality zones).

CHAPTER 4: Hydrogen Fuel Cell Electric Vehicles and Infrastructure

4.1 Introduction

FCEVs and fueling infrastructure have been in development for well over two decades, promising zero emissions at the tailpipe, rapid refueling, and, if renewable energy is used to produce hydrogen fuel, the potential for significant reductions in GHG and air pollution impacts. To convert this potential into reality, the state of California and major automakers are investing substantial resources in new vehicles and fueling infrastructure. As of late 2016, 23 hydrogen fueling stations are open, with an additional 30 in the planning stages.[46] The opening of these new stations will soon make FCEV travel convenient for most Californians in major urban centers. To assess the future potential of FCEVs in San Francisco and the greater Bay Area, and the actions that local stakeholders can take to support FCEV readiness, this chapter covers these key issues:

- Overview of operating attributes of FCEVs
- FCEVs and related fueling infrastructure deployment in the region and statewide
- Environmental and economic characteristics of FCEVs and potential contribution to air quality and GHG goals
- Sources of funding for FCEV infrastructure and vehicle incentives and potential market acceleration initiatives
- Recommendations on FCEV-related policies and programs

4.2 FCEV Overview and Adoption

4.2.1 Hydrogen Vehicles Overview

FCEVs offer performance, range, and refill time similar to conventional gasoline vehicles, yet drivers also benefit from the quiet operation and zero tailpipe emissions characteristic of BEVs. The driving range of FCEVs is also similar to ICE vehicles; 230 to 400 miles is typical depending upon the vehicle's tank capacity. FCEVs are generally cheaper to operate than gasoline (as of September 2016, hydrogen fuel retails for approximately $15 per kilogram (kg) and OEM subsidies are providing a substantial amount of "free fuel" for most early adopters. From an environmental perspective, the emissions benefits of FCEVs are highly dependent on the feedstock from which the fuel was developed. Although current production is dominated by natural gas feedstocks, the potential exists for fuel production from "green" feedstocks, including renewable electricity and RNG, among other lower-carbon pathways.

A key concern of consumers regarding FCEVs is vehicle safety. Automakers and federal agencies have conducted extensive safety testing at the component, system and vehicle level. FCEVs have

46 California Fuel Cell Partnership. Accessed November 13, 2016 at: http://cafcp.org/sites/default/files/h2_station_list.pdf

several safety systems designed to protect passengers and first responders in case of an accident. FCEVs have been in real-world accidents and performed as designed with safety ratings equivalent to ICE vehicles. There have been no known catastrophic failures of hydrogen fueling equipment for vehicles as of the early introduction period of hydrogen fuel vehicles in mid-2016.

The key barriers to FCEV adoption are not likely to be safety related, but rather the relative capital and operating costs of FCEVs (which will depend in part on the sustainability of OEM and government subsidies) and the limited fueling infrastructure. These issues will be addressed in this chapter.

4.2.2 FCEV Operations

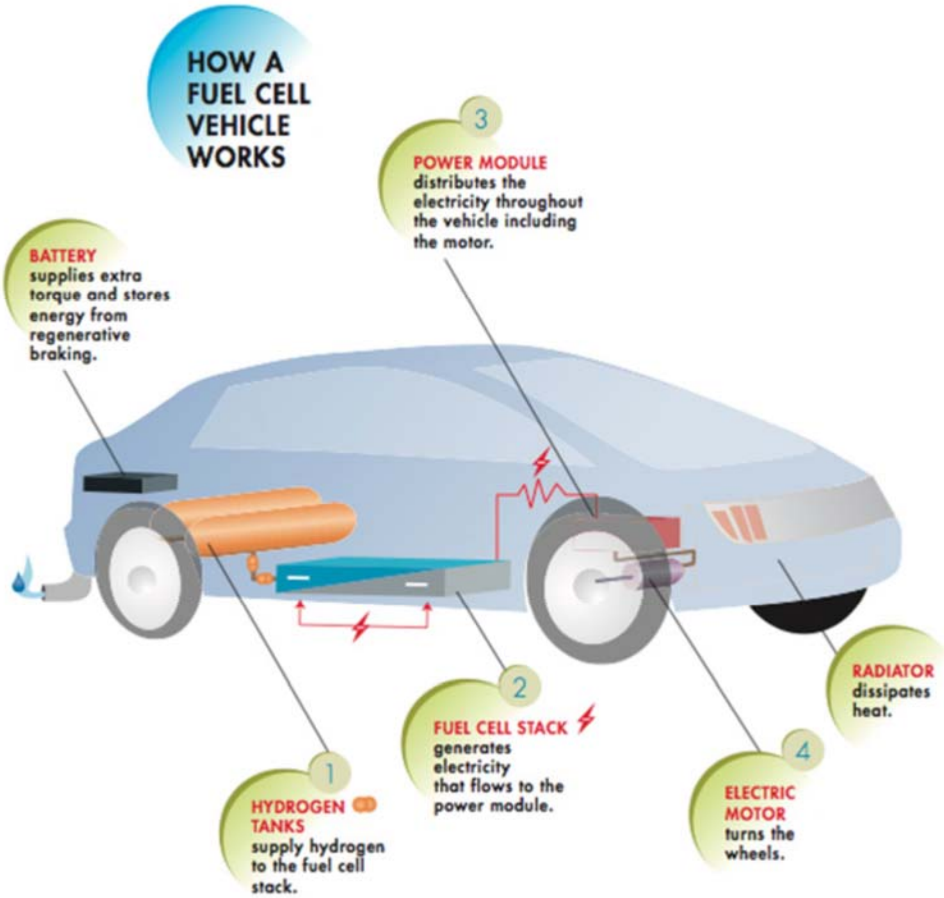
The California Fuel Cell Partnership (CaFCP) has provided the following description of a typical FCEV operation:

> Fuel cells create electricity from reactants stored externally. A proton exchange membrane (PEM) fuel cell uses hydrogen and oxygen as the reactants. In its simplest form, a PEM fuel cell is two electrodes— the anode and the cathode—separated by a catalyst-coated membrane. Hydrogen from the vehicle's storage tank enters one side of the fuel cell stack and air on the other side. The hydrogen is naturally attracted to the oxygen in the air. As the hydrogen molecule moves through the stack to get to the oxygen, the catalyst forces the hydrogen to separate into electron and proton. The proton moves through the membrane and the electron moves to the anode. The electricity flows into a power module, which distributes electricity to the electric motor that turns the wheels of the car. The power module also distributes electricity to the air conditioning, sound system and other on-board devices. At the cathode, the electron recombines with the proton, and the hydrogen joins with the oxygen to create the vehicle's only tailpipe emission—water. Fuel cells produce electricity as long as fuel is supplied.[47]

The following diagram describes the workings of the various key components of a FCEV.

47 How It Works. California Fuel Cell Partnership, accessed October 15, 2016 at http://cafcp.org/cars#cars_how_works.

Figure 4-1: FCEV Function



Source: *How a Hydrogen Fuel Cell Vehicle Works*. Hygen, accessed November 20, 2016 at http://www.hygen.com/how-a-hydrogen-fuel-cell-vehicle-works/

4.2.3 Current FCEV Availability

FCEVs are currently available in sizes ranging from sedans to sports-utility vehicles to full-sized transit buses. Several leading models are pictured below.

Figure 4-2: First Generation Fuel Cell Electric Vehicles Available in California

Honda FCX Clarity

Mercedes-Benz B-Class F-CELL

Toyota Mirai (FCEV)

Hyundai Tucson Fuel Cell

AC Transit buses

SunLine Transit buses

Source: Images sourced from company websites

4.2.3.1 Fuel Cell Electric Buses

FCEBs were one of the earliest applications of FCEV technology and demonstrate promise as an alternative to diesel and CNG. In the Bay Area, AC Transit has led a consortium of Bay Area transit operators in testing a total of 13 FCEBs over 15 years of revenue operation. SunLine transit agency (Riverside) has a total of five FCEBs, with seven more buses and two shuttles on order. UC Irvine and Orange County Transit Authority each are operating one FCEB. Altogether, California FCEBs have travelled more than 2.7 million miles in revenue service, with more than 2.5 million passengers carried. While FCEBs have initially been very costly, prices are projected to come within range of existing Battery-Electric Buses (BEBs or E-Buses) in future years, and could provide a new near-zero-emissions alternative to E-Buses where duty cycles exceed the capability of E-Buses. Prices for FCEBs have been in $1.5M+ range, but group procurement may bring prices down below $1M soon, according to the UC Berkeley Transportation Sustainability Research Center. This pricing contrasts with approximately $525,000 for diesel transit vehicles and $600,000 to 750,000 for electric transit vehicles. Of course, initial FCEV adoption will also require a hydrogen fueling station, which typically requires $1.2 to $2.4 million in new investment. (Note that recharging infrastructure costs for electric transit buses must also be considered when comparing the two vehicle types to fossil alternatives on a TCO basis.)

Several companies are conducting additional FCEB trials. These include Daimler AG, Thor Industries (the largest maker of buses in the U.S.) based on UTC Power fuel cell technology, Toyota, Ford (based on the E-350 shuttle bus platform), and others.

4.2.3.2 Development of Medium and Heavy Duty FCEVs

The Energy Commission has funded development of an Action Plan by CaFCP to outline a research and development path for new FCEV platforms to be developed with Energy Commission support. The Action Plan (to be published in late 2016) will call for development of a medium duty platform for Class 4-6 package delivery trucks, and a heavy-duty platform for Class 8 short haul/drayage trucks. The Action Plan will define several years of development work leading to scaled demonstrations of these technologies after 2020, along with a specialized medium and heavy duty fueling infrastructure.

4.2.3.3 Development of Light Duty FCEVs

Most FCEVs are being leased rather than sold. A typical scenario for light-duty use is the new Hyundai Tucson, which is currently being offered via a three-year closed end lease at $499/month after a $4,000 signing deposit (including incentives). The Toyota Mirai and Honda Clarity are priced at nearly identical levels. Both include free fueling for three years. The purchase pricing for the Mirai has been set at $58,325 before incentives. However, Toyota projects that about 90 percent of Mirai customers will choose the $499-per-month lease with approximately $3,700 due at signing as of mid-2016. The current Mirai package deal includes roadside assistance, $7,500 in purchasing support, three years of vehicle maintenance, eight years or 100,000 miles of warranty coverage for fuel-cell components, as well as the complimentary fuel for three years. Still unanswered are questions regarding longer-term maintenance and replacement costs for the fuel-cell powertrain and supporting hardware, and how much hydrogen will cost in future years.

4.2.4 FCEV Market Positioning

From a technical standpoint, FCEVs are a form of electric drive vehicle (and thus referred to as Electric Vehicles). However, consumers are likely to view FCEVs in their own category, given their unique performance characteristics (fast fill-up, limited fueling infrastructure, highly differentiated technology). Thus, a key issue for adoption is how consumer perspectives on

FCEVs will compare to both PHEVs and BEVs. PEVs clearly have a head start in consumer awareness, cost competitiveness, and infrastructure deployment. The following table compares the attributes of these vehicle types from a consumer perspective.

Table 4-1: Comparison of Key Consumer Attributes of Fuel Cells and Plug-in Vehicles

	Hydrogen Fuel Cell Electric Vehicles	Plug-in Hybrid Electric and Battery Electric Vehicles
Refueling time	Shorter (3-5 minutes)	Longer (20 min to many hours), PHEVs can refuel gasoline quickly
Vehicle sizes	Small to large vehicles	Small to midsize vehicles
Vehicle range	300+ miles per refill	10-200 miles of all electric range
Refueling paradigm	Similar to gas stations	Chargers (home and public)
Fuel cost per mile	\$0.13/mile at \$8/kg H_2 \$0.08/mile at \$5/kg H_2	\$0.04/mile at \$0.12/kWh

Given the current market position of PEVs, under which circumstances might a consumer choose an FCEV relative to a BEV? Based on battery costs, BEVs may be best suited for commuters with localized driving patterns that fit within the vehicle's range, especially in a multi-car household. As more diverse FCEV models are introduced, these could be particularly advantageous for drivers needing larger cars, light trucks, and SUVs, whose driving range is greater, and for whom fast refueling is critical. FCEVs might also appeal to those who cannot charge a PEV at home.

As noted in a study by the University of California at Davis (U.C. Davis), FCEV sales are dependent on these diverse market factors and market actors:[48]

- **Vehicle costs** – purchase prices, fuel prices, and incentives (set by automakers, fuel providers, and government)
- **Consumer utility and convenience** – vehicle characteristics, performance, range and availability of refueling locations (determined by automakers and fuel providers)
- **Infrastructure availability** – expansion of hydrogen station deployment to additional regions (supported by automakers, fuel providers, and government)
- **Technology and environmental factors** – future FCEV technology, performance vs. other vehicle types, and environmental benefits (automakers and government.)

Of these factors, purchase or leasing cost, fueling convenience and coverage, and a clear environmental value proposition are likely to be most important particularly in a relative context in which PEV choice and price/performance will be increasing substantially in the next several years.

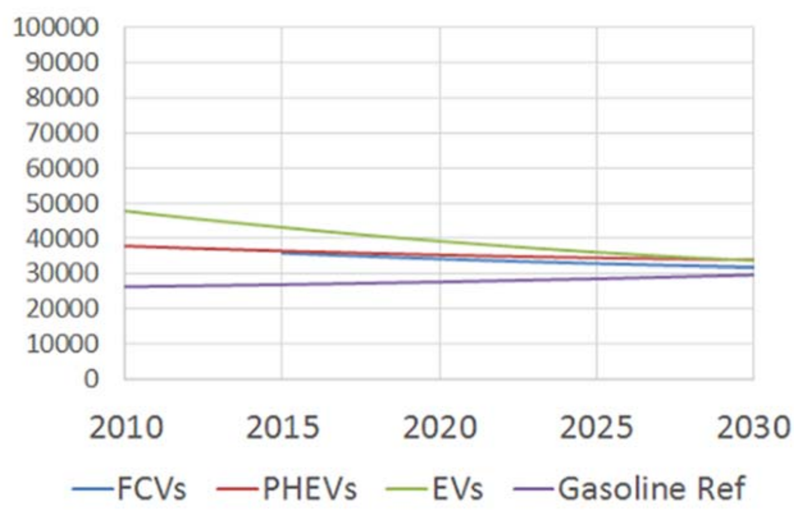
[48] NextSTEPS White Paper: The Hydrogen Transition, ITS, U.C. Davis, July 2014, p. 13.

4.2.5 FCEV Market Trends

4.2.5.1 Pricing Outlook for FCEVs

The Manufacturers Suggested Retail Price of FCEVs is approximately twice that of comparable ICE vehicles if purchased new (prior to incentives). However, initial OEM lease deals, which combine fuel supplies with the monthly lease and incorporate federal and state incentives, are competitive with similarly equipped ICEs and PEVs. The cost of fuel cell systems for FCEVs has dropped more than 50 percentage since 2006, and cost reductions will continue as manufacturing scales up. Although the actual costs to manufacture FCEVs in the early years of deployment are likely to continue exceeding vehicle selling prices, this is typical for many new vehicle technologies, including conventional hybrids and PEVs. OEMs and state and federal agencies will likely continue with the pricing strategies and incentives necessary to keep FCEVs price competitive in their segments to build the FCEV ecosystem over the coming 5-10 years. The table below from the National Research Council illustrates projected pricing for BEVs, PHEVs and FCEVs between 2010 and 2030.[49] A "base case" projection shows cost parity in 2045, while the more optimistic projection suggests 2030 for all three vehicle types. This study has been criticized by some analysts as an overly optimistic assessment of future FCEV pricing and a pessimistic assessment of PEV pricing, but the near-term trend toward price convergence is generally viewed as plausible given BEV and FCEV scale economies.

Figure 4-3: Retail Price Equivalent Projections for FCEVs, EVs, PHEVs, & Gasoline Cars



Assumptions: All cars will be at mass production levels. The BEV is assumed to have a 100 mile all-electric range and the plug-in hybrid electric 30 mile all-electric range.

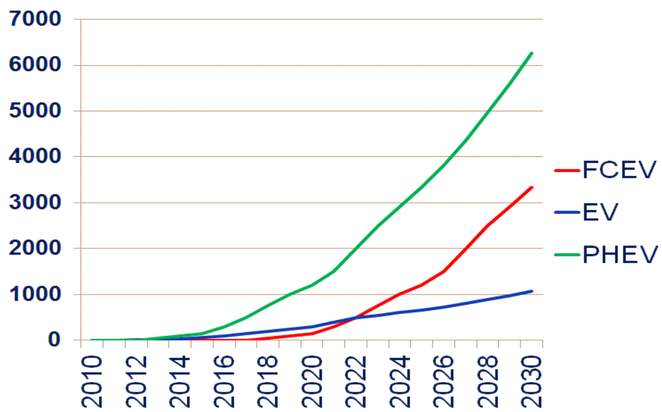
Source: NextSTEPS White Paper: The Hydrogen Transition, ITS, UC Davis, July 2014, p. 13.

49 National Research Council. Transitions to Alternative Vehicles and Fuels. Washington, DC: National Academies Press, 2013. http://www.nap.edu/catalog.php?record_id=18264

4.2.5.2 Nationwide Market Trends

The National Research Council data on price parity for FCEVs in turn informed a U.C. Davis Institute of Transportation Studies scenario illustrated below, which shows modest penetration by 2020, and a substantial uptake, to approximately 300,000 new car sales per year nationally by 2030 vs. 700,000/year for EVs, including both BEVs (indicated as EVs below) and PHEVs.

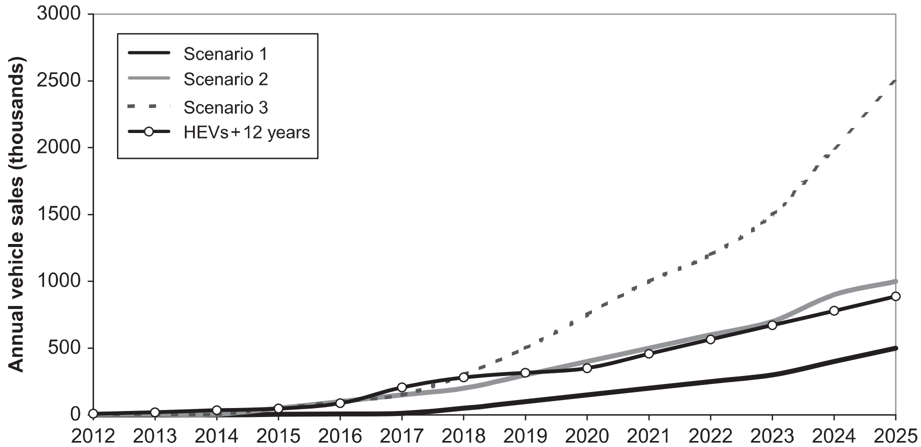
Figure 4-4: New Car Sales are in 1000s Per Year (2010 – 2030)



Source: UC Davis Institute for Transportation Studies - (Ogden, Fulton and Sperling, 2014), p. 15.

For both PEVs and FCEVs, many analysts look at the conventional hybrid vehicle market as an illustrative case for new vehicle technology adoption. In the case of conventional hybrids, annual sales grew very slowly in the early years, reaching the 500,000 per year threshold 14 years after their late-1999 mass-market release. In the case of PEVs (counting BEVs plus PHEVs), it is likely that at current adoption rate growth, PEVs will likely achieve this level by 2020, within ten years of their mass-market introduction in 2010. Given the many variables in FCEV adoption, the U.S. DOE has also produced a variety of different scenarios for FCEVs in the 2015 to 2025 period. Two out of the three scenarios show a gradually progressive upslope after 2017, toward 500,000 by 2020 and 700,000 by 2025. The final more aspirational scenario, suggesting 2.5M in annual sales by 2025, would likely require significant price reductions, large-scale infrastructure roll-out, new incentives, and potentially a significant increase in gasoline prices to enhance the relative economies of hydrogen operation. Even the 500,000 units by 2020 scenario could be off by as much as 10X or more considering the limited distribution of fueling infrastructure, high FCEV prices, low market awareness, and consumer wariness of radical new vehicle technologies.

Figure 4-5: Alternative Scenarios for National FCEV Sales Growth



Source: Greene, Leiby and Bowman 2007, as shown in NRC 2008, cited in UC Davis Institute for Transportation Studies - (Ogden, Fulton and Sperling, 2014), p. 21.

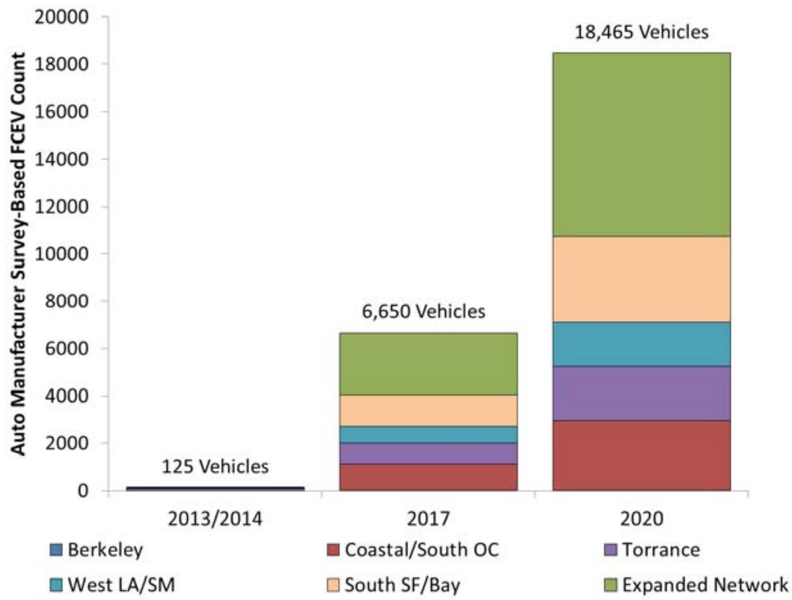
4.2.5.3 California Market Trends

California sales estimates have been low for the 2015-2020 period, and difficult to assess thereafter. As of August, 2016, only 566 CVRP rebates had been claimed for FCEVs within the state of California (though more vehicles may have been purchased and rebates not sought).[50] While a variety of automakers have announced that they will be ready to produce thousands or even tens of thousands of vehicles *if demand warrants,* none have publicly projected how many cars will be produced or where they will be deployed.

One of the most recent public estimates for regional FCEV introduction was developed based on a 2014 OEM survey conducted by ARB (Figure 4-6). ARB distributed mandatory surveys to 16 auto manufacturers requesting information on planned deployment of FCEVs in the five geographic "clusters" used by ARB and Energy Commission to plan FCEV infrastructure. These clusters include the San Francisco Bay Area, Sacramento Area, Los Angeles/Orange County/Ventura, San Diego, and "Other" (encompassing the rest of California). Auto OEMs forecast a rapid acceleration in the number of vehicles coming to California beginning in 2015 and sustaining growth at least to 2020 (the last year included in the survey). According to the OEMs, by 2017 the state's fleet is expected to grow to more than 6,600 vehicles and by 2020 to nearly 18,500 vehicles.

50 Center for Sustainable Energy (2016). California Air Resources Board Clean Vehicle Rebate Project, Rebate Statistics. Data last updated November 02, 2016. Accessed November 12, 2016 from https://cleanvehiclerebate.org/rebate-statistic

Figure 4-6: Current and Projected Cumulative FCEV Deployment in California



Source: California EPA, California Air Resources Board, Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development, June 2014, p. 4.

Because there is very little sales history for FCEVs, estimates of future sales in general, and sales beyond 2020 in particular, are exceedingly difficult to project. Many of the goals set forth by both manufacturers and policy makers are aspirational. For example, the California ZEV regulation initially suggested that 50,000 FCEVs may be on California roads by 2017 to 2018. Given the low vehicle numbers as of 2016 and the slow deployment of fueling infrastructure, achieving this goal is unlikely. That said, the ARB ZEV credit system will help sustain the ongoing *production* of at least at trickle of "compliance car" FCEVs in the face of *potentially* persistent low demand, as these credits provide manufacturers with a substantial economic incentive for production. Additionally, ARB will continue to provide consumers with a larger incremental state rebate for hydrogen vehicles ($5,000 for FCEVs vs. $2,500 for PEVs) to further incentivize sales through the 2023 period authorized by Assembly Bill 8.[51]

4.3 Hydrogen FCEV Fueling

4.3.1 Hydrogen Fuel Overview

Unlike fossil fuels, hydrogen fuel does not occur naturally on Earth and thus is not considered an *energy source;* rather it is an *energy carrier.* Like electricity, hydrogen can be produced by using diverse primary resources, such as coal, oil, natural gas or biomass, to power a thermochemical hydrocarbon conversion that creates an intermediate product known as syngas

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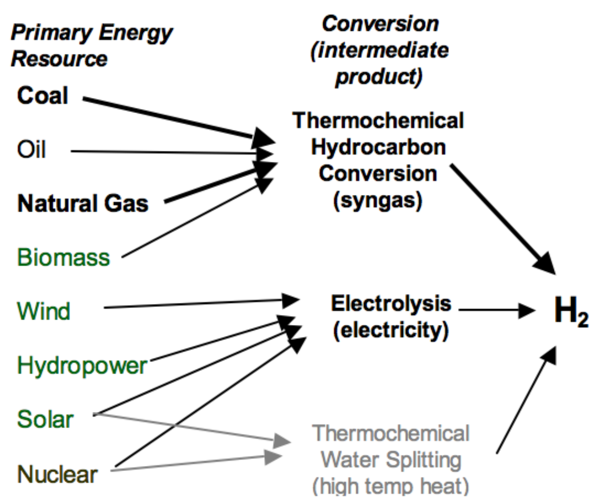
[51] *The California Vehicle Rebate Program (CVRP) process is essentially the same for both EVs and FCEVs, and is administered by the Center for Sustainable Energy on behalf of the state. The rebate application of the Honda Clarity (one of the initial FCEVs for sale in California) is shown on this site:* https://energycenter.org/clean-vehicle-rebate-project/requirements/919

(or synthesis gas). In the United States, about nine million metric tons of hydrogen are produced each year by this process, also known as steam reforming, mainly for industrial and refinery purposes. This is the equivalent amount of fuel required to power a fleet of about 35 million FCEVs. Steam reforming of natural gas is the most common method of hydrogen production today, accounting for about 95 percent of domestic production. However, as noted in the chart below, other primary energy resources, including renewable resources, can be used to produce hydrogen, with varying costs, environmental impacts, and technical complexity.

Figure 4-7: Production pathways for hydrogen



Source: *NextSTEPS White Paper: The Hydrogen Transition,* Institute of Transportation Studies, UC Davis, July 29, 2014, p. 15

Although current hydrogen production is dominated by natural gas feedstocks, hydrogen can be produced with electricity via a process known as electrolysis, in which an electric current splits water into hydrogen and oxygen. If the electricity used in this process is itself produced from renewable sources, such as solar or wind, the resulting hydrogen gas is considered renewable as well, with a more favorable emissions profile. Because renewable electricity is increasingly available in surplus in California, typically in the form of excess wind at night and excess solar in the early afternoon, large "power-to-gas" projects are beginning to emerge. These renewable projects have the potential to become more economical as the market for hydrogen grows through expansion of both the FCEV market and stationary fuel cell energy production for the electrical grid.

Many hydrogen advocates hope that the use of surplus renewable energy for hydrogen fuel production will become the dominant fuel pathway as renewables are more widely deployed. However, studies by UC Davis indicate that natural gas rather than electricity will continue to be the least expensive and most energy-efficient resource from which to produce hydrogen through the 2020s.[52] Although the full GHG impact of natural gas is still under review (see Chapter 4), current estimates suggest that *natural gas based FCEV emit approximately half as much GHG as a comparable gasoline car on a well to wheels basis, but much more than PEVs fueled on the current California "grid mix" of electricity*.[53] The domestic shale gas boom has been a significant factor in keeping natural gas prices low and further boosting policy maker interest in (natural gas produced) hydrogen. Of course, natural gas is also used directly as an electricity feedstock in California (and thus is an important factor in the emissions profile of both PEVs and FCEVs also running on the California grid mix). FCEVs fueled by electricity-produced hydrogen (via electrolysis) as well as PEVs using the standard grid mix will benefit from the progressive greening of California's grid. The CI per kWh of electricity in California will steadily decline as Renewable Portfolio Standards ratchet up from the current 33 percent by 2020 to 50 percent or more in 2030 and beyond, impacting the CI of electricity-produced hydrogen.

That said, PEVs more efficiently convert electricity to propulsion than FCEVs. As a result, when comparable feedstocks are assessed, PEVs will always environmentally outperform FCEVs on a well-to-wheels basis.

4.3.2 Use of Excess Renewable Energy in Hydrogen Production

As noted above, a promising approach to producing hydrogen from electrolysis both cleaner and more economically competitive is for companies to take advantage of surplus renewable energy production. In California, renewable energy currently makes up 20 percent of retail electricity sales and is mandated to reach 33 percent or more in future years. However, an overproduction of solar and wind during the middle of the day is already forcing the state to "dump" power, i.e., to pay out of state utilities to take power when there is insufficient aggregate demand. The total amount of power dumped in 2014 was 19 gigawatt-hours of pre-purchased renewable energy, enough to refuel tens of thousands of cars with electrically produced hydrogen or via PEV charging. For this reason, the CPUC has coupled their renewable energy mandates with a recent energy storage mandate that requires California utilities to provide 1.325 gigawatts of energy storage capacity. Additionally, utilities are mandated to develop much more robust "demand response" programs that would enable a variety of variable electric loads, including potentially both PEV charging systems and hydrogen production facilities, to take power from the grid when there is excess energy supply, likely to be generated by intermittent solar and wind.

As attractive tariffs are established to encourage distributed generation and storage resources to plug into these time-of-use rates and demand response programs, large scale "power-to-gas"

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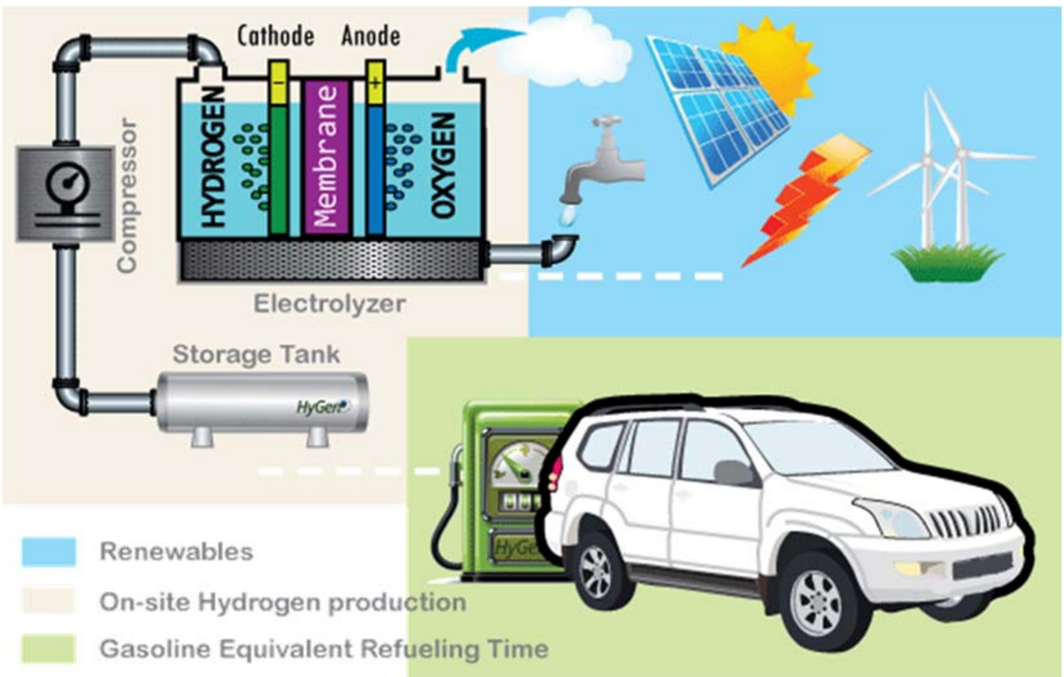
[52] Joan Ogden, Christopher Yang, Michael Nicholas, Lew Fulton , *NextSTEPS White Paper: The Hydrogen Transition,* Institute of Transportation Studies University of California, Davis, July 29, 2014, p. 15 http://steps.ucdavis.edu/files/08-13-2014-08-13-2014-NextSTEPS-White-Paper-Hydrogen-Transition-7.29.2014.pdf

[53] Nguyen, T., J. Ward, K. Johnson, "Well-to-Wheels Greenhouse Gas Emissions and Petroleum Use for Mid-Size Light-Duty Vehicles," Program Record (Offices of Bioenergy Technologies, Fuel Cell Technologies & Vehicle Technologies, US Department of Energy, Record #: 13005 (revision #1), May 10, 2013.

electrolyzers, often sited adjacent to renewable generation resources, will become more economical as they utilize excess generation to make renewable hydrogen. Like a battery storage device connected to the grid, electrolysis is considered a “dispatchable load,” which means the hydrogen fuel production system can rapidly adjust its power flow to stabilize electricity demand and supply. According to NREL, electrolyzers are able to respond fast enough to offer frequency regulation or ancillary services to the grid, which can provide new sources of revenue for hydrogen fuel producers via payments from California utilities and/or the CAISO. The revenue from energy market participation is not considered sufficient to recuperate all the original investment in a renewable hydrogen project. However, electrolysis systems that offer ancillary services and sell hydrogen fuel will be more economically competitive.

Figure 4-8: Small Scale Hydrogen Production from Renewables



Source: Hygen Industries, Inc. Accessed October 16, 2016 at: http://www.hygen.com/how-a-renewable-hydrogen-fueling-station-works/

In addition to larger-scale “power to gas” projects, hydrogen fueling companies can reduce the CI of hydrogen fuel by purchasing renewably produced electricity from their local utility for onsite hydrogen production, or they can utilize Renewable Energy Credits, which represent renewable power injected into the grid at another location. A compact production process can be installed at hydrogen fueling stations, consisting of an electrolyzer, a compressor, and a storage tank. A California company known as HyGen has opened a hydrogen fueling station in Orange County that features this relatively simple onsite hydrogen production process using renewable energy, illustrated in the diagram above. Renewable energy purchased from the utility is used to split water to obtain pure hydrogen, which is held in a buffer tank. Oxygen is the by-product of this process and is released to the atmosphere in most on-site hydrogen stations.

Depending on production capacity requirements, the company claims a HyGen system can be installed for as little as $1.5 million, although a station of this size would have the capacity to fuel only up to 100 vehicles per week. Some experts maintain that onsite electrolysis is as much as twice as expensive per kilogram of hydrogen delivered as stations that procure hydrogen using natural gas.[54] The UC Davis estimated that production of hydrogen through electrolysis will continue to be significantly more expensive than natural gas (even accounting for future carbon sequestration costs) through 2020, and that subsidies will be required for at least the first five to seven years of station operation.[55] The Energy Commission is providing operations and maintenance funding along with their capital grants in recognition of the fact that FCEV deployments will not be sufficient to support breakeven operation of fueling stations 2020s or later in most regions of the state.

4.3.3 Use of Biogas and Biomass in Hydrogen Production

Perhaps the most sustainable approach to hydrogen production is known as "biogas to hydrogen." In this process, wastewater solids enter an anaerobic digester at a wastewater treatment plant. Microbes convert the waste into a biogas/methane, which is similar in composition to natural gas, but with more impurities. A scrubber removes many of the impurities, including carbon and sulfur. The purified biogas then enters a stationary fuel cell where heat and water vapor separate biogas into hydrogen and carbon dioxide. This heat and water vapor powers the reaction in the fuel cell, with excess heat going back into the digester. The fuel cell also produces electricity that can be sent to the grid. The hydrogen then undergoes additional cleaning processes and is compressed and stored for distribution via underground pipelines to a public station.

From well to wheels, a biogas system creates net zero greenhouse gases, virtually zero criteria pollutant emissions, and makes commercial use of hazardous waste. Because of the many environmental virtues of biogas to hydrogen production, the Energy Commission is particularly interested in supporting such projects, and has invested in several throughout the state. However, the total amount of hydrogen that can be produced through this method is limited by the finite size of the waste stream. Additionally, hydrogen suppliers must compete with other productive uses of bio-waste, such as biofuel creation, composting for use in agriculture, and in soil carbon sequestration or "carbon farming."

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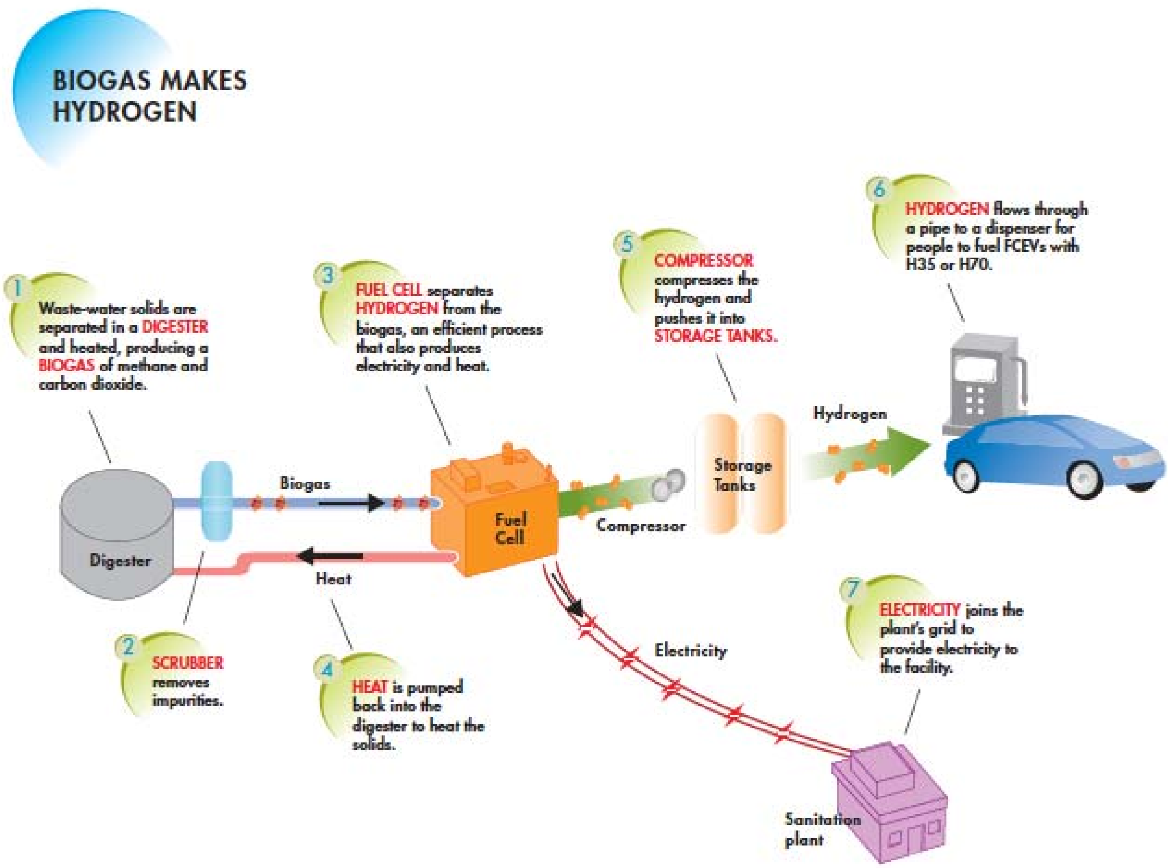
[54] Julia Pyper, "Is electrolysis the pathway to reach totally carbon-free hydrogen fuel?," *Climatewire,* November 20, 2014. http://www.eenews.net/stories/1060009250

[55] Joan Ogden, Christopher Yang, Michael Nicholas, Lew Fulton , *NextSTEPS White Paper: The Hydrogen Transition,* Institute of Transportation Studies University of California, Davis, July 29, 2014, p. 12 http://steps.ucdavis.edu/files/08-13-2014-08-13-2014-NextSTEPS-White-Paper-Hydrogen-Transition-7.29.2014.pdf

Figure 4-9: Hydrogen Produced from Biogas



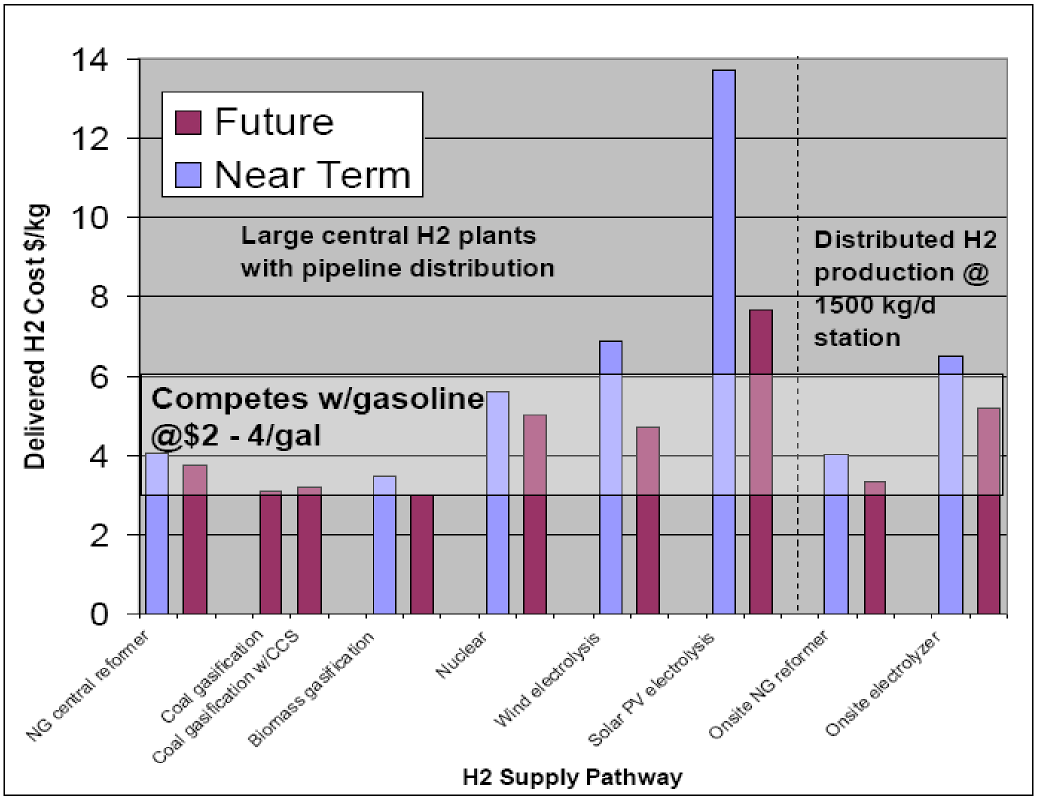
Source: California Fuel Cell Partnership, accessed October, 12, 2016 at http://cafcp.org/.

A final method of creating hydrogen is known as syngas or synthesis gas. Syngas can be created by reacting coal or biomass with high-temperature steam and oxygen in a pressurized gasifier, through a process called gasification. The resulting synthesis gas contains hydrogen and carbon monoxide, which is reacted with steam to produce more hydrogen. This approach is much less common than steam methane reforming with natural gas or other methods and is not yet viewed as cost competitive.

4.3.4 Hydrogen Fueling Infrastructure

Among other factors, the long-term success of FCEVs depends on the development of a low-cost, low-carbon, high-capacity hydrogen fuel supply chain. As in the case of electricity, it is likely that diverse primary sources will be used to make hydrogen in different regions of the state and nation, depending on local costs, feedstocks, and infrastructure. The chart below indicates the relative costs of these diverse fuel production pathways, based on research from UC Davis. Note that the chart illustrates the delivered cost of hydrogen *after large-scale deployments have enabled scale economies for all the fuel production approaches.* These cost projections do <u>not</u> reflect current pricing available in 2016 through 2017. It is also important to note that use of biomass may not be scalable beyond the early years of FCEV deployment, due to competing uses of land and declining agricultural productivity expected in a warming world.

Figure 4-10: Hydrogen Supply Pathway



Delivered Cost of Hydrogen: The grey shaded area indicates where the fuel cost per mile for hydrogen FCEVs would compete with a gasoline hybrid. Costs assume that hydrogen supply technologies are mature and mass-produced. Source: NextSTEPS White Paper: The Hydrogen Transition, Institute of Transportation Studies, UC Davis, 2014.

4.3.4.1 Distribution and Production Logistics

Currently, most hydrogen is transported from the point of production to the point of use initially via pipeline, rail, or barge, with final "over the road" delivery by truck. The location of hydrogen production has a significant impact on the cost of fuel, and on the choice of delivery methods to locally sited stations. A large, centrally located hydrogen production facility can produce fuel at a lower cost, but a longer trip to the final distribution location can eliminate these cost savings.

Developing a ubiquitous hydrogen fueling infrastructure across the state (and ultimately, across the nation) poses significant challenges in the near-term. These include reducing delivery cost, increasing energy efficiency, maintaining hydrogen purity, and minimizing hydrogen leakage. To address these challenges, NREL and Sandia National Laboratories have announced the *Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST)* project, which is expected to reduce the cost and time of fueling station construction, increase station availability, and improve reliability in future years. In the meantime, the initial wave of station operators must choose among many alternative production and distribution pathways now available, with a variety of economic and technology profiles. Table 4-2 below highlights key advantages of each production and distribution approach.

Table 4-2: Comparison of Hydrogen Fuel Delivery Methods: Advantages vs. Disadvantages

Method	Equipment at Station	Advantages	Disadvantages
Liquid Delivery	▪ Liquid storage tank ▪ Heat exchanger ▪ Compressor ▪ Gaseous storage ▪ Booster compressor ▪ Chiller ▪ Dispenser	▪ Can store more fuel	▪ Much larger footprint ▪ Potential for fuel to boil off ▪ Expense of two types of storage tanks (liquid & gaseous)
Gaseous Delivery	▪ Gaseous storage ▪ Compressor ▪ Chiller ▪ Dispenser	▪ Smaller footprint than liquid ▪ Equipment can be in various locations	▪ Least amount of storage capacity without multiple trailers/ storage tubes
On-site Electrolysis	▪ PV or wind system (optional) ▪ Water purifier ▪ Electrolyzer ▪ Compressor ▪ Gaseous storage ▪ Booster compressor ▪ Chiller ▪ Dispenser	▪ Make fuel on site ▪ Potential to sell carbon credits	▪ More equipment ▪ Larger footprint ▪ Can be more expensive
Hydrogen from Pipeline	▪ Scrubber ▪ Gaseous storage ▪ Booster compressor ▪ Chiller ▪ Dispenser	▪ Larger capacity ▪ Can require less storage	▪ Station must be near ▪ pipeline ▪ More equipment ▪ Larger footprint
On-site Reforming	▪ Natural gas or biogas supply ▪ Scrubber ▪ Water purifier ▪ Reformer ▪ Compressor ▪ Gaseous storage ▪ Booster compressor	▪ Make fuel on site ▪ Potential to sell carbon credits	▪ More equipment ▪ Larger footprint ▪ Can be more expensive

Method	Equipment at Station	Advantages	Disadvantages
	▪ Chiller ▪ Dispenser		

4.3.4.2 The Hydrogen Fueling Experience

The hydrogen fueling experience is similar in appearance, function, and timing to diesel and gasoline, and hydrogen fueling stations can be co-located with conventional liquid fueling stations. FCEVs are designed to accept hydrogen in gaseous form pressurized at two levels, either 350 bar (which is notated on pumping stations as H35, and is the equivalent of 5,000 psi) or 700 bar (H70 or 10,000 psi). Currently, 700 bar (H70) gaseous onboard storage has been chosen for the first generation of consumer vehicles, while 350 bar (H35) is utilized for buses, forklifts, and other lift trucks.

A hydrogen dispenser functions like a gasoline fuel dispenser and usually has one hose and nozzle for each pressure level. Users cannot attach the high-pressure nozzle to a lower pressure receptacle, so there is no chance of fueling at the wrong pressure level. When a driver activates the dispenser, hydrogen flows from the storage tanks and through the nozzle into the vehicle in a closed-loop system. If filling with H70 (the LDV standard), the hydrogen passes through a booster compressor and chiller before entering the dispenser. If the nozzle is not correctly attached, fuel will not flow. Volume is displayed in kilograms. A light duty FCEV, fully fueled with four to six kilograms of hydrogen, has a range of approximately 300 miles, which is similar to a conventional ICE vehicle. As with conventional gas pumps, the dispensers are designed to accept credit cards and display sales information conforming to state weights and measures requirements. Fueling time is approximately five minutes for a "full tank" for a typical LDV. Stations are designed for unattended operation.

The higher pressure level (H70) fuel provides more energy density per kilogram of fuel and thus higher driving range, but it is also more expensive per kilogram due to the additional cost of higher pressurization. H70 is currently in the range of $15 per kilogram, which translates to a $3.00-$3.50 per GGE, although it is important to note that these prices reflect the significant operational subsidies now provided by the Energy Commission while stations ramp up to volume levels that enable profitable operation.

A hydrogen station has multiple safety systems to protect against fire, leakage, or explosion. If flame detectors or gas sensors detect a fire or leak, safety measures turn on automatically. These measures include sealing the storage tanks, stopping hydrogen flow or, in the case of an extreme fire, safely venting the hydrogen. Strategically placed emergency stops will manually shut down hydrogen equipment. Retaining walls, equipment setbacks, and bollards are also designed into station site plans to maximize safety.

4.3.4.3 Comparison of Hydrogen Fueling to Other Fueling Types

The expectation of FCEV automakers is that the more convenient fueling experience of hydrogen will be preferred by many consumers when compared to the longer time required for BEV charging. Other analysts believe the more time-intensive fueling of BEVs will not be a major barrier to mass adoption once 200-300 mile BEVs are common and priced in the $30K range. Analysts also point to the likelihood that charging rates will increase to the 350KW – 800KW level in the early 2020's, making possible a five to fifteen minute BEV refueling experience. While the markets for both FCEVs and long-range, mid-price BEVs are still nascent, the slow deployment of H2 stations is likely to give BEVs an edge with early adopters at least until the early 2020's, when the charging station availability and charging times for the two technologies begins to converge.

4.3.4.4 Hydrogen Fueling Station Cost and Regional Site Selection Process

Hydrogen fueling stations are estimated to cost between approximately $1.2M and $2.4 million dollars on average. California's stations are typically constructed with a combination of public and private funds, including significant grants from the Energy Commission. The Energy Commission, ARB, and the CaFCP have worked closely together to develop a "cluster strategy" for hydrogen stations, based on co-locating the first several thousand vehicles and tens of stations in likely early adopter metro areas (especially the South Coast, Bay Area, and San Diego area). The table below illustrates a possible scenario for the seven-year FCEV rollout at a regional level, based on the state's proposed cluster strategy. By year seven, the system hopes to serve 34,000 FCEVs in a region (this example is from the South Coast) with a network of 78 stations. Equivalent station to FCEV densities are illustrative for the 12 county greater San Francisco Bay Area as well.

Table 4-3: Illustrative Regional Deployment of Hydrogen Stations Relative to FCEVs

	Year 1	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Year 6*	*Year 7*
FCEVs in fleet	197	240	347	1,161	12,106	23,213	34,320
Hydrogen demand (kg/day)	137	168	250	800	8,500	16,000	24,000
# New Stations Installed per year by Station Size (kg/day) and Type							
	Year 1	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Year 6*	*Year 7*
Mobile Refuelers (100kg/d)	4	0	0	0	0	0	0
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**
Compressed Gas Truck Deliveries/Station Size							
170 kg/d	0	0	4	0	0	0	0
250 kg/d	0	0	0	10	0	0	0
500 kg/d	0	0	0	0	20	20	20
Total station capacity (kg/year)							
	400	400	1,080	3,580	11,580	21,580	31,580
Total number of stations							

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
	4	4	8	18	38	58	78
Average travel time home to station (minutes)							
	4	4	3.5	3	2.8	2.6	2.6

Source: *NextSTEPS White Paper: The Hydrogen* Transition, Institute of Transportation Studies, UC Davis, July 2014, p. 25

In the scenario illustrated above, hydrogen is supplied via truck delivery, building on the current industrial gas supply system, and the hydrogen is largely derived from natural gas or industry by-products. Initially, hydrogen is supplied via mobile refuelers, small-scale portable stations incorporating storage and dispensers that can be towed to any site. By year three, a network of small fixed stations (170 kg/day) is established to ensure coverage. As demand rises, larger stations (250 kg/d and then 500 kg/d) are added to the network.

To put these quantities in perspective, a mid-size FCEV consumes approximately 0.7 kg of hydrogen per day on average (if it is traveling 15,000 miles per year in a 60 mile per gallon ([mpg] equivalent car). This would require a station capacity of perhaps one kg per day per FCEV served, accounting for 70 percent station utilization. If these calculations hold, a 100 kg/d station might serve a fleet of about 100 FCEVs, and 500 kg/d stations would serve about 500 FCEVs.

The charts below describe both the capital cost and the estimated levelized cost of hydrogen assuming the stations are operated at their rated capacities (e.g., 100 kg/d, 170 kg/d 250 kg/d or 500 kg/d), based on studies from UC Davis. Note that hydrogen fuel costs become more competitive as station technology develops and larger stations are deployed.

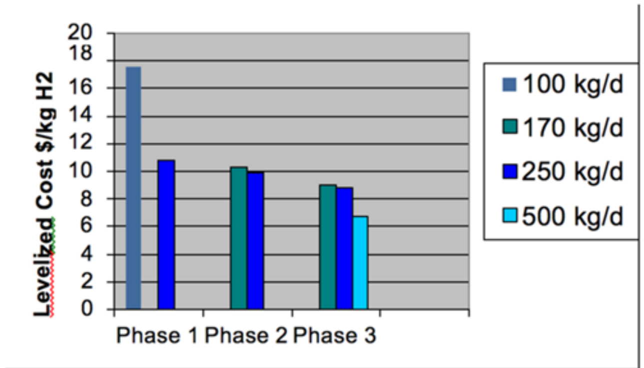
Table 4- 4: California Hydrogen Station Cost Model

Time frame	Capital Cost	Annual O&M cost $/year
Phase 1 (years 1-2) **100 kg/d** **250 kg/d**	$1 million $1.5 million	$100 K (fixed O&M) + 1 kWh/kgH2 x kg H2/yr x $/kWh (compression electricity cost) + H2 price $/kg x kg H2/yr
Phase 2 (years 3-4) **170 kg/d** **250 kg/d**	$0.9 million $1.4 million	
Phase 3 (year 5+) **170 kg/d** **250 kg/d** **500 kg/d**	$0.5 million $0.9 million $1.5-2 million	

Assumptions: Truck gas delivery. 700 bar dispensing. Stations built at least 12 months prior to FCEV deployment in significant numbers. Source: *NextSTEPS White Paper: The Hydrogen Transition,* ITS, UC Davis, July 2014, p. 26

In the chart above, cash flow for station operators is negative initially, but after about year seven, it becomes positive. By year nine, the cumulative cash flow become positive as well, and the network can pay for itself, even though the initial years show a negative balance. Hydrogen costs that enable station owners to earn a 12 percent rate of return are estimated below.

Figure 4-11: Hydrogen Cost for Different Station Sizes



Source: NextSTEPS White Paper: The Hydrogen Transition, ITS, UC Davis, July 2014, p. 26

The assumptions in the cost model above include the following:

- Compressed hydrogen costs $6/kg truck-delivered to the station
- Rate of return = 12 percent
- Station life is 10 years
- The levelized cost is what the station would have to sell hydrogen for to make a 12 percent rate of return
- Stations dispense a fuel amount equal to their full capacity
- Hydrogen costs decline due to reductions in capital costs and increased output.

If the FCEV market accelerates rapidly, UC Davis studies indicates that larger (500 kg/d) stations will have a business case that should attract investors. In contrast, the earlier smaller stations (100 - 250 kg/d) involve more risk if FCEV deployment is slow. This study indicates that a self-sustaining economic case is reached once 100-200 hydrogen stations have been built and approximately 50,000-100,000 FCEVs are deployed. To reach these FCEV deployment thresholds, ongoing state subsidy for H2 station developers will be needed for at least five years or more.

4.3.4.5 The Statewide Hydrogen Station Network and Infrastructure

The *ZEV Action* Plan prescribes a minimum network of hydrogen stations to establish the foundation for robust, commercial-scale FCEV adoption. Focused on early adopter areas in Southern California and the San Francisco Bay Area, the FCEV station network includes both "connector" and "destination" stations intended to anchor the network and enable north-south travel. State plans envision a 100-station network as the minimum viable level of infrastructure to support regional FCEV adoption. As of late 2016, 23 stations are open statewide, and 30 more are in planning stages. The state's rapidly growing infrastructure investment stands at $91 million since 2009, and nearly $200 million has been pledged to build out the planned 100 stations.[56]

Table 4-5: Existing California Hydrogen Station Locations and Company

Company	Location
FirstElement	Campbell
FirstElement	Coalinga
FirstElement	Costa Mesa
Air Products	Diamond Bar
Truzero	Fairfax LA
FirstElement	Hayward
Air Products	Irvine
FirstElement	La Canada Flintridge
FirstElement	Lake Forest
FirstElement	Long Beach
Air Products	Los Angeles
FirstElement	Los Angeles
FirstElement	Playa Del Rey
Truzero	Mill Valley
FirstElement	San Jose
Linde	San Juan Capistrano
FirstElement	Santa Barbara
Air Products	Santa Monica
FirstElement	Saratoga
TruZero	South San Francisco

[56] *California rolling out $200M for Hydrogen Fueling Infrastructure.* Auto Rental News, December 3, 2013. Accessed November 12, 2016 at: http://www.autorentalnews.com/channel/fuel-smarts/news/story/2013/12/calif-rolling-out-100m-for-hydrogen-vehicle-infrastructure.aspx

Company	Location
TruZero	Truckee
Propel Fuels	West Sacramento
Air Products	Woodland Hills

Source: *Hydrogen Stations* List. California Fuel Cell Partnership, accessed November 12, 2016 at http://cafcp.org/sites/default/files/h2_station_list.pdf. Validated with further internet research.

The most recent update to the state's *FCEV Road Map,* known as the *Hydrogen Progress, Priorities and Opportunities Report* has further refined the locational strategies of the CaFCP and its OEM Advisory Group, which includes Honda, General Motors, Hyundai, Mercedes-Benz, Nissan, Toyota, and Volkswagen. In 2015, the OEM Advisory Group produced a consensus list of recommended priority locations for the next series of planned hydrogen stations, to ensure that customer travel-time to the nearest station is minimized within a regional market, inter-regional travel is facilitated, and there is at least some redundancy in the network. These recommendations are preliminary and will likely be further refined through more extensive consultation with stakeholders. San Francisco Bay Area stakeholders will note that several stations are recommended as a Primary Priority for this region. This strategy is based on market analysis that suggests that early adoption will be strongly clustered in the South Coast and Bay Areas, necessitating only a few connector stations in the rest of the state during the initial years of market development.

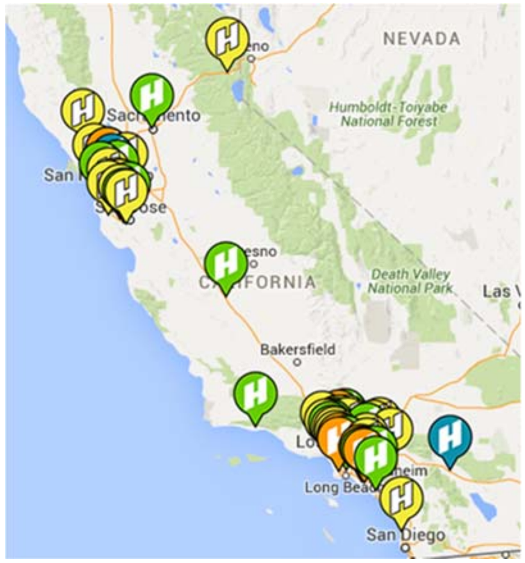
Table 4-6: Station Location Prioritization

Primary Priority*	Secondary Priority*
Berkeley/Richmond/Oakland Beverly Hills/Westwood Fremont Lebec** Manhattan Beach Sacramento San Diego #2 San Diego #3 San Francisco Thousand Oaks/Agoura Hills Torrance/Palos Verdes	Culver City Dublin/Pleasanton Encino/Sherman Oaks/ Van Nuys Granada Hills Irvine South Los Banos** Palm Springs Ventura/Oxnard

Source: *Hydrogen Stations* List. California Fuel Cell Partnership, accessed September 1, 2015 at http://cafcp.org/.
*The locations are listed in alphabetical order and not ranked within the priority lists.
** These two locations will further strengthen the I-5 corridor

Existing (green) and planned (yellow) stations are shown on the map below. In this map, the cluster strategy is clearly evident in station siting.

Figure 4-12: California Hydrogen Fueling Stations

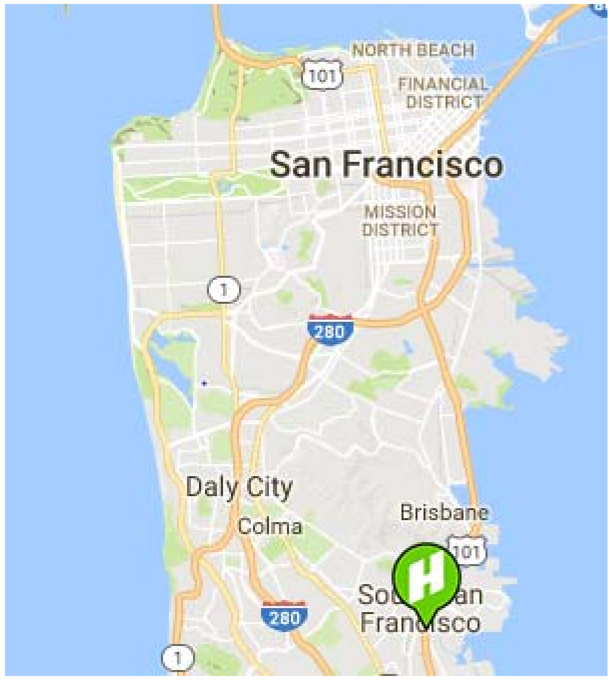


Source: *Hydrogen Stations Map*. California Fuel Cell Partnership, accessed November 12, 2016 at http://cafcp.org/stationmap

4.3.4.6 Current Status of Station Siting in San Francisco and the Greater Bay Area

The first hydrogen station in the city opened on February 15, 2016, located in South San Francisco on 248 South Airport Boulevard. The San Francisco site is part of a 19-station state-wide development by Element Fuels, which has branded the stations as "True Zero." Element Fuels won a $27.6 million contract with the California Energy Commission to develop this fueling station network in California, supplemented with loans from Honda and Toyota. The project is being constructed and managed by Black and Veatch, which also managed development of Tesla's national Supercharger network. Per California state mandate, 33 percent of the hydrogen provided is sourced from renewable sources.

Figure 4-13: South San Francisco Fueling Station Location: 248 South Airport Road

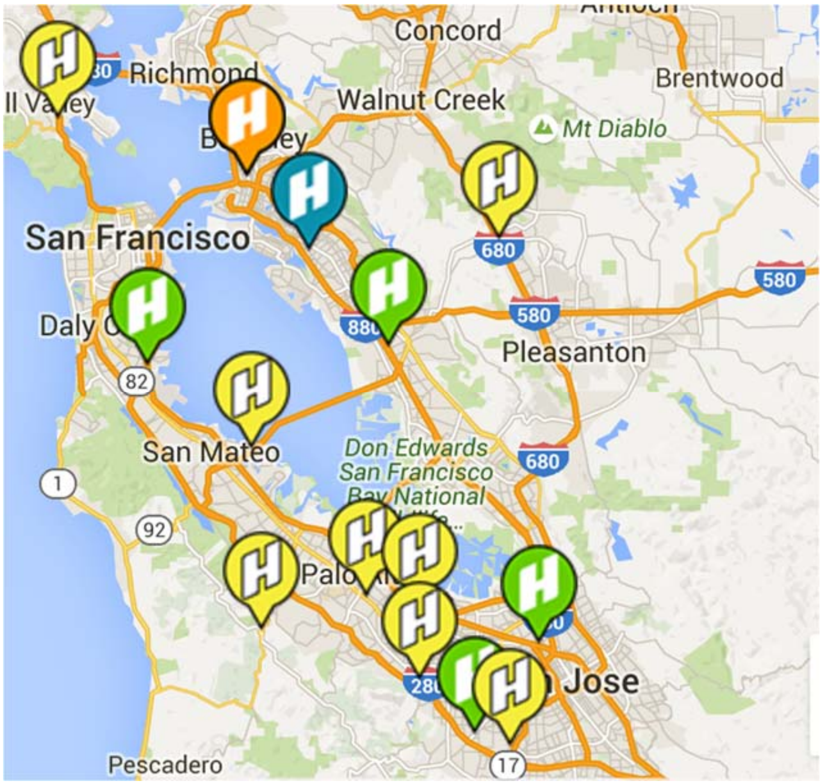


Source: California Fuel Cell Partnership, *Accessed October 12, 2016 at* http://cafcp.org/stationmap

In addition to South San Francisco, there are four publicly available hydrogen stations in the greater San Francisco Bay Area. Three of these are operated by Element Fuels (highlighted in green below), and one is operated by AC Transit in Emeryville (highlighted in orange). Although the Emeryville station is technically open to the public, vehicle owners are required to set up an account and undergo training in advance.

An additional seven publicly accessible stations are planned in the greater Bay Area, developed by First Element, Linde, and Air Liquide. Expected opening dates range from end of 2016 through 201**7.**

Figure 4-14: Current and Planned Bay Area Stations



Source: California Fuel Cell Partnership, accessed June 24, 2016 at http://cafcp.org/stationmap.
(green = public and open, yellow = planned, orange = public but operated by city, blue = private)

Maritime H2 Station Planning: San Francisco's hydrogen fuel vision is not just limited to land vehicles. The U.S. DOT's Maritime Administration, in partnership with Sandia National Laboratories, is exploring a project to replace diesel powered ferries with hydrogen ferries for the local fleet of Red and White ferryboats. The project is still in development, but if successful, would have the capacity to deliver up to 1,500 kilograms of hydrogen a day at a dockside H2 station at the Port of San Francisco, effectively double that of today's largest fueling stations. This fuel would be available for cars and trucks in addition to maritime vehicles.

4.3.4.7 Hydrogen Fuel and Station Companies and Suppliers

Final decisions regarding hydrogen fueling infrastructure locations require collaboration between private station developers, state funders, and relevant permitting authorities. Local planners and permitting authorities are encouraged to reach out both to the CaFCP for more information on local options for hydrogen fueling production and delivery infrastructure, as well as directly to the companies in the field. Key market actors in California include industrial gas companies such as Air Liquide, Air Products, and Linde, which provide equipment, design and construction of stations. Proton OnSite makes electrolyzers and SunHydro branded stations. Hydrogenics and Powertech also provide equipment.

4.4 GHG Impacts of Hydrogen FCEVs

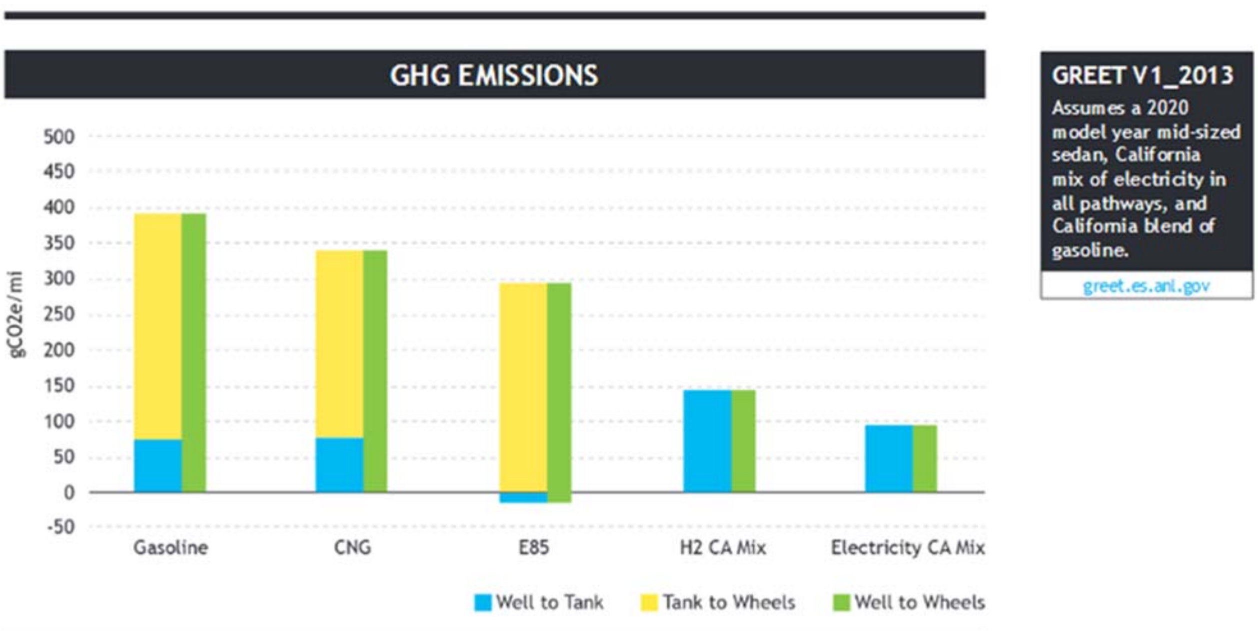
4.4.1 Current GHG Emissions Impact

The methodology used by the California Energy Commission to assess hydrogen fuel attributes is based on the greenhouse gases, regulated emissions, and energy use in transportation (GREET) assessment model. GREET assesses emission impacts of fuels for the full fuel cycle from "well to wheels." The GREET model demonstrates that the current "California mix" of hydrogen in a FCEV reduces GHG by slightly more than half compared to a current average ICE.

As noted above, the California hydrogen fuel mix in Energy Commission-subsidized stations must include at least 33 percent renewable sources. In local practice, however, the CI of hydrogen (as well as electricity) varies by territory, season, and other factors. According to data from the CaFCP, the California average mix of hydrogen produces a total environmental impact of 150 grams of CO2e per mile on a well-to-wheels basis. By contrast, the well-to-wheels impact of gasoline is nearly 400 grams of CO2e per mile, while electricity is 100 grams of CO2e per mile, given the California average grid mix as of 2013.

It is important to note that the carbon impact of both PEVs and FCEVs powered by hydrogen produced through electrolysis will decline significantly in time, as the California grid power mix becomes lower carbon. However, the relative well-to-wheels advantage of PEVs will remain because of higher efficiencies inherent in: 1) the PEV powertrain; 2) direct use of electricity in PEVs vs. use of electricity in FCEVs after the additional conversion losses that occur when producing hydrogen fuel from electricity through electrolysis.

Figure 4-15: GHG Emissions



Source: California Fuel Cell Partnership, accessed November 12, 2016 at http://cafcp.org/sites/default/files/W2W-2014_Final.pdf.

The relative environmental impact of hydrogen fuel will also be subject to future changes in both actual feedstock CI and potentially in the measurement methodologies used to assess key feedstocks. On the environmentally positive scale, the electricity used to manufacture hydrogen will steadily be reduced in CI, thereby reducing the CI of hydrogen fuels produced via electrolysis. On the environmentally negative scale, the assessment of well-to-wheels CI of natural gas (for natural gas-produced hydrogen) is likely to be adjusted upward (toward higher CI) based on emerging research that suggests that methane leakage in the fuel supply chain may be much higher than previously assumed (potentially in the range of 3 percent leakage rather than slightly above 1.3 percent, which was the previous U.S. EPA estimate.[57]) These refinements in the understanding of well-to-wheels impacts of natural gas are likely to reduce the rated environmental performance of both FCEVs and natural gas vehicles (NGVs) compared. PEVs. A comprehensive review of the issue of methane leakage in the natural gas supply chain is underway by the U.S. EPA and is expected to be completed in the 2016-17 timeframe.[58]

4.4.2 The Transition to Green Hydrogen

In recent years, natural gas prices have been relatively low due to a glut of gas produced from shale formations through hydraulic fracturing, commonly known as fracking. Low natural gas prices have in turn helped support low hydrogen prices, and natural gas is thus considered the "feedstock to beat" in a cost-driven market for hydrogen fuels. However, natural gas fueled hydrogen production does not have significant advantages over regular gasoline from a GHG perspective when used in a 100 percent natural gas powered hydrogen fuel formulation (rather than blended with renewable H2 feedstocks.) However, hydrogen produced from any source can provide important local air emissions benefits by eliminating tailpipe emissions (notably a significant reduction in PM when replacing diesel trucks or buses). To address the limitations of natural gas as the principal hydrogen fuel feedstock, and to encourage the integration of cleaner renewable feedstocks in the hydrogen supply chain, the state of California has advanced these four key strategies.

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[57] Fares, Robert, "Methane Leakage from Natural Gas Supply Chain Could Be Higher Than Previously Estimated." Scientific American, July 13, 2015.

[58] For more information, see Heath, G., E. Warner, D. Steinberg, and A. Brandt, 2015. "*Estimating U.S. Methane Emissions from the Natural Gas Supply Chain: Approaches, Uncertainties, Current Estimates, and Future Studies*." Joint Institute for Strategic Energy Analysis. Technical Report NREL/TP-6A50-62820. http://www.nrel.gov/docs/fy16osti/62820.pdf

and Paranhos, E., T.G. Kozak, W. Boyd, J. Bradbury, D.C. Steinberg, D.J. Arent, 2015. "*Controlling Methane Emissions in the Natural Gas Sector: A Review of Federal & State Regulatory Frameworks Governing Production, Processing, Transmission, and Distribution*." Joint Institute for Strategic Energy Analysis, Technical Report NREL/TP-6A50-63416.

www.energy.gov/epsa/downloads/controlling-methane-emissions-natural-gas-sector- review-federal-state-regulatory

1. **The 33 percent renewable hydrogen standard:** The state mandated that 33 percent of hydrogen fuel be renewably produced, per Senate Bill SB 1505. The 33 percent standard is based on the energy content of the fuel and can be averaged over multiple stations within the state. The statute also requires that hydrogen fuel blends shall provide a 50 percent reduction of NOx and Reactive Organic Gases, and a 30 percent reduction of GHGs on a well-to-wheels basis compared with gasoline, along with zero increase in toxic air contaminants. The regulation applies to state co-funded hydrogen stations currently, and it will apply to all hydrogen stations once a volume of 3.5 million kg/year is reached state-wide (equivalent to a statewide FCEV fleet of about 10,000 vehicles.)[59] For purposes of assessing the 33 percent renewable standard for hydrogen production (as well as electricity), renewable fuels are defined by ARB to include:
    a. **Biomass,** which is any organic material not derived from fossil fuels, including agricultural crops, agricultural wastes and residues, waste pallets, crates, dunnage, manufacturing, and construction wood wastes, landscape and right-of-way tree trimmings, mill residues that result from milling lumber, rangeland maintenance residues, sludge derived from organic matter, and wood and wood waste.
    b. **Digester gas** - gas from the anaerobic digestion of organic wastes.
    c. **Geothermal**, landfill gas, municipal solid waste
    d. **Ocean wave**, ocean thermal, or tidal current technologies
    e. **Solar PV** or solar thermal technologies
    f. **Small hydroelectric** (30 megawatts or less)
    g. **Wind energy**
2. **Renewable Portfolio Standard for electricity:** The state has also mandated that electricity be produced from 33 percent renewable sources by 2020. Further, Governor Brown has proposed increasing the Renewable Portfolio Standard to 50 percent by 2030. Thus, as California's grid becomes less carbon intensive, hydrogen produced by electrolysis will become cleaner (as will PEVs driven by the California grid power mix).
3. **Low Carbon Fuel Standard (LCFS):** The LCFS benefits lowest-carbon fuel producers with economically advantageous tradable credits. Hydrogen fuel producers are eligible to achieve LCFS credits if the hydrogen fuel meets LCFS standards for carbon content.
4. **Preferential Support of Renewable Hydrogen Fueling Infrastructure:** The state is preferentially supporting the development of renewable hydrogen projects vs. non-renewable production to increase the available supply and reduce the cost of renewable hydrogen.

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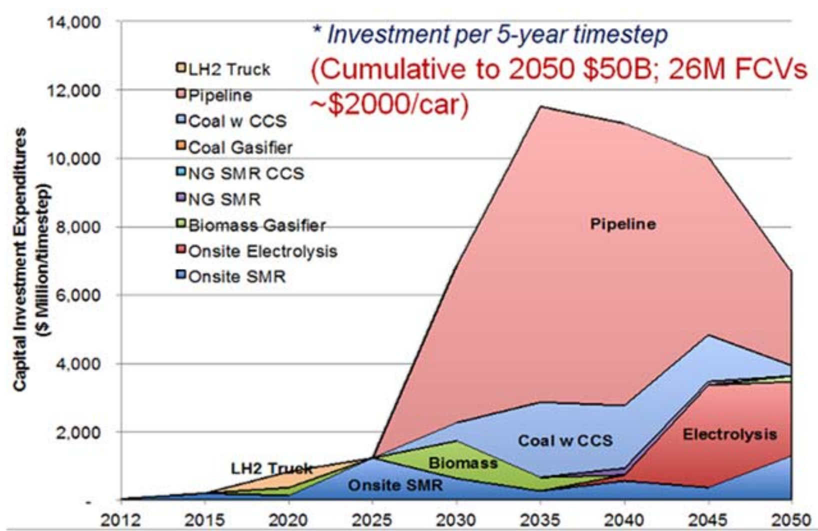
[59]Presentation by Gerhard Achtelik, California Air Resources Board, *California Regulation of Renewable Hydrogen and Low-Carbon Technologies,* November 16, 2009, http://energy.gov/sites/prod/files/2014/03/f12/renewable_hydrogen_workshop_nov16_achtelik.pdf

Given the strategies described above, the hydrogen fuel supply chain in California will likely become lower carbon over time. Although cleaner fuel pathways are technically achievable, bringing costs into alignment with other alternative fuels may be an ongoing challenge at large production volumes.

In theory, hydrogen produced by fossil fuels with CO_2 sequestration could also result in very low emissions, but decades of research have yet to produce cost-efficient methods of sequestration of coal or natural gas emissions at scale. UC Davis has analyzed alternative strategies for achieving a near zero carbon hydrogen fuel supply system in California by 2050 and produced a scenario that assumes future progress in three low-carbon approaches: 1) carbon capture and sequestration (CCS), 2) biomass-derived hydrogen, 3) hydrogen produced with renewable electricity. Of the three strategies, the existence of *cost-efficient* CCS must be considered speculative at this time.

Notably, the scenario without CCS demonstrates that either *emissions* will rise (due to continued use of fossil resources without CCS) or *costs* will rise due to reliance on more expensive renewables. According to the projections illustrated below, to develop a sufficiently large, low-carbon hydrogen infrastructure to meet the 80 percent carbon reduction in the transportation sector called for under AB 32 will require *a $50 billion capital investment.* Although state investment in hydrogen infrastructure been relatively robust compared to other alternative fuels, the investment has been in the tens of millions rather than the tens of billions. Note that in the chart below, the designated "pipeline" hydrogen represents a natural gas formulation, rather than RNG.

Figure 4-16: Strategic Pathways and Costs for California's Transition to Green Hydrogen



Acronyms: NG SMR CCS = Natural gas powered steam methane reforming of hydrogen with Carbon Capture and Storage. (Steam methane reforming is the most common method of producing hydrogen fuel.) LH2 – Liquid hydrogen fuel. Source: *NextSTEPS White Paper: The Hydrogen Transition,* ITS, UC Davis, July 2014, p. 33.

In the UC Davis "base case" scenario, hydrogen is made primarily from distributed Steam Methane Reformation (the most common method in use today) with natural gas as the key feedstock. This is expected to continue in the first several years of hydrogen station operations through 2020. As demand grows in the 2020 through 2030 timeframe, medium-scale biomass gasification systems are also deployed. Beyond 2030, large-scale fossil fuels with CCS (in this case coal) is envisioned to provide hydrogen at low cost and low emissions, *if such technologies are available and effective*. Also envisioned in 2045 to 2050 is the emergence of larger-scale distributed renewable electrolysis to ensure that producers can scale renewable H2 supply to continue to meet (or exceed) the 33 percent renewable hydrogen mandate. In this scenario, average hydrogen costs decline from over $10/kg in 2012 to $4.20/kg in 2050. Average hydrogen CI declines from an efficiency-adjusted value of 4,350 grams CO_2/kg hydrogen to 1,630 grams CO_2/kg hydrogen in 2050, which represents an *85 percentage reduction from current gasoline CI on a well-to-wheels basis,* taking into account higher FCEV efficiency. The UC Davis analysis also suggests that the development of a low-carbon hydrogen supply pathway could become economically competitive with gasoline on a cost-per-mile basis with just 50,000 FCEVs in a region with 100 stations, at an initial capital investment of $100-200 million.

4.5 FCEV Policy and Funding Opportunities

4.5.1 Federal Efforts

The national prevalence of hydrogen vehicles will only occur if a nationwide market develops that complements state-level efforts. To that end, the U.S. DOE, automakers, hydrogen producers, and allied organizations launched H2USA in 2013, a public-private partnership focused on advancing hydrogen infrastructure. The partners, which include the CaFCP and the State of California, are encouraging early adoption of FCEVs with a focus on cost reductions and scale economies in both fuel production and FCEV manufacturing. In their 2013 report entitled *Transitions to Alternative Vehicles and Fuels*, the National Research Council assessed the potential of the light-duty fleet to enable an 80 percent reduction in petroleum consumption and GHGs by 2050, and indicated that FCEVs ranked high among the various options. That said, the federal government has no active plans to invest the $50 billion or more that would likely be required to extend a robust FCEV fueling infrastructure nationwide. In the meantime, more modest research and development investments are being made in reducing fueling infrastructure costs and developing technologies for producing renewable and lower carbon hydrogen fuel supplies.

4.5.2 California Policy and Planning

FCEVs have been embraced by key state policy makers because, supported by an appropriate fueling infrastructure, they will combine the convenience and utility of conventional ICE vehicles with many of the quiet and clean attributes of PEVs. The California Hydrogen Highway Network was initiated in April of 2004 by Executive Order S-07-04 under then Governor Arnold Schwarzenegger. The intent of the Order and associated investments in FCEV technology by the Energy Commission has been to ensure that hydrogen fueling stations will be in place to meet the needs of future FCEV drivers and to provide additional fuel pathways for the advancement of lower carbon vehicles.

To provide an overall strategic framework for FCEV deployments across all vehicle types, the CaFCP published *A California Road Map: The Commercialization of Hydrogen Fuel Cell Electric Vehicle* in

2012.[60] This Road Map (and subsequent updates) articulated the core policy and program framework for FCEV market development, including the all-important development of a new hydrogen fueling infrastructure. The *Road Map* in turn served as a basis for Governor Jerry Brown's March 2012 executive order that directed California state agencies to support the accelerated deployment of the full range of ZEVs, including FCEVs.[61] The state's comprehensive 2013 *ZEV Action Plan* provided further guidance on bringing FCEVs to market.[62] Most recently, the passage of Assembly Bill 8 (Perea, 2013) enabled funding of at least 100 hydrogen stations with up to $20 million a year in competitive grants and operating subsidies for fueling station developers, provided through the Energy Commission.

As of 2016, California has begun establishing the necessary matrix policies and programs to enable a viable FCEV market, including vehicle incentives, fueling infrastructure investments, and station operating subsidies. California's station funding program is establishing the "cluster" and "corridor" fueling network to provide assurance to drivers and automakers that they will be able to refuel FCEVs as they travel within and between major population centers throughout the state.

State incentives exist for all sizes of FCEVs. Heavy-duty FCEVs, in particular FCEBs, are eligible for HVIP vouchers. HVIP vouchers normally range from $8,000 to $45,000 and are provided on a first-come, first-served basis for the purchase of each eligible new truck or bus. For the largest vehicles, rebates of up to $110,000 can be claimed. The complete rules and conditions of the program are available in the Year 4 HVIP Implementation Manual (https://www.californiahvip.org/docs/HVIP_Y4_Implementation%20Manual_2014-08-01.pdf). Light-duty FCEVs are eligible for the CVRP rebate, which provides $5,000 rebates to Californians, though income eligibility is capped at $150,000 for single filers, $104,000 for head of household, and $300,000 for joint filers.

Matching the low-emissions attributes of PEVs will require that sufficient quantities of renewably produced hydrogen fuel are economically available to FCEV drivers. Although current state law mandates that 33 percent of hydrogen fueling supplies in state-supported stations be fueled by renewable hydrogen, most of the remaining hydrogen fuel is derived from natural gas, limiting its environmental advantage relative to pure BEVs. Key state and regional agencies intend to develop a more robust low-carbon hydrogen fuel supply chain. This is outlined in the *Vision for Clean Air*, developed by several leading air quality management agencies, which highlight

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[60] *A California Road Map: The Commercialization of Hydrogen Fuel Cell Electric Vehicles, June 2012*

http://cafcp.org/sites/files/A%20California%20Road%20Map%20June%202012%20%28CaFCP%20technical%20version%29_1.pdf

[61] Executive Order B-16-2012, March 23, 2012 http://gov.ca.gov/news.php?id=17472

[62] *ZEV Action Plan A roadmap toward 1.5 million zero-emission vehicles on California roadways by 2025, February 2013. http://opr.ca.gov/docs/Governor's_Office_ZEV_Action_Plan_(02-13).pdf*

strategies to accelerate the introduction of FCEVs as well as PEVs in the context of air quality policy and goals.[8]

Policies for FCEV promotion will of necessity be driven primarily at the state level, as most cities, regional agencies, and Air Districts do not have resources to offer a substantial quantity of vehicle incentives adequate for FCEV incremental cost buy-down, or sufficient grant funds to support hydrogen fueling infrastructure. That said, local and regional stakeholders can work together with hydrogen fuel suppliers and the CaFCP to accelerate existing plans for hydrogen fueling station deployment, or even to develop new plans and funding applications to the Energy Commission for hydrogen stations. In addition, local and regional stakeholders can proactively assess whether FCEVs can meet local fleet needs not otherwise achievable by PEVs or sustainable biofuels, in particular for transit needs.

4.6 Proposed Actions to Support Hydrogen FCEV Readiness

4.6.1 Requirements for FCEV success

Hydrogen fuel cell electric vehicles have overcome significant technical and economic obstacles to provide a potentially viable alternative fuel and vehicle choice for California consumers and fleet operators. To fully develop the potential of the hydrogen vehicle ecosystem, however, OEMs, fuel producers, and state policy makers must accelerate accomplishment of these key goals:

1. **Product manufacturing costs and retail pricing must achieve parity** with both ICEs and other PEVs
2. **Fueling infrastructure must become ubiquitous,** beginning with the 100 station FCEV network that the Energy Commission plans to complete by 2020
3. **The hydrogen fuel supply chain must continuously improve its "well-to-wheels" emissions while remaining economically competitive** with gasoline and electricity by developing cost-efficient renewable and low-carbon feedstocks at scale
4. **The FCEV product range must diversify** to fully leverage hydrogen's refueling advantages over EVs, especially in the medium and heavy-duty segments
5. **State policy-makers must maintain support for both vehicle incentives and fueling infrastructure** to bridge the "valley of death" between early and mass adoption.

4.6.2 Proposed Action for the City of San Francisco

Most of the challenges above must be addressed by state agencies and industry partners. However, larger municipalities such as San Francisco can take important steps to strengthen the foundation for a viable FCEV ecosystem. The recommendations below outline actions the City can take to accelerate FCEV readiness and adoption.

Recommendation	Next Steps
1. Assess potential of FCEVs to meet the City's municipal fleet GHG reduction goals	▪ Assess FCEV deployment opportunities in the context of the City of San Francisco vehicle fleet.
2. Determine station needs and identify hydrogen fueling sites	▪ Complete planning process for FCEV fueling needs, currently underway with the UC Berkeley Transportation Sustainability Research Center in partnership with the San Francisco Department of Environment. ▪ Support applications for Energy Commission funding for hydrogen stations from local station developers (building on the applications submitted in 2016)
3. Streamline permitting and inspection processes for implementation of hydrogen fueling stations.	▪ Coordinate among relevant City departments to identify best practices and streamline permitting and inspection processes for implementation of hydrogen fueling stations.
4. Coordinate/deliver training on hydrogen fueling safety, code, and standards for all relevant City agencies	▪ Coordinate and deliver training on hydrogen fuel safety, codes, and standards for all relevant City agencies, including public safety.
5. Increase community awareness of FCEVs and hydrogen fueling.	▪ Conduct outreach and awareness campaign to local communities with existing or planning hydrogen fueling stations.
6. Develop and implement group procurement of FCEVs.	▪ Develop and implement a group procurement program that reduces the cost and complexity of FCEVs to the community and local fleets.

Recommendation	Next Steps
7. Evaluate traffic congestion data and develop proposals for congestion pricing in priority areas of the City to improve air quality and accelerate market transformation of FCEVs.	▪ Collaborate with SFMTA and SFCTA to assess data and key planning process and policy steps that lead to •Congestion pricing zones with preferential pricing/access for FCEVs. •Preferential street-parking zones for FCEVs and FCEV car share vehicles; block parking exemption. •HOV lane expansion in combination with transit lanes.
8. Consider City requirement for 100 percent renewable hydrogen fuel at all hydrogen stations	▪ Work with local utilities, station developers and fuel providers to assess feasibility of 100 percent renewable fuel requirements for hydrogen stations in San Francisco.
9. Assess feasibility of local production of renewable hydrogen	▪ Assess potential for locally produce renewable hydrogen in collaboration with internal and external stakeholders with industrial operations.
10. Collaborate with FCEV OEMs to accelerate deployment of medium- and heavy-duty options.	▪ Accelerate adoption of medium and heavy-duty options in public and private fleets by pursuing funding through HVIP and potential funding ARB Medium-and Heavy-Duty vehicle solicitations.

Chapter 5: Biofuel Vehicles and Infrastructure

5.1 Biofuel Overview

Biofuels are fuels produced directly or indirectly from biological materials or any source of organic carbon that is renewed rapidly as part of the carbon cycle. Biofuels are distinguished from fossil fuel feedstocks in part by the age of the organic materials involved in their production. As their name indicates, fossil fuels are derived from fossilized biological sources living eons ago, while biofuels are produced from recently living organic material, including plant materials, FOG, and animal and human waste.

The state views biofuels as critical to reducing carbon emissions from the transportation sector and achieving AB 32 goals. Plant and waste-derived biofuels are typically blended with petroleum-based gasoline or diesel in order to meet the state's LCFS goals ("blendstock"), but they can also be sold as stand-alone fuels ("drop in"), potentially in proportions up to 100 percent biofuel. Growth in the production and utilization of biofuels is being spurred by regulations and incentive funds through the federal RFS, the LCFS, a federal blender's tax credit for biodiesel and renewable diesel sales, and Energy Commission grants for development of biofuel production plants, as well as private investment.

Table 5-1: Biofuels Overview

Fuel substituted	Substitute fuels available	Category
Gasoline	Ethanol blends (e.g., E85)	Blendstock
Diesel	Biodiesel	Blendstock
	Renewable Diesel	Drop in
Natural Gas	Renewable Natural Gas/Biomethane (discussed in Chapter 6)	Drop in

CI Values of Biofuels: CI values of biofuels vary widely depending on the specific alternative fuel feedstocks involved. As originally presented in Chapter 2 of this document, the charts below illustrate the carbon intensity of biofuels compared to electricity based on the current PG&E grid mix. Superior environmental results are obtained for City fleet vehicles due to the 100 percent renewable electricity supply now available in San Francisco through both the SFPUC Hetch Hetchy power supply to City government accounts, as well as the available CleanPowerSF 100 percent renewable "SuperGreen" product, available at a modest price premium over the baseline CleanPowerSF product (which also has a lower CI than PG&E's grid mix).

The landfill biogas assessed in this chart is indicated to have a very low (but still positive) CI value, whereas other biogas feedstocks have been rated as having a negative value, depending on specific biogas sources.

Table 5-2: Full Fuel Cycle Comparison of Alternative Fuels to Standard Gasoline

Fuel / Feedstock	Carbon Intensity (gCO2e/MJ)	CO2e Reduction from Gasoline
Gasoline, conventional	***95.86***	***N/A***
Ethanol, conventional CA average	95.66	0
Ethanol, CA corn	80.70; decreasing to 70.70 in 2016	16% to 26%
Ethanol, Low CI Corn	73.21	24%

Ethanol, Sugarcane	73.40; decreasing to 67.38 by 2020	23% to 30%
Renewable Gasoline	25.00[a]	74%
LNG	83.13	13%
CNG	67.70 [b]	29%
Biogas, landfill	11.56	88%
Electricity, marginal [c]	30.80; decreasing to 26.32 by 2020	68%
Hydrogen [d]	39.42	59%

Source**:** ARB LCFS lookup table and CCR sections 95480-95490. [a] Estimated carbon intensity based on stakeholder consultation, as noted in *California's Low Carbon Fuel Standard: Compliance Outlook for 2020,* June 2013, ICF International. pp. 11-12. [b]North American NG delivered via pipeline; liquefied in CA using liquefaction with 80percent efficiency. [c]Includes the energy economy ratio (EER) of 3.4 for electric vehicles. [d]Includes the EER of 2.5 for Fuel Cell Electric Vehicles.

Table 5-3: Full Fuel Cycle Comparison of Alternative Fuels to Standard Diesel

Carbon Intensity Values for Fuels that Substitute for Diesel		
Fuel / Feedstock	**Carbon Intensity (gCO2e/MJ)**	**CO2e Reduction from Diesel**
Diesel, conventional	94.71	N/A
Biodiesel - waste oil conversion	15.84	83%
Biodiesel – Midwest soybeans	83.25	12%
Renewable Diesel - average scenario[a]	29.49	69%
CNG	67.70 [b]	29%
LNG	83.13	12%
Electricity, marginal [c]	30.80	67%
Hydrogen [d]	39.42	58%

Source**:** ARB LCFS lookup table and CCR sections 95480-95490. [a]Based on conversion of tallow, average of high energy and low energy scenario. [b]North American NG delivered via pipeline; liquefied in CA using liquefaction with 80 percent efficiency. [c]Includes the energy economy ratio (EER) of 3.4 for electric vehicles. [d]Includes the EER of 2.5 for Fuel Cell Electric Vehicles.

As summarized above, vehicles powered by biofuels such as renewable diesel are approximately equal in CI to PEVs powered by the PG&E grid mix, and biofuels produced from waste oil have a lower CI than PG&E grid mix electrons. However, it should again be emphasized that: 1) 100 percent renewable sourcing of electrons is already available in San Francisco for those on Hetch Hetchy power and those who choose the CleanPowerSF SuperGreen product, and that electricity CI in San Francisco will trend toward near-zero as CleanPowerSF sources its electrons from increasingly renewable sources for all its customer accounts. For customers still on PG&E, by 2020, California's grid is expected to produce 40 percent lower emissions than the grid in 2008, due to an increase in renewable generation. Specifically, grid power carbon emissions are expected to be reduced from the 2009 average of 447 grams/CO2 per kWh to 261 grams/C02 per kWh by 2020.[63]

Given the environmental and economic security advantages offered by both electricity and biofuels, it is not surprising that the market for these alternative fuels is growing rapidly. The California biofuels industry is experiencing an especially robust increase in market demand for biodiesel blends and renewable diesel sources that are considered a "drop-in" replacement for petroleum diesel, i.e., one that requires no modification of engines and which present no significant maintenance or operating challenges. However, scaling biofuels to a meaningful proportion of conventional fuels will prove challenging due to: 1) current feedstock supply limitations on waste-based oils and greases (which are among the most ecologically benign of the fully renewable feedstocks), as well as; 2) agricultural production limitations on new biomass sources grown especially for fuel use, which are exacerbated by California's long-term drought and competing land uses.

Despite these limitations, the existing supply of biofuels suitable for end use in vehicles, including gasoline substitutes, diesel substitutes, and biomethane, *represents the largest existing stock of alternative fuel in California's transportation sector.* Of the approximately 28.4 million vehicles on California's roads, more than 96 percent rely on gasoline or diesel for fuel. If low-carbon (advanced) biofuels were to become available in the right quantity and price, they could directly displace the approximately 13 billion gallons of conventional gasoline and 3.3 billion gallons of diesel used per year in California, thereby reducing transportation GHG emissions by more than 50 percent, and potentially eliminating foreign petroleum dependence. For this reason, the Energy Commission continues to invest heavily in companies and communities with the potential to develop economically competitive biofuels (including both biodiesel and biofuel blends for regular gasoline), with an emphasis on the lowest-carbon, most economically and environmentally sustainable feedstocks.

GHG impacts can be summarized in the CI figures presented above. However, other air emissions impacts are also important and differ among biofuel types. These and other environmental impacts related to sustainable sourcing and scalability of feedstocks will be reviewed later in this chapter. The expanding array of vehicle types able to run on ethanol and other biofuels will also be discussed, along with a review of state and federal policy measures and funding sources now shaping the dynamic biofuels market. Finally, this Chapter will close

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[63] *Ibid, p. 17.*

with a discussion of how biofuels can continue to play a key role in enabling the City of San Francisco to meet its emissions goals.

5.2 Biofuel Overview and Types

In California and globally, several types of biofuels are being produced from a wide range of organic materials and conversion processes. The primary biofuels commercially available today are ethanol, made from various forms of sugar and starches, and biodiesel and renewable diesel, produced primarily from animal fats and vegetable oils. Some of these fuels are used as "blendstocks" with petroleum-based fuels to enable combustion in existing engines; while others are considered "drop-in fuels," or fuel substitutes that are essentially identical in operating characteristics to the petroleum products for which they substitute. These drop-in fuels require virtually no modification in engines, maintenance processes, or fueling infrastructure. The characteristics of blendstock fuels are discussed below.

5.2.1 Blendstock Implications and Nomenclature

Biofuels are used primarily to fuel motor vehicles. However, they can also fuel engines for other industrial processes such as agricultural pumping or electric power production, or to produce hydrogen for fuel cells which in turn generate electricity. The preponderance of biodiesel and ethanol production is used as blendstocks with petroleum fuels. In California, most ethanol and biodiesel fuels are blended with fossil-based gasoline and diesel to power the full spectrum of vehicles and engines. These biofuels have reduced energy densities than their 100 percent petroleum-based equivalents, among other operating differences. However, the operating capabilities of these blended biofuels (and the variety of blended formulations) are constantly expanding as manufacturers design, test, and certify their engines for increasingly high percentages of biofuel content, and fuel developers create new blend options.

To alert consumers to the biofuel to petroleum ratio in any given biofuel, a standardized numbering scheme has been developed in which B5 signifies 5 percent biofuel blend with petroleum diesel, and E5 signifies 5 percent ethanol blend with petroleum gasoline. The percentages of biofuel content range up to B100, or 100 percent biodiesel, and E85, which is a blend of 85 percent ethanol and 15 percent fossil gasoline. As noted above, the standard gasoline in California is already a biofuel blend of 5 percent to 10 percent with ethanol, and is the principal means by which biofuels are integrated into the transportation fuel ecosystem as a whole.

5.2.2 First Generation and Advanced Biofuels

Biofuels are further divided into two "generations" based on scale of production and environmental impact of feedstock. First generation biofuels include starch-based ethanol as well as oil crop-based biodiesel. Corn, wheat, sugar, soybean, and palm oil are the commonly used first-generation feedstocks. These biofuels typically reduce CI by 5 percent to 30 percent compared to a gasoline or petroleum diesel baseline. Production of these biofuels is now at a large commercial scale nationally, and first-generation biofuels are blended into existing fossil-fuel based with strong economic support through federal and state incentives and investment policies.

Some first-generation biofuels are widely considered to be environmental sub-optimum insofar as they may displace food production and have a higher CI and a lower "energy return on energy invested" than more advanced or second generation biofuels. Additionally, many first-generation biofuels are made from feedstocks that displace agricultural crops, causing some food systems analysts to warn that the trend toward fossil-fuel intensive biofuel production is raising food prices beyond the reach of some of the world's poorest populations.

Second-generation or advanced biofuels are produced from non-corn starch, sugar, or cellulosic biomass. These feedstocks have more favorable environmental profiles insofar as many of these do not directly displace other agricultural crops, and can be grown on lower-quality land with reduced inputs of fossil-fuel based resources, such as nitrogen fertilizer. According to a formally established U.S. EPA definition, advanced biofuels reduce CI by 50 percent or more compared to the gasoline baseline.[64] Feedstocks for advanced biofuels include agricultural waste, perennial grasses, farmed woody biomass that can be derived from bamboo or other trees, waste oils, algae, and post-recycled waste. In addition, RNG can be made from waste biogas (a full discussion of RNG and biogas production options is included in Chapter 6).

5.2.3 Ethanol

5.2.3.1 Ethanol Production

As noted earlier, ethanol is used primarily as a fuel additive with gasoline in concentrations of either 10 percent (E10) or 85 percent (E85). The vast majority of ethanol is consumed in the E10 blend, which is widely distributed in alignment with the federal RFS. Consumers in California use E10 in their regular gasoline supplies typically without awareness of the biofuel content and the special formulations involved. By contrast, E85 is used exclusively in ethanol-ready Flexible Fuel Vehicles (FFVs) and comprises a much smaller supply. While there are 1 million FFVs registered in California, they used just 6.6 million gallons of E85 in 2013. However, 1.5 billion gallons of ethanol were used in the blending of E10, and used by nearly all the 26 million motor vehicles in California running on gasoline.

5.2.3.2 Ethanol Production in California

Virtually all of the ethanol currently used in California is imported from out of state. ICF and other sources project that ethanol supplies will continue to be produced from imported Midwest corn in the near term, while future in-state production will increasingly utilize waste stream sources and purpose-grown energy crops, such as switchgrasses and sugar cane from the Imperial Valley. Maximizing in-state production of ethanol has been a policy goal of the state for the last decade, with biomass residues from agricultural, forestry, and urban sources heavily favored for ethanol production, given the large volume of California's untapped biomass resource. Currently, the state is estimated to have the capacity to produce nearly 220 million

[64] http://www.c2es.org/technology/overview/biofuels

gallons of ethanol per year (about 1/5th of current total ethanol consumption in California), using primarily corn or sorghum as a feedstock.

5.2.3.3 Ethanol Trends in California

Ethanol consumption in California in the 2015 through 2020 period is projected to be nearly flat, as can be seen in the table below. However, biofuel production must grow rapidly by 2050 to meet ARB goals. Although take-up of E85 has been slow, ARB and the Energy Commission remain committed to both FFVs and the broader biofuels opportunity, for the simple reason that the potential for GHG reduction is so large.

Table 5-3: Ethanol Volumes by Feedstock Type

(in millions of gallons)								
Feedstock	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Corn, Conventional	264	0	0	0	0	0	0	0
California Corn	215	220	220	220	220	220	220	220
Low CI Corn	780	884	699	526	408	311	214	87
Sugarcane	120	240	360	480	500	500	500	500
Cellulosic	5	41	100	150	246	328	406	511
Total	1,384	1,385	1,379	1,376	1,374	1,359	1,340	1,318
Ethanol in gas	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**

Source**:** California's Low Carbon Fuel Standard: Compliance Outlook for 2020, June 2013, ICF International. p. 18.

5.2.3.4 Shifting to Lower Carbon Ethanol

Total in-state ethanol consumption has not substantially changed since 2011; however, production has steadily shifted to lower-carbon-intensity ethanol feedstocks, which has been crucial to advance the state's LCFS and GHG reduction goals. Like other biofuels, ethanol is eligible for LCFS credits. The number of credits provided to ethanol increased almost 40 percent in 2013 vs. 2012 because of the shift to lower-carbon production (with LCFS credits being distributed in proportion to CI). It is anticipated that ethanol will continue its trend toward lower CI thanks to a combination of LCFS incentives and advances in low-carbon biofuel production capacity.

5.2.4 Biodiesel

5.2.4.1 Biodiesel Production

Biodiesel is a blendstock diesel substitute produced using what is known as a transesterification process, whereby vegetable oils or animal fats react catalytically with methanol, ethanol, or another alcohol type. Through transesterification, glycerin in the feedstocks is separated from the fat or vegetable oil. This process leaves behind two products, methyl esters (the chemical name for biodiesel) and glycerin, which is considered a valuable byproduct and is usually sold for use in soaps and related products. Biodiesel is defined under the standard of ASTM D6751 as "a fuel comprised of mono-alkyl esters of long-chain fatty acids derived from vegetable oils or animal fats." Biodiesel is also referred to as FAME (fatty acid methyl ester) or RME (rape seed methyl ester) in Europe. Unlike renewable diesel, biodiesel is not a "drop-in" replacement for petrodiesel. Biodiesel users must be aware of the key differences that can affect the operation of diesel engines.

Some of biodiesel's properties can present benefits over traditional petrodiesel. The use of biodiesel can reduce net CO2 emissions, reduce hydrocarbon and CO2 emissions, and lower visible smoke. Biodiesel also has a higher cetane number than petrodiesel, contains no aromatics, and is non-toxic and biodegradable. Lastly, biodiesel has low sulfur content and improves lubricity. On the other hand, biodiesel may not be compatible with certain metals, causing corrosion with metals that include zinc, copper-based alloys, tin, and lead. Biodiesel can also cause certain elastomers and seals to swell or harden. Biodiesel may also increase NOx emissions, especially at higher blend levels. This is especially critical to consider when using biodiesel in newer vehicles equipped with certified emission control technologies for the more stringent 2007 NOx emission standards.

Biodiesel can also negatively impact low-temperature operability due to its higher cloud point and pour point properties. Biodiesel compatible additives may be needed to mitigate these low-temperature operating challenges and oxidative stability of biodiesel. Lastly, biodiesel has lower energy content than petrodiesel. Although this lower value may not be noticeable at blend levels of B2 or B5, users of high blend levels (B20 to B100) may notice a reduction in power output as well as fuel efficiency.

Over the past few years, manufacturers have been working to support the use of biodiesel in their engines and equipment. While some OEMs permit use of biodiesel at blends of B2, B5 and even B20 in their engines, others are still assessing the issue. Of course, for blending at any level, it is critical to know that the original biodiesel blending stock (B100) meets the industry quality standard, known as ASTM D6751, EN 14214 or equivalent specification. For this reason, biodiesel users are strongly encouraged to purchase their fuel blends from sources that have been fully accredited and quality-tested by the National Biodiesel Board. This accreditation is indicated by the designations: *BQ-9000 Certified Marketer* and *BQ-9000 Accredited Producer*.[65] ***Please note that it is critical to consult your vehicle and engine manufacturer before switching to biodiesel***. Some brands, such as John Deere, utilize multiple engine manufacturers,

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[65] BQ-9000® is a voluntary program for the accreditation of producers and marketers of biodiesel fuel. The program combines adherence to the ASTM standard for biodiesel, ASTM D6751, and a quality systems program that includes storage, sampling, testing, blending, shipping, distribution, and fuel management practices. BQ-9000® helps companies improve fuel testing and quality control. To receive accreditation, companies must pass a rigorous review and inspection of their quality control processes by an independent auditor.

and therefore it is important to confirm which engine type you are using and check directly with the engine manufacturer as appropriate. Use of non-certified, non-approved fuels can void warranties.

5.2.4.2 Biodiesel Trends

With just over a decade of commercial-scale production, biodiesel production has increased from about 25 million gallons in the early 2000s to about 1.7 billion gallons of advanced biofuel in 2014. This represents a small but growing component of the annual U.S. on-road diesel market of about 35 billion to 40 billion gallons. Consistent with projected feedstock availability, the industry has established a goal of producing fuel for about 10 percent of the diesel transportation market by 2022. There are currently about 200 biodiesel plants across the country with registered capacity to produce some 3 billion gallons of fuel. However, a crucial factor in the further expansion of biodiesel production infrastructure is diversifying feedstocks to include more cellulosic sources, reliable sources of fats and oils, and next-generation feedstocks such as algae and camelina. Opportunities for expanding biodiesel and renewable diesel production in California will be explored below.

5.2.4.3 Biodiesel in California

California has seven biodiesel production facilities, with a combined production capacity of 59 million gallons per year, accounting for 35 percent of LCFS credits from a combined total of about 174 million gallons of low carbon fuel in 2013. Though the Energy Commission has funded upstream biodiesel infrastructure projects, the LCFS regulation has encouraged the regulated fuel distributors to integrate larger shares of biodiesel into their upstream infrastructure without special state incentives. Several major oil terminals throughout the state have either converted or begun converting existing infrastructure to accommodate biodiesel blending. Given that private investment is supporting large-scale biodiesel blending, the Energy Commission is not currently proposing additional funding for diesel substitutes infrastructure. The table below projects the likely volume of future California biodiesel production by feedstock.

Table 5-4: Estimated California Biodiesel Consumption Through 2020 (million gallons)

Feedstock	2013	2014	2015	2016	2017	2018	2019	2020
Soy Oil	3	5	8	11	14	16	19	23
Waste Grease	19	29	48	51	51	51	51	51
Corn Oil	19	29	48	67	86	95	112	189
Canola Oil	3	5	8	27	49	59	80	62
Total Biodiesel	**45**	**68**	**113**	**157**	**200**	**221**	**262**	**325**
Biodiesel Blend	1%	2%	4%	5%	7%	8%	10%	12%

Source: California's Low Carbon Fuel Standard: Compliance Outlook for 2020, June 2013, ICF International. p. 18.

As noted above, both renewable diesel and biodiesel fuels can be produced from a broad range of feedstock options, including animal waste, soy beans, vegetable oils, wood wastes, animal fats, and protein. The U.S. Navy and Marine Corps are particularly aggressive early adopters, using B20 in nearly all their non-tactical diesel vehicles, and consuming approximately one-third to one-half of all biodiesel sold in California. To strengthen the integrity and security of the domestic fuel supply chain, the military has robust goals for increased use of both biofuel and electric vehicles. ARB is also committed to fast biofuel production growth as a key part of their AB 32 GHG reduction roadmap.

5.2.4.4 Biodiesel in San Francisco

Prior to its current adoption and use of renewable diesel at the end of 2015, the City of San Francisco led the way in introducing biodiesel, primarily B20, into its fleets. The City of San Francisco achieved nearly 100 percent use of B20 biodiesel as early as 2007 under Mayor Gavin Newsom. Norcal Recycling/Waste Management, then the city's waste hauler, converted 100 percent of their fleet to B20. The City was also instrumental in helping open the City's first biodiesel fueling station in the Bayview Hunters Point neighborhood, at the Olympic station at 2690 Third Street, which supplied commercially licensed diesel vehicles with B20 produced by converting local restaurant waste grease to biodiesel. This station has since closed, but locally sourced biodiesel is still available through Dogpatch Biofuels, located at 765 Pennsylvania Avenue in the San Francisco. As of late 2016, Dogpatch is the only retail outlet for biodiesel in San Francisco. Dogpatch Biofuels produces a hybrid fuel known as RB20, which consists of 80 percent renewable diesel and 20 percent locally sourced biodiesel. Unlike B100, most commercially sold diesel engines can run on RB20 without any adjustment or adaptation. renewable diesel is not yet available at retail locations in San Francisco.

5.2.4.5 Biodiesel Emissions Impact

Within the biodiesel fuel type, emissions factors vary according to the blend. The U.S. EPA has surveyed a large body of biodiesel emissions studies and averaged the health effects testing results with other major studies. The results are presented in the table below.

Table 5-5: Biodiesel Emissions vs. Conventional Diesel Without Advanced Emissions Controls

Emission Type	B100	B20
Regulated Emissions		
Total Unburned Hydrocarbons	-67%	-20%
Carbon Monoxide	-48%	-12%
Particulate Matter	-47%	-12%
NOx	+10%	+0% [1]
Non-Regulated Emissions		
Sulfates	-100%	-20% [2]
PAH (Polycyclic Aromatic Hydrocarbons) [3]	-80%	-13%

Emission Type	B100	B20
nPAH (nitrated PAH's)[4]	-90%	-50% [5]
Ozone potential of speciated hydrocarbon	-50%	-10%
Lifecycle CO_2 Emissions [6]	-76%	-15%

Source: "A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions," U.S. EPA, 2001. www.epa.gov/otaq/models/analysis/biodsl/p02001.pdf

1 Eur. J. Lipid Sci. Technol. 2009 "Effect of biodiesel blends on North American heavy-duty diesel engine emissions." 2 Estimated from B100 result. 3 Average reduction across all compounds measured. 4 Average reduction across all compounds measured. 5 2-nitroflourine results were within test method variability. 6 Univ. of Idaho/USDA "Reassessment of Life Cycle GHG Emissions for Soybean Biodiesel."

5.2.5 Renewable Diesel

5.2.5.1 Renewable Diesel Production

While renewable diesel is chemically the same as petrodiesel, it is made from recently living biomass. renewable diesel is a second generation "drop-in" diesel substitute using biological sources that are chemically not esters and thus distinct from biodiesel. (Esters are a class of organic compounds that react with water to produce alcohols and organic or inorganic acids.) renewable diesel meets the industry standard for chemical "identity" with petroleum diesel quality, known as the ASTM D975 specification, and is thus considered chemically and operationally nearly identical to petrodiesel. The principal distinction is that the organic material used in renewable diesel production is (like most biodiesel feedstocks) is made of recently living organic material, in contrast to the fossilized organics used in petrodiesel. renewable diesel has also been defined in a technically specific manner by the U.S. DOE, the Internal Revenue Service, and the U.S. EPA to enable producers to participate in the formal RFS program and the Renewable Identification Numbers (RIN) system required to qualify for various subsidies, discussed in section 5.4.1.3.

Although renewable diesel can be made from the same feedstocks as biodiesel, renewable diesel has been hydrocracked and refined in a manner similar to petroleum diesel, using hydrotreating, thermal conversion, and Biomass-to-Liquid processes. From an end use standpoint, the key difference between renewable diesel and biodiesel is biodiesel's usability as a "drop in" replacement. renewable diesel blends follow the same nomenclature as biodiesel. For example, renewable diesel in its pure form is designated R100 while a blend comprised of 20 percent renewable diesel and 80 percent petroleum diesel is called R20. Because renewable diesel is chemically the same as petroleum diesel, it can be mixed with petroleum diesel in any proportion. The "drop in" replacement capability of renewable diesel means that it can be used effectively in all types of diesel applications, including light, medium, and heavy duty vehicles, nearly all marine applications and some aviation applications. A United Airlines Los Angeles to San Francisco flight is soon to begin operation using a combination of renewable diesel and petroleum diesel marketed as BioJet. The only reported operating issue with renewable diesel is that some users may need an additive to address lubricity issues.

5.2.5.2 Renewable Diesel Trends

Renewable diesel production capacity is ramping up quickly. Currently, there are ten plants worldwide producing renewable diesel, with four additional projects in development. New plans have very high capital requirements, typically in excess of $200M per facility. There are four renewable diesel producers as of 2016, including Neste, the world's largest, and Italy's ENI, US-based Diamond Green Diesel (a subsidiary of Valero), and Swedish refiner Preem. With growing biofuel demand and the search for higher quality renewable fuels, the outlook is for continued growth of several hundred million gallons of capacity per year, as in the 2011-2014 period.[66]

- *2011: 300M gallons*
- *2012: 700M gallons*
- *2013: 900M gallons*
- *2014: 1.2 billion gallons*

5.2.5.3 Renewable Diesel in California

Renewable diesel is now the most common diesel substitute used in California, recently supplanting biodiesel. Volume is currently about 95 million gallons (vs. nearly 3 billion gallons of regular diesel.) The majority of this increase is accounted for by overseas imports; however, additional in-state renewable diesel producers are expected to come on-line soon.

5.2.5.4 Renewable Diesel in California Fleets

Renewable diesel has only recently been available in quantity in California, and public and private fleets began integrating use of this fuel in the 2015 to 2016 period. Golden Gate Petroleum is currently the largest renewable diesel distributor in the Western United States and is supplying a growing number of fleets. In addition to San Francisco, other municipal users of the product include the cities of Walnut Creek, Oakland, and the California Department of General Services. Within the private sector, the product is being used by Google (for its gBus employee commuter fleet serving San Francisco and other cities in the Bay Area) and UPS. renewable diesel distribution is becoming more robust, as Propel Fuels recently began carrying renewable diesel at many of its stations throughout the state.

Fleet managers have responded positively to renewable diesel that, in contrast to biodiesel, does not require any special handling or pose operational challenges. According to Richard Battersby, Oakland fleet director and the chair of the East Bay Clean Cities Coalition: "At first, renewable diesel seemed like a 'too good to be true' cost-neutral way to achieve our goals. But Renewable Diesel gives you the ability to convert your entire diesel-powered fleet to alternative fuel overnight. The most common reaction I've experienced is disbelief that there is a cleaner

[66] Tina Caparella, "Global Renewable Diesel Use Triples," *Render, 12/15,* http://www.rendermagazine.com/articles/2015-issues/december-2015/biofuels/

burning direct diesel fuel substitute that is made from renewable sources, doesn't require any additional expense for the fuel itself, and does not require equipment and infrastructure modifications." The City of Oakland is now using Nexgen Renewable Diesel supplied by Golden Gate Petroleum to power the 250+ diesel vehicles in its fleet, at price parity with petroleum diesel.

5.2.5.5 Renewable Diesel in San Francisco

At the end of 2015, the City of San Francisco contracted with Golden Gate Petroleum to supply renewable diesel with a CI level that is at least 60 percent lower than ultra-low sulfur diesel fuel. The City utilizes 100 percent renewable diesel for the nearly 2,000 city vehicles previously relying on petroleum diesel or biodiesel, which is distributed to 53 city-run fueling facilities. Given the challenges of sustainable sourcing for these fuels, San Francisco elected to define a CI requirement in its specification, rather than to indicate which feedstocks would be used. City staff have indicated that neither palm oil nor food feedstocks such as corn will be included in their renewable diesel supply given this CI level, since these feedstocks typically have higher CI values. At this time, some "technical corn oil" is used in the Neste product, utilizing waste distillers' grain, although there is no palm oil coming into California from Neste (although Neste does use palm oil in products shipped to other regions). To meet the contract specification, Golden Gate Petroleum blends the Neste fuel, with a CI level of approximately 30 to 33, and Diamond Green renewable diesel, with a CI level of approximately 15 (compared with conventional diesel's CI of 94).

5.2.5.6 Renewable Diesel Emissions Impacts

The overall GHG profile of renewable diesel varies according to feedstock. As noted above, the CI value of Neste RD99, the current dominant product blend in terms of volume and market share, is in the 30 to 33 range (with the reference petroleum gasoline being measured at 100.) The overall profile of the Neste RD99 product is as follows:[67]

- Approximately 80 percent lifecycle reduction in GHG vs. fossil diesel (depending on renewable diesel feedstock)
- PM = 33 percent lower
- NOx = 9 percent lower
- Hydrocarbons (HC) = 30 percent lower
- Carbon monoxide (CO) = 24 percent lower

In the CI analyses performed by ARB, the relative carbon inputs of different stages in the fuel supply chain are assessed per each individual feedstock source. However, in actual production

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[67] *Neste RD product description on website, based on ARB-certified CI values. Accessed November 12, 2016 at: https://www.neste.com/na/en/customers/products/renewable-products/neste-renewable-diesel*

environments, diverse feedstocks are blended and therefore the CI calculation of each batch of blended feedstocks must be separately assessed and will vary depending on the specific production timeframe and sourcing. In the example below, ARB has assessed the CI of Australian tallow, which is an animal fat that conforms to certain technical criteria (e.g., melting point), and is typically of little or no value in commercial food production, and thus minimizes the fuel vs. food tension associated with biofuels sourced from crops such as corn or sugarcane. This examples demonstrate the relatively significant contribution of fuel transportation to the total carbon impact, and thus underscores the environmental as well as economic importance of in-state or in-region sourcing of biofuels where feasible.

Table 5-6. Carbon Intensity of Renewable Diesel Sourced from Tallow (well-to-wheels)

	Carbon Intensity in gCO_2e/MJ
Tallow Production (By rendering)	16.06
Tallow Transport	3.95
Renewable Diesel Production	10.63
Renewable Diesel Transport and Distribution	5.79
Total WTT	36.43
Total TTW	0.78
Propane Rich Off-Gas Credit	-3.75
Total WTW	**33.46**

Source: ARB – Neste, *NExBTLRD Singapore Plant, Tallow Pathway Description,* http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/neste-aus-rpt-031513.pdf

5.2.6 The Role of Biofuels in Achieving Greenhouse Emissions Goals

Global, national, and state-level climate and energy analyses have concluded that low carbon biofuels will be essential to reduce greenhouse gases to the levels needed to mitigate the worst impacts of global warming, given the relatively slow uptake of PEVs on a national and global basis. Biofuels are particularly essential to decarbonize those transportation sectors which are most dependent on fossil fuels, and the costliest and most technically challenging to electrify, notably long-haul trucking, aviation, rail, and marine transport. For many of these applications, batteries are currently too heavy to support the relevant loads and travel distances, while hydrogen suffers from relatively low energy density, limited and costly fueling infrastructure, and costly pathways to scaled low-carbon production. Given these constraints, the International Energy Agency (IEA, 2012) projects that approximately 25 percent of global transportation energy in 2050, or nearly 250 billion GGE, must come from advanced, low carbon biofuels if the world is to limit global warming to a two-degree Celsius increase or less, the current goal of international climate policy and the 2015 Paris Agreement. Comparably aggressive targets are also essential to achieving California's 80 percent by 2050 GHG reduction goal.

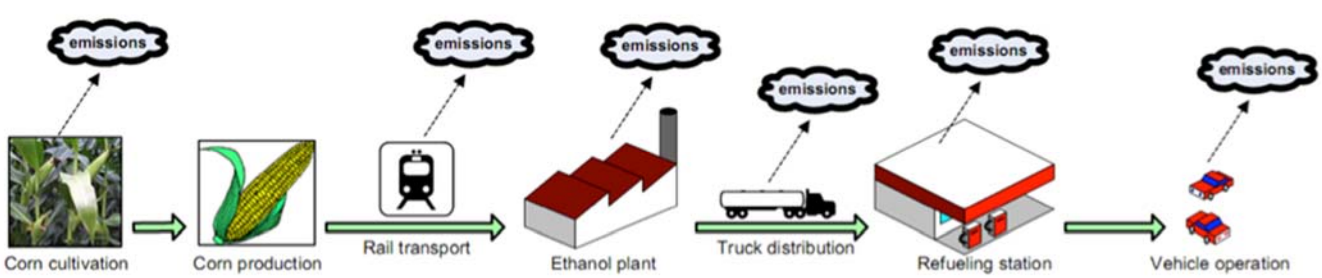
5.2.6.1 Comparative GHG Impacts and CI Values for Biofuels

If grown in a sustainable manner, biomass (in and of itself) is considered a carbon-neutral energy source, meaning that the GHG emissions released from converting biomass to energy are equivalent to the amount of CO2e absorbed by the plants during their growing cycles. Sustainable biomass sources refer to those that limit land use change, avoid pollution, prioritize waste materials, and regrow quickly without substantial energy and chemical inputs. Without actions to ensure ecological sustainability, however, an increase in dedicated biofuel crops can result in undesirable land use impacts, such as deforestation to make way for palm oil plantations, which is a key driver of Amazonian deforestation and attendant GHG emissions in South America. Additional problematic impacts that accompany some biofuel production methods include unfavorable energy return on energy invested (a problem with corn ethanol in the Midwest) and increased use of nitrogen fertilizers which degrade riverine and ocean ecosystems and introduce additional pesticides and pollutants into drinking supplies. Finally, fossil fuels used in biomass harvesting, transporting, and processing have a negative effect on total emissions. It is ARB's policy to include all *carbon-related* impacts their full life-cycle analysis, including secondary impacts such as land use changes.

5.2.6.2 The GREET Model for Assessing Lifecycle Greenhouse Emissions

To create a scientifically based, equitable methodology for estimating lifecycle greenhouse gas emissions for both petroleum- and bio-based fuels, the Argonne National Laboratory has developed a full life-cycle model called GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation). It enables researchers to evaluate various vehicle and fuel combinations on a full fuel-cycle and a full vehicle-cycle basis. The first version of GREET was released in 1996. Since then, Argonne has continued to update and expand the model. The most recent GREET versions are the GREET 1/ 2014 version for fuel-cycle analysis and GREET 2/ 2014 version for vehicle-cycle analysis. GREET is provided as a public domain, multidimensional spreadsheet model in Microsoft Excel, and is available free of charge at https://greet.es.anl.gov. With GREET or any other model, some emissions are directly measured, including tailpipe CO2, while others must be estimated, such as indirect land use change that occur when food crops are displaced by biofuel production. In the case of biofuels, the following diagram of the lifecycle pathway of corn ethanol indicates the complexity of the measurement process.

Figure 5-1: Lifecycle Emissions Pathway, Corn Ethanol



Source: Delucchi, M., A Lifecycle Emissions Model (LEM): Lifecycle Emissions from Transportation Fuels, Motor Vehicles, Transportation Modes, Electricity Use, Heating and Cooking Fuels, and Materials, http://www.its.ucdavis.edu/publications/2003/UCD-ITS-RR-03-17X.pdf

5.2.6.3 CI Values of Various Biofuels

As the chart below indicates, the CI of biofuels varies considerably, depending on the feedstock. Feedstocks for both ethanol and biodiesel or renewable diesel have the potential to reduce GHGs by anywhere from 5 percent for conventional ethanol, to 30 percent for lower-CI corn and sugarcane, to 80 percent for cellulosic feedstocks such as switchgrass, to 90 percent or more for biogas. Note that for comparative purposes, grid average electricity in California has a CI of about 70 percent below conventional gasoline per unit of energy (gramsCO2e/Megajoule), and locally available 100 percent green electricity from CleanPowerSF can achieve near-zero CI. Unless otherwise noted, CI values were derived directly from ARB's look-up tables, which use the GREET methodology, depicting CI in grams of CO2e per megajoule.

Table 5-7: Carbon Intensity Values for Fuels that Substitute for Gasoline

Fuel / Feedstock	CI (gCO2e/MJ)
Ethanol, conventional	95.66
Ethanol, CA corn	80.70; decreased to 70.70 in 2016
Ethanol, Low CI Corn	73.21
Ethanol, Sugarcane	73.40; decreasing to 67.38 by 2020
Ethanol, Cellulosic	21.30 [a]
Renewable Gasoline	25.00 [b]
Compressed natural gas	68.00
Biogas, landfill	11.56
Electricity, marginal [c]	30.80; decreasing to 26.32 by 2020
Hydrogen [d]	39.42

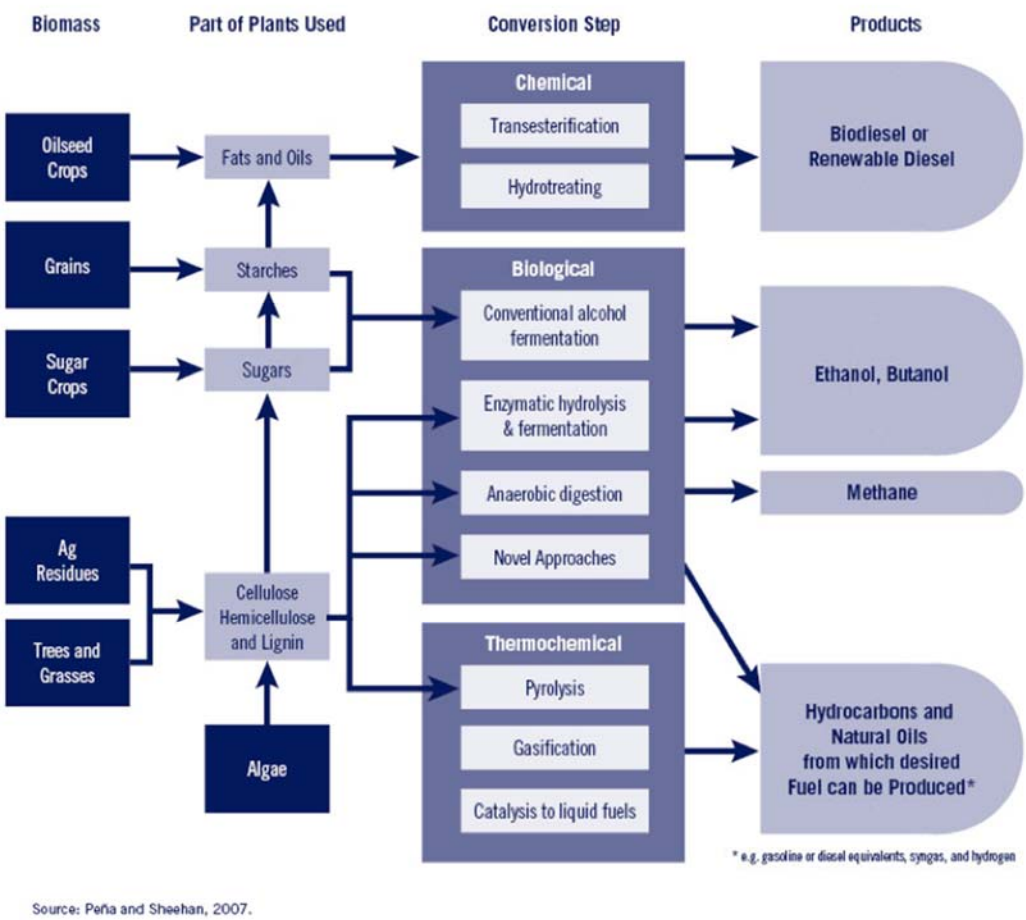
Source: *California's Low Carbon Fuel Standard: Compliance Outlook for 2020,* June 2013, ICF International. pp. 11-12. [a]The average of ARB pathways for ethanol from farmed trees and forest ways. [b]Estimated CI based on stakeholder consultation. [c]Includes the energy economy ratio (EER) of 3.4 for electric vehicles. [d]Includes the EER of 2.5 for fuel cell vehicles

Additional opportunities for GHG savings through biofuel use in LDVs may emerge as renewable gasoline comes onto the marketplace, potentially as early as 2017. Renewable gasoline is under development as a 100 percent renewable biofuel that could be utilized as a "drop-in" replacement for petroleum gasoline. Currently, California fuel producers already incorporate at least 5 percent ethanol into the fuels marketed as standard gasoline, whereas renewable gasoline would go far beyond this threshold while enabling use in regular vehicles. Neste is one of the leaders in renewable gasoline development. However, it is important to note that renewable gasoline supplies may be constrained from rapid scale-up due to sourcing limitations that persist for some time, much as biofuel production generally has scaled much more slowly than originally projected by agencies such as the U.S. EPA and ARB.

5.2.6.4 Innovative Biofuel Feedstocks

The diverse biofuel feedstocks currently in use or under development differ significantly in the types of lands on which they can be grown, yields per acre, and the fuels into which they are processed. The table below indicates the various biomass types, plant elements, conversion steps, and products that can be produced among the diversity of biofuel pathways available, and the current and emerging pathways for these diverse feedstocks.

Figure 5-2: Current and Emerging Biofuel Pathways



Source: Pena, N., Biofuels for Transportation: A Climate Perspective, 2008. http://www.c2es.org/publications/biofuels-transportation-climate-perspective.

As mentioned above, the dominant methods of biofuel production convert simple sugars, starches, or oils to produce biofuels. For example, the fermentation of cornstarch (from the corn kernel), sugar beets, or sugarcane produces ethanol, while the transesterification of oils (such as soybean or palm oil) produces biodiesel. Of the feedstocks in use today, sugar beets, sugarcane, and palm oil yield the highest amount of fuel per acre on a GGE basis. However, these feedstocks are also very energy intensive to grow, compete with food supplies, and have other sustainability issues because they are water, fossil-fuel, and pesticide intensive.

In principle, the majority of available plant material for biofuels is in the form of cellulose, hemicellulose, and lignin (not food crops), which would significantly lower the resources needed to grow biofuel feedstocks.[68] Furthermore, once the cellulose is extracted from the plant to produce the biofuel, the remaining lignin can be used as a fuel to power the biofuel conversion process. Lignin yields energy when burned and further limits the fossil fuel inputs required to produce the biofuel. Researchers are also looking at different sources for oils that can be converted into biodiesel. However, early federal subsidies for biofuel production and existing agricultural subsidies have favored corn and other sugar and starch-based biofuels, and technology for biofuel production with these feedstocks is more advanced. Algal feedstocks have proven very challenging to scale economically and are not expected to provide meaningful supplies in the time horizon of this plan.

California policy makers are seeking to advance more sustainable approaches over the medium and longer-term with a targeted investment approach that emphasizes cellulosic sources, wastes, algae, and crops that can be grown on marginal lands (such as jatropha), further described below.

- **Cellulosic feedstocks** include perennial grasses (e.g., switchgrass and Miscanthus) or short rotation woody crops, which can be converted to ethanol or other biofuels.
- **Industrial waste** includes agricultural wastes such as manure and other processing wastes that are high in protein and fats; these can be converted to oils and then to biodiesel. Other waste biomass includes wood residues from the forest industry and agricultural residues from corn farming; the cellulose in these materials can be converted into ethanol.
- **Algae** can produce oil that can be converted to several different biofuels. Additional opportunities are in microalgae (microscopic algae) that can create biomass even more efficiently than terrestrial plants. Algae based biofuel research has been ongoing for many years, but has been slow to demonstrate commercial scalability.
- **Jatropha**, a species able to grow on barren, marginal land, especially in many parts of Asia. Jatropha oil is extracted from the seeds of the plant and can be used to produce biodiesel.

Following harvesting or collection, all forms of biomass must be converted to sugar or other feedstocks through three processes: pretreatment, conditioning and hydrolysis, and fermentation using microorganisms. Pretreatment processes remove the protective sheath of lignin and hemicellulose to allow for further enzyme hydrolysis of the cellulose biomass to glucose or simple sugar. Conditioning and enzymatic hydrolysis lowers the acidity of the material so that enzymes and organisms can thrive. The feedstock is then fermented using

[68] Cellulose is complex carbohydrate and the main structural component of plants. Hemicellulose is similar to cellulose and found in plant cell walls. Cellulose and hemicelluloses account for 25 to 50 percent of plant material. Lignin is a polymer that provides rigidity to plants cell walls and is second largest component of plant biomass.

specially developed microorganisms that can more effectively ferment all the sugars in biomass, improving the final ethanol product and expanding feedstock options.

All the feedstocks identified above have the ability to reduce greenhouse gas emissions significantly relative to conventional gasoline and diesel fuel. Because they are not food-based and are often processing wastes from other industries, they also have the added benefit of limiting competition between transportation fuel uses and food crops.

5.3 Vehicles with Biofuel Potential

5.3.1 Ethanol and Flexible Fuel Vehicles

5.3.1.1 Flexible Fuel Vehicle Characteristics

FFVs are defined as vehicles that are warrantied to run on *either* regular gasoline or on E85 (or another intermediate blend, such as E20). The size and substantial market penetration of FFVs may be the best-kept secret in American transportation. E85 fuel has been in the marketplace for nearly two decades, but sales were modest until 2013, when RFS requirements and favorable blending economics spurred substantial sales growth. There are now approximately 3,250 retail stations offering E85 today in the US, *although only about 100 E85 stations in California.* As of 2014, approximately 25 percent of new vehicles sold in the United States were FFVs capable of operating on E85, and this percentage is growing year by year. This includes approximately half of new models produced by Ford, Chrysler, and General Motors, as well as select models from Volkswagen, Land Rover, Jaguar, Toyota, Mercedes-Benz, Bentley and Audi. On a cumulative basis, nearly one of out every ten cars on the road nationally is an FFV, and thus could run exclusively on E85. However, many consumers are completely unaware of whether they are already driving an FFV, and may never have fueled their car with E85.

To determine if a particular car is an FFV, one can check the fuel door, look for an exterior FFV badge or a yellow gas cap, or consult the owner's manual. The Renewable Fuels Association also maintains a comprehensive listing of FFVs at their website at: http://ethanolrfa.3cdn.net/c1cbb67143f6ec4358_97m6buo45.pdf According to the most recent data available from the US Energy Information Administration (Annual Energy Outlook 2013), there were nearly 13 million flexible fuel cars on the road nationwide as of 2013, *and over 400,000 FFVs in California* (http://www.eia.gov/tools/faqs/faq.cfm?id=93&t=4). FFVs cost only approximately $100 more per vehicle to manufacture compared to a non-FFV of the same model (Reuters, 2010; Hess, 2007). Through 2016, automakers receive additional credits from selling FFVs to comply with the U.S. EPA's greenhouse gas standards. Despite the slightly higher cost of manufacture, this incentive has effectively driven substantially increased production and sales of FFVs in recent years.

Despite the large and rapidly growing availability of FFVs, drivers of FFVs in the US have consumed relatively little E85, choosing instead to power their vehicles with regular gasoline (or technically speaking with the E5 or E10 blends that are now deployed nationwide in compliance with the federal RFS). *In recent years, only 1-3 percent of the fuel consumed by FFVs has been E85,* as noted in the table below. The low consumption of E85 is likely due to multiple factors: 1) low awareness of the FFV "feature;" 2) limited E85 distribution; 3) low awareness of ethanol availability; 4) the fact that E85 reduces fuel economy by more than 20 percent on average vs. standard gasoline. Lower mpg increases refueling frequency even if the overall economics of E85 remain favorable. Despite these challenges, ethanol use is rising and could become a significant contributor to reduced GHG emissions as market penetration continues to increase. As the FFV fleet has grown, the percentage of VMT driven on E85 has expanded by 500 percent in just the 2011 through 2014 period, growing from .6 percent to 3 percent.

Table 5-8: Flexible Fuel Vehicle Deployment and E85 Fuel Consumption in the U.S. in 2011-2013

	2011	**2012**	**2013**
Flexible Fuel Vehicles (millions)	9.94	11.38	12.82
E85 (million gallons)	25.4	132.0	175.8
% of FFV miles driven on E85	0.6%	2.5%	3.0%

Source: EIA, 2014.

5.3.1.2 Flexible Fuel Vehicle Fueling Availability

A comprehensive listing of E85 retailers is available at the U.S. DOE's Alternative Fuel Station Locator at http://www.afdc.energy.gov/locator/stations/. At this website, the user can specify the kind of fuel wanted, enter an address, and the locator will map out the closest stations that sell that fuel. Drivers using a Garmin or TomTom GPS device can also use the Renewable Fuel Association's *Points of Interest E85 Fuel Locator* application to identify nearby stations. A Flexible Fuel Station Locator can also be downloaded from the Apple App Store or the Android Marketplace. Information on E85 pricing can be found at www.chooseethanol.com. A recent search (October 2016) found prices as low as $1.09 in Indiana and as high as $3.19 in California, with average pricing in the $2.50 range nationally and somewhat higher in California. Within California, there are only 98 E85 fueling stations listed at the e85.com website (http://www.e85vehicles.com/e85-stations.html). Within San Francisco, there is one public E85 outlet at the All Star gasoline station on Cesar Chavez Street, and a private fleet depot at the Veteran's Affairs facility near the Presidio.

The revised federal RFS mandate (RFS2, discussed further below) establishes a maximum volume of federally incentivized corn ethanol production, and mandates specific volumes of lower-carbon biofuels that meet the technical specifications for U.S. EPA designation as an "advanced biofuel," with a minimum 50 percent reduction in CI vs. petroleum fuels. These RFS2 volume mandates apply to all petroleum fuel producers nationwide. The Energy Commission projects that the federal RFS combined with the state's LCFS will spur the production and sale of 2.7 billion to 3 billion gallons of ethanol in California by 2030. Reaching these levels of E85 consumption is contingent upon the number of FFVs on the road, adequate E85 fueling stations, and the willingness of California FFV drivers to actually purchase E85 fuels if available.

To realize the 2030 RFS2 forecast, the consulting firm ICF International estimates that the installation of between 1,300 and 13,000 new E85 dispensers will be required nationally by 2022, depending on total consumer demand and dispenser throughput.[69] The estimated average cost per E85 dispensing unit, including installation and permitting, is approximately $330,000, based on recent grant award data from the Energy Commission. However, California retail gas station owners and operators have no obligations under the RFS2 regulations or the LCFS to offer E85 for sale, and little financial incentive to make an investment of this size for new E85 infrastructure. Expanded E85 fueling is challenging not only because of the up-front capital outlay, but also because owners face significant difficulty in setting the retail price of E85 low enough relative to regular gasoline (with its superior energy density and mpg) to attract customers while still making a profit. Recently, the ethanol price has been below the 20 percent discount relative to gasoline that is required to compensate drivers for the decreased fuel economy of E85. However, this modest advantage has not been viewed as significant enough in a period of relatively low gas prices to power greatly increased ethanol use.

5.3.1.3 Flexible Fuel Vehicle Sales Projections

Despite only modest success in boosting E85 consumption, the outlook for FFV deployment is robust in both the automobile and light truck segments (including pickups and SUVs). The strong sales projections below reflect the fact that there is no substantial price premium on FFVs compared to regular gas vehicles, and consumers have no reason to "opt out" of vehicle models that come with FFV capability as standard equipment. Given these factors, the ICCT projects that 2020 sales of FFVs will be 3 percent for cars and 15 percent for light trucks at the "low" case, and 13 percent for cars and 52 percent for light trucks in the "high" case.

Table 5-9: Flexible Fuel Vehicle Sales Growth Projections (percentage of annual sales)

Scenario	Vehicle type	2010	2020	2030
Low	Cars	3%	3%	3%
	Light trucks	15%	15%	15%
Low-Medium	Cars	3%	5%	5%
	Light trucks	15%	18%	18%
Medium	Cars	3%	6%	6%
	Light trucks	15%	22%	22%
Medium-High	Cars	3%	7%	7%
	Light trucks	15%	26%	29%

[69] *Potential Low Carbon Fuel Supply to the Pacific Coast Region of North America. ICCT, 2015, accessed November 22,2016 at: http://www.theicct.org/sites/default/files/publications/PacificCoastRegionLCF_Jan2015.pdf*

Scenario	Vehicle type	2010	2020	2030
High	Cars	3%	13%	15%
	Light trucks	15%	52%	58%

Source: Potential low-carbon fuel supply to the Pacific Coast region of North America, The International Council on Clean Transportation (ICCT). Washington, D.C., Malins, C., Lutsey, N., Galarza, S., Shao, Z., Searle, S., Chudziak, C., & van den Berg, M. (2015).

As discussed above, the volume of ethanol consumed by FFVs does not exist in a linear relationship to the number of FFVs deployed, and FFVs in the U.S. only use E85 for 3 percent of total miles traveled. However, this fraction is expected to rise in the future, according to ICCT estimates.

Table 5-10: Projected Share of Vehicle Miles Traveled on E85 by FFVs

CASE	2010	2020	2030
Low	1%	4%	8%
Low - Medium	1%	6%	12%
Medium	1%	7%	14%
Medium - High	1%	9%	18%
High	1%	15%	30%

Source: Potential low-carbon fuel supply to the Pacific Coast region of North America, The International Council on Clean Transportation. January 2015. P. 84

5.3.2 Petroleum Diesel Vehicles

The use of petroleum diesel fuels has an enormous impact on air quality and public health in San Francisco, and on the economic security of the state and nation. Diesel engines emit a complex mixture of air pollutants, composed of gaseous and solid material. The visible emissions in diesel exhaust are PM, and are significant contributors to respiratory disease, including childhood asthma and other health impacts that disproportionately impact children, the elderly, and low-income communities immediately adjacent to truck corridors. While diesel-powered vehicles account for only approximately 4 percent of California motor vehicles, they produce nearly 60 percent of directly emitted PM, over 25,000 tons per year, and use about 16 percent of the total refined petroleum.

The 1,250,000 diesel-fueled engines and vehicles used in California include trucks and buses, large off-road equipment such as bulldozers and tractors, engines used in portable equipment such as cranes, refrigerating units on trucks (TRUs), and stationary engines used to generate power or pump water. On-highway motor vehicles use about 75 percent of this total, with the rest consumed by off-highway construction, farming equipment, military, railroad equipment, and marine transport.[70]

In 1998, California identified diesel exhaust PM as a toxic air contaminant based on its potential to cause cancer, premature death, and other health problems. According to ARB, diesel PM contributes each year to approximately 2,000 premature deaths, with an uncertainty level that places the potential impact in a range of 1,500 to 2,400 deaths. In addition, diesel soot causes visibility reduction and is a potent contributor to global warming. According to ARB and the Union of Concerned Scientists, diesel trucks produce 9 percent of the greenhouse gases emitted from all sources statewide. Despite their small numbers relative to LDVs, diesel vehicles produce more than double the PM and NOx of the 20 million LDV fleet. Just one heavy duty diesel truck with a pre-2010 engine can produce the emissions impact of 150 regular LDVs.

Unfortunately, growth in diesel emissions is substantial, increasing by 77 percent from 1990 to 2013, a growth rate three times greater than LDVs in that period. Further, the Energy Commission predicts a 42 percent increase in use of diesel by 2030, and the U.S. DOE predicts transport GHGs from freight trucks will grow from 17 percent in 2007 to 20 percent in 2030.[71] In addition to the GHG and PM challenge, diesel vehicles and equipment remain major contributors to statewide emissions of NOx. Compared to today's levels, a 90 percent reduction in NOx emissions by 2031 will be necessary to achieve compliance with current federal ozone standards, in addition to the 80 percent reduction in GHG emissions by 2050 required to meet AB 32 targets. Achieving both targets will require dramatic increases in the supply and availability of cleaner non-petroleum diesel, and progress in the electrification of goods movement.

5.3.2.1 Diesel Vehicle Use Characteristics, Models, and State Funding

Diesel LDVs, including autos, pick-ups, and SUVs, have historically suffered in consumer perception from association with the soot and smells of heavy-duty diesel trucks and buses. However, the performance and sales of diesel LDVs are changing dramatically. There are now a total of 7.4 million diesel cars and SUVs on US roads, out of a total vehicle pool of roughly 250 million, an increase of 47.6 percent since 2010, compared to an overall market rise of just 6.4 percent during the same period. Data provided by IHS Automotive to the Diesel Technology Forum showed that some of the highest year-over-year increases since 2010 have come from California.[72]

A key milestone in the recent renaissance of diesel LDVs was reached in 2006, when Mercedes introduced its BlueTEC clean diesel technology for the E-Class sedan. The core of this technology is an injected liquid solution known by the trade name AdBlue that reduces smog-causing NOx

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[70] *California Energy Commission, Energy Almanac, July 2015,* http://energyalmanac.ca.gov/transportation/diesel.html

[71] *UCS/ ARB, "California: Diesel Trucks, Air Pollution and Public Health,"* http://www.ucsusa.org/clean-vehicles/california-and-western-states/diesel-trucks-air-pollution.html#.V0cIXGOeyAY

[72] *"Texas And California Lead The Country In Diesel Vehicles," The Association for Convenience and Fuel Retailing,* http://www.nacsonline.com/news/daily/pages/nd0331155.aspx#.VcjIgngf9p8

to nitrogen and water vapor. BlueTEC's introduction coincided with the rollout of the ultralow-sulfur diesel fuel requirement in California, giving diesel a “green halo” that it had not had previously. Another milestone was reached at the 2008 Los Angeles Auto Show, where the 2009 Volkswagen Jetta TDI was named Green Car of the Year with an estimated 41 mpg U.S. EPA performance on the highway and compliance with emissions standards in all 50 states. The subsequent revelation of the VW emissions fraud has set back the reputation of diesel LDVs. However, it is important to note that the liquid after-treatment technologies used by Mercedes and others are not implicated in the VW fraud.

As of 2015, diesel offerings are proliferating not only from Mercedes and VW, but also from BMW, Jeep, Mazda, Porsche, and even Chevrolet, which has promoted the diesel version of the strong-selling Cruz as a "clean turbo diesel sedan," with an U.S. EPA highway rating of 46 mpg. Altogether, there are estimated to be 47 new clean diesel car, light-duty truck, and SUV models available now or launching in the 2016 model year, with forecasts of 62 diesel LDV models available throughout North America by 2017.

Nationwide, diesels make up only about 3 percent of the passenger vehicle market, but this percentage is expected to grow in the next few years. Currently, diesel LDVs are approximately $2,000 to $5,000 more expensive than the equivalent conventional gasoline vehicle, but resale value is typically proportionately higher. Further, diesel engines have a reputation for very long life, which supports strong resale values. Additional benefits of diesel use include enhanced fuel economy (20 percent to 40 percent improvement), and greater power availability for towing and heavier vehicles. Diesel fuel pricing is variable, but in general has been close to that of regular gasoline, sometimes slightly higher or lower. The availability of diesel vehicles and their clean fuel capabilities are outlined in the chart below. Dates indicated below indicate when the OEM first approved B20 or higher biodiesel blends.

Table 5-11: Diesel Cars, Trucks, and Low-Carbon Biodiesel Fuel Capabilities

OEMs Supporting B100	OEMs Supporting B20	OEMs Supporting B5
Case IH (2007)	**Arctic Cat** (2006)	**Audi** * (Allowing up to B20 in IL and MN in 2009---2015 models)
Deutz AG (2012)	**Buhler** (2007)	**BMW**
Fairbanks Morse	**Caterpillar** (All model years)	**Hustler Turf Equipment**
New Holland (2007)	**Fiat Chrysler (FCA) –** **Ram** (2007) **& Jeep** (2013)	**Mercedes Benz** * (For blends over B5, see MB brochure)
	Cummins (2002)	**Mitsubishi Fuso** *
	Daimler Trucks --- Including:)	**PACCAR* --- Including:**

OEMs Supporting B100	OEMs Supporting B20	OEMs Supporting B5
	--- **Detroit Diesel** * (Series 60 engines only; other models approved for B5) **Freightliner / Custom Chassis** (with Cummins engines)	--- **Kenworth** (Allow up to B20 in models with Cummins engines) --- **Peterbilt** (Allow up to B20 in models with Cummins engines)
	Thomas Built Buses	**Volkswagen** * allowing up to B20 in IL and MN in 2009-2015 models)
	Western Star (w/ Cummins engines)	
	Ferris (2011)	
	Ford (2011)	
	GMC & Chevrolet (2011 all; SEO available since 2007)	
	HDT USA Motorcycles (2008)	
	Hino Trucks (2011)	**Biodiesel Position Not Yet**
	Navistar --- International / MaxxForce (2007)	**JCB**
	IC Bus (2007)	**Jaguar / Land Rover**
	Isuzu Commercial Trucks (2011)	**Mahindra**
	John Deere (2004)	**Mazda**
	Kubota (2006)	**Porsche**
	Mack (EPA 2007 & EPA 2010 models)	**Nissan**
	Monaco RV (2007)	**Toyota**
	Perkins (2008)	
	Tomcar (2008)	
	Toro (2008; SEO kits for <2008)	
	Volvo Trucks (EPA 2010 models)	
	Workhorse (2007)	
	Yanmar (2011)	

Source:Biodiesel.org, accessed October 2016 at: http://biodiesel.org/docs/default-source/ffs-engine_manufacturers/oem-support-summary.pdf?sfvrsn=16; * indicates manufacturers actively researching B20

In summary, all major OEMs producing diesel vehicles for the U.S. market support at least B5 and lower blends, and nearly 80 percent of those manufacturers now support B20 or higher biodiesel blends in at least some of their equipment. Importantly, nearly 90 percent of the medium and heavy duty truck OEMs support B20 or higher blends of biodiesel. However, the biodiesel component of the fuel must meet the approved standard for pure biodiesel, known as ASTM D6751, and the B20 blends must meet ASTM D7467 specifications. For a complete listing of OEM position statements on biodiesel, visit: www.biodiesel.org/using---biodiesel/oem---information.

5.3.2.2 Diesel Market Outlook

Many industry analysts predict that diesel vehicles will make up to 10 to 15 percent of the US light-duty market by the year 2025, up from just over 3 percent in 2014.[73] With diesels delivering up to 40 percent better real-world fuel economy than gasoline counterparts, automakers are turning to diesel platforms to help them meet the new Corporate Average Fuel Economy standards, which mandate a fleet average of 54.5 MPG by 2025. In the medium and heavy-duty truck, bus, and RV markets, there are 27 brands with over 115 different diesel models. While numerous companies are working on both electric and hydrogen product offerings in the medium and heavy-duty sector, it could be as much as a decade before many of these are ready for mass production with pricing that is competitive with current diesel offerings. Therefore, the short- to medium-term outlook for diesel in all segments is quite strong. There is corresponding urgency to replace fossil diesel with renewable diesel and Biodiesel. Only in combination with very low-carbon biofuels can diesel provide a strong economic and environmental benefit.

5.3.2.3 Diesel and Biodiesel Fueling Infrastructure

The current diesel fuel infrastructure (including refineries, pipelines, terminals, and service stations) covers the entire state and country and operates at very large scale. There are approximately 160,000 service stations and 5,000 truck stops in the United States, which supply approximately 140 million gallons of diesel per day (blended with biodiesel). Diesel biofuels are attractive as an alternative fuels strategy in large part because they can use this existing large-scale infrastructure, though there are cost factors involved in developing additional tanks and pumps. Diesel retail outlets are plentiful throughout the state and Bay Area region.

5.3.3 Freight Transit

As discussed in Chapter 2, diesel freight trucks are deeply intertwined with the economy of San Francisco and the greater Bay Area, with “goods movement-dependent industries” providing approximately 1.1 million jobs and composing more than half ($490.3B) of the San Francisco Bay Area’s economy.[74] Trucks currently haul more than two thirds of goods in the region, and regional commodity flows are expected to almost double between 2011 and 2040. Given the scale of the diesel truck-based goods movement sector, it is vital to accelerate biofuel use in trucks.

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[73] *The Diesel Technology Forum, Clean Diesel Resources, July 2015.* http://www.dieselforum.org/resources/clean-diesel-vehicles-currently-available-in-the-u-s-

[74] *Sciammas, Charlie, et al. “Traffic Causes Death and Disease in San Francisco Neighborhoods”. Race and Regionalsm, Vol. 15, No. 1, Fall 2008.*

5.4 Biofuel Funding Opportunities and Policy Context

5.4.1 Federal Biofuels Policies

5.4.1.2 Renewable Fuel Standards

The RFS programs and mandates have been the key driving force behind increased biofuel production and adoption nationally. The first generation of this program, known as RFS1, established federal renewable fuel volume production and blending mandates. Under the Energy Independence and Security Act (EISA) of 2007, the RFS program was updated (now called RFS2) and set these new policies in motion:

- The RFS was expanded to include diesel, in addition to gasoline
- The volume of renewable fuel required to be blended into transportation fuel was increased from 9 billion gallons in 2008 to 36 billion gallons by 2022
- EISA established new categories of renewable fuel, and set separate volume requirements for each one, including biomass based (renewable) diesel and biodiesel (now classified as an Advanced Biofuel).

EISA also required U.S. EPA to apply lifecycle greenhouse gas performance threshold standards to ensure that each category of renewable fuel emits fewer greenhouse gases than the petroleum fuel it replaces. For the purposes of implementing the RFS, U.S. EPA's lifecycle analysis includes emissions related to feedstock production and transportation, fuel production and distribution, and use of the finished fuel. As required by the Clean Air Act, U.S. EPA's analysis also includes significant indirect emissions such as emissions from land use changes, agricultural sector impacts, and co-products from biofuel production. The results of these analyses are used to determine if the fuel pathways meet the GHG reduction thresholds required by the Clean Air Act.

The initial focus of RFS was on the mass production of corn ethanol, which was intended to enable cellulosic and algal biofuels to leapfrog forward. The RFS established a flexible production and distribution infrastructure that could integrate diverse feedstocks with increasingly superior GHG and sustainability characteristics. However, the leap from demonstration to commercial stage has proven more difficult than expected for cellulosic and algal biofuel companies. In 2013, the production of starch and oil-crop-based fuels topped 14 billion gallons, while less than one *million gallons* of cellulosic biofuels were produced. The original nationally mandated level of cellulosic biofuels for 2013 had been one *billion* gallons. To date, the production of algae-based fuels has been even smaller than cellulosic biofuel. The U.S. EPA's original 2014 target ranges for each fuel category are shown below.

Table 5-12: National Renewable Fuel Production Targets, Standards, and Incentives

Category	Range of Volume*	Proposed Volume*	Required Percent of Fuels
Cellulosic Biofuel	8-30 million gallons	17 million gallons	0.01 percent
Biomass-Based Diesel	1.28 billion gallons	1.28 billion gallons	1.16 percent
Advanced Biofuel	2.0-2.51 billion gallons	2.20 billion gallons	1.33 percent
Total Renewable Fuels	15.00-15.52 billion gallons	15.21 billion gallons	9.20 percent

Source: U.S. EPA website. *All volume is reported in ethanol-equivalent gallons, except for biomass-based diesel, which is in native gallons.

When the RFS was passed into law, Congress decided to treat biodiesel differently than other fuels. Rather than setting year-by-year targets through 2022, as it did for other types of renewable fuels, lawmakers decreed only that the U.S. EPA must mandate at least 1 billion gallons a year of biodiesel production by 2012. After that, they left the decision up to the agency whether and by how much to increase the annual target. Accordingly, U.S. EPA has set its own targets for conventional ethanol and advanced biofuel, including biodiesel, for the years 2014 through 2017. Some biofuel producers have come out in opposition to the U.S. EPA's targets, suggesting that they reflect the reluctance of major oil refiners to include more biofuels in their product.

For biomass-based diesel made from soybean oil, animal fats and used cooking grease, the U.S. EPA required refiners to use 1.7 billion gallons of biodiesel in 2015 and 1.8 billion gallons in 2016. For 2017, the current proposal would set the biodiesel mandate at 1.9 billion gallons. According to the National Biodiesel Board, the foremost trade association for the biodiesel industry, more than 50 biodiesel facilities have either idled or gone bankrupt since 2012 as a result of a lack of robust RFS targets and Congressional inaction. This has allowed the industry's $1-a-gallon tax credit to expire periodically. Retroactive reinstatement, which has occurred numerous times, does not support stable pricing or market confidence in the same way that a permanent credit would. Under the RFS program, the biodiesel mandate is contained in the larger mandate for advanced biofuel use. After enough of the fuel is produced to satisfy the biodiesel mandate, it can compete in the broader advanced biofuel mandate. There, biodiesel's toughest competition has come from imported sugarcane ethanol from Brazil, which U.S. EPA also considers an advanced biofuel. However, imported sugarcane based ethanol can be more problematic from a GHG and sustainability perspective than many domestic feedstocks.

The long-term outlook for stabilizing federal biofuel tax credits and production mandates remains uncertain, as recent Congressional action has tended to subject biofuel and renewable energy tax credits to annual cancellation or retroactive reinstatement, while petroleum industry credits and incentives are permanent or of long duration.

5.4.1.3 Renewable Volume Obligations and Renewable Identification Numbers

To increase the amount of biofuels in gasoline, the federal government's RFS also created a program of Renewable Volume Obligations (RVOs) and Renewable Identification Numbers (RINs). RVOs represent the biofuel targets for each refiner or importer of petroleum-based gasoline or diesel fuel, while RINs allow for flexibility in how each of them may choose to comply. The volumes for the four RFS targets (cellulosic, biodiesel, advanced, and total) are assigned to the "obligated parties," which include refiners and importers of gasoline and diesel fuels. The RVOs are calculated by dividing each RFS target by the total estimated supply of nonrenewable gasoline and diesel fuel in each year. As an example of RVO impact, in 2013, the four RVO targets added up to a total of approximately 12 percent of the renewable plus nonrenewable total of 100 percent. The RVO's mandated the obligated parties to produce the following proportions of renewable fuels:

- Cellulosic biofuels, 0.008 percent
- Ethanol equivalent for biomass-based diesel, 1.12 percent
- Advanced biofuels, 1.6 percent
- Total renewable fuels, 9.63 percent

The RVOs are applied to each obligated party's actual supply of gasoline and diesel fuel to determine its specific renewable fuel obligation for that calendar year. Obligated parties must cover their RVOs by surrendering RINs within 60 days after the end of each calendar year. Each RIN is a 38-character alphanumeric code assigned to each gallon of renewable fuel that is produced in or imported into the United States. RINs are valid for the year in which they are generated. However, up to 20 percent of a year's mandate can be met with RINs generated in the previous year. When renewable fuels are blended into gasoline and diesel fuel or sold to consumers in what is known as "neat form" (typically 100 percent biofuel), the RIN representing the renewable attribute of the fuel becomes separated from the physical biofuel and can be used for either compliance purposes or traded (like the status of Renewable Energy Credits [in the solar and wind industry). Separated RINs have a market value attached to them and provide flexibility for obligated parties in meeting their RVOs. Obligated parties have the option to either acquire RINs by purchasing and blending physical quantities of biofuels, or by purchasing already separated RINs and submitting them to the U.S. EPA for compliance.

The value of RINs provides an economic incentive to use renewable fuels. If RIN prices increase, blenders are encouraged to blend greater volumes of biofuels, based on their abilities to sell both the blended fuel and the separated RIN. If a biofuel is already economical to blend up to or above the level required by the RFS program, such as ethanol was from 2006 through much of 2012, one would expect the RIN price to be close to zero. When the biofuel is more costly than nonrenewable fuels but is needed to meet RFS standards or must be blended in greater volumes to be economic, the RIN value should increase to a point at which firms will increase biofuel blending.

The flexibility to trade RIN credits was requested by the petroleum industry so they would have the option of using an actual gallon of biofuel or "over-complying" in a certain market and applying that "extra credit" to another area of the country. Given the marketability of the RINs, if an obligated party is required to use 1,000 gallons and actually used 1,200 gallons, then the first thousand RINs are "retired" as they are turned in to demonstrate compliance. The remaining 200 credits are available to be traded, sold, or held for another time.

Based on this system, biofuel stakeholders have long complained that oil companies have elected to meet their RFS requirement by purchasing RINs (which have escalated in price from ten cents to nearly $1/gallon) and "hoarding" them by paying this economic penalty, rather than actually blending ethanol at volumes above 10 percent which would require them to market blends such as E85 more aggressively in order to encourage consumption of the resulting production. Using this mechanism, Congress intended that ethanol and other biofuels would gradually be integrated into the US gasoline supply, and anticipated that E85 and other ethanol/biofuel blends would be scaled up through the RIN. However, the oil industry appears to be willing to forego additional profit to prevent biofuels from gaining greater market share. Therefore, many analysts consider that the RIN mechanism has failed in its original purpose. Corruption in RIN trading has further undermined confidence in the mechanism. Currently the most effective alternative policy mechanism to force greater biofuel production has been the mandatory minimum production requirement enacted through the RFS, which operates in a manner similar to California's biofuel mandate. For more information on the RIN program, see the US Energy Information Agency website fact sheet at http://www.eia.gov/todayinenergy/detail.cfm?id=11511.

Additional federal support for local biofuel production is available through R&D funds set aside for advanced biofuels production, which could potentially be combined with Energy Commission funds to support the expansion of local biofuels production capability.

5.4.2 Federal Funding Opportunities

5.4.2.1 Biodiesel Tax Credit

A federal biodiesel tax credit has been an important support in keeping prices for biodiesel and renewable diesel competitive with petroleum diesel. This credit allows blenders of biodiesel and renewable diesel to claim a credit of $1 per gallon against their U.S. federal tax liability. The tax credit has expired four times since 2009 and then subsequently been reinstated retroactively three times, most recently at the end of 2015. There is a clear correlation between the tax incentive and increased biodiesel production, which has grown from about 100 million gallons in 2005, when the tax incentive was first implemented, to almost 1.8 billion gallons in 2013, and more than 2 billion gallons in 2015. The biodiesel credit expired at the end of 2014, but was reinstated in 2015 with a controversial amendment that shifted the tax credit upstream to producers rather than blenders and retailers. This provision took effect on Jan. 1, 2016. An economic analysis of the complex impacts of shifting the credit upstream is provided by the *Farm Doc Daily* website at http://farmdocdaily.illinois.edu/2015/08/implications-of-changing-biodiesel-tax-credit.html.

In addition to the structural changes to the biodiesel tax credit, the package includes a 30 percent investment tax credit for alternative fuel pumps, a provision that enables small businesses to deduct certain property expenses from their taxes known as Section 179 expensing, as well as bonus depreciation provisions. Recent information and relevant documents on the tax credit are available at the National Biodiesel Board website http://biodiesel.org/policy/fueling-action-center. The reinstatement of the production credit and the provision for accelerated depreciation strengthen the business case for expanded biofuels production and distribution, although additional policy certainty on federal biofuels subsidies is still need to optimize market conditions for new entrants.

5.4.2.2 Federal R&D Funds for Advanced Biofuels Production

Biofuel feedstock and production process technology is still in its infancy compared to many other clean technologies. To achieve very low CIs, further R&D is needed. In addition to the Energy Commission support described earlier, the federal U.S. EPA Bioenergy Program for Advanced Biofuels, authorized under the 2009 Farm Bill, Section 9005, provides payments to eligible producers that expand production of advanced biofuels from sources other than corn starch. These incentives are intended to diversify the source of biofuel production as well as increase overall output.[75]

Additional support is available through the joint U.S. DOE and Department of Agriculture Biomass Research and Development Initiative for advanced biofuels. The DOT also carries out biofuel research in its Bio-based Transportation Research Program to promote innovation in transportation infrastructure.

5.4.3 California Biofuels Policies and Goals

At approximately the same time as President George W. Bush first proposed a major federal biofuels policy initiative, the administration of Governor Schwarzenegger developed the *Bioenergy Action Plan for California*, released in July 2006. This Action Plan established for the first time a set of specific biofuels use targets in California: 0.93 million GGE of biofuel in 2010, 1.6 billion GGE in 2020, and 2 billion GGE in 2050. In addition, in-state production goals were established to ensure that California's economy would reap the benefits of the new mandates.

In-state production goals called for a minimum of 20 percent of biofuels production within California by 2010, 40 percent by 2020, and 75 percent by 2050. In-state production potential is estimated to be substantial because California produces approximately 80 million dry tons of biomass from the state's farms, dairies, forests, and landfills. Using waste materials from the agricultural, forestry, and urban waste streams could advance many environmental goals at once, including reducing air emissions, landfill requirements, and wildfire risk, among other benefits.

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[75] *EPA, Program for Advanced Biofuels,*

http://www.epa.gov/agstar/tools/funding/incentive/USbioenergyprogramforadvancedbiofuels.html

5.4.3.1 Biofuels and California's LCFS

California's LCFS sets targets for reductions in greenhouse gas intensity for biofuels along with the entire transportation fuel sector. The LCFS specifies the average CI for transportation fuels, typically for a given year, expressed as a percent reduction from the petroleum baseline. Based on Executive Order S-1-07 (issued on January 18, 2007), ARB has set a goal of reducing the CI of passenger fuels statewide by a minimum of 10 percent by 2020. For more information on how the standard is set, see the Low Carbon Fuel Standard Map created by the consulting firm, C2ES. For the LCFS, the greenhouse gas intensity of a fuel is calculated on a lifecycle basis, which includes the emissions from production or extraction, processing, and combustion of the fuel. This policy allows manufacturers to produce and retailers to purchase the mix of fuels that most cost-effectively meets the standard. LCFS credits are tradable to enable cost-efficient compliance (similar in that respect to Cap and Trade credits, RINs, or the ZEV mandate programs). LCFS credits help strengthen the business case for biofuel production and lower consumer prices for biofuels. They can also enable larger fleets and intermediaries, such as manufacturers of alternative fueling infrastructure, to monetize LCFS credits earned for deployment of alternative fuels and related infrastructure.

5.4.3.2 California Blending Requirements

For more than a decade, gasoline sold in California has been blended with 5.7 percent biofuel on average. In June 2007, ARB revised its reformulated gasoline regulations to enable up to 10 percent ethanol to be blended with gasoline. Increasing California's ethanol/biofuels use beyond the 10 percent level will require widespread use of FFVs designed to operate on E85. The development of advanced biofuels could also allow system-wide blends beyond 10 percent as a "drop-in" gasoline substitute without requiring use of purpose-built FFVs. As advanced biofuels are U.S. EPA-designated to have a minimum of a 50 percent reduction in CI over gasoline and diesel, even modestly increased blend levels in California's fuel supply could help California meet the its LCFS targets.

5.4.3.3 ARB Diesel Regulations

In 2002, California adopted AB 1493 to control emissions from motor vehicles. The regulation became effective from January 1, 2006. The AB 1493 standards have been phased-in over the period of 2009 to 2016, as shown in the table below. The GHG standards are incorporated into the California low emission vehicle legislation. There are two fleet average GHG requirements: (1) for passenger car/light-duty truck 1 (PC/LDT1) category, which includes all passenger cars and light-duty trucks below 3,750 lbs. equivalent test weight; and (2) for light-duty truck 2 (LDT2) category, including light trucks between 3,751 lbs. equivalent test weight and 8,500 lbs. GVWR. In addition, medium-duty passenger vehicles from 8,500 to 10,000 lbs. GVWR are included in the LDT2 category for GHG emission standards.

Table 5-13: California Diesel Fleet Average GHG Emission Standards

Year	GHG Standard, g CO2/mi (g CO2/km)		Corporate Average Fuel Economy Equivalent, mpg (l/100 km)	
	PC/LDT1	LDT2	PC/LDT1	LDT2
2009	323 (201)	439 (274)	27.6 (8.52)	20.3 (11.59)
2010	301 (188)	420 (262)	29.6 (7.95)	21.2 (11.10)
2011	267 (166)	390 (243)	33.3 (7.06)	22.8 (10.32)
2012	233 (145)	361 (225)	38.2 (6.16)	24.7 (9.52)
2013	227 (142)	355 (221)	39.2 (6.00)	25.1 (9.37)
2014	222 (138)	350 (218)	40.1 (5.87)	25.4 (9.26)
2015	213 (133)	341 (213)	41.8 (5.63)	26.1 (9.01)
2016	205 (128)	332 (207)	43.4 (5.42)	26.8 (8.78)

Source: California ARB, in California Cars: Diesel Emissions, accessed November 17, 2016 at https://www.dieselnet.com/standards/us/ca_ghg.php

In addition to these fuel standards, ARB has initiated a comprehensive set of emissions strategies to address diesel particulate matter, air toxics, and GHG emissions from trucks over a multi-decade time scale. Key milestones in this regulatory effort include the following:

- **2002 – 2010:** With the passage of AB 1493 in 2002, ARB and the U.S. EPA introduced Ultra Low Sulfur Diesel (ULSD) requirements beginning in 2010. The use of ULSD, in combination with advanced diesel engines (required since 2007), will help to decrease diesel emissions by over 90 percent compared to earlier (pre-2010) diesel engine performance. The ULSD specification calls for no more than 15 ppm sulfur.
- **2004**: ARB passes 5-minute idling regulation for diesel heavy duty vehicles.
- **2008**: Requirement issued for all heavy duty trucks and buses to have a model 2010 or equivalent diesel engine by 2023, with intermediary regulatory requirements beginning in 2011 (in tandem with the lower carbon fuel requirements identified above). Key technologies applied to the diesel engine to meet these mandates include diesel particle filters, which remove most PM, and selective catalytic reduction (SCR), which removes most NOx.
- **2017:** All approximately 1M California trucks & buses must have diesel particle filters
- **2031:** Federal ozone standards require a 90 percent reduction in NOx by 2031[76]

[76] The overall EPA diesel program regulations can be accessed at http://www.epa.gov/otaq/fuels/dieselfuels/ and are located in 40 CFR Part 80 subpart I.

5.4.4 California State Biofuels Funding Opportunities

5.4.4.1 State Investments in Biofuel Production Facilities

To ensure that use of sustainable feedstocks is significantly expanded, the Energy Commission has invested in expanding research, development, and commercial deployment of production facilities associated with promising biofuel pathways. State investments in biofuel infrastructure are focused on options with the lowest CIs. Biofuels derived from waste-based feedstocks typically represent the lowest CIs among all biofuels and often among all alternative fuels. The Energy Commission is also investing in pre-commercial biofuel production demonstrations aimed at demonstrating very low carbon technology pathways, including diesel and gasoline substitutes. The following chart illustrates the GHG reduction potential of emerging technologies which have been awarded Energy Commission grants in recent Alternative Fuel Investment Plan solicitations.

Table 5-14: Energy Commission Funded Pre-Commercial Low-Carbon Biofuel Projects

Fuel Type	Pathway Description	Estimated GHG Reduction	# of Projects	Annual Capacity for Individual Projects Diesel or Gasoline Equivalent
Biomethane	Wastewater	88%	1	160,000
Diesel Substitutes	Algae	66%-122%	2	1,200 – 5,000
Diesel Substitutes	Green Waste	66%	1	365,000
Gasoline Substitutes	Woodchips and Switchgrass	76%	1	21,000
Gasoline Substitutes	Sugar Beets	82%	1	215,000

Source: *2016-2017 Investment Plan Update for the Alternative and Renewable Fuel and Vehicle Technology Program.* California Energy Commission, October 2015. Pg 36. Accessed September 2, 2016 at: http://www.energy.ca.gov/2015publications/CEC-600-2015-014/CEC-600-2015-014-SD.pdf.

Other state programs also provide support and incentives to biofuel producers. The California Department of Resources Recycling and Recovery (CalRecycle) receives cap-and- trade revenue funds to administer grant and loan programs, some of which may be used to support waste-based bio-methane production. Also, the LCFS and RFS requirements can support biofuel producers by creating markets for carbon credits and renewable fuels.

5.4.4.2 State Funding for Biofuel Vehicles via the Carl Moyer Program

Operating since 1998, the Carl Moyer state grant program provides about $60 million annually in incentives to both private companies and public agencies to purchase cleaner engines, equipment, and emission reduction technologies, focused on the medium and heavy-duty sectors, including off-road equipment. The program operates as a partnership between ARB and

California's 35 local air pollution control and air quality management districts, and is funded by tire fees and vehicle registration fees. Projects that reduce emissions from heavy-duty on-road and off-road equipment qualify for Moyer grants.

Eligible engines can include on-road trucks over 14,000 lbs GVRW, off-road equipment such as construction and farm equipment, marine vessels, locomotives, stationary agricultural equipment, forklifts, light-duty vehicles, airport ground support equipment, lawn and garden equipment, and emergency vehicles. The program pays up to 85 percent of the cost to repower engines with cleaner technology, and up to 100 percent to purchase a ARB-verified retrofit device. Maximum grant amounts vary for purchase of new vehicles and equipment. Moyer Program grants are intended to cover the "incremental cost" of the equipment and emission benefits. The BAAQMD assists local applicants in determining funding eligibility. More information on eligible source categories can be found on ARB's Carl Moyer Program website at *http://www.arb.ca.gov/msprog/moyer/moyer.htm* along with links to local Air District program contacts.

5.4.4.3 Energy Commission Efforts to Spur E85 Availability

To spur broader access to E85, the Energy Commission has plans to fund over 100 new E85 locations by the end of 2016. In addition, the Energy Commission has invested $6 million in recent years to encourage California ethanol producers to leverage their efforts in new and retrofitted production technologies, feedstocks, and facilities through the California Ethanol Producer Incentive Program, known as CEPIP. This program has provided targeted production incentives to reduce the CI of ethanol and to promote cellulosic feedstock use. Despite these efforts, economic conditions have slowed expansion of in-state ethanol production, and Energy Commission investment strategies in ethanol are being reassessed.

5.4.4.4 California 2007 BioEnergy Action Plan

As part of the 2007 state *BioEnergy Action Plan,* the state articulated biofuel policy goals and measures that complement federal policy. These measures will accelerate the availability of in-state biofuels for the City of San Francisco and other major consumers of biofuels. Highlights of the Action Plan include the following measures, most of which are now well-advanced:[77]

Ethanol – Immediate Actions

1. **Develop 30-60 ethanol production plants** in California using imported corn feedstocks initially, but transitioning to production from agricultural, forestry, and urban wastes; producing biomethane and biogas; using purpose-grown crops such as sugar cane [note that this goal is lagging due to economic challenges in the ethanol industry, especially low gasoline prices]
2. **Complete a cellulosic ethanol proof-of-concept production plant**.

[77] California Alternative Fuels Investment Plan, 2007, CEC and ARB. CEC-600-2007-011-CMF, pp. 23-25.

3. **Facilitate automaker commitments to produce FFVs** to enable FFVs to comprise a sizeable portion of a total of 750,000 alternative fuel vehicles added per year over five years.
4. **Expand installation of higher blends of ethanol (E85) pumps in 2,000 stations** over the next 10 years based on geographic distribution of FFVs within the state.
5. **Conduct consumer education and outreach programs to highlight FFV and biofuel attributes** and identify locations for alternative fueling stations.

Ethanol – Mid-Term Actions

1. **Ease transition of ethanol production facilities in California from imported corn feedstocks to low-carbon California biomass feedstocks.**

Renewable Diesel and Biodiesel Immediate Actions

1. **Develop Renewable Diesel and biodiesel production plants** in California to displace 1 billion gallons of diesel over 10 years.
2. **Establish a California fuel producer's tax credit or subsidy** to complement the existing federal fuel producers' credit.
3. **Continue and expand ongoing R&D to optimize fuel characteristics**, performance, fuel quality, and environmental impacts, such as NOx emissions of higher blend renewable/biodiesel in ratios between 5 to 20 percent.
4. **Facilitate development of "sustainability standards" for Renewable Diesel and biodiesel** feedstocks (canola oil, palm oil, soy oil, waste grease, and other sources).
5. **Research and develop ways to resolve cold weather performance for higher level biodiesel blends** in engines.

5.5 Proposed Actions to Support Biofuel Readiness

5.5.1 Market Context

Despite California's forward-thinking approach to developing more sustainable in-state biofuels production capability, economic conditions for expanding biofuel production have been weak, in part because of the fracking boom and the oversupply of petroleum in global markets. As a result, California has not yet seen the promised upsurge from in-state production. However, many analysts believe that as oil and gas prices rebound in coming years, the economic case for localized biofuel production will be strong, especially for feedstocks such as waste FOG along with sustainable cellulosic feedstocks. The economic case is strongest when local economic multipliers are considered in the analysis, along with the social cost of carbon.

Biodiesel and renewable diesel offer substantial GHG reductions and other air emissions benefits that are crucial for cleaning up higher-polluting medium and heavy-duty diesel truck fleets. Given the dangerous impact of diesel emissions on public health, it is vital that local stakeholders come together with the state and private industry to accelerate the City's transition to cleaner-running diesel vehicles and biofuels, especially for applications where electric drive alternatives are not yet available or feasible.

5.5.2 Key Recommendations for Biofuel Development

Recommendation	Next Steps
1. Conduct outreach and education about renewable diesel to maximize deployment in public and private fleets	▪ Continue to monitor success of renewable diesel in San Francisco's municipal fleet. Provide technical assistance, outreach, and education to public and private sector fleets to maximize implementation of renewable diesel, including SF Port and SFO tenants, BC3 members, medium duty delivery and shuttle fleets, bus fleets, school districts, public safety agencies, small businesses, and other diesel users. ▪ Provide technical assistance to stakeholders) that opt to integrate renewable diesel into their fleet vehicle contracts.
2. Periodically update renewable diesel procurement goals to identify lowest CI fuels practically obtainable and to refine sustainable feedstock sourcing policy for City fleet vehicles	▪ Identify policy process to ensure that the City's AFV procurement and fueling policies are consistent with the most recent regulations or validation criteria on the economic and environmental LCA of available alternative fuel and vehicle technologies.
3. Periodically review opportunities for development of local biomethane fuel sources.	▪ Develop feasibility study and cost-benefit analysis of local sourcing opportunities to produce biofuels from anaerobic or landfill sources.

CHAPTER 6: Natural Gas Vehicles

6.1. Natural Gas Vehicle Overview and Adoption Trends

6.1.1 Introduction

Petroleum-based fuels have long dominated U.S. transportation, accounting for approximately 93 percent of domestic transportation fuel consumption. However, the search for petroleum substitutes has gained new urgency due to primarily to three co-occuring challenges: 1) the air quality and climate crisis; 2) the need to reduce foreign oil dependence to mitigate the risk of supply disruption; and, 3) the need to reduce exposure to the price volatility of the global oil market. Thanks to its recently low price, relatively abundant supply, and potential for criteria emissions reduction, natural gas has received significant attention as an alternative fuel, especially for medium and heavy duty vehicles, and most notably in the municipal transit and refuse segments. Moreover, the development of expanded biomethane and RNG supplies hold promise for substantially reducing the carbon intensity of natural gas and mitigating existing fugitive methane leakage from landfills. For all these reasons, natural gas (especially RNG) merits serious consideration as a viable alternative fuel and vehicle technology option in San Francisco. Natural gas is particularly relevant to the heavy duty vehicle segment where viable electric drive alternatives are currently lacking.

Natural gas has been notably inexpensive and abundant on the domestic U.S. market in recent years thanks to the recent boom in hydraulic fracturing ("fracking"). In terms of its environmental performance, natural gas can significantly reduce tailpipe emissions of some criteria pollutants (especially particulate matter) as much as 90 percent below that of conventional petroleum diesel. However, U.S. EPA estimates of natural gas carbon impacts are currently undergoing revision, raising questions about the performance of natural gas compared to petroleum *from a climate perspective.* In addition, depending on the quality of state and local regulation, enforcement, and industry practice, fracking techniques in natural gas production can pose serious and long-term risks to water quality.

In light of the many complex issues particular to NGVs, this chapter will address these questions:

- What are likely trends in natural gas pricing, vehicle availability, and vehicle performance in the 2016 to 2025 period?
- What are key best practices in natural gas fleet management and fueling infrastructure development?
- What are the most recent estimates and trends in natural gas emissions and other natural gas environmental impacts?
- What is the outlook for RNG supply and pricing?
- What are key recommendations for further deployment of NGVs and fuel in the City of San Francisco?

6.1.1.1 Liquefied Natural Gas versus Compressed Natural Gas

Natural gas has been commercialized in two forms, Liquefied Natural Gas (LNG) and Compressed Natural Gas (CNG). LNG is the liquefied form of natural gas, produced by cooling natural gas to temperatures below -260° F. As LNG has higher energy density than CNG, it offers significant potential in NGV market segments where long driving range is required. To date, however, LNG has had extremely limited uptake in the United States, with approximately 3,300 vehicles registered as of 2010 vs. approximately 113,000 CNG vehicles.

The potential for LNG vehicles has not yet been fully realized due to the high initial cost, operational complexity of fuel management, and limited distribution of LNG infrastructure and vehicles. Because LNG must be stored at extremely low temperatures, large insulated tanks are required to maintain these temperatures in stationary fuel storage and in vehicles. Due to constraints of fuel temperature change, LNG works best with vehicles in consistent use. Together, these factors limit the use case for LNG primarily to heavy duty vehicles, which can accommodate the volume of fuel needed to sustain long-range truck travel.

LNG in the U.S. has been produced in large centralized plants where it is then trucked (often over long distances) to fueling stations where it must be stored at very cold temperatures and used within a few days to avoid evaporation. The use of long distance trucking to deliver LNG reduces the emissions benefits of the fuel and raises its expense when compared to pipeline-delivered CNG. New technologies are making on-site liquefaction plants more practical and widespread, thereby reducing truck-based deliveries, but these plants remain in the early stages of market deployment.

Given the finite applications of LNG as well as their limited environmental benefits, this report will focus primarily on CNG, though many of the challenges and opportunities for CNG are applicable to both forms of natural gas.

6.1.2 Natural Gas Vehicle Types

There are three principal types of NGVs currently deployed in the United States. These include:

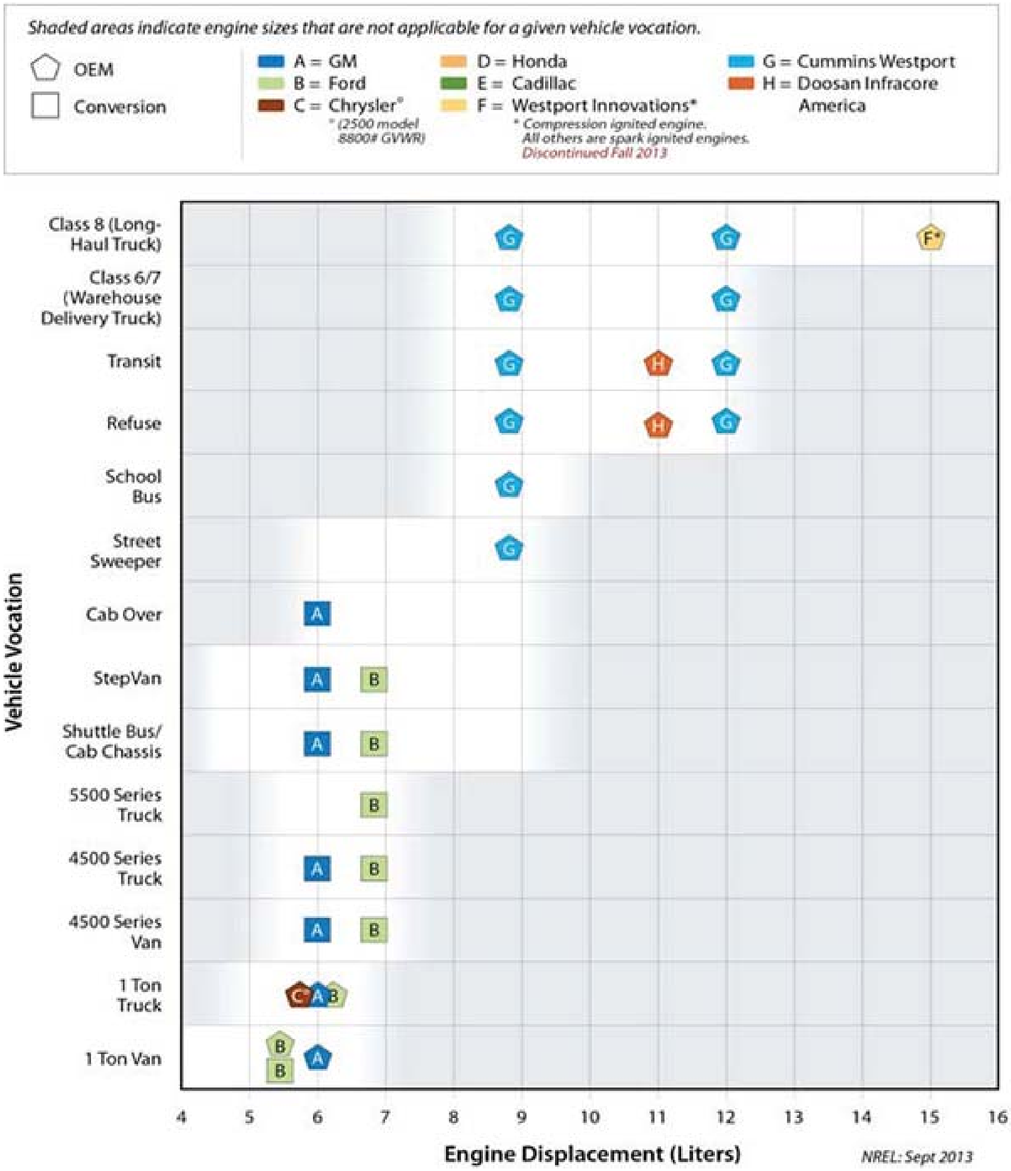
- **Dedicated NGVs** – operating on 100 percent natural gas, either in the form of CNG or LNG.

- **Bi-Fuel NGVs** – operating on either gasoline or natural gas (with two completely separate fuel systems operating side-by-side in a single vehicle).

- **Dual-Fuel NGVs** – operating on natural gas but using diesel fuel for pilot ignition assistance. This design is primarily used in heavy duty vehicles.

NGVs can be deployed to meet diverse transportation needs, from light-duty sedans to specialty trucks, buses, and off-road vehicles. The chart below indicates the relevant engine sizes and types associated with major vehicle applications. Note that CNG fuel is used for vehicles in all application domains, whereas LNG fuel is only used in long-haul trucks, transit and refuse vehicles, and marine and rail applications.

Figure 6-1: Natural Gas Vehicle Types and Engine Displacement



Source: 2013 NREL data reported in: *Reducing the Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicle, Phase Two: First Report (2014),* National Academies Press, p. 58, https://www.nap.edu/read/18736/chapter/7

6.1.3 Natural Gas Vehicles in the United States

Despite the recent abundance of low-cost domestic natural gas supplies, the United States is one of the last industrialized countries to embrace natural gas as a transportation fuel. Worldwide, there are more than 15.2 million NGVs. However, there are only approximately 120,000 NGVs of all types on U.S. roads today, according to the trade association, NGV America.

6.1.3.1 Light-Duty Natural Gas Vehicle Availability in the United States

Major automakers have been selling dedicated light-duty NGVs in Europe, South America, and elsewhere for years, but American market availability has been limited due to lack of demand. In the United States, only a handful of LDVs have been available, predominantly larger pickups and vans. In the light-duty sedan segment, the Chevrolet Impala has been the only offering recently. Table 6-1 below indicates the model year 2016 CNG LDVs available for purchase from OEMs.

Table 6-1: 2016 Light Duty Natural Gas Vehicles, Including Pick-Ups and Vans

Natural Gas Vehicle Model	Vehicle Type	Engine Size	Starting MSRP
Chevrolet Impala	Sedan	3.6L V6	-
Chevrolet Silverado 2500 HD	Pickup	6.0L V8	$32,955
GMC Sierra 2500 HD	Pickup	6.0L V8	-
Ram 2500	Pickup	5.7L V8	-
Chevrolet Express Prisoner Transport	Van	6.7L V8	-
Chevrolet Express 2500	Van	6.0L V8	-
GMC Savana 2500	Van	6.0L V8	-
Ford F-150*	Pickup	5.0L V8	$26,315
Ford Super Duty F-250*	Pickup	6.2L V8	$32,385
Ford Transit 150/250*	Van/Wagon	3.7L V6	$30,960
Ford Transit 250*	Cassis Cab	3.7L V6	$30,960
Ford Transit Connect*	Van/Wagon	2.5L I4	$22,675

Source: 2016 Clean Cities Vehicle Buyer's Guide, p. 37. Accessed 10/3/16 at: http://www.afdc.energy.gov/uploads/publication/vehicle_buyers_guide.pdf

For the most current information on available vehicles, a definitive resource is the *Clean Cities Vehicle Buyer's Guide* available at the federal Alternative Fuel Data Center (http://www.afdc.energy.gov/). Manufacturer websites also provide links to local dealers and special pricing.

6.1.3.2 Medium and Heavy Duty Natural Gas Vehicle Availability

NGVs can be procured either new or in the form of retrofits to vehicles previously equipped for liquid fuel. The chart below provides an overview of sources of both new vehicles and retrofit equipment.

Table 6-2: Natural Gas Vehicle Manufacturers and Retrofit Providers

Heavy-Duty Vocational OEMs

- Mack
- Peterbilt
- Crane Carrier
- Autocar Truck
- ALF Condor
- Elgin
- Johnston
- Schwarze
- Tymco
- Capacity
- Ottawa

Heavy-Duty Bus OEMs

- Thomas Built Bus
- Blue Bird Bus
- Optima/NABI
- El Dorado
- New Flyer
- Motor Coach Ind.
- Gillig
- DesignLine

Light-Duty OEMs

- American Honda
- General Motors
- Ram Trucks
- Ford

Light-Duty/Medium-Duty Retrofits

- Altech-Eco
- Landi Renzo USA/Baytech
- IMPCO Automotive
- Westport/BAF Technologies
- Crazy Diamond Performance
- NGV Motori USA
- M-Tech Solutions
- STAG
- NatGasCar
- AGA Systems
- Greenkraft
- PowerFuel Conversions
- World CNG
- Zavoli

Heavy-Duty Truck OEMs

- Freightliner Truck
- Volvo
- International
- Kenworth
- Peterbilt
- Mack

Heavy-Duty Retrofit/Repowers

- American Power Group
- Clean Air Power
- Fyda Energy Solutions
- NGV Motori
- Omnitek Engineering
- Diesel 2 Gas

Source: NGV America, accessed October 23, 2016 at: http://www.ngvamerica.org/vehicles/vehicle-availability/

Retrofits are most commonly implemented by OEM-trained qualified system retrofitters (QSRs), also known as qualified vehicle modifiers (QVMs). A QSR/QVM can economically and reliably convert medium and heavy duty vehicles for natural gas operation. Typically, a QSR/QVM will only perform CNG conversions on new or nearly new vehicles. CNG conversion equipment must meet or exceed the same emissions standards that apply to the original vehicle or engine according to stringent U.S. EPA and/or ARB requirements. For this and other reasons, it is important that conversions be performed by reputable QSRs/QVMs certified by the state.

Numerous aftermarket engine conversion kits are certified by ARB and available for a wide range of vehicle platforms and classes. Most conversion kits allow for bi-fueling (CNG/gasoline) or even tri-fueling (CNG/gasoline/E85) capability. As with new OEM vehicles, payback periods vary but can be less than two years, depending on annual miles traveled, current fuel price differentials, and retrofit costs.

Retrofit options are expanding, thanks in part to state and federal investment in research and development. Medium and heavy duty engine manufacturers such as Cummins Westport, Volvo, and Navistar have received Energy Commission funds to develop new natural gas engines which are being integrated into several heavy duty chassis, such as Peterbilt and Kenworth. Product offerings in the heavy-duty segment are expected to increase in future years based on stronger emissions requirements for diesel (which will increase their relative purchase price vs. CNG), and the return of larger fuel price differentials between diesel and natural gas.

6.1.3.3 Natural Gas Vehicle Market Trends in the US

Although CNG was initially introduced as a transportation fuel during World War II when gasoline was in short supply, NGVs were not generally commercially available until the 1980s. They were introduced primarily to reduce criteria air pollutants, especially NOx and PM, and to take advantage of the price differential between natural gas and diesel. NGVs still enjoy substantial advantages in meeting criteria emission standards compared to conventional diesel, but the gap is narrowing significantly as clean diesel vehicle regulations tighten in 2017 and beyond.

For most fleet managers, cost is a primary concern when choosing between natural gas and diesel vehicles. However, due to a variety of factors including fluctuating crude oil and natural gas prices, and improving operational efficiencies for other vehicle options, the relative TCO of a CNG vehicle over the potential 20-year lifetime of a fleet vehicle is hard to predict relative to its gasoline, diesel, or electric equivalents. The change of one input (especially crude oil vs. natural gas prices) can drastically shift the value proposition for fleet managers.

Despite these uncertainties, the recent low price and relative price stability of natural gas has led Navigant Research to project that sales of medium-duty and heavy-duty NGVs in North America will show a Compounded Annual Growth Rate (CAGR) of 3.2 percent between 2014 and 2024, with 18,195 units being sold in 2014, increasing to 23,283 annually in 2024. For LDVs, Navigant projects a more robust CAGR of 6.1 percent between 2014 and 2024, with sales of natural gas cars growing at a CAGR of 4.7 percent and sales of natural gas light duty trucks, mainly pickups and vans (including both dedicated and bi-fuel vehicles), growing at a CAGR of 6.3 percent.

Table 6-3: Navigant Research Natural Gas Vehicle Sales Projections for North America

	2015	2024	CAGR
Light Duty Cars	4,949	7,279	4.7
Light Duty Trucks	29,400	48,972	6.3
MD & HD Trucks & Buses	18,195	23,283	3.2

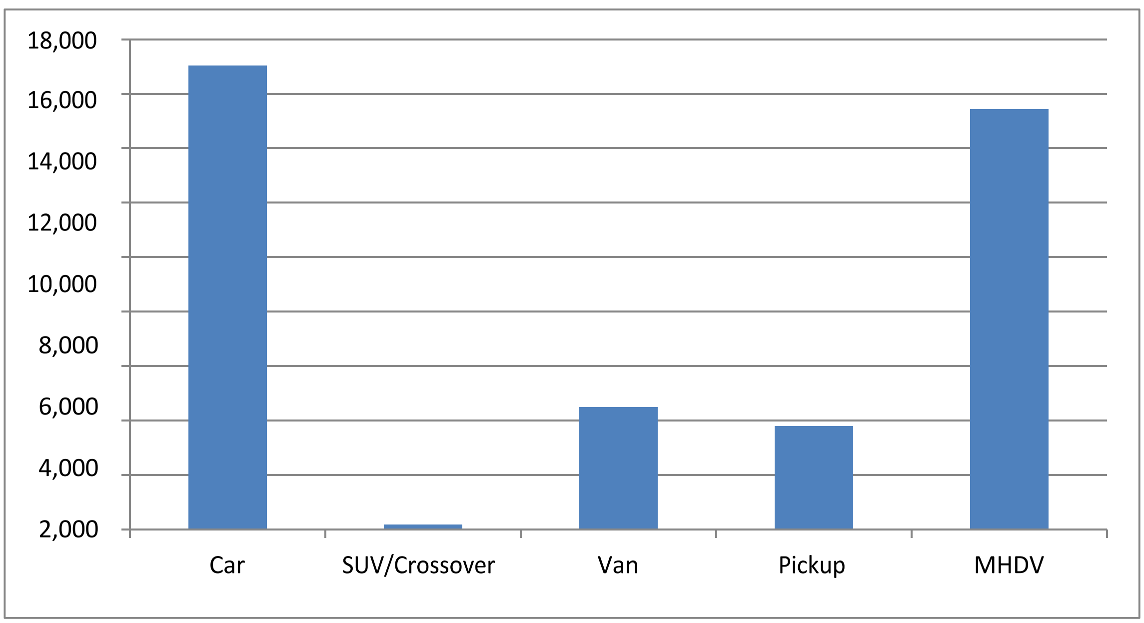
Source: Natural Gas Passenger Cars, Light Duty Trucks and Vans, Medium/Heavy Duty Trucks and Buses, and Commercial Vehicles: Global Market Analysis and Forecasts, Navigant. Accessed October 15, 2016 at: http://ngvtoday.org/2015/02/04/growth-in-north-american-ngv-sales-projected-for-coming-decade/

These numbers remain a tiny fraction of overall new vehicle sales in the United States, which topped 17 million new vehicles in 2015.

6.1.4 Natural Gas Vehicles in California

The most recently available statewide data indicate that approximately 13,500 Class 3-8 NGVs are registered with the California Department of Motor Vehicles, along with nearly 20,000 CNG-fueled LDVs. Cumulative registrations of NGVs in the state of California by vehicle type are shown in the following chart.

Figure 6-2: Natural Gas Vehicle Registrations in California (2013 data)



Source: Energy Commission staff analysis of 2013 Department of Motor Vehicles vehicle registration database, cited in *Strategies to Maximize the Benefits Obtained From Natural Gas as an Energy Source. California Energy Commission.* pp. 41-42.

6.1.5 Natural Gas Vehicles in San Francisco

The City of San Francisco has a sizeable fleet of 484 CNG vehicles. As seen in Table 6-4 below, the Enterprise Division (including the Airport, SFMTA, etc.) has the largest amount totaling 260, including 65 light duty and 195 medium/heavy duty vehicles. This is followed by General Government, which has a total of 199 CNG vehicles composed of 131 light duty and 68 medium/heavy duty vehicles. Finally, Safety Departments have the fewest CNG vehicles, with a total of 25, of which 20 are light duty and 5 are medium/heavy duty vehicles.

Table 6-4: CNG Vehicles by City and County of San Francisco Division

	Light Duty	Medium/Heavy Duty	Total
Enterprise	245	4	249
General Government	162	8	170
Safety	19	1	20
Total	**427**	**13**	**440**

Source: City and County of San Francisco Fleet Inventory Report, June 2016

Because RD offers a compelling option for achieving very low CI, without additional fueling infrastructure investment, NGVs are not often specified by City departments. Total numbers of CNGs in use in San Francisco are difficult to estimate, as most fleet operators do not domicile their vehicles within City boundaries. However, extrapolation of state data for total DMV registration of CNG vehicles divided by population (Table 6-4) yields CNG deployment of approximately 900 natural gas powered vehicles in San Francisco.

6.2 Natural Gas Fueling

6.2.1 Natural Gas Composition

Natural gas is primarily composed of methane (88 to 93 percent) but it also contains other components in smaller quantities, including ethane, propane, butane, and inert gases. In its natural state, natural gas is noncorrosive, colorless, and odorless. Natural gas is also an asphyxiant and, in sufficient quantities, can cause suffocation. The need for proper venting and handling of natural gas in fleet fueling contexts is discussed in more detail below.

6.2.2 CNG Transmission

Natural gas is transported from the well to the gas utility in underground transmission pipelines that flow at 150 to 450 pounds per square inch gauge (psig). At the distribution level, the pressure is reduced from 15 to 45 psig. The gas dispensed to customers is measured by the local utility using a Meter Set Assembly or MSA, which serves as the meter and cash register for the utility. An emergency gas supply shutoff is also installed at the MSA in case of an earthquake or other catastrophic event. To determine whether the existing distribution system will support a new natural gas station, a prospective station developer must assess the inlet pressure at the point of connection to the distribution system.

Natural gas moves through multiple steps in preparation and delivery from the pipeline to the inlet on a CNG vehicle. As described in the CNG Infrastructure Guide developed by the American Gas Association, from a fueling infrastructure perspective, the process begins at the gas utility connection to the CNG station site. The gas is metered at this connection, and then the steps described below are required to make the gas "vehicle ready." [78]

6.2.2.1 Inlet Gas

The municipal "inlet" gas connection requires sufficient flow rate and pressure for the designed application. Many CNG infrastructure applications can use the standard low pressure available in municipal gas lines, but it is important to know the pressure available at the line and if the envisioned application will require a larger line or more pressure. It is recommended that potential station owners/operators check with the local utility and/or gas supplier to determine the "guaranteed" minimum inlet pressure available at your selected location.

6.2.2.2 Gas Quality

The quality of inlet gas may vary based on moisture content and the presence of scale or other foreign matter that may be contained in the inlet line. Moisture content in natural gas is measured in millions of parts per cubic foot. Inlet gas with high moisture content will require "drying" to make it serviceable for fueling vehicles, and dryers are standard equipment in most fueling applications. A filter may occasionally be necessary if there is a quantity of pipe scale or foreign matter in the gas line. Filters come standard on many models of compressors.

6.2.2.3 Gas Compression

Dried and filtered inlet gas is compressed by one or more compressors and often stored in tanks, or delivered directly to a fuel dispenser. This pressurized gas is now "Compressed Natural Gas" ready for vehicle fueling.

6.2.2.4 Priority Distribution

Moving the CNG from the compressor to storage tanks or directly to the vehicle requires directed control, and this function is supplied by a computerized "priority panel." Priority panels direct the flow of CNG from the compressor to on-site storage tanks. Sequential panels direct the flow of CNG from the compressor or tanks to fuel dispenser units and/or vehicles. Based on the pressure measured in the vehicle tank, the priority panel switches between the low, medium, and high-pressure tanks to ensure a complete fill.

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78 CNG Infrastructure Guide, America's Natural Gas Alliance and the American Gas Association, pp. 5-6. https://www.aga.org/sites/default/files/sites/default/files/media/cng_infrastructure_guide.pdf

6.2.2.5 Dispensing CNG

CNG dispensers are available in different sizes, shapes, and varieties. However, they all conform to either a fast fill or a time fill configuration and are available in different hose form factors and with different flow rates and methods of metering. Time fill units typically dispense fuel through a fixed pressure regulator. When the fuel flow reaches a minimum rate, the fuel flow is shut off. Fast fill units measure the pressure in the tank, then a small amount of precisely measured fuel is dispensed into the tank and the pressure rise is measured. From these figures, the volume of the tank is calculated and the tank is filled rapidly to this level. When the tank is full, the flow is shut off. Many dispensers come with temperature compensators that ensure a complete fill in cold environments.

6.2.3 Fueling Experience

Refueling of NGVs can be easier and safer than with gasoline or diesel. It takes about the same amount of time, but there is no chance of liquid spills and stains as CNG fuel is in a gaseous state. In the case of bi-fuel cars (shown below), the CNG fuel inlet may be paired with the liquid fuel inlet, while in dedicated CNG vehicles, there is no option for liquid fueling.

Figure 6-3: Dual Inlet

Source: NGV Global website. Accessed October 13 at: http://www.iangv.org/refuelling_ngvs/

6.2.3.1 Public Refueling

Public CNG stations operate much like gasoline or diesel stations. The driver pulls up at a dispenser, switches the engine off and then connects the nozzle to the receptacle. However, some nozzles have an isolator fitted, which prevents the engine from being switched on while connected to the dispenser. In some converted vehicles, the refueling receptacle may be located under the hood or in the trunk. In most OEM vehicles, the receptacle is located where the gasoline or diesel inlet is typically located. Refueling usually takes the same amount of time as a gasoline or diesel vehicle, though if station demand is particularly high, a resulting pressure drop may slightly extend the time to refuel.

6.2.3.2 Depot Based Refueling

A depot based CNG station usually serves a limited fleet, though facilities are often shared with fleets or private vehicle owners that are not related to the depot. Depot based refueling may deploy either a “fast-fill” or a “time-fill” system. A fast-fill CNG system will refuel a vehicle in approximately five minutes or less. A time-fill system fills a fleet of vehicles over a period of hours, often overnight, depending on the specific system pressure level and vehicle tank size. Time-fill systems are usually used for vehicles that have regular extended periods of non-operation, such as refuse and utility trucks, courier vans, private vehicles, school buses, and other fixed route vehicles. Time fill systems utilize slower fuel delivery rates and typically multiple dispensers (in fleet depot contexts) to reduce infrastructure costs per vehicle.

Figure 6-4: "Time-Fill" Depot Refueling Multiple Vehicles at Once

Source: NGV Global, Accessed October 13 at: http://www.ngvglobal.org/

6.2.3.3 CNG Fueling Infrastructure Cost Factors

The cost associated with constructing a CNG refueling station can vary significantly based on land costs, size, and application, with costs ranging from $800,000 to $1,850,000 or more. The following cost ranges are representative of recent low and high costs of constructing a CNG fueling station and are suggested as a general guideline. Each specific site will have its unique requirements that inform cost factors. Note that internal project management costs and land costs are not included in these estimates.

Table 6-5: Equipment Cost Components

Component	Estimated Costs, $
Gas Supply Line	20,000 - 150,000
Compressor Package	200,000 - 400,000
Noise Abatement	0 - 40,000
Gas Dryer	50,000 - 80,000
Storage (3 or 6 ASME)	100,000 - 200,000
Dispenser (1 or 2 00M-hose)	60,000 - 120,000
Card Reader Interface	20000- 30,000
Engineering	25,000- 75,000
Construction	300,000 — 600,000
Contingencies	10 — 150,000
Estimated Total (Excludes land cost)	**805,000 – 1,845,000**

Source: American Gas Association *CNG Infrastructure Guide.* Accessed October 20, 2016 at http://www.houstonngvalliance.org/uploads/cms/1432762920CNG_Infrastructure_Guide.pdf

6.2.3 LNG Fueling

LNG as a vehicle fuel has the potential to be successful in select vehicle market segments based upon favorable economics and strong government support for expanded infrastructure. As noted, LNG is most promising for long duration, heavy-duty applications. Currently there are fewer than 200 LNG stations in the United States and 61 LNG stations in California, with approximately 50 percent of these open to the public across the United States, and 25 percent publicly accessible in California.

6.2.4 Natural Gas Fueling Stations in the United States

There are approximately 1,300 public and private CNG stations located in the United States compared to over 120,000 retail gas stations. According to the California NGV Coalition (whose data is cited by the Energy Commission), California leads the United States in the number of CNG and LNG fueling stations, with more than 500 CNG stations and roughly 45 LNG stations.[79] According to the U.S. DOE's Alternative Fuel Data Center, of this total, there are about 140 public CNG stations and 14 public LNG stations in the state. Consumers in most areas can also purchase a slow-fill system for at-home, overnight fueling, although no data is readily available on slow-fill residential deployment. Nationally, approximately half of all CNG stations are for private fleet use.

6.2.4.1 Growth in Natural Gas Vehicle Stations

During the early 1990s, the country's CNG refueling infrastructure experienced a period of growth, largely driven by the alternative fuel vehicle mandates of the Energy Policy Act, which also boosted biofuel production. Following a peak in 1997, national CNG refueling infrastructure declined for approximately a decade, then has trended upward again since 2006 (see Figure 6-5 below). CNG stations are in the early stages of development in Canada, which currently reports 56 stations with public access. To fuel the projected moderate NGV sales growth, the energy-consulting firm Navigant expects there will be about 2,100 to 2,200 NGV fueling stations open in the United States and Canada combined in 2024, up from about 1,500 today. Globally, sales of NGVs are projected to grow from 2.3 million units annually in 2014 to 3.9 million units in 2024, which should drive additional fueling station growth and potential reduction in fueling equipment unit costs.[80]

The first major national strategy to boost natural gas use in the transportation sector was developed by an industry-led effort known as the NGV Coalition, which published the first *NGV (NGV) Industrial Strategy* in 1995. This coalition helped increase the demand for natural gas by

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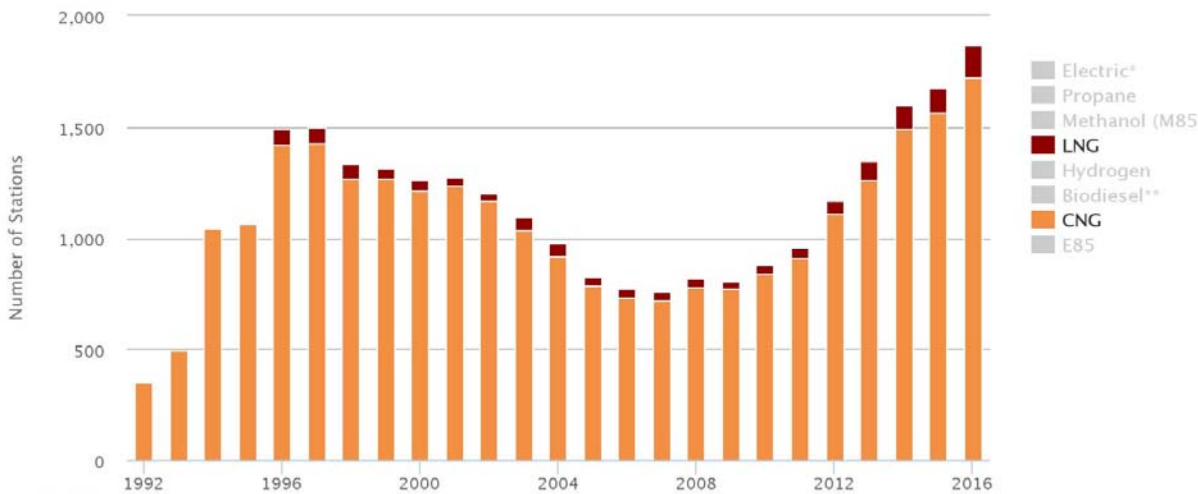
[79] 2015-16 Investment Plan Update for the Alternative and Renewable Fuel and Vehicle Technology Program, California Energy Commission, May 2015, p. 49. http://www.energy.ca.gov/2014publications/CEC-600-2014-009/CEC-600-2014-009-CMF.pdf

[80] http://ngvtoday.org/2015/02/04/growth-in-north-american-ngv-sales-projected-for-coming-decade/

focusing on increasing awareness and adoption of NGVs by transit agencies, delivery and refuse services, and other medium and heavy duty truck fleets with high fuel usage. Between 1997 and 2009, annual demand for natural gas fuels grew threefold to 3.2 billion cubic feet, or 27.7 million GGE. The NGV Strategy document estimates that the United States will require between 12,000 and 24,000 CNG stations, equivalent to 10 to 20 percent of traditional liquid fuel outlets, to make CNG public access competitive with current gasoline station convenience.

Figure 6-5: U.S. CNG and LNG Fueling Station Count

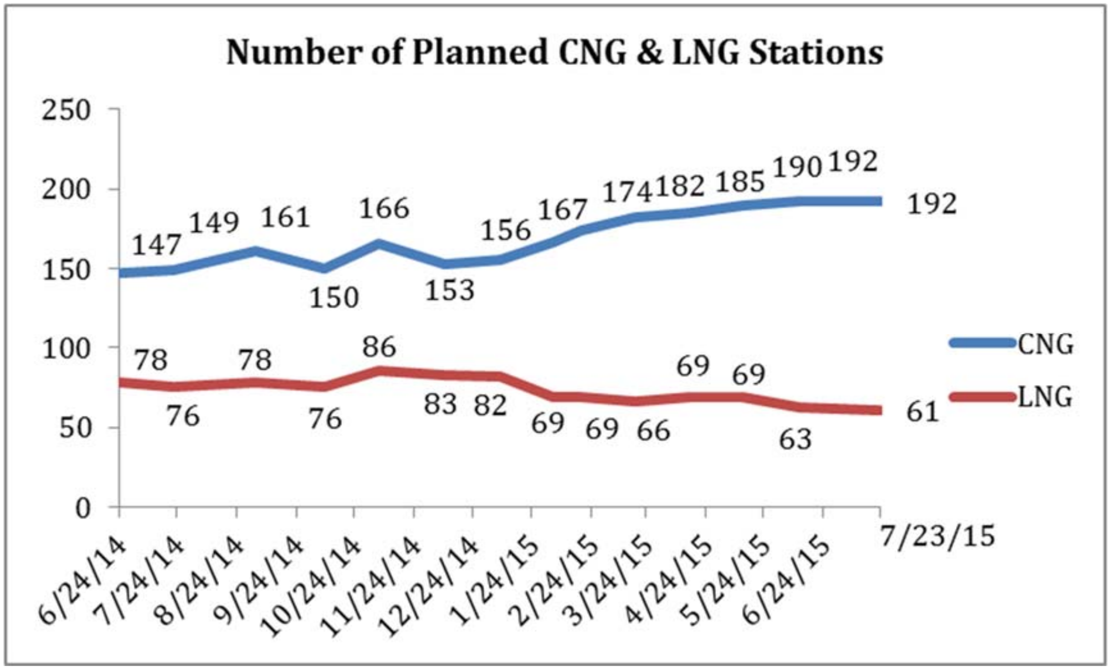


Source: U.S. Department of Energy, Alternative Fuels Data Center (AFDC). Accessed September 12, 2016 at: http://www.afdc.energy.gov/data/

6.2.5 California Natural Gas Fueling Infrastructure

As in the case of other AFVs, the overall NGV deployment outlook is clouded in part by the “chicken or egg” dilemma that inadequate fueling infrastructure is limiting consumer confidence in NGVs, while the limited quantity of NGV sales in turn reduces investor incentive to provide more retail fueling outlets. In the California context, the chart below illustrates that as of mid-2015, 192 CNG stations were in the planning phase, as well as 61 LNG stations. The Alternative Fuels Data Center does not indicate planned stations by whether they will offer public or private access. However, if national averages hold, approximately 50 percent of these could be publicly accessible. Planned stations have been: 1) publicly announced; 2) are in permitting; or 3) are under construction. The list also includes stations where installation of fueling infrastructure has been completed but the stations have yet to begin dispensing fuel. Note that in the case of LNG stations, installation of fueling infrastructure has been completed at many of the LNG stations reported in the AFDC database, but these stations have not yet experienced enough customer demand to justify opening.

Figure 6-6: Planned CNG and LNG Stations



Source: NGV Today, Accessed November 10, 2016 at: http://www.ngvtoday.org/2015/07/23/number-of-planned-cng-and-lng-stations-8/ Based on AFDC data.

6.2.6 San Francisco Bay Area Natural Gas Vehicle Fueling Infrastructure

There are a total of 25 CNG stations in Bay Area, operated by either Trillium, PG&E, Clean Energy Fuels, or UPS. Access requirements are indicated below. RNG availability and percentage values vary by station and is dynamic as supply chains evolve. (Overall, RNG is more than 50 percent of the transportation CNG supply in California.) There are no public LNG stations in the nine Bay Area Counties.

Table 6-6: Natural Gas Vehicle Fueling Stations in San Francisco

San Francisco County			
PG&E San Francisco Service Center	536 Treat Ave	San Francisco	Public - Card key
Clean Energy - Yellow Cab Co-op	1200 Mississippi St	San Francisco	Public - Credit card
San Mateo County			
PG&E Martin Service Center	3100 Geneva Ave	Daly City	Public - Card key
Clean Energy - San Francisco Airport	790 N McDonnell Rd	San Francisco	Public - Credit card

Trillium CNG - San Francisco Airport	50 Old Bayshore Hwy	Millbrae	Public - Credit card
PG&E San Carlos Service Center	275 Industrial Way	San Carlos	Public - Card key
Santa Clara County			
PG&E Cupertino Service Center	10900 N Blaney Ave	Cupertino	Public - Card key
Trillium CNG - Specialty Solid Waste & Recycling	3351 Thomas Rd	Santa Clara	Public - Credit card
Trillium CNG - San Jose Junction	2265 Junction Ave	San Jose	Public - Credit card
Trillium CNG - Mineta San Jose International Airport	2151 Airport Blvd	San Jose	Public - Credit card
PG&E San Jose Service Center	308 Stockton Ave	San Jose	Public - Card key
Trillium CNG - San Jose Unified School District	2230 Unified Way	San Jose	Public - Credit card
Alameda County			
PG&E Hayward Service Center	24300 Clawiter Rd	Hayward	Public - Card key
Clean Energy - San Leandro	8515 San Leandro St	Oakland	Public - Credit card
Clean Energy - Oakland International Airport	7855 Earhart Rd	Oakland	Public - Credit card
Clean Energy - Port of Oakland	205 Brush St	Oakland	Public - Credit card
Trillium CNG - City of Berkeley	1101 2nd St	Berkeley	Public - Credit card
Contra Costa County			
PG&E Richmond Service Center	1100 S 27th St	Richmond	Public - Card key
Trillium CNG - Mount Diablo Unified School District	2352 Bisso Ln	Concord	Public - Credit card
PG&E Concord Service Center	1030 Detroit Ave	Concord	Public - Card key
United Parcel Service	4500 Norris Canyon Rd	San Ramon	Public - Credit card
Marin County			
PG&E San Rafael Service Center	1220 Andersen Dr	San Rafael	Public - Card key
Sonoma County			
PG&E Santa Rosa Service Center	3965 Occidental Rd	Santa Rosa	Public - Card key
Napa County			
Clean Energy - Napa Petroleum	2008 Redwood Rd	Napa	Public - Credit card

Solano County			
PG&E Vacaville Service Center	158 Peabody Rd	Vacaville	Public - Card key

Source: NGV America triangulated with data from Alternative Fuel Data Center, accessed November 12, 2016 at http://www.afdc.energy.gov/locator/stations/

6.2.7 Propane Fuels and Vehicles

Propane, also known as liquid petroleum gas, is a byproduct of natural gas processing and crude oil refining. Most widely used in rural areas for heating homes and powering farm and industrial equipment, less than 3 percent of propane produced in the United States is currently used in vehicles. However, propane is the most commonly used alternative motor fuel in the world, and its price has historically been lower and more stable than gasoline. Local pricing can vary widely depending on supply and demand. Propane's energy content is approximately 25 percent less than gasoline. However, due to its lower cost, propane remains an attractive choice for fleet operators. As of early 2016, California propane prices varied from $1.60 to $2.80, with most prices closer to $2.00 per gallon. At lower prices, cost savings can quickly offset increased vehicle purchase price.

Propane-fueled vehicles produce about 10 percent fewer GHG emissions than equivalent conventional vehicles. Propane is available at more than 2,600 stations throughout the country, and at approximately 1,500 stations in California.[81] Available propane vehicles include the nation's most popular vehicle series, which is the Ford F-150 pickup and related larger models.

Table 6-7: Available Propane Vehicles

Propane Vehicle Model	Vehicle Type	Engine Size	Starting MSRP
Ford F-150*	Pickup	5.0L V8	$26,315
Ford Super Duty F-250*	Pickup	6.2L V8	$32,385
Ford Transit 150/250*	Van/Wagon	3.7L V6	$30,960
Ford Transit 250*	Cassis Cab	3.7L V6	$30,960
Ford Transit Connect*	Van/Wagon	2.5L I4	$22,675

Source: 2016 Clean Cities Vehicle Guide, p. 34. Accessed online November 11, 2016 at http://www.afdc.energy.gov/uploads/publication/vehicle_buyers_guide.pdf

6.3 GHG Impacts of Natural Gas

Significant analysis is ongoing by government agencies and other scientific authorities on the environmental attributes of natural gas as a transportation fuel. Understanding of these

[81] California Energy Commission, Drive Clean website, http://www.energy.ca.gov/drive/technology/propane.html

attributes may continue to evolve and shift in future years based on the results of current research and policy actions in two key areas: the ongoing assessment of the methane leakage rate across the natural gas fuel supply chain, and the analytic timeframe preferred by scientists and policy makers for assessing the Global Warming Potential impact of methane.

6.3.1 Methane: Leakage Rates Drive Climate Impact of Natural Gas

Fossil fuel based natural gas is comprised of approximately 87 percent methane, a highly potent GHG. A key factor in determining the overall climate impact of natural gas is the methane leakage rates in the fuel supply chain, including pre-production, production, processing, and delivery. All stakeholders agree that some methane leakage occurs throughout the system, and that data limitations impede the certainty by which current models evaluate its climate impact. As a result of this uncertainty, the U.S. EPA's officially defined leakage rate is now undergoing potentially significant revision.

A possible outcome of this analysis is the doubling or tripling of the scientifically validated methane leakage rate (from just over 1 percent to potentially 3 percent). The outcome of this controversy may significantly impact future natural gas utilization. In addition to the methane leakage rate issue, there is an equally important debate about the appropriate timeframe that should be used to assess the Global Warming Potential of methane.

6.3.2 Evaluation Timeframe

A 100-year analytic timeframe has customarily been used in many analytic models to assess the Global Warming Potential of methane and other greenhouse gases. However, many scientists and policy makers make a compelling case that methane and other GHGs should be evaluated for their impact within *a 20-year timeframe* rather than the currently used 100-year timeframe. This is due to the catalytic role that methane is expected to play in the imminent triggering of climatic "tipping points" within a 20-year timeframe. While methane accounts for only 14 percent of emissions worldwide as measured by volume, methane traps far more heat per molecule of gas than carbon dioxide. Specifically, the latest Global Warming Potential data accepted by the UN Intergovernmental Panel on Climate Change indicate that any methane molecule released today traps over 100 times more heat than a molecule of carbon dioxide when assessed on a five-year basis. This impact is approximately 86 times more potent than carbon dioxide when "amortized" over a 20-year timeframe, and 34 times more potent in the 100-year timeframe.

In summary, the emerging data and statements from the ARB suggest that NGVs powered by fossil fuels (as opposed to biomethane/RNG) may <u>not</u> have a clear environmental advantage from a climate perspective. However, NGVs can reduce criteria pollution emissions relative to existing diesel vehicles. That said, the relative virtues of natural gas and diesel are not at all static, as both NGV and diesel technology (as well as relevant low-carbon biofuel pathways for both vehicle types) are evolving very rapidly. Stricter regulatory standards are currently pushing *both* NGVs and diesel manufacturers toward significant reductions in harmful emissions.

6.4 Potential for Biomethane to Reduce Natural Gas Emissions Impacts

6.4.1 Overview and Importance

According to the most recent ARB scoping plan for meeting AB 32 goals, natural gas from traditional fossil fuel sources cannot represent a significant share of energy use by 2050 if the state is to meet its long-term GHG targets (80 percent below 1990 levels by 2050.) By 2050, traditional uses of natural gas will need to be mostly, if not fully, decarbonized. However, decarbonized gaseous fuels could have a longer-term future in California *if biomethane production can be scaled up.*

Biomethane, also known as RNG, is a very low-carbon biogas option (with potentially negative CI) for fueling NGVs and for other uses such as heating and power generation. The Energy Commission defines biogas as anaerobic digester gas, landfill gas, and any other gas derived from an eligible biomass feedstock. Biogas can be produced from anaerobic digestion (the decomposition of organic material in the absence of oxygen) or biomass conversion. Organic waste sources of biomethane include food and food processing waste; FOG; yard and other green waste; forest and wood waste; dairy and agricultural waste; biosolids and gas from wastewater treatment; and landfill gas. Large amounts of biogas (the raw, freshly emitted and untreated gas) can be collected at many landfills, wastewater treatment plants, commercial food waste facilities and agricultural digesters (notably dairies). Once the raw biogas is cleaned and conditioned to meet natural gas pipeline quality specifications, it is known as RNG. Although regulations to support pipeline injection are under development, RNG can be blended with or otherwise serve as a direct substitute for most natural gas applications without any operational changes in the gas engines or NGV. Thus, RNG can be used as a drop-in vehicle fuel, for renewable electric power generation, and for cooking, heating, and industrial processes.

Although biogas plants produce CO2 and other GHGs, they are generally considered to be nearly carbon-neutral (or better) because they can, depending on collection and processing methods, reduce the amount of methane and other GHGs that would otherwise have been released into the atmosphere if the organic matter was left to decompose naturally. According to the Energy Commission, RNG from landfill gas and dairy digester biogas reduces life-cycle GHG emissions to 85 to 90 percent below those of diesel fuel, while biomethane derived from high-solids anaerobic digestion can reduce life-cycle GHG emissions by approximately 115 percent below those of diesel.

Although biogas has many favorable attributes as a fuel source, there are major hurdles in bringing biogas into production, distribution, and use at large commercial scale. A significant level of research and development effort will be needed to make biogas a reality at commercial scale. Biomethane pathways will require a much larger infrastructure for efficient (and low-carbon) collection of organic waste. To fully develop the state's capacity for low-carbon natural gas production, the research firm E3 identifies a need for the following key research, development, and demonstration initiatives.

Table 6-8: Priority Research and Development Needs to Accelerate Low-Carbon Natural Gas Fuel Pathway Development

Timeframe of RD&D payoff	RD&D Area	Challenge
Near-term	Energy efficiency	Achieving greater customer adoption and acceptance
	Reduction in methane leakage	Cost-effectively identifying and repairing methane leaks in natural gas mining, processing, and distribution
	Use of anaerobic digestion gas in the pipeline and pilot biomass gasification	Quality control on gas produced via anaerobic digestion for pipeline delivery
Medium-term	Agronomic and supply chain innovation for biomass feedstocks	Competition with liquid fuels, food, fodder, fiber may limit amount of biomass available as a source of decarbonized gas
	Pilot decarbonized SNG technology to improve conversion efficiency and cost	Gasification, electrolysis, and methanation need efficiency improvements, reductions in cost to be competitive; safety, scale, and location challenges must be addressed
	Limits on hydrogen volumes in existing pipelines	Need pipeline and operational changes to accommodate higher volumes
Long-term	Emerging technologies (e.g., P2G, artificial photosynthesis, CO_2 capture from seawater for fuel production)	P2G must be scalable and available as a renewable resource balancing technology; in general, emerging technologies still require innovations in material science

Source: *Decarbonizing Pipeline Gas to Help Meet California's 2050 Greenhouse Gas Reduction Goal,* Energy + Environmental Economics (E3). accessed October 1, 2016 at: https://ethree.com/documents/E3_Decarbonizing_Pipeline_01-27-2015.pdf

6.4.2 Increasing RNG Production in California

The Energy Commission estimates that California's current recoverable RNG resources could displace more than 900 million gallons of diesel fuel annually, representing about 25 percent of the diesel fuel used for transportation in California each year. The Energy Commission is committed to working with California dairies, landfill operators, and other stakeholders to expand RNG production, building on initial investments of almost $40 million in 12 major projects to demonstrate and produce in-state RNG.

Regulatory, technological, and economic scale issues are paramount in this effort. On the regulatory and technological front, RNG can be delivered by truck, but gaining regulatory approval to inject RNG into the pipeline system is critical to economic distribution and broader availability. Currently, rules vary among utilities, and PG&E has been slow to permit injections into their system. The CPUC is establishing new rules addressing this issue relative to gas quality requirements and cost recovery that will determine the near-term feasibility of pipeline distribution of RNG.

Currently, RNG production costs are relatively high due to the small scale of most non-landfill production facilities. A powerful coalition of dairies is pushing for more funding for biogas projects on California farms, and as Cap and Trade revenues increase, it is likely that production efforts will begin to scale. Larger projects, competitive pricing for equipment and contractor services, and reduced costs for interconnecting with utilities will all help lower costs over time. Most importantly, the LCFS program has provided credits for renewable fuels that effectively offset the extra cost of producing biomethane, making RNG competitive with fossil natural gas despite historically low fossil fuel prices.

This investment clearly has positive impacts. Although the national share of the NGV transportation fuel market that is RNG is about 35 percent, California passed the 50 percent threshold in the third quarter of 2015. According to ARB, some 10.2 million diesel gallon equivalents (DGE) of natural gas was used as a vehicle fuel in California in 2013, growing to 27 million DGEs in 2014 and 68.1 million last year, a growth rate of about 250 percent per year. The total for the fourth quarter of 2015 was 19.6 million DGEs.[82] Diesel Gallon Equivalent is used to compare liquid vs. NGV fuel because nearly all NGV vehicles not running on natural gas would be running instead on diesel fuel rather than gasoline (which is rendered in GGE).

With California importing more than 91 percent of the natural gas that it uses, at a cost of more than $9 billion, the economic multiplier for in-state biogas production would be substantial. It has been estimated that California could generate more than 10 percent of its total gas consumption, 284 billion cubic feet of gas per year, from organic waste. If all technically available organic waste were converted to biogas, it would be equivalent to 2.5 billion GGEs of transportation fuels or nearly 7,000 megawatts of renewable power. The technically achievable biogas production in the state is reflected below in a 2008 assessment of biomass resources in California by the Energy Commission.

[82] Patrick Couch, "RNG in California: More Than You Think," Fleets and Fuels, April 20, 2016 http://www.fleetsandfuels.com/fuels/cng/2016/04/rng-in-california-more-than-you-think/

Table 6-9: California RNG Potential

Feedstock	Amount Technically Available (Bone Dry Tons or Billion Cubic Feet)	Potential Fuels Production (Million gasoline gallon equivalents gge)
Agricultural Residue (lignocellulosic)	5.4 M BDT	272 gge
Animal Manure	3.4 M BDT	170 gge
Fats, Oils and Greases	207,000 tons	56 gge
Forestry and Forest Product Residue	14.2 M BDT	710 gge
Landfill Gas	106 BCF	457 gge
Municipal Solid Waste (67% of food, leaves, grass fraction)	1.2 M BDT	106 gge
Municipal Solid Waste (67% of lignocellulosic fraction)	7.0 M BDT	350 gge
Waste Water Treatment Gas	11.8 BCF	66 gge
Fuel Potential		**2,187 gge**

Source: Decarbonizing the Gas Sector: Why California Needs a Renewable Gas Standard, November 2014, BioEnergy Association of California, p. 11.

6.4.3 RNG Outlook and Relevance to San Francisco, including Production Incentives

There is certain to be greater availability of RNG in the region and the state in the near term. This will provide additional opportunities for both the City of San Francisco and other fleets serving the City to use RNG rather than fossil gas. It is recommended that the City of San Francisco fleet switch to RNG at its earliest available opportunity, which will capture the carbon savings of RNG and help encourage RNG supply chain development. The leading regional CNG wholesale and retail provider, Clean Energy, is providing access to 100 percent RNG in its Bay Area stations as of early 2017, under the trade name "Redeem" (see the Clean Energy RNG website http://redeem.cleanenergyfuels.com for information on local availability). Further, it is anticipated that there will be funding available for expanded RNG and biogas production through the Energy Commission and the ARB. Recent initiatives include investments of $25 million for CalRecycle for projects to reduce organic waste and promote recycling, and $15 million via the California Department of Food and Agriculture for dairy digester projects and related measures in 2016-17. Although it is unlikely that there are extensive biomethane production opportunities within the borders of San Francisco, RNG projects in the greater Bay Area can help provide climate and criteria emissions benefits for San Francisco residents.

6.5 Assessing Fleet Adoption of NGVs

Fleet managers need to assess the economics and environmental attributes of NGVs, as well as their operational characteristics. For fleets that find RNG compelling as an environmentally friendly fuel source, a key initial question is whether to purchase new OEM-produced NGVs or retrofit existing fleet vehicles. The number and variety of factory- and conversion-ready NGVs available from OEMs is increasing. Some of the NGVs built by the OEMs include popular models such as the Chevrolet Silverado HD, GMC Sierra HD, Ram 2500, and the Chevrolet Impala. Fleet customers can also order many Ford vehicles, including the F-150, with an optional gaseous engine prep package (with hardened engine components), making it ready for conversion to CNG by a Ford Qualified Vehicle Modifier (QVM). Many vehicles are also available in bi-fuel or NGV only configurations. A good resource for assessing the merits of each can be found in Green Fleet Magazine at: http://www.greenfleetmagazine.com/channel/natural-gas/article/story/2014/12/deciding-whether-bi-fuel-or-ngv-is-the-best-for-your-fleet.aspx.

6.6 NGV Funding Opportunities and Policy Incentives

6.6.1 Policy Basis for NGV and Fueling Infrastructure Development in California

As discussed in Chapter 2, AB 1007 (Pavley), the LCFS, and AB 118 all provide support for natural gas development as a vehicle fuel. AB 118 specifically requires that alternative vehicle and fuel technology deployment and commercialization emphasize support for fuels that "lead to sustainable feedstocks." In 2013, the California Legislature passed Assembly Bill 1257 (Bocanegra), which required that the Energy Commission develop a report to "identify strategies to maximize the benefits obtained from natural gas, including biomethane." The resulting report reaffirms current state policy on NGVs, citing opportunities for improved criteria pollutants but limited opportunity for GHG benefits with fossil-based natural gas. However, the natural gas strategy of ARB and Energy Commission may be modified as the scientific understanding of the environmental effects of natural gas evolves (discussed in Section 6.3).

6.6.2 The ARB Strategy

ARB has indicated that achieving the state's 80 percent carbon reduction goals will require a dramatic transformation across the transportation system in California, and that developing near-zero emission vehicles and cleaner fuel pathways in the medium and heavy-duty vehicle segment will be essential. ARB laid out its preliminary approach in a July, 2016 planning document known as the *Sustainable Freight Action Plan*,[83] with a goal of dramatically reducing emissions across the state's goods movement system, including truck, rail, and marine components. Many elements of this strategy target increased utilization of NGVs and cleaner biomethane pathways, as well as new emissions reduction strategies for diesel trucking. Two of the measures with potential for regional action are highlighted in the chart below.

[83] See http://www.dot.ca.gov/casustainablefreight/theplan.html

Table 6-10: NGV Portion of ARB Initiatives Relevant to Regional and Local AFV Strategy

Actions	Policy Development	Policy Implementation
All sectors/freight hubs: Collect data (such as facility location, equipment, activity, and proximity to sensitive receptors) from seaports, airports, railyards, warehouse and distribution centers, truck stops, etc. to identify and support proposal of facility-based approach and/or sector-specific actions to reduce emissions and health risk, as well as efficiency improvements.	2015	2015-2016
Incentive programs: Develop modifications to existing incentive programs to increase the emphasis on and support for zero and near-zero equipment used in freight operations, including introduction of truck engines certified to optional low-NOx standards.	2015-2016	2016-2020

6.6.3 Opportunities for Coordinated Regional Action on NGV and Low-Carbon Goods Movement

Most of the actions listed in the ARB Sustainable Freight Action Plan require state policy intervention or new state investments. However, the strategy to develop “facility-based approaches” to low-emissions and zero-emissions freight movement suggests the potential for cities, counties, air quality districts, and freight stakeholders to take action at the local and regional level. The 2014 Caltrans District Four *San Francisco Bay Area Freight Mobility Study* [84] provides information regarding the region’s current goods movement system, and identifies a range of key projects that would benefit Bay Area freight movement.

The Bay Area Goods Movement Collaborative, consisting of diverse stakeholders led by the Alameda County Transportation Commission, is helping to prioritize and advocate for those short- and long-term strategies that will address freight needs while providing other community benefits. Finally, the MTC and Alameda County Transportation Commission jointly published a long-range *San Francisco Bay Regional Goods Movement Plan* in February 2016, which identifies priority strategies.[85] Key initiatives for lowering the emissions impact of regional freight could include goods transfer to PEVs or other ZEVs, which would also serve to consolidate urban shipments and reduce congestion. The key elements of the *Goods Movement Plan* that will be targeted for priority funding are to be identified by MTC and freight stakeholders for inclusion in the *Bay Area Plan 2040,* which is the consolidated regional transportation and development plan. It is anticipated that ARB will create a competitive RFP process to fund sustainable freight planning and implementation proposals statewide 2017-18. To prepare for such a process, it is

[84] http://www.dot.ca.gov/hq/tpp/offices/ogm/regional_level/FR3_SFBAFMS_Final_Report.pdf

[85] http://mtc.ca.gov/sites/default/files/RGM_Exec_Summary.pdf

recommended that San Francisco stakeholders work closely with MTC to ensure that projects providing the greatest environmental and economic benefit to the City are prioritized for regional, state, and federal funding.

6.7 Summary of Proposed Actions to Support NGV Assessment and Readiness

The following recommendations define high-level actions that public and private fleet managers, as well as AFV stakeholders generally, can take to assess the potential role of NGVs and low-carbon natural gas fuel pathways in advancing their organization's economic and environmental goals.

Recommendation	**Next Steps**
1. Ensure that the City's existing fleet of CNG cars, trucks, and vans have access to the lowest Carbon Intensity (CI) natural gas available.	▪ Work with fleet and enterprise departments to identify lower CI natural gas supplies for the City's existing fleet of CNG vehicles.
2. Periodically update natural gas procurement goals to identify lowest CI fuels practically obtainable and to refine sustainable feedstock sourcing policy for City vehicles.	▪ Identify policy process to ensure that the City's AFV procurement and fueling policies are consistent with the most recent regulations or validation criteria on the economic and environmental LCA of available alternative fuel and vehicle technologies. ▪ Require procurement of RNG for all relevant City CNG fleet vehicles based on results of LCA.
3. Identify local supplier of RNG with low CI and explore partnership to replace fossil-based natural gas in public/private fleets traveling in San Francisco	▪ Initiate dialogue on RNG supply options with appropriate city leaders, likely to include the Mayor's Office, ADM, Department of Environment, SFMTA and others as appropriate. ▪ Based on recommendations of key stakeholders, develop RNG supply plan and policy approach.

Recommendation	Next Steps
4. Consider development of regulatory guidance requiring that CNG sold in the City be replaced by RNG	▪ See above.

GLOSSARY

ABAG	Association of Bay Area Governments
AFV	Alternative Fuel Vehicle
AQIP	Air Quality Improvement Program
ARB	California Air Resources Board
ARFVTP	Alternative and Renewable Fuel and Vehicle Technology Program
BAAQMD	Bay Area Air Quality Management District
BART	Bay Area Rapid Transit District
BEVs	Battery Electric Vehicles
CaFCP	California Fuel Cell Partnership
CAISO	California Independent System Operator
CCS	carbon capture and sequestration
CI	Carbon Intensity
City	City and County of San Francisco
CNG	Compressed Natural Gas
CO2e	carbon dioxide equivalent values
CPUC	California Public Utilities Commission
CVRP	Clean Vehicle Rebate Program
DCFC	Direct Current Fast Charger
DGE	diesel gallon equivalents
Energy Commission	California Energy Commission
EPIC	Electric Program Investment Charge
EPRI	Electric Power Research Institute
EV	Electric Vehicle
eVMT	Electric Vehicle Miles Travelled
EVSE	Electric Vehicle Supply Equipment
FCEBs	Fuel Cell Electric Buses

FCEVs	Fuel Cell Electric Vehicles
FFVs	Flexible Fuel Vehicles
FOG	fats, oil, or grease
gCO_2e/MJ	grams of CO_2 equivalent per megajoule
GGE	gallons of gasoline equivalent
GHG	Greenhouse Gases
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Transportation
GVWR	Gross vehicle weight rating
HACTO	Healthy Air and Clean Transportation Ordinance
HDV	Heavy Duty Vehicle
HOA	Home Owner Association
HOV	High Occupancy Vehicle
HVIP	Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project
ICE	Internal combustion engine
IOU	Investor-owned utilities
kg/d	Kilograms per day
LCA	Life Cycle Assessment
LCFS	Low Carbon Fuel Standard
LDV	Light Duty Vehicle
MaaS	Mobility as a Service
mpg	miles per gallon
mT	metric tons
MTC	Metropolitan Transportation Commission
MUD	Multi-Unit Dwelling
NGVs	Natural Gas Vehicles
NOx	Nitrous oxide

OEM	Original Equipment Manufacturer
PEM	proton exchange membrane
psig	per square inch gauge
PG&E	Pacific Gas & Electric
PHEVs	Plug-in Hybrid Electric Vehicles
PM	Particulate matter
R&D	Research and development
RFS	Renewable Fuel Standard
RIN	Renewable Identification Numbers
RNG	renewable natural gas
RPH	Range per Hour
RVOs	Renewable Volume Obligations
SF PORT	Port of San Francisco
SFCTA	San Francisco County Transportation Agency
SFMTA	San Francisco Municipal Transportation Agency
SFO	San Francisco International Airport
SFPUC	San Francisco Public Utilities Commission
SFTP	San Francisco Transportation Plan
SFTP	San Francisco Transportation Plan
TCO	Total cost of ownership
TDM	Transportation demand management
U.C. Davis	University of California at Davis
U.S. DOE	United States Department of Energy
U.S. DOT	United States Department of Transportation
U.S. EPA	United States Environmental Protection Agency
ULSD	Ultra Low Sulfur Diesel
V1G	Vehicle to Grid (unidirectional)
V2G	Vehicle to Grid (bidirectional)

VGI	Vehicle-Grid Integration
VMT	Vehicle miles travelled
ZEVs	Zero Emission Vehicles

APPENDIX A

HEALTHY AIR AND CLEAN TRANSPORTATION ORDINANCE (HACTO)

SEC. 403. FLEET MANAGEMENT PROMOTING HEALTHY AIR AND CLEAN TRANSPORTATION:

NOTE: The ordinance language below includes Section 403b and 404 pertaining to Fleet Management practices[86]

(b) **Optimizing Fleet Management.** To help the City achieve its air pollution and greenhouse gas reduction goals, and promote the effective, efficient, and safe use of all general purpose, light-duty vehicles owned, leased, or rented by the City, the City Administrator will adopt and implement policies to:

(1) Optimize the size and utilization of the City's general purpose, light-duty fleet, with emphasis on right-sizing the fleet and eliminating unnecessary or non-essential vehicles;

(2) Use technology such as telematics and vehicle assignment systems, to the furthest extent practicable, to promote the safe use of vehicles, minimize environmentally harmful practices such as excessive vehicle idling, and reduce underutilization of vehicles;

(3) Align greenhouse gas reduction goals with the Federal Executive Order – Planning for Federal Sustainability in the Next Decade, dated March 19, 2015 – reducing average per-mile greenhouse gas emissions from general purpose, light-duty fleet vehicles, relative to a baseline of emissions in fiscal year 2014, to achieve the following percentage reductions: (A) not less than 4 percent by the end of fiscal year 2017; and (B) not less than 15 percent by the end of fiscal year 2021; and

(4) Conduct a review one year after the initial implementation of these policies, and every year thereafter, to assess telematics data, review developments in low carbon fuels, evaluate possible coverage of additional vehicle classes, evaluate additional GHG goals, and other topics the City Administrator deems are relevant, to serve as a basis for the City Administrator, in consultation with the Director of the Department of the Environment, to adopt and implement further policy changes regarding fleet management as appropriate. The City

86 The full text of the ordinance is available on the Department of the Environment website, available at: http://library.amlegal.com/nxt/gateway.dll/California/environment/chapter4healthyairandcleantransportation?f=templates&fn=default.htm&3_0=&vid=amlegal%3Asanfrancisco_ca

Administrator shall submit an annual report to the Board of Supervisors and the Mayor outlining the findings of this annual review and any additional resulting policy changes in fleet management, including recommendations for mandatory fleet reductions if warranted.

(Added by Ord. 278-10, File No. 101009, App. 11/18/2010; amended by Ord. 116-15 , File No. 140950, App. 7/15/2015, Eff. 8/14/2015)

SEC. 404. NEW OR REPLACEMENT MOTOR VEHICLES.

(a) Unless granted a waiver under Section 404(b) or exempt under subsection 404(c), City officials may not purchase or authorize the purchase of any motor vehicle unless the purchase complies with each of the following:

(1) The purchase complies with the Transit-First policy required under Section 403(a) and adopted by the department or City official for whose use the vehicle is principally intended;

(2) A passenger vehicle or light-duty truck requested for purchase is an approved make and model under the applicable Vehicle Selector List; and,

(3) The motor vehicle requested for purchase meets all applicable safety standards and other requirements for the intended use of the vehicle.

(b) **Waivers.** The City Administrator may waive the requirements of Section 404(a) where he or she finds that

(1) there is no passenger vehicle or light-duty truck approved by the Vehicle Selector List that meets all applicable safety standards and other requirements for the intended use of the motor vehicle; or

(2) the passenger vehicle or light-duty truck will be used primarily outside of the geographic limits of the City and County of San Francisco in location(s) which lack required fueling or other infrastructure required for a complying motor vehicle.

As part of his or her annual report to the Board of Supervisors and the Mayor under Section 403(b)(4), the City Administrator shall report on the number of new waivers granted under this subsection (b) for the prior year.

(c) **Exemptions.** This Section shall not apply in the following circumstances:

(1) To the purchase of emergency vehicles where the Public Safety Department concludes, after consultation with the City Administrator, that the purchase of a complying vehicle is not feasible or would otherwise unduly interfere with the Department's public safety mission.

(2) To the acquisition of buses by the San Francisco Municipal Transportation Authority for public transportation purposes.

(3) To any purchase necessary to respond to an emergency that meets the criteria set in Administrative Code Sections 21.15(a) or 6.60. In such cases, the department shall, to the

extent feasible under the circumstances, acquire the noncomplying vehicles only for a term anticipated to meet the emergency need. Any City department invoking this exemption shall promptly notify the City Administrator, in writing, of the purchase and the emergency that prevented compliance with this section.

(4) Wherever the purchase of a passenger vehicle or light-duty truck is exempt from the requirements of this section, City departments and officials shall select a vehicle with as low emissions and high efficiency ratings as practicable.

(Ord. 278-10, File No. 101009, App. 11/18/2010; amended by Ord. 116-15 , File No. 140950, App. 7/15/2015, Eff. 8/14/2015)