South Coast
Air Quality
Management District

Clean Fuels Program

2022 Annual Report & 2023 Plan Update

Technology Advancement Office

Leading the way to cleaner air

Cover Photo Credits

Top to bottom:

- BYD Gen2 8TT Class 8 battery electric truck for the GGRF Zero Emission Drayage Truck Project
- Chassis emissions testing of a goods movement truck from 200 Vehicle Study
- Moreno Valley Unified School District battery electric bus charger
- Freightliner eCascadia Class 8 battery electric Superbowl truck for the Innovation Fleet Project
- Volvo LIGHTS VNR Electric Class 8 battery electric truck

South Coast Air Quality Management District

Governing Board

Chair: VANESSA DELGADO
Senator (Ret.)
Senate Rules Committee Appointee

Vice Chair: MICHAEL A. CACCIOTTI
Council Member, South Pasadena
Cities of Los Angeles County/Eastern Region

Members:

ANDREW DO*
Supervisor, Fifth District
County of Orange

CURT HAGMAN
Supervisor, Fourth District
County of San Bernardino

GIDEON KRACOV*
Governor's Appointee

LARRY MCCALLON*
Mayor, Highland
Cities of San Bernardino County

HOLLY J. MITCHELL
Supervisor, Second District
County of Los Angeles

VERONICA PADILLA-CAMPOS*
Speaker of the Assembly Appointee

V. MANUEL PEREZ
Supervisor, Fourth District
County of Riverside

NITHYA RAMAN
Council Member, Fourth District
City of Los Angeles Representative

CARLOS RODRIGUEZ**
Council Member, Yorba Linda
Cities of Orange County

VACANT
Cities of Los Angeles County/Western Region

VACANT
Cities of Riverside County Representative

Executive Officer: WAYNE NASTRI

*Technology Committee Member (as of 2/17/23) **Technology Committee Chair

[This Page Intentionally Left Blank]

South Coast Air Quality Management District

Technology Advancement Office

Aaron Katzenstein, Ph.D., Deputy Executive Officer

Vacant, Assistant Deputy Executive Officer

Daniel Garcia, Community Programs & Special Incentives
Walter Shen, Off-Road Incentives, Inspections & Special Projects Manager
Mei Wang, On-Road Incentives, Contracts & Outreach Manager
Vacant, Technology Demonstration Manager

Sam Cao, Ph.D., Program Supervisor
Ping Gui, Program Supervisor
Seungbum Ha, Ph.D., Program Supervisor
Maryam Hajbabaei, Ph.D., Program Supervisor
Victor Juan, Program Supervisor
Patricia Kwon, Program Supervisor
Tom Lee, Program Supervisor
Joseph Lopat, Program Supervisor
Yuh Jiun Tan, Program Supervisor
Kelly Trainor Gamino, Program Supervisor
Alyssa Yan, Program Supervisor

Christina Kusnandar, Sr. Staff Specialist
Ash Nikravan, Sr. Staff Specialist

David Chen, Air Quality Specialist
Darren Ha, Air Quality Specialist
Justin Joe, Air Quality Specialist
Charlize Li, Air Quality Specialist
Alicia Ibarra Martinez, Air Quality Specialist
Frances Maes, Air Quality Specialist
Krystle Martinez, Air Quality Specialist
Greg Ushijima, Air Quality Specialist
Nick Volpone, Air Quality Specialist
George Wu, Air Quality Specialist
Fan Xu, Ph.D., Air Quality Specialist
Andrew Yoon, Air Quality Specialist
Liliana Garcia, Assistant Air Quality Specialist
Mariel Maranan, Assistant Air Quality Specialist
Kevin Perozo, Assistant Air Quality Specialist
Veronica Tejada, Assistant Air Quality Specialist
Kristina Voorhees, Assistant Air Quality Specialist
Alan Wang, Assistant Air Quality Specialist

Justin Chuang, Air Quality Inspector II
Matthew Fung, Air Quality Inspector II
Kenny Heralal, Air Quality Inspector II
Jonathan Rocha, Air Quality Inspector II

Penny Shaw Cedillo, Sr. Administrative Assistant
Maria Allen, Administrative Assistant I
Marjorie Eaton, Administrative Assistant I
Donna Vernon, Administrative Assistant I

Michelle White, Sr. Public Affairs Specialist
Ana Troccoli, Staff Assistant
Tribrina Brown, Contracts Assistant
Margarita Cabral, Contracts Assistant
Jessie Conaway, Contracts Assistant
Priscilla Pineda, Contracts Assistant
Benigna Taylor, Contracts Assistant
Cynthia Snyder, Sr. Office Assistant
Emmanuel Del Rosario, Office Assistant

[This Page Intentionally Left Blank]

Table of Contents

List of Figures

List of Tables

List of Appendices

[This Page Intentionally Left Blank]

EXECUTIVE SUMMARY

Introduction

South Coast Air Quality Management District (South Coast AQMD) is the air pollution control agency for Orange County and the urban portions of Los Angeles, Riverside and San Bernardino counties. This region, which encompasses the South Coast Air Basin (Basin) as well as small portions of the Mojave Desert and Salton Sea Air Basins, historically experiences the worst air quality in the nation due to the natural geographic and atmospheric conditions of the region, coupled with the high population density and associated mobile and stationary source emissions.

In 1988, SB 2297 (Rosenthal) was signed into law (Chapter 1546). It initially established a "five-year program to increase the use of clean fuels," but subsequent legislation extended and eventually removed the sunset clause for the Program. That legislation also reaffirmed the existence of the Technology Advancement Office (TAO) to administer the Clean Fuels Program. The Clean Fuels Program is an integral part of South Coast AQMD's effort to achieve the significant nitrogen oxides (NOx) emission reductions called for in the 2022 Air Quality Management Plan (AQMP) because it affords South Coast AQMD the ability to fund research, development, demonstration and accelerated deployment of clean fuels and transformative transportation technologies.

Using funding from a $1 motor vehicle registration fee, the Clean Fuels Program encourages, fosters and supports clean fuels and transportation technologies, such as hydrogen fuel cells, advanced natural gas (NG) technologies, alternative fuel engines, battery electric vehicles, plug-in hybrid electric vehicles and related fueling infrastructure including renewable fuels. A key strategy of the Program is its public-private partnerships with private industry, technology developers, academic institutions, research institutions, and government agencies. Since 1988, the Clean Fuels Program leveraged nearly $250 million into $1.6 billion in projects. Leveraging of the Clean Fuels Fund is based on executed contracts and total project costs from the prior year's Clean Fuels Annual Report and Plan Update.

As technologies move towards commercialization, such as battery and fuel cell electric trucks, the Clean Fuels Program has been able to partner with large original equipment manufacturers (OEMs), such as Daimler, Volvo, Hyundai and Peterbilt to deploy these vehicles at scale. These OEM partnerships allow the Program to leverage their research, product development, customer relationships, and financial resources needed to move advanced technologies from the laboratories to the field and into customers' hands. The OEMs have the resources and capabilities to design, engineer, test, manufacture, market, distribute and service quality products under brand names that are trusted. This is the type of scale needed to achieve emission reductions to attain national ambient air quality standards (NAAQS).

While South Coast AQMD aggressively seeks to leverage funds, it plays a leadership role in technology development and commercialization, along with its partners, to accelerate the reduction of criteria pollutants. The Clean Fuels Program has traditionally supported a portfolio of technologies at different technology readiness levels. This helps with the development of new technologies across many different mobile sectors in need of new technologies that provide emission reductions and health benefits. This approach enhances the region's chances of achieving the NAAQS.

California Health and Safety Code (H&SC) 40448.5(e) calls for the Clean Fuels Program to consider factors such as: current and projected economic costs and availability of fuels; cost-effectiveness of emission reductions associated with clean fuels compared with other pollution control alternatives; use of new pollution control technologies in conjunction with traditional fuels as an alternative means of reducing

emissions; potential effects on public health, ambient air quality, visibility within the region; and other factors determined to be relevant by South Coast AQMD. The Legislature recognized the need for flexibility, allowing focus on a broad range of technology areas, including cleaner fuels, vehicles and infrastructure, which helps South Coast AQMD continue to make progress toward achieving its clean air goals.

California H&SC 40448.5.1 requires South Coast AQMD to prepare and submit a Clean Fuels Annual Report and Plan Update annually to the Legislative Analyst by March 31. The Clean Fuels Annual Report looks at Program accomplishments in the prior calendar year (CY) and Clean Fuels Plan Update looks ahead at proposed projects for the next CY, re-calibrating technical emphasis of the Program.

Setting the Stage

The overall strategy of the Clean Fuels Program is largely based on emission reduction technology needs identified in the AQMP and the South Coast AQMD Board directives to protect the health of almost 18 million residents (nearly half the population of California) in the Basin. The 2022 AQMP, which was released in May 2022 and adopted in December 2022 by the South Coast AQMD Board, is the long-term regional "blueprint" that identifies the fair-share emission reductions from all jurisdictional levels (e.g., federal, state and local). The 2022 AQMP is composed of stationary and mobile source emission reductions from traditional regulatory control measures, incentive-based programs, projected co-benefits from climate change programs, mobile source strategies and other innovative approaches, including indirect source measures and incentive programs, to reduce emissions from federally regulated sources (e.g., aircraft, locomotives and ocean-going vessels). CARB's Proposed 2022 State SIP Strategy included a revised mobile source strategy required for the Basin to meet the 2015 8-hour ozone standard of 70 ppb by 2037. The Proposed 2022 State SIP Strategy for both mobile and stationary sources require rapid deployment of zero emission technologies to achieve air quality targets.

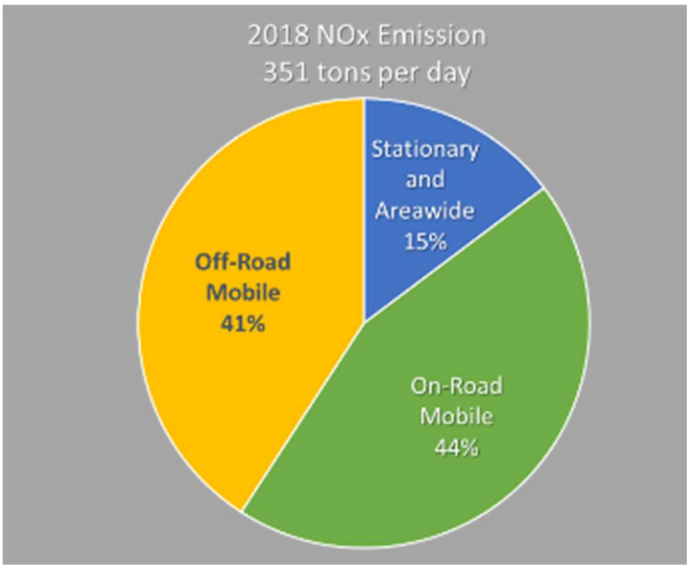


Figure 1: NOx Emissions by Source Category

Ground level ozone (a key component of photochemical smog) is formed by a chemical reaction between NOx and volatile organic compound (VOC) emissions in the presence of sunlight. NOx emission reduction is the key to improve ozone air quality and attain the ozone NAAQS in the Basin. Approximately 85 percent of NOx emissions are from mobile sources in 2018, as shown in Figure 1. Furthermore, NOx emissions, along with VOC emissions, also lead to the secondary formation of PM2.5 in the atmosphere [particulate matter measuring 2.5 microns or less in size, expressed as micrograms per cubic meter (µg/m3)].

The emission reductions and control measures in the 2022 AQMP rely on commercial adoption of a mix of currently available technologies as well as the expedited development and commercialization of clean fuel mobile and stationary advanced technologies in the Basin to achieve air quality standards. The 2022 AQMP identifies that 83 percent NOx emission reductions from the 2018 level and 67 percent additional reductions in 2037 beyond already adopted regulations and programs are necessary to meet the 2015 8-hour ozone standard by 2037. Figure 2 illustrates the needed NOx reductions in the Basin by source category. The majority of NOx reductions must come from mobile sources, both on-road and off-road sources. Notably, South Coast AQMD is currently only one of two regions in the nation designated as an extreme nonattainment area of the 2015 8-hour ozone NAAQS (the other region is California's San Joaquin Valley).

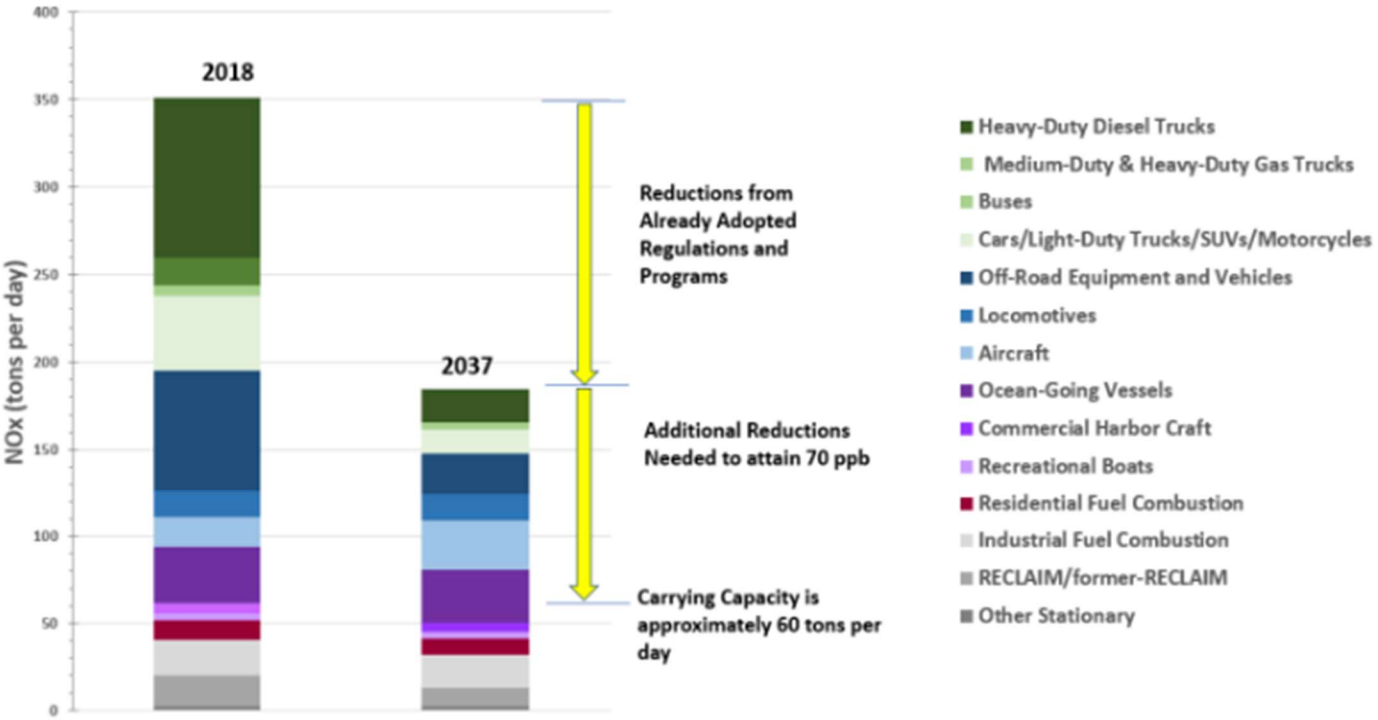


Figure 2: NOx Emissions and Reductions Required to Attain 2015 Standard

The 2022 AQMP shows the need for economy-wide transition to zero emission technologies where feasible along with the CARB 2020 Mobile Source Strategy, and low NOx technologies in other applications.

Clean Fuels Program

The Clean Fuels Program, established in California H&SC 40448.5, is an important mechanism to encourage and accelerate the advancement and commercialization of clean fuels in stationary and mobile source technologies.

Figure 3 provides a conceptual design of the wide scope of the Clean Fuels Program and the relationship with incentive programs. Various stages of technology projects are funded to provide a portfolio of technology choices as well as achieve near-term and long-term emission reductions. The Clean Fuels Program typically funds projects in the Technology Readiness Level (TRL) ranging between 3-8.

Figure 3: Stages of Clean Fuels Program Funding

Below is a summary of the 2022 Clean Fuels Annual Report and 2023 Plan Update. Every Annual Report and Plan Update is reviewed by two advisory groups–the Clean Fuels Advisory Group, legislatively mandated by SB 98 (chaptered, 1999), and the Technology Advancement Advisory Group, created by the South Coast AQMD Board in 1990. These stakeholder groups review and assess the overall direction of the Program. The two groups meet approximately every six months to provide expert analysis and feedback on potential projects and areas of focus. Key technical experts working in the fields of the Program's core technologies also typically attend and provide feedback. Preliminary review and comment are also provided by South Coast AQMD's Board and other interested parties and stakeholders, as deemed appropriate.

2022 Annual Report

In CY 2022, the South Coast AQMD Clean Fuels Program executed 21 new contracts, projects or studies and modified 5 continuing projects adding dollars toward research, development, demonstration and deployment projects as well as technology assessment and transfer of alternative fuel and clean fuel technologies. Table 2 shows major funding partners in CY 2022. Table 5 lists the 26 projects or studies, which are further described in this report. The Clean Fuels Program contributed over $7.4 million in partnership with other governmental organizations, private industry, academia and research institutes, and interested parties, with total project costs of approximately $74.1 million. The $7.4 million includes $304,000 recognized into the Clean Fuels Fund as pass-through funds from project partners for project administration by the Clean Fuels Program. Table 6 provides information on this outside funding received into the Clean Fuels Fund. Additionally, in CY 2022, the Clean Fuels Program continued to leverage outside funding opportunities, securing new awards totaling almost $3.3 million from federal, state and local funding opportunities. Table 7 provides a comprehensive summary of these federal, state and local revenues awarded to South Coast AQMD during CY 2022. Like the last several years, the significant project scope of a few key contracts executed in 2022 resulted in high leveraging of Clean Fuels dollars. Typical historical leveraging is $4 for every $1 in Clean Fuels funding. In 2022, South Coast AQMD exceeded this upward trend with almost $10 leveraged for every $1 in Clean Fuels funds. Leveraging dollars and aggressively

pursuing funding opportunities is critical given the magnitude of needed funding identified in the 2022 AQMP to achieve NAAQS.

The projects or studies executed in 2022 included a diverse mix of advanced technologies. The following core areas of technology advancement for 2022 executed contracts (in order of funding percentage) include:

1. Electric and Hybrid Vehicle Technologies and Infrastructure (including battery electric and hybrid electric trucks developed by OEMs and container transport technologies with zero emission operations);
2. Technology Assessment and Transfer/Outreach;
3. Engine Systems/Technologies (including alternative and renewable fuels for truck and rail applications);
4. Hydrogen and Mobile Fuel Cell Technologies and Infrastructure;
5. Stationary Clean Fuels Technologies (including microgrids and renewables);
6. Fuel and Emissions Studies;
7. Fueling Infrastructure and Deployment (NG and renewable fuels); and
8. Emissions Control Technologies; and
9. Health Impacts Studies

Figure 11 on page 25 shows the distribution by percentage of executed agreements in 2022 across these core technologies.

During CY 2022, South Coast AQMD supported a variety of projects and technologies, ranging from near-term to long-term research, development, demonstration and deployment activities. This "technology portfolio" strategy provides South Coast AQMD the ability and flexibility to leverage state and federal funding while also addressing the specific needs of the Basin. Projects included significant battery electric and hybrid electric technologies and infrastructure to develop and demonstrate medium- (MD) and heavy- (HD) vehicles in support of transitioning to near-zero and zero emission goods movement; development, demonstration and deployment of large displacement ultra-low NOx engines; and demonstration of hydrogen fuel cell MD and HD vehicles and infrastructure.

In addition to the 26 executed contracts and projects, 46 research, development, demonstration and deployment projects or studies and 11 technology assessment and transfer contracts were completed in 2022, as listed in Table 15 on page 62. Appendix C includes two-page summaries of technical projects completed in 2022. As of January 1, 2023, there were 74 open contracts in the Clean Fuels Program; Appendix B lists these open contracts by core technology.

In accordance with California H&SC Section 40448.5.1(d), this annual report must be submitted to the state legislature by March 31, 2023, after approval by the South Coast AQMD Board.

2023 Plan Update

The Clean Fuels Program is re-evaluated annually to develop the annual Plan Update based on a reassessment of the technology progress and direction for the agency. The Program continually seeks to support the development and deployment of cost-effective clean fuel technologies with increased collaboration with OEMs to achieve large scale deployment. The design and implementation of the Clean Fuels Program Plan must balance the needs in the various technology sectors with technology readiness on the path to commercialization, emission reduction potential and co-funding opportunities. For several years, the state has focused a great deal of attention on climate change and petroleum reduction goals, but South Coast AQMD has remained committed to developing, demonstrating and commercializing technologies that reduce criteria pollutants, specifically NOx and toxic air contaminants (TACs). Most of these technologies address the Basin's need for NOx and TAC reductions and garner reductions in greenhouse

gases (GHG) and petroleum use. Due to these co-benefits, South Coast AQMD has been successful in partnering with the state and public/private partnerships to leverage its Clean Fuels funding.

To identify technology and project opportunities where funding can make a significant difference in deploying cleaner technologies in the Basin, South Coast AQMD engages in outreach and networking efforts. These activities range from close involvement with state and federal collaboratives, partnerships and industrial coalitions, to the issuance of Program Opportunity Notices (PONs) to solicit project ideas and concepts and Requests for Information (RFIs) to determine the current state of technologies and their development and commercialization challenges. Additionally, unsolicited proposals from OEMs and other clean fuel technology developers are regularly received and reviewed. Potential development, demonstration and certification projects resulting from these outreach and networking efforts are included conceptually within the 2023 Clean Fuels Plan Update.

Assembly Bill (AB) 617[1] requires reduced exposure to communities most impacted by air pollution; TAO conducts additional outreach to AB 617 communities regarding available zero and near-zero emission technologies and incentives to accelerate deployment of cleaner technologies. Cleaner technologies such as near-zero and zero emission HD trucks are now included in the Community Emission Reduction Plans (CERPs) for these AB 617 communities, and an RFP for a zero emission HD truck loaner program is being developed and will be released in 2023. This program will allow smaller fleets and independent owner operators to learn about zero emission trucks by trying them out in their business operations. This program is being funded through Community Air Protection Program (CAPP) funds but utilizes zero emission truck technologies developed under the Clean Fuels Program.

Since 2020, CARB has adopted several critical milestone regulations for reducing emissions from on-road HD mobile sources. These regulations include: 1) Advanced Clean Truck (ACT) regulation which mandates an increasingly higher percentage of zero emission truck sales starting in 2024, 2) Omnibus Low NOx regulation which requires lower exhaust NOx standards on HD engines starting in 2024, and 3) HD Vehicle Inspection and Maintenance Program for removing high emitters from legacy trucks. CARB is also taking the proposed Advanced Clean Fleets regulation as well as the 2022 State Implementation Plan (SIP) Strategy for Board consideration in 2023.

On the federal level, U.S. EPA has finalized a national low NOx truck rule in December 2022. The "Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards," sets more stringent emissions from HD vehicles starting in model year 2027. This regulation is one of three rulemakings planned under the EPA Clean Trucks Plan. Two additional rulemakings are planned for 2023 that would include Phase 3 heavy-duty GHG standards and light- (LD) and MD vehicle standards for model years 2027.[2] Though there are some slight differences when compared to CARB Omnibus regulation for 2027. Both the federal and state low-NOx regulations complement various zero emission regulations and will together bring much needed mobile source NOx reductions to the South Coast Air Basin.

Regionally, South Coast AQMD adopted the Warehouse Actions and Investments to Reduce Emissions (WAIRE) program to reduce NOx and DPM emissions from indirect sources such as warehouse facilities. The San Pedro Bay Ports implemented the Clean Truck Fund (CTF) to generate funds for achieving the goal of zero emission drayage trucks by 2035. Despite these major efforts, additional NOx emission reductions in the South Coast Air Basin are needed to meet ozone attainment target deadlines.

[1] https://ww2.arb.ca.gov/capp

[2] Final Rule and Related Materials for Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards | US EPA

The Plan Update includes projects to develop, demonstrate and commercialize a variety of technologies, from near-term to long-term commercialization, that are intended to provide significant emission reductions over the next five to ten years. Areas of focus include:

- developing and demonstrating technologies to reduce emissions from goods movement and Port-related activities, including zero emission drayage trucks and infrastructure;
- developing and demonstrating ultra-low NOx, gaseous and liquid alternative/renewable fueled, large displacement/high efficiency engines and HD zero emission engine technologies;
- mitigating criteria pollutant emissions from the production of renewable fuels, such as renewable natural gas, diesel and hydrogen as well as other renewable, low/zero carbon fuels and waste streams;
- producing transportation fuels and energy from renewable and waste stream sources;
- developing and demonstrating electric-drive (fuel cell, battery, plug-in hybrid and non-plug-in hybrid) technologies across LD, MD and HD platforms;
- establishing large-scale hydrogen fueling and electric vehicle (EV) charging infrastructure to support LD, MD and HD zero emission vehicles;
- ultra-fast, higher power charging for HD battery electric vehicles;
- developing and demonstrating zero emission microgrids that utilize battery energy storage systems and onsite clean power generation to support transportation electrification demands associated with goods movement and freight handling activities.

Table 16 (page 87) lists potential projects across ten core technologies by funding priority:

- Hydrogen / Mobile Fuel Cell Technologies;
- Electric / Hybrid Technologies (battery electric and hybrid electric trucks and container transport technologies with zero emission operations);
- Zero Emission Infrastructure (especially large-scale fueling and production facilities and stations that support MD and HD vehicles);
- Engine Systems / Technologies (alternative and renewable fuels for truck and rail applications);
- RNG Infrastructure (renewable natural gas and renewable fuels);
- Stationary Clean Fuel Technologies (microgrids that support EV and Hydrogen infrastructure and renewables);
- Fuel and Emission Studies;
- Emission Control Technologies;
- Health Impact Studies within disadvantaged communities; and
- Technology Assessment and Transfer / Outreach
- These potential projects for 2023 total $19.8 million of Clean Fuels funding, with the anticipation of total project costs of $118.7 million, leveraging $6 for every $1 of Clean Fuel funds spent. Some proposed projects may also be funded by other funding sources, such as state and federal grants for clean fuel technologies, incentive programs such as AB 617 CAPP funding, Volkswagen Mitigation, and Carl Moyer, and other mitigation funds.

[This Page Intentionally Left Blank]

CLEAN FUELS PROGRAM

Background and Overview

Program Background

The Basin, which comprises all of Orange County and the urban portions of Los Angeles, San Bernardino and Riverside counties, has the worst air quality in the nation due to a combination of factors, including high vehicle population, high vehicle miles traveled within the region, and geographic and atmospheric conditions favorable for photochemical oxidant (smog) formation. This region, which encompasses the South Coast Air Basin as well as small portions of the Mojave Desert and Salton Sea Air Basins, is home to almost 18 million residents (nearly half the population of California). Due to this confluence of factors, which present unique challenges, the state legislature enabled South Coast AQMD to implement the Clean Fuels Program to accelerate the implementation and commercialization of clean fuels and advanced mobile source technologies.

In 1988, SB 2297 (Rosenthal) was signed into law (Chapter 1546). It initially established a "five-year program to increase the use of clean fuels," but subsequent legislation extended and eventually removed the sunset clause for the Program. That legislation also reaffirmed existence of the Technology Advancement Office (TAO) to administer the Clean Fuels Program. The Clean Fuels Program is an integral part of South Coast AQMD's effort to achieve the significant NOx reductions called for in the 2022 AQMP.

California H&SC section 40448.5(e) calls for the Clean Fuels Program to consider, among other factors, current and projected economic costs and availability of fuels, cost-effectiveness of emission reductions associated with clean fuels compared with other pollution control alternatives, use of new pollution control technologies in conjunction with traditional fuels as an alternative means of reducing emissions, potential effects on public health, ambient air quality, visibility within the region, and other factors determined to be relevant by South Coast AQMD. The Legislature recognized the need for flexibility, allowing focus on a broad range of technology areas, including cleaner fuels, vehicles and infrastructure, which helps South Coast AQMD continue to make progress toward achieving its clean air goals.

In 1999, further state legislation was passed which amended the Clean Fuels Program. Specifically, as stated in the H&SC section 40448.5.1(d), South Coast AQMD must submit an annual report to the Legislature, on or before March 31, that includes:

1. Description of the core technologies that South Coast AQMD considers critical to ensure attainment and maintenance of ambient air quality standards and a description of the efforts made to overcome barriers to commercialization of those technologies;
2. Analysis of the impact of South Coast AQMD's Clean Fuels Program on the private sector and on research, development and commercialization efforts by major automotive and energy firms, as determined by South Coast AQMD;
3. Description of projects funded by South Coast AQMD, including a list of recipients, subcontractors, co-funding sources, matching state or federal funds and expected and actual results of each project advancing and implementing clean fuels technology and improving public health;
4. Title and purpose of all projects undertaken pursuant to the Clean Fuels Program, names of the contractors and subcontractors involved in each project and amount of money expended for each project;
5. Summary of progress made toward the goals of the Clean Fuels Program; and
6. Funding priorities identified for the next year and relevant audit information for previous,

current and future years covered by the Clean Fuels Program.

Furthermore, H&SC section 40448.5.1(a)(2) requires South Coast AQMD to find that the proposed program and projects funded as part of the Clean Fuels Program will not duplicate any other past or present program or project funded by the state board and other government and utility entities. This finding does not prohibit funding for programs or projects jointly funded with another public or private agency where there is no duplication. Concurrent with adoption and approval of the annual report and plan update every year, the Board will consider the efforts TAO has undertaken in the prior year to ensure no such duplication has occurred then make a finding through a Resolution attesting such.

The following section describes the various panels of external experts that help review the Clean Fuels Program every year.

Program Review

In 1990, South Coast AQMD initiated an annual review of its technology advancement program by an external panel of experts. That external review process has evolved, in response to South Coast AQMD policies and legislative mandates, into two external advisory groups. The Technology Advancement Advisory Group (one of six standing Advisory Groups that make up the South Coast AQMD Advisory Council) is made up of stakeholders representing industry, academia, regulatory agencies, scientific community and environmental non-governmental organizations (NGOs). The Technology Advancement Advisory Group serves to:

- Coordinate the Clean Fuels program with related local, state and national activities;
- Review and assess the overall direction of the program; and
- Identify new project areas and cost-sharing opportunities.

In 1999, the second advisory group was formed as required by SB 98 (Alarcon). Under H&SC Section 40448.5.1(c), this advisory group must comprise 13 members with expertise in clean fuels technology and policy or public health and appointed from the scientific, academic, entrepreneurial, environmental and public health communities. This legislation further specified conflict-of-interest guidelines prohibiting members from advocating expenditures towards projects in which they have professional or economic interests. The objectives of the SB 98 Clean Fuels Advisory Group are to make recommendations regarding projects, plans and reports, prior to submittal of the required annual report to the South Coast AQMD Governing Board. In 1999, after formation of the SB 98 Clean Fuels Advisory Group, South Coast AQMD revisited the charter and membership of the Technology Advancement Advisory Group to ensure their functions would complement each other.

On an as-needed basis, changes to the composition of the Clean Fuels Advisory Group are reviewed by the South Coast AQMD Board while changes to the Technology Advancement Advisory Group are reviewed by the South Coast AQMD Board's Technology Committee.

The charter for the Technology Advancement Advisory Group calls for approximately 12 technical experts representing industry, academia, state agencies, scientific community and environmental interests. Traditionally, there has been exactly 12 members on this advisory group, but in CY 2019 staff recommended to the Board's Technology Committee that it add representatives from the Ports of Long Beach and Los Angeles, as both entities are integral players and stakeholders in demonstrating near-zero and zero emission technologies in and around the Ports and surrounding disadvantaged communities. With the addition of the Port representatives, there are currently 13 members on the Technology Advancement Advisory Group.

Current membership changes to both advisory groups are considered by the South Coast AQMD Board and its Technology Committee, respectively, as part of consideration of each year's Annual Report and Plan Update. Members of the SB 98 Clean Fuels Advisory Group and Technology Advancement Advisory Group are listed in Appendix A, with proposed changes, duly noted, subject to either South Coast AQMD Board approval or the Board's Technology Committee, per the advisory group's charters.

The review process of the Clean Fuels Program now includes, at minimum: 1) two full-day retreats of both Advisory Groups, typically in the summer and winter; 2) review by other technical experts; 3) occasional technology forums or roundtables bringing together interested parties to discuss specific technology areas; 4) review by the Technology Committee of the South Coast AQMD Board; 5) public hearing of the Annual Report and Plan Update before the full South Coast AQMD Board, along with adoption of the Resolution finding that the proposed program and projects funded as part of the Clean Fuels Program will not duplicate any other past or present program or project funded by the state board and other government and utility entities, as required by the H&SC; and 6) annual submittal of the Clean Fuels Program Annual Report and Plan Update to the Legislature by March 31.

The Need for Advanced Technologies & Cleaner Fuels

Achieving federal and state clean air standards in South Coast Air Basin will require emission reductions from both mobile and stationary sources beyond those expected using current technologies.

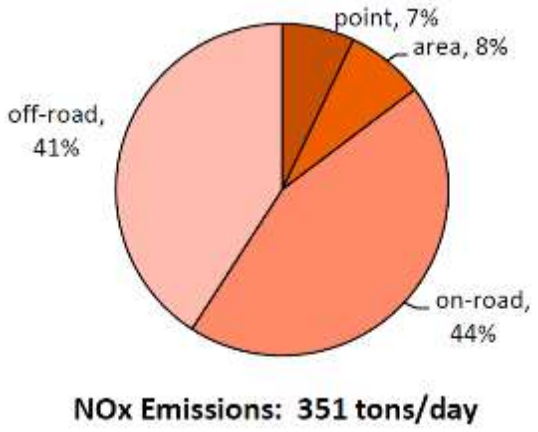


Figure 4: NOx Contribution by Source Category to 2018 Emission Inventory

Ground level ozone (a key component of smog) is created by a chemical reaction between NOx and volatile organic compound (VOC) emissions in sunlight. This is noteworthy because the primary driver for ozone formation in the Basin is NOx emissions, and mobile sources contribute approximately 85 percent of the NOx emissions in this region, as shown in Figure 4. Furthermore, NOx emissions, along with VOC emissions, also lead to the formation of PM2.5 [particulate matter measuring 2.5 microns or less in size, expressed as micrograms per cubic meter (µg/m3)], including secondary organic aerosols.

To fulfill near- and long-term emission reduction targets, the 2022 AQMP currently relies on a mix of currently available technology as well as accelerated development and demonstration of advanced technologies that are not yet commercialized. Significant reductions are anticipated from implementation of advanced control technologies for on-road and off-road mobile sources. Air quality standards for ozone (70 ppb, 8-hour average) and fine particulate matter, promulgated by U.S. EPA, are projected to require

additional long-term control measures for NOx and VOC.

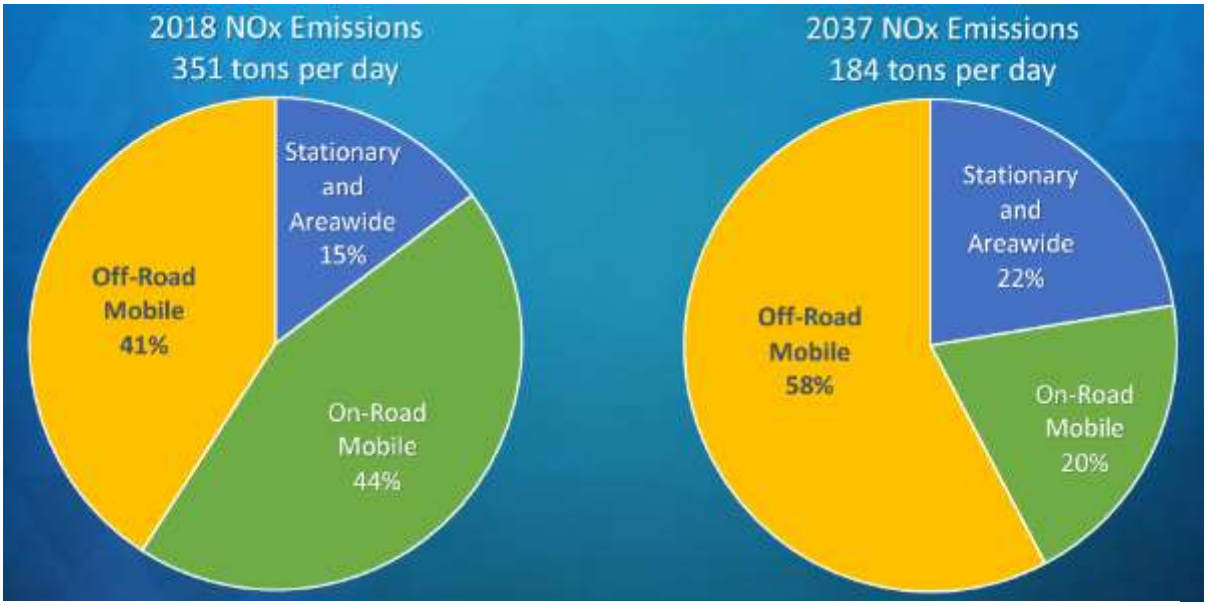


Figure 5: NOx Contribution Source Category in 2018 and 2037

The need for advanced mobile source technologies and clean fuels is best illustrated by Figure 5 which identifies NOx emissions by source category in 2018 and 2037. NOx reductions identified in the 2022 AQMP will require the Clean Fuels Program to accelerate advancement of clean transportation technologies used as control strategies in the AQMP. Given this contribution, significant emission reductions from these sources are needed. 2022 AQMP mobile source strategies call for deploying cleaner technologies (both zero and near-zero emission) into fleets, requiring cleaner and renewable fuels, and ensuring continued clean performance in use. Federal actions are also required to address sources that are subject to federal regulations and beyond the regulatory authority of South Coast AQMD and CARB.

Health studies also indicate a greater need to reduce NOx emissions and TAC emissions. The South Coast AQMD Multiple Air Toxics Exposure Study (MATES) V study (2021), and the prior four MATES studies, assessed air toxic levels, updated risk characterization, and determined gradients from selected sources.

In summary, advanced, energy efficient and renewable technologies are needed for attainment, but also to protect the health of residents, reduce long-term dependence on petroleum-based fuels, and support a more sustainable energy future. Conventional strategies and traditional supply and consumption need to be retooled to achieve NAAQS. To meet this need for advanced, clean technologies, the South Coast AQMD Board continues to aggressively carry out the Clean Fuels Program and promote alternative fuels through its TAO.

As technologies move towards commercialization, such as battery electric and fuel cell trucks, the Clean Fuels Program partners with large OEMs, such as Daimler Trucks North America, LLC (DTNA), Volvo and Kenworth, to deploy these vehicles at scale. These OEM partnerships allow the Program to leverage the research, product creation and financial resources that are needed to move advanced technologies from the laboratories to the field and into customers' hands. OEMs have the resources and abilities to design, engineer, test, manufacture, market, distribute and service quality products under brand names that are trusted. This is the type of scale needed to achieve emission reductions to meet NAAQS.

As advanced technologies and cleaner fuels are commercial-ready, there needs to be a concerted effort to get them into the marketplace and on the roads. South Coast AQMD's Carl Moyer Program, which was

launched in 1988, along with recent Volkswagen Mitigation Trust and CAPP, help achieve these results. These programs provide incentives to push market penetration of the technologies developed and demonstrated by the Clean Fuels Program. The synergy between the Clean Fuels program and incentive programs enable South Coast AQMD to play a leadership role in both technology development and commercialization efforts targeting reduction of criteria pollutants. Funding for both research, development, demonstration and deployment ($RD^{3)}$ projects as well as incentives remains critical given the magnitude of additional funding identified in the 2022 AQMP to achieve NAAQS.

Emission Reductions Resulting from Clean Fuels Program

The Clean Fuels Program has encouraged projects that increase the utilization of clean-burning fuels over the 34-year lifetime of the program. Many of the technologies that were supported during the early years of the program, are now seeing commercial deployments, e.g. fuel cell buses, while others saw great success only to be eventually phased out, e.g., methanol buses and vehicles. Of all the technologies that the Clean Fuels Program have supported, there are two recent technologies that have been commercialized and are providing emissions benefits through incentives programs, ultra-low NOx (near-zero emission or NZE) NG engines and zero emission trucks (ZETs).

The Clean Fuels Program has been supporting the development of low and near-zero emission HD NG engines since the early 2000's. In 2003, South Coast AQMD conducted a joint project with California Energy Commission (CEC), U.S. DOE and National Renewable Energy Laboratory (NREL) to advance development of HD NG engines to meet the upcoming 2010, 0.2 g/bhp-hr NOx standard. The result was the Cummins-Westport, Inc (CWI) 8.9-liter engine that certified to 0.2 g NOx/bhp-hr, three years before the mandated 2010 national standard. In 2013, recognizing the need for accelerated NOx reductions in the HD sector, South Coast AQMD, CEC, and SoCalGas issued a joint solicitation to develop and demonstrate an NZE engine for commercial use. CWI developed and commercialized the first 0.02 g/bhp-hr NOx 8.9-liter NG engine (L9N). Additional projects with CEC, SoCalGas and Clean Energy produced the CWI 11.9-liter NZE engine (ISX12N) certified in 2018 for port fleet operations, also first of its kind, including a 20-truck demonstration project at the San Pedro Bay Ports. These engines are now commercially available and offered by all major truck OEMs.

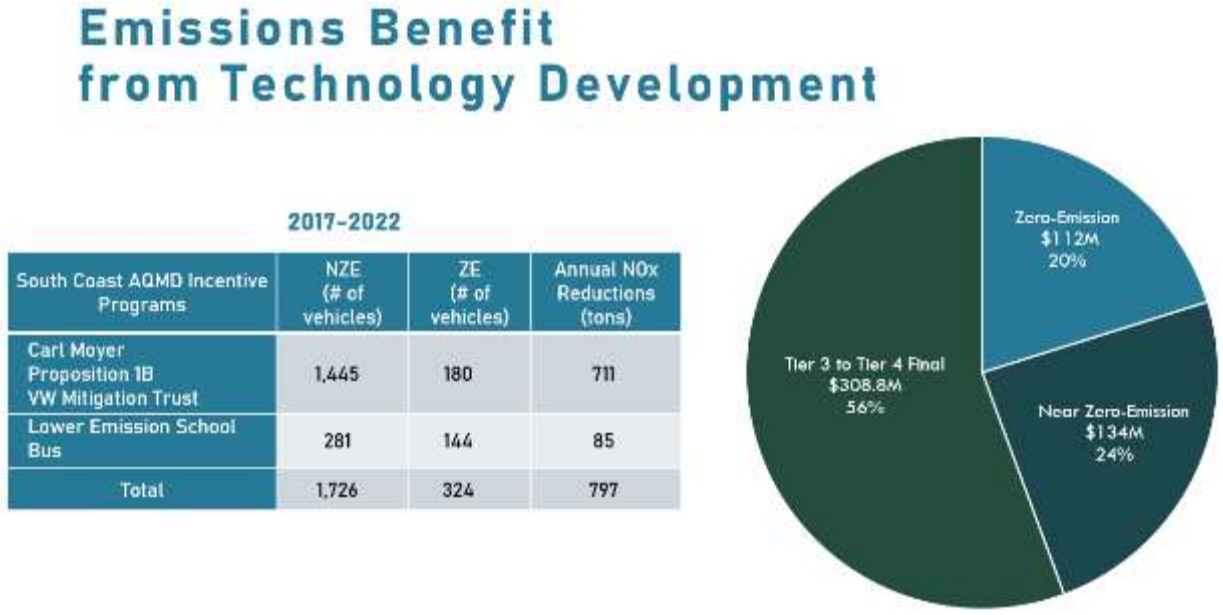
The Clean Fuels Program has also supported the development of ZETs including battery electric trucks (BETs) and fuel cell electric trucks (FCETs). U.S. DOE funded the Zero Emission Cargo Transport 1 (ZECT 1) project developed and demonstrated Class 8 battery electric trucks. The ZECT 1 project gave birth to many other BET and hybrid truck projects, including subsequent projects such as the CARB Greenhouse Gas Reduction Fund (GGRF) Zero Emission Drayage Truck (ZEDT) project, which demonstrated 44 battery electric and CNG and diesel hybrid electric drayage trucks at multiple California Ports. The ZEDT project included 25 BYD 8TT BETs, 12 Peterbilt/Meritor/ TransPower 579 BETs, two Kenworth CNG hybrid electric trucks based on their T680 daycab, three Volvo diesel plug-in hybrid electric trucks, and two Volvo VNR Electric BETs. More recently, the Clean Fuels Program co-funded large Daimler and Volvo BET projects. For the Daimler Innovation Fleet project, Daimler deployed 14 Class 8 eCascadia and six Class 6 eM2 trucks and installed seven DC fast charging stations at fleet locations in 2019. Volvo deployed 30 Class 8 BETs and installed Level 2, AC, 50 and 150 kW DC fast chargers, and solar/storage as part of their CARB GGRF Low Impact Green Heavy Transport Solutions (LIGHTS) in 2022. Daimler deployed two Class 6 and six Class 8 BETs for its Customer Experience project which will be completed in 2023. Daimler will be deploying 15 Class 6 and 20 Class 8 BETs and chargers for commercial fleet distribution/delivery operations for its Zero Emission Electric Delivery Trucks project which will be completed in 2024. In 2021, South Coast AQMD was awarded CARB and CEC funding for the Joint Electric Truck Scaling Initiative (JETSI) Pilot project to deploy 100 BETs and 350 kW DC fast chargers for two fleets, NFI Interactive Logistics, LLC (NFI) and Schneider National Inc (Schneider). The Volvo VNR Electric truck and DTNA eCascadia will be deployed in 2023 and are commercially available. Examples of BETs that South Coast AQMD has developed and demonstrated with co-funding from various

partners are shown in Figure 6.

Figure 6: Clean Fuel Technology Trucks South Coast AQMD and Partners Developed and Demonstrated

To quantify some of the emissions benefit from NZE and ZE truck deployments, Table 1 summarizes the potential emissions reductions as result of the technologies directly supported by the Clean Fuels Program. South Coast AQMD staff compiled incentive program data between 2017 and 2022 from our Technology Incentives Group to calculate the NOx emissions reductions associated with deployment projects of NZE and ZE heavy-duty vehicles (HDVs) in the Basin. Note the programs below required scrappage, that meant each vehicle deployed eliminated an older diesel truck, and the emission reductions are based on the program guidelines established by CARB.

Table 1: Potential Emissions Benefit from NZE and ZE Truck Deployment Projects (2017-2022)



Although the emission reductions may seem modest, these technologies represent almost 4% of the total emission reductions for on-road heavy-duty diesel trucks in 2023[3], and the numbers will only continue to grow, thanks in part to the support by the Clean Fuels Program.

Program Funding

The Clean Fuels Program is established under H&SC Sections 40448.5 and 40512 and Vehicle Code Section 9250.11. This legislation establishes mechanisms to collect revenues from mobile and stationary sources to support the program objectives and identifies the constraints on the use of funds. In 2008, these funding mechanisms were reauthorized under SB 1646 (Padilla), which removed the funding sunset of January 1, 2010, and established the five percent administrative cap instead of the previous cap of two-and-half percent.

Specifically, the Clean Fuels Program is funded through a $1 fee on motor vehicles registered in the South Coast AQMD. Revenues collected from these motor vehicles must be used to support mobile source projects. Stationary source projects are funded by an emission fee surcharge on stationary sources emitting more than 250 tons of pollutants per year within South Coast AQMD. This revenue is typically about $13.5 million and $350,000, respectively, every year. For CY 2022, the funds available through each of these mechanisms were as follows:

- Mobile sources (DMV revenues) $13,762,116
- Stationary sources (emission fee surcharge) $292,311

The Clean Fuels Program also receives grants and cost-sharing revenue contracts from various agencies, on a project-specific basis, that supplement the South Coast AQMD program. Historically, such cooperative project funding revenues have been received from CARB, CEC, U.S. EPA (including but not limited to their Diesel Emissions Reduction Act or DERA, Clean Air Technology Initiative or CATI, and Airshed

[3] 1.69 tpd reductions vs. 44.5 tpd in on-road heavy-duty diesel inventory in 2023.

programs), U.S. Department of Energy (DOE) and U.S. Department of Transportation (DOT). These supplemental revenues depend in large part on the originating agency, its budgetary and planning cycle and the specific project or intended use of the revenues. Table 6 on page 27 lists the supplemental grants and revenues totaling $304,000 for contracts executed in CY 2022.

Table 7 on page 28 lists the federal, state and other revenue totaling almost $3.3 million awarded to South Coast AQMD in 2022 for projects that are part of the overall Clean Fuels Program's RD^3 efforts, even if for financial tracking purposes revenue is recognized into another special revenue fund other than the Clean Fuels Fund (Fund 31).

The final and perhaps most significant funding source can best be described as an indirect source, i.e., funding not directly received by South Coast AQMD. This indirect source is the cost-sharing provided by private industry and other public and private organizations. The public-private partnerships with private industry, technology developers, academic institutions, research institutions and government agencies are a key strategy of the Clean Fuels Program. Historically, the TAO has been successful in leveraging its available public funds with $4 of outside funding for each $1 of South Coast AQMD funding. Since 1988, the Clean Fuels Program has leveraged nearly $250 million into over $1.6 billion in projects. For 2022, the Clean Fuels Program leveraged $1 of Clean Fuels Funds to almost $10 of outside funding. This leverage was the result of two key significant project awards for the JETSI pilot project in 2022. Specifically, two contracts with DTNA and NFI to deploy Class 8 BETs, charging infrastructure and distributed energy resource technologies with substantial co-funding of $26.6 and $30.5 million, respectively. Through these public-private partnerships, South Coast AQMD shared the investment risk of developing new technologies along with the benefits of expedited development and commercial availability, increased end-user acceptance, reduced emissions from demonstration projects and ultimately increased use of clean technologies in the Basin. While South Coast AQMD aggressively seeks to leverage funds, it continues to act in a leadership role in technology development and commercialization efforts, along with its partners, to accelerate the reduction of criteria pollutants. Leveraging dollars and aggressively applying for additional funds whenever funding opportunities arise is more important than ever given, as previously noted, the magnitude of additional funding identified in the 2022 AQMP to achieve NAAQS. The Clean Fuels Program has also avoided duplicative efforts by coordinating and jointly funding projects with major funding agencies and organizations. The major funding partners for 2022 are listed in Table 2 on page 19.

2022 Overview

This report summarizes the progress of the Clean Fuels Program for CY 2022. The Clean Fuels Program cost-shares projects to develop and demonstrate zero, near-zero and low emissions clean fuels and advanced technologies to advance technology and promote commercialization and deployment of promising or proven technologies not only for the Basin but Southern California and the nation as well. These projects are conducted through public-private partnerships with industry, technology developers, academic and research institutes and local, state and federal agencies.

This report also highlights achievements and summarizes project costs of the Clean Fuels Program in CY 2022. During the period between January 1 and December 31, 2022, South Coast AQMD executed 21 new contracts/agreements, projects or studies and modified 5 continuing projects adding dollars during CY 2022 that support clean fuels and advanced zero, near-zero and low emission technologies (see Table 5). The Clean Fuels Program contribution for these projects was over $7.4 million, inclusive of $304,000 received into the Clean Fuels Fund as cost-share for contracts executed in this reporting period. Total project costs are over $74.1 million.

The projects executed in 2022 address a wide range of issues with a diverse technology mix including near-term emissions reductions and long-term planning efforts. The report not only provides information on outside funding received into the Clean Fuels Fund as cost-share for contracts executed in this period (summarized in Table 6), but also funds awarded to South Coast AQMD for projects that fall within the

scope of the Clean Fuels Program's RD^3 efforts but may have been recognized (received) into another special revenue fund for financial tracking purposes (nearly $3.3 million in 2022, see Table 7). In 2022, the South Coast AQMD was awarded nearly $2.6 million from US EPA for electrification of cargo handling equipment, $220,000 from CARB for the JETSI Pilot Project, and $500,000 from U.S. EPA for deployment of zero emission mobile clinics. These projects will advance the commercialization of BETs and FCETs, and cargo handling equipment technologies. More details on this financial summary are in this report. South Coast AQMD will continue to pursue federal, state and private funding opportunities in 2023 to amplify leverage, while acknowledging that support of a promising technology is not contingent on outside cost-sharing and affirming that South Coast AQMD will remain committed to playing a leadership role in developing advanced technologies that lower criteria pollutants.

Core Technologies

Given the diversity of sources that contribute to the air quality problems in the Basin, there is no single technology or "Silver Bullet" that can solve all the problems. A number of technologies are required, and these technologies represent a wide range of applications, with full emissions benefit "payoffs," i.e., full commercialization and mass deployment occurring at different times. The broad technology areas of focus – the "Core Technologies" – for the Clean Fuels Program are as follows:

- Hydrogen / Mobile Fuel Cell Technologies and Infrastructure;
- Engine Systems / Technologies (including alternative and renewable fuels for truck and rail applications);
- Electric / Hybrid Vehicle Technologies and Related Infrastructure (including battery electric and hybrid electric trucks and container transport technologies with zero emission operations);
- Fueling Infrastructure and Deployment (NG and renewable fuels);
- Stationary Clean Fuels Technologies (including microgrids and renewables);
- Fuel and Emissions Studies;
- Emissions Control Technologies;
- Health Impacts Studies; and
- Technology Assessment and Transfer / Outreach.

At its January 2022 retreat, the Technology Advancement and SB-98 Clean Fuels Advisory Groups asked staff to take another look at these core technologies to determine if they still fit within the strategy of the Clean Fuels Program. That effort will be undertaken in 2023.

South Coast AQMD continually seeks to support the deployment of lower-emitting technologies. The Clean Fuels Program is shaped by two basic factors:

1. Zero, near-zero and low emission technologies needed to achieve clean air standards in the Basin; and
2. Available funding to support technology development within the constraints imposed by that funding.

South Coast AQMD strives to maintain a flexible program to address dynamically evolving technologies and the latest progress in the state of the technology while balancing the needs in the various technology sectors with technology readiness, emissions reduction potential and co-funding opportunities. Although the Clean Fuels Program is significant, national and international activities affect the direction of technology trends. As a result, the Clean Fuels Program must be flexible to leverage and accommodate these changes in state, national and international priorities. Nonetheless, while state and federal governments have continued to turn a great deal of their attention to climate change, South Coast AQMD has remained committed to developing, demonstrating and commercializing zero and near-zero emission technologies. Fortunately, many, if not the majority, of technology sectors that address our need for NOx reductions also garner GHG reductions. Due to these "co-benefits," South Coast AQMD has been

successful in partnering with state and federal government. Even with leveraged funds, the challenge for South Coast AQMD remains the need to identify project or technology opportunities in which its available funding can make a difference in achieving progressively cleaner air in the Basin.

To achieve this, South Coast AQMD employs various outreach and networking activities as well as evaluates new ways to expand these activities. These activities range from close involvement with state and federal collaboratives, partnerships and industrial coalitions, to the issuance of PONs to solicit project ideas and concepts as well as the issuance of RFIs to determine the state of various technologies and the development and commercialization challenges faced by those technologies. Additionally, in the absence of PONs, unsolicited proposals from OEMs and other clean fuel technology developers are accepted and reviewed.

Historically, mobile source projects have targeted low-emission developments in automobiles, transit buses, MD and HD trucks and non-road applications. These vehicle-related efforts have focused on advancements in engine design, electric powertrains and energy storage/conversion devices (e.g., fuel cells and batteries); and implementation of clean fuels (e.g., NG, propane and hydrogen) including infrastructure development. Stationary source projects have included a wide array of advanced low NOx technologies and clean energy alternatives such as fuel cells, solar power and other renewable and waste energy systems. The focus in recent years has been on zero and near-zero emission technologies with increased attention to HD and MD trucks to reduce emissions from mobile sources, which contribute to more than 80 percent of the current NOx emissions in this region. However, while mobile sources include both on- and off-road vehicles as well as aircraft and ships, only the federal government has the authority to regulate emissions from aircraft and ships. South Coast AQMD is exploring opportunities to expand its authority in ways that would allow the agency to do more to foster technology development for ship and train activities as well as locomotives related to goods movement. In the absence of regulatory authority, South Coast AQMD is expanding its portfolio of RD^3 projects to include marine and ocean-going vessels. Utilizing mitigation funds, funding from San Pedro Bay Ports and industry partners, RD^3 projects to demonstrate emissions reduction technology in the marine sector where NOx emissions are increasing are being pursued.

The 2022 AQMP included five facility-based mobile source measures, also known as indirect source measures. Staff has been developing both voluntary and regulatory measures in a process that has included extensive public input. Indirect source measures are distinct from traditional air pollution control regulations in that they focus on reducing emissions from the vehicles associated with a facility rather than emissions from a facility itself.

For example, newly established indirect source measures for warehouses focuses on reducing emissions from trucks servicing the warehouse. Measures for Ports will concentrate on emissions from ships, trucks, locomotives and cargo handling equipment at the Ports. Measures covering new development and redevelopment projects could aim to reduce emissions from construction equipment, particularly HD diesel earth-moving vehicles.

Specific projects are selected for co-funding from competitive solicitations, cooperative agency agreements and unsolicited proposals. Criteria considered in project selection include emissions reduction potential, technological innovation, potential to reduce costs and improve cost effectiveness, contractor experience and capabilities, overall environmental impacts or benefits, commercialization and business development potential, cost-sharing and cost-sharing partners, and consistency with program goals and funding constraints. The core technologies for South Coast AQMD programs that meet both the funding constraints and 2022 AQMP needs for achieving clean air are briefly described below.

Hydrogen / Mobile Fuel Cell Technologies and Infrastructure

Toyota and Hyundai commercialized HD fuel cell vehicles in passenger sector in 2015 and Honda started delivering their Fuel Cell Clarity in 2016. Automakers continue development efforts and collaborate to

broaden application of fuel cells to increase manufacturing scale and reduce cost to commercialize fuel cell vehicles. However, although progress is being made, the greatest challenge for the viability of fuel cell vehicles remains the installation and operations of hydrogen fueling stations. AB 8 requires CEC to allocate $20 million annually from the Alternative and Renewable Fuel and Vehicle Technology Program until there are at least 100 publicly accessible hydrogen stations in operation in California. Of the 107 stations funded by CEC and CARB by the end of 2022, partially funded by South Coast AQMD for those in our region, there is one legacy and 54 retail operational in California. CEC and CARB staffs expect that California will exceed the 100-station goal in AB 8 in 2023, with more than 179 stations by 2027. AB 8 also requires CARB to annually assess current and future fuel cell vehicles (FCVs) and hydrogen stations in the marketplace. *The Joint Agency Staff Report on Assembly Bill 8: 2021 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California*[4] released in December 2021 covering 2021 findings states that there were 9,647 fuel cell vehicles registered in California by October 2021. CARB's 2022 Annual Evaluation projects 37,500 fuel cell electric vehicles (FCEVs) in California by 2025 and 65,600 by the end of 2028, after accounting for estimated vehicle retirements. Additionally, the California Fuel Cell Partnership's (CaFCP) *The California Fuel Cell Revolution, A Vision For Advancing Economic, Social, and Environmental Priorities* (Vision 2030) includes the need for up to 1,000 refueling stations statewide as well as the need for 200 heavy-duty stations to support 70,000 fuel cell trucks by 2035.

Clearly, South Coast AQMD must continue to support infrastructure required to refuel retail fuel cell vehicles and the nexus to MD and HD trucks including reducing the cost to deploy HD hydrogen infrastructure. To that end, South Coast AQMD co-funded a liquid hydrogen station capable of fueling up to 50 fuel cell transit buses and 10 fuel cell transit buses at OCTA. South Coast AQMD Clean Fuels funding of $1,000,000 is committed towards the CARB Zero and Near Zero-Emission Freight Facilities (ZANZEFF) Ship to Store project to deploy 10 HD FCETs and install three HD hydrogen stations in Wilmington and Ontario; this contract is also supported by the $1,200,000 Clean Fuels funding committed to the CEC co-funded HD Shell station on Port of Long Beach (POLB) property leased to Toyota. South Coast AQMD is also actively engaged in finding alternatives to reduce the cost of hydrogen (e.g., large-scale hydrogen refueling stations or production facilities) and potential longer-term fuel cell power plant technology. South Coast AQMD is also administering the DOE-funded ZECT project (ZECT 2), to develop and deploy six HD drayage FCETs. Two FCETs are manufactured by Transportation Power Inc. (TransPower), two FCET by US Hybrid, one FCET by Kenworth, and one FCET by Hydrogenics (a Cummins Inc. company). Six of the seven vehicle designs, and integration, are completed, and four of the FCETs are in demonstration. The battery and fuel cell dominant FCETs have a range of 150-200 miles.

South Coast AQMD also cofounded research studies on hydrogen systems and heavy-duty hydrogen fueling infrastructure, and high-flow bus fueling protocols that are led by UC Davis, DOE, and NREL.

Engine Systems / Technologies

MD and HD on-road vehicles contributed approximately 23 percent of the Basin's 2018 NOx emissions inventory based on 2022 AQMP data. More importantly, on-road HD diesel trucks account for 33 percent of the on-road mobile source PM2.5, a known TAC. Furthermore, according to CARB, trucks and buses are responsible for 37 percent of California's GHGs and criteria emissions. While MATES IV found a dramatic decrease in ambient levels of diesel PM and other air toxics, diesel PM is still the major driver of air toxics health risks. Clearly, significant emission reductions will be required from mobile sources, especially from the HD sector, to attain the NAAQS. Even with the announced rollout of ZETs in 2021 by Volvo and Daimler, it is anticipated that it would take ten years for a large enough deployment of those trucks to have an impact on air quality.

The use of alternative fuels in HD vehicles can provide significant reductions in NOx and particulate

[4] https://www.energy.ca.gov/publications/2021/joint-agency-staff-report-assembly-bill-8-2021-annual-assessment-time-and-cost

emissions. The current NOx emissions standard for HD engines is 0.2 g/bhp- hr. South Coast AQMD, along with various local, state and federal agencies, continues to support the development and demonstration of alternative-fueled low emission HD engine technologies, using NG, renewable natural gas or hydrogen, renewable diesel and potentially other renewable or waste stream fuels, for applications in HD trucks, transit and school buses, rail operations, and refuse collection and delivery vehicles to meet future federal emission standards. South Coast AQMD is supporting three contracts to convert the model year 2021 new Ford MD gasoline engine to near-zero NOx level by using NG and propane.

In 2021, CARB adopted Heavy-Duty Engine and Vehicle Regulation (Omnibus Regulation), which is to drastically cut NOx from conventional HD engines. The new regulation reduces the current heavy-truck NOx standard from 0.20 grams per brake horsepower hour to 0.050 g/bhp-hr from 2024 to 2026, and to 0.020 g/bhp-hr in 2027. In late 2022, EPA adopted HD truck standards for tighter emission limits in two stages, starting in model year 2027. However, the U.S. EPA standard doesn't provide the same level of emission reductions as California's Omnibus rule. It is anticipated that additional action will be necessary to reduce emissions from HD trucks.

Electric / Hybrid Vehicle Technologies and Infrastructure

There has been more developments and attention on electric and hybrid vehicles due to a confluence of factors, including the highly successful commercial introductions of hybrid LD passenger vehicles, plug-in electric vehicles (PEVs), and battery electric vehicles (BEVs) by the major OEMs and increased public attention on global warming, approval of the CARB Advanced Clean Cars II regulation establishing an annual roadmap for 100% ZEV for new LD and light trucks by 2035. This regulation codifies the LD vehicle goals in California Governor Newsom's Executive Order N-79-20.

According to the CEC[5], new LD ZEV sales in California are 345,818 in 2022 with cumulative sales of 1,399,913 vehicles. This includes annual LD ZEV sales of 292,496 BEVs, 50,748 PHEVs, and 2,574 FCEVs. In the four counties comprising the South Coast Air Basin, 167,375 LD ZEVs were sold, including 141,436 BEVs, 24,342 PHEVs, and 1,595 FCEVs. Larger batteries and longer range continue to be the trend for LD BEVs with the Lucid Air Dream Performance with a 118 kWh battery and 520 mile U.S. EPA estimated range and the Tesla Model S with a 100 kWh battery and 405 mile U.S. EPA estimated range as two examples of these longer range LD BEVs.

Technology transfer to MD and HD applications has made significant progress, especially with commercialization of Class 6 - 8 BETs by the major OEMs as well as MD shuttle bus, delivery van, transit bus, and cargo handling equipment through freight handling and goods movement demonstration and deployment projects in the South Coast Air Basin. As with hydrogen and fuel cell technologies, South Coast AQMD is actively pursuing research, development and demonstration projects for MD and HD BETs and their commercialization. The Clean Fuels Program has also supported the development of ETs including BETs and FCETs. U.S. DOE funded the ZECT 1 project to develop and demonstrate BETs and plug-in hybrid electric trucks (PHETs): four BETs from TransPower, two BETs from US Hybrid, two series PHETs from TransPower, and three parallel PHETs from US Hybrid. As the models developed in ZECT I project have been improved, BETs have an all-electric range of up to 220-275 miles for the latest 2023 models and PHETs have a range of up to 250 miles. The ZECT 1 project gave birth to many other BET and hybrid truck projects including subsequent projects such as the GGRF ZEDT project, which demonstrated 44 battery electric and CNG and diesel hybrid electric drayage trucks at multiple California Ports. The ZEDT project included 25 BYD 866 BETs, 12 Peterbilt/Meritor/TransPower 579 BETs, two Kenworth CNG hybrid electric trucks based on their T680 daycab, three Volvo diesel plug-in hybrid electric trucks, and two Volvo VNR Electric BETs. More recently, the Clean Fuels Program co-funded large Daimler and

[5] https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics/new-zev-sales. Accessed January 22, 2023.

Volvo BET projects. For the Daimler Innovation Fleet project, Daimler deployed 14 Class 8 eCascadia and six Class 6 eM2 trucks and installed seven DC fast charging stations at fleet locations in 2019. Volvo deployed 30 Class 8 BETs and installed Level 2, AC, 50 kW and 150 kw DC fast chargers, and solar/storage as part of their CARB GGRF Low Impact Green Heavy Transport Solutions (LIGHTS) in 2022. Daimler deployed two Class 6 and six Class 8 BETs for its Customer Experience project which will be completed in 2023. Daimler will be deploying 15 Class 6 and 20 Class 8 BETs and chargers for commercial fleet distribution/delivery operations for its Zero Emission Electric Delivery Truck project which will be completed in 2024. In 2021, South Coast AQMD was awarded CARB and CEC funding for the Joint Electric Truck Scaling Initiative (JETSI) Pilot Project to deploy 100 BETs and 350 kW DC fast chargers for two fleets, NFI and Schneider.

Battery and hybrid electric off-road and marine applications including battery electric yard tractors, forklifts, top handlers, RTG cranes, locomotives, ocean going vessels, and construction equipment are included in multiple demonstration projects to accelerate commercialization and deployment of these technologies. South Coast AQMD has demonstrated a battery electric excavator and wheel loader with Volvo Construction Equipment as part of a FY 18 U.S. EPA Targeted Airshed Grant award and is proposing to demonstrate 1.5 ton and 2.5 ton asphalt compactors. South Coast AQMD is also demonstrating in 2023 the first battery electric line haul locomotive deployed in California in partnership with U.S. EPA, BNSF, and Progress Rail. An electric drive diesel hybrid tugboat will be demonstrated by fleet operator Centerline Logistics Corporation with co-funding from POLB and CARB. These pilot demonstration and deployment projects are key to additional emission reductions from the off-road construction, locomotive, and marine sectors.

Fueling Infrastructure and Deployment (Natural Gas/Renewable Fuels)

A key element for increased use of alternative fueled vehicles and resulting widespread acceptance is the availability of the supporting refueling infrastructure. The refueling infrastructure for gasoline and diesel fuel is well established and accepted by the driving public. Alternative, clean fuels, such as alcohol-based fuels, propane, hydrogen, and even electricity, are much less available or accessible, whereas NG and renewable fuels have recently become more readily available and cost-effective. Nonetheless, to realize emissions reduction benefits, alternative fuel infrastructure, especially fuels from renewable feedstocks, must be developed in tandem with the growth in alternative fueled vehicles. While California appears to be on track to meet its Renewable Portfolio Standard targets of 33 percent by 2020 and 50 percent by 2030 as required by SB 350 (chaptered October 2015), the objectives of the South Coast AQMD are to expand the infrastructure to support zero and near-zero emission vehicles through the development, demonstration and installation of alternative fuel vehicle refueling technologies. However, this category is predominantly targeted at NG and renewable natural gas (RNG) infrastructure and deployment (electric and hydrogen fueling are included in their respective technology categories). The Clean Fuels Program will continue to examine opportunities where current incentive funding is either absent or insufficient.

Stationary Clean Fuel Technologies

Given the limited funding available to support low emission stationary source technology development, this area has historically been limited in scope. To gain the maximum air quality benefits in this category, higher polluting fossil fuel-fired electric power generation needs to be replaced with clean, renewable energy resources or other advanced zero and near zero-emission technologies, such as solar, energy storage, wind, geo-thermal energy, bio-mass conversion and stationary fuel cells. Although combustion sources are lumped together as stationary, the design and operating principles vary significantly and thus also the methods and technologies for control of their emissions. Included in the stationary category are boilers, heaters, gas turbines and reciprocating engines as well as microgrids and some renewables. The key technologies for this category focus on using advanced combustion processes, development of catalytic add-on controls, alternative fuels and technologies and stationary fuel cells in novel applications.

Although stationary source NOx emissions are small compared to mobile sources in the Basin, there are applications where cleaner fuel technologies or processes can be applied to reduce NOx, VOC and PM emissions. Recent demonstration projects funded in part by the South Coast AQMD include a local sanitation district retrofitting an existing biogas engine with a digester gas cleanup system and catalytic exhaust emission control. The retrofit system resulted in significant reductions in NOx, VOC and carbon monoxide (CO) emissions. This project demonstrated that cleaner, more robust renewable distributed generation technologies exist that not only improve air quality but enhance power quality and reduce electricity distribution congestion. Another ongoing demonstration project consists of retrofitting a low NOx ceramic burner on an oil heater without the use of reagents, such as ammonia nor urea, which is anticipated to achieve selective catalytic reduction (SCR) NOx emissions or lower. SCR requires the injection of ammonia or urea that is reacted over a catalyst bed to reduce the NOx formed during the combustion process. Challenges arise if ammonia distribution within the flue gas or operating temperature is not optimal resulting in ammonia emissions leaving the SCR in a process referred to as "ammonia slip". The ammonia slip may also lead to the formation of particulate matter in the form of ammonium sulfates. Based on the successful deployment of this project, further emission reductions may be achieved by other combustion sources (such as boilers) by the continued development of specialized low NOx burners without the use of reagents.

Health Impacts, Fuel and Emissions Studies

The monitoring of pollutants in the Basin is extremely important, especially when focused on (1) a sector of the emissions inventory (to identify the responsible technology) or (2) exposure to pollution (to assess potential health risks). Several studies indicate that areas with high levels of air pollution can produce irreversible damage to children's lungs. This information highlights the need for further emissions and health studies to identify the emissions from high polluting sectors as well as the health effects resulting from these technologies. As we transition to new fuels and forms of transportation, it is important to understand the impacts that changing fuel composition will have on exhaust emissions and in turn on ambient air quality. This area focuses on exhaust emissions studies, with a focus on NOx and PM2.5 emissions and a detailed review of other potential toxic tailpipe emissions, for alternative fuel and diesel engines. These types of in-use emissions studies have found significantly higher emissions than certification values for heavy-duty diesel engines, depending on the duty-cycle. South Coast AQMD has recently completed a three-year in-use emissions study of 200 next-generation technology HD vehicles in the Basin. Multiple Air Toxics Exposure Study V (MATES V) was completed in 2021 and is aimed at understanding the activity pattern of different vocations and real-world emissions emitted from different technologies. Key findings of the MATES V study showed a 54% decline in overall multi-pathway cancer risk from MATES IV and diesel PM remains the main risk driver contributing to 67% of the overall multi-pathway cancer risk based on population-weighted estimates. Cancer risk decreased at every monitoring station in the South Coast Air Basin with the highest risk at the Inland Valley San Bernardino monitoring station. Communities adjacent to the Ports are in the top 96th percentage of air toxics cancer risk. Other studies launched in 2020 will evaluate emissions produced using alternative diesel blends in off-road HD engines, assess emissions impact of hydrogen-natural gas blends on near-zero emission HD NG engines as well as evaluating emissions produced using higher blend ethanol in LD gasoline vehicles.

Emissions Control Technologies

This broad category refers to technologies that could be deployed on existing mobile sources, aircraft, locomotives, marine vessels, farm and construction equipment, cargo handling equipment, industrial equipment, and utility and lawn-and-garden equipment. The in-use fleet comprises most emissions, especially older vehicles and non-road sources, which are typically uncontrolled and unregulated, or controlled to a much lesser extent than on-road vehicles. The authority to develop and implement regulations for retrofit on-road and off-road mobile sources lies primarily with U.S. EPA and CARB. Both agencies are currently planning research efforts for off-road mobile sources.

Low emission and clean fuel technologies that appear promising for on-road mobile sources should be effective at reducing emissions for off-road applications. For example, immediate benefits are possible from particulate traps and SCR technologies that have been developed for on-road diesel applications although retrofits are often hampered by physical size and visibility constraints. Clean fuels such as NG, propane, hydrogen and hydrogen-natural gas mixtures may also provide an effective option to reduce emissions from some off-road applications, even though alternative fuel engine offerings are limited in this space, but retrofits such as dual-fuel conversions are possible and need to be demonstrated. Reformulated gasoline, ethanol and alternative diesel fuels, such as biodiesel and gas-to-liquid (GTL), also show promise when used in conjunction with advanced emissions controls and new engine technologies. Emissions assessments are important in such projects as one technology to reduce one contaminant can increase another.

Technology Assessment and Transfer / Outreach

Since the value of the Clean Fuels Program depends on the deployment and adoption of the demonstrated technologies, technology assessment and transfer efforts are an essential part of the Clean Fuels Program. This core area encompasses assessment of advanced technologies, including retaining outside technical assistance as needed, efforts to expedite implementation of low emission and clean fuels technologies, and coordination of these activities with other organizations, including networking opportunities seeking outside funding. Assembly Bill (AB) 617[6], which requires reduced exposure to communities most impacted by air pollution, required TAO to carry out additional outreach in CY 2022 to AB 617 communities regarding available zero and near-zero emission technologies as well as the incentives to accelerate those cleaner technologies into their communities. TAO staff also provide input as part of working groups, such as the San Pedro Bay Ports Technology Advancement Program, Metro I-710 South Corridor Task Force, Electric Power Research Institute (EPRI) eTRUC technical advisory committee, CALSTART EnergIIZE Funding Advisory Committee, 21st Century Truck Partnership Charging and Infrastructure Work Group, LA 28 Olympic and Paralympic Games Sustainability Working Group, and Los Angeles Cleantech Incubator projects. Technology transfer efforts also include support for various clean fuel technology incentive programs (i.e., AB 617 CAPP, Carl Moyer Program, Proposition 1B-Goods Movement, etc.). Furthermore, general and, when appropriate, targeted outreach is an effective part of any program. Thus, the other spectrum of this core technology is information dissemination to educate and promote awareness of the public and end users. TAO staffed information booths to answer questions from the general public and provided speakers to participate on panels on zero and near-zero emission technologies at events, such as the 2022 ACT Conference and Expo, UCR 2022 Portable Emission Measurement Systems Conference, 31st Coordinating Research Council, Inc. Real World Emissions Workshop, California Hydrogen Leadership Summit, 15th Annual VerdeXchange Conference, Driving Mobility 9, AltCar Expo and Conference and International Colloquium on Environmentally Preferred Advanced Generation (ICEPAG) 2022. While South Coast AQMD's Legislative, Public Affairs & Media Office oversees and carries out such education and awareness efforts on behalf of the entire agency, TAO cosponsors and occasionally hosts various technology-related events to complement their efforts (see page 38 for a description of the technology assessment and transfer contracts executed in CY 2022 as well as a listing of the 10 conferences, workshops and events funded in CY 2022. Throughout the year, staff also participates in various programmatic outreach for the various incentive programs implemented by TAO, including the AB 617 CAPP, Carl Moyer, Proposition 1B-Goods Movement, Volkswagen Mitigation, Replace Your Ride, U.S. EPA funded Commercial Electric Lawn and Garden Incentive and Exchange, residential lawn mower and residential EV charger rebate programs.

[6] https://ww2.arb.ca.gov/our-work/programs/community-air-protection-program/about

[This Page Intentionally Left Blank]

CLEAN FUELS PROGRAM

Barriers, Scope and Impact

Overcoming Barriers

Commercialization and implementation of advanced technologies come with a variety of challenges and barriers. A combination of real-world demonstrations, education, outreach and regulatory impetus and incentives is necessary to bring new, clean technologies to market. To reap the maximum emissions benefits from any technology, widespread deployment and user acceptance must occur. The product manufacturers must overcome technical and market barriers to ensure a competitive and sustainable business. Barriers include project-specific issues as well as general technology concerns.

Technology Implementation Barriers	Project-Specific Issues
• Viable commercialization path	• Identifying committed demonstration sites
• Technology price/performance parity with convention technology	• Overall project cost and cost-share using public monies
• Consumer acceptance	• Securing charging or fuel infrastructure
• Fuel availability/convenience issues	• Identifying and resolving real and perceived safety issues
• Certification, safety and regulatory barriers	• Quantifying actual emissions benefits
• Quantifying emissions benefits	• Viability of technology providers
• Sustainability of market and technology	

Other barriers include reduced or shrinking research budgets, infrastructure and energy uncertainties and risks, sensitivity to multi-media environmental impacts and the need to find balance between environmental needs and economic constraints. South Coast AQMD seeks to address these barriers by establishing relationships through unique public-private partnerships with key stakeholders; e.g., industry, end-users and other government agencies with a stake in developing clean technologies. Partnerships that involve all key stakeholders are essential to address these challenges in bringing advanced technologies from development to commercialization.

Each of these stakeholders and partners contributes more than just funding. Industry can contribute technology production expertise as well as the experience required for compatibility with process operations. Academic and research institutes bring current technology knowledge and testing proficiency. Governmental and regulatory agencies can provide guidance in identifying sources with the greatest potential for emissions reductions, assistance in permitting and compliance issues, coordinating of infrastructure needs, facilitation of standards and outreach. There is considerable synergy in developing technologies that address multiple goals of public and private agencies regarding environment, energy and transportation.

Scope and Benefits of the Clean Fuels Program

Since the time needed to overcome barriers can be long and the costs high, manufacturers and end-users find it challenging to undertake the risks in developing advanced technologies prior to commercialization.

The Clean Fuels Program accelerates commercialization of these technologies by co-funding research, development, demonstration and deployment projects to share the risk of emerging technologies with technology developers and eventual users.

Figure 7 below provides a conceptual design of the wide scope of the Clean Fuels Program. As mentioned in the Core Technologies section, various stages of technology projects are funded not only to provide a portfolio of emissions technologies but to achieve emission reductions in the near-term and long-term horizon. The Clean Fuels Program funds projects in the Technology Readiness Level ranging between 3-8.

Figure 7: Stages of Clean Fuels Program Projects

Due to the nature of these advanced technology R D[3] projects, benefits are difficult to quantify since their full emissions reduction potential may not be realized until sometime in the future, or not at all if displaced by superior technologies. Nevertheless, a good indication of the impacts and benefits of the Clean Fuels Program overall are provided by this selective list of sponsored projects that have resulted in commercialized products or helped to accelerate advanced technologies.

- Near-zero NOx Engine Development and Demonstrations for HD Vehicles
  - CWI: low-NOx natural gas ISN- G 8.9L and 12L engines (0.2 & 0.02 g/bhp-hr);
  - Southwest Research Institute (SwRI) project to develop a near-zero NOx HD diesel engine;
  - Kenworth CNG Hybrid Electric Drayage Truck project;
  - DOE ZECT II project – Kenworth developed one fuel cell truck & one CNG hybrid truck;
  - CARB GGRF project – Kenworth developed advanced CNG hybrid truck by improving ZECT II CNG hybrid; and
  - US Hybrid NZE Plug-In Hybrid demonstration with DOE/NREL/CEC.
- Hydrogen Fuel Cell Development and Demonstration Projects
  - Kenworth Fuel Cell Range Extended Electric Drayage Truck project;
  - SunLine Transit Agency Advanced Fuel Cell Bus projects;
  - UPS demonstration of fuel cell delivery trucks;
  - Kenworth, TransPower, US Hybrid, Cummins developed and demonstrated 6 fuel cell drayage trucks under ZECT II project; and
  - Hyundai's Class 8 fuel cell truck under development (Hyundai Exient)
- Electric and Hybrid Vehicle Development and Demonstration Projects
  - Innovation Fleet – Daimler Class 6 and 8 BETs with Penske and NFI;
  - Daimler Zero Emission BET Delivery Truck Project – Daimler Class 6 and 8 BETs;
  - Volvo LIGHTS – Volvo Class 8 BET deployment with TEC Fontana, Dependable Highway Express (DHE), NFI, and 11 additional fleets;
  - Volvo Switch-On – Volvo Class 8 BET deployment with eight fleets;

- JETSI: Daimler and Volvo Class 8 BET large scale deployment with NFI and Schneider;
- TransPower/US Hybrid HD BETs and yard hostlers; and
- CARB GGRF ZEDT: 44 Class 8 BET, CNG hybrid, and diesel hybrid electric truck demonstration including 25 BYD BETs, 12 Peterbilt/Meritor/TransPower BETs, 2 Kenworth CNG hybrid electric, 2 Volvo diesel hybrid electric and 2 Volvo BETs;

➢ Aftertreatment Technologies for HD Vehicles

- Johnson Matthey and Engelhard trap demonstrations on buses and construction equipment;
- Johnson Matthey SCRT and SCCRT NOx and PM reduction control devices on heavy-duty on-road trucks; and
- SwRI development of aftertreatment for HD diesel engines

South Coast AQMD played a leading or major role in the development of these technologies, but their benefits could not have been achieved without all stakeholders (i.e., manufacturer, end-users and government) working collectively to overcome the technology, market and project-specific barriers encountered at every stage of the RD^3 process.

Strategy and Impact

In addition to the feedback and input detailed in Program Review, South Coast AQMD actively seeks additional partners for its program through participation in various working groups, committees and task forces. This participation has resulted in coordination of the Clean Fuels Program with state and federal government organizations, including CARB, CEC, U.S. EPA and DOE/DOT and several national laboratories. Coordination also includes the AB 2766 Discretionary Fund Program administered by the Mobile Source Air Pollution Reduction Review Committee (MSRC), various local air districts including but not limited to Bay Area AQMD, Sacramento Metropolitan AQMD, San Diego Air Pollution Control District (APCD) and San Joaquin Valley Air Pollution Control District (SJVAPCD), as well as the National Association of Fleet Administrators (NAFA), major local transit districts, local gas and electric utilities, national laboratories, San Pedro Bay Ports and several universities with research facilities, including but not limited to Universities of California Berkeley, Davis, Irvine, Los Angeles and Riverside, and West Virginia University. The list of organizations with which South Coast AQMD coordinates research and development activities also includes organizations specified in H&SC Section 40448.5.1(a)(2).

In addition, South Coast AQMD holds periodic meetings with several organizations specifically to review and coordinate program and project plans. For example, South Coast AQMD staff meets with CARB staff to review research and development plans, discuss project areas of mutual interest, avoid duplicative efforts and identify potential opportunities for cost-sharing. Periodic meetings are also held with industry-oriented research and development organizations, including but not limited to Hydrogen Fuel Cell Partnership, California Stationary Fuel Cell Collaborative, EPRI, Veloz, Los Angeles Cleantech Incubator Regional Transportation Partnership, and West Coast Collaborative. The coordination efforts with these various stakeholders have resulted in several cosponsored projects.

Descriptions of key contracts executed in CY 2022 are provided in the next section of this report. It is noteworthy that most projects are cosponsored by various funding organizations and include active OEM involvement. Such partnerships are essential to address commercialization barriers and expedite implementation of advanced technologies. Table 2 below lists major funding agency partners and manufacturers actively involved in South Coast AQMD projects for this reporting period. It is important to note that, although not listed, there are many other technology developers, small manufacturers and project partners who make important contributions critical to the success of the Clean Fuels Program. These partners are identified in the more detailed 2022 Project Summaries by Core Technologies contained within this report, as well as Table 7 which lists federal, state and local funding awarded to South Coast AQMD in CY 2022 for RD^3 projects (which will likely result in executed project contracts in 2023).

Table 2: South Coast AQMD Major Funding Partners in CY 2022

Research Funding Organizations	Major Manufacturers/Technology Providers
California Air Resources Board	Daimler Trucks North America LLC
California Energy Commission	Volvo Technology of America LLC
Department of Energy	SunLine Transit Agency
National Renewable Energy Laboratory	**Local Entities & Utilities**
U.S. Environmental Protection Agency	Mobile Source Reduction Committee
Fleet Providers	Southern California Edison Company
NFI Interactive Logistics Inc	Southern California Gas Company
Schneider National Inc	Ports of Los Angeles & Long Beach

The following two subsections broadly address South Coast AQMD's impact and benefits by describing specific accomplishments including commercial or near-commercial products supported by the Clean Fuels Program in CY 2022. Such examples are provided in the following sections on TAO Research, Development and Demonstration projects and Technology Deployment and Commercialization efforts.

Research, Development and Demonstration

Important examples of the impact of South Coast AQMD research and development coordination efforts in 2022 include: (a) Joint Electric Truck Scaling Initiative: Deploy 100 Electric Trucks at Scale; and (b) Develop and Demonstrate Hydrogen Fuel Cell Medium-Duty Buses.

- **Joint Electric Truck Scaling Initiative: Deploy 100 Electric Trucks at Scale**

The JETSI Pilot Project received $27 million in CARB and CEC funding in April 2021 to deploy 50 Class 8 Daimler and Volvo BETs at two fleets, NFI and Schneider, located in disadvantaged communities in Ontario and South El Monte. South Coast AQMD led a regional collaborative with the MSRC, SCE, POLB, and Port of Los Angeles (POLA), which collectively are providing $21.4 million in funding. Fleets NFI and Schneider are providing $25.4 million in match share.

JETSI will significantly advance penetration of Class 8 BETs through at-scale manufacturing production by Daimler and Volvo. Both fleets will deploy HD charging infrastructure. NFI will also deploy distributed energy resource (DER) technologies including solar and battery energy storage, as well as build a BET maintenance shop at its site. The 100 BETs will operate almost solely through disadvantaged communities, including several designated under the AB 617 CAPP.

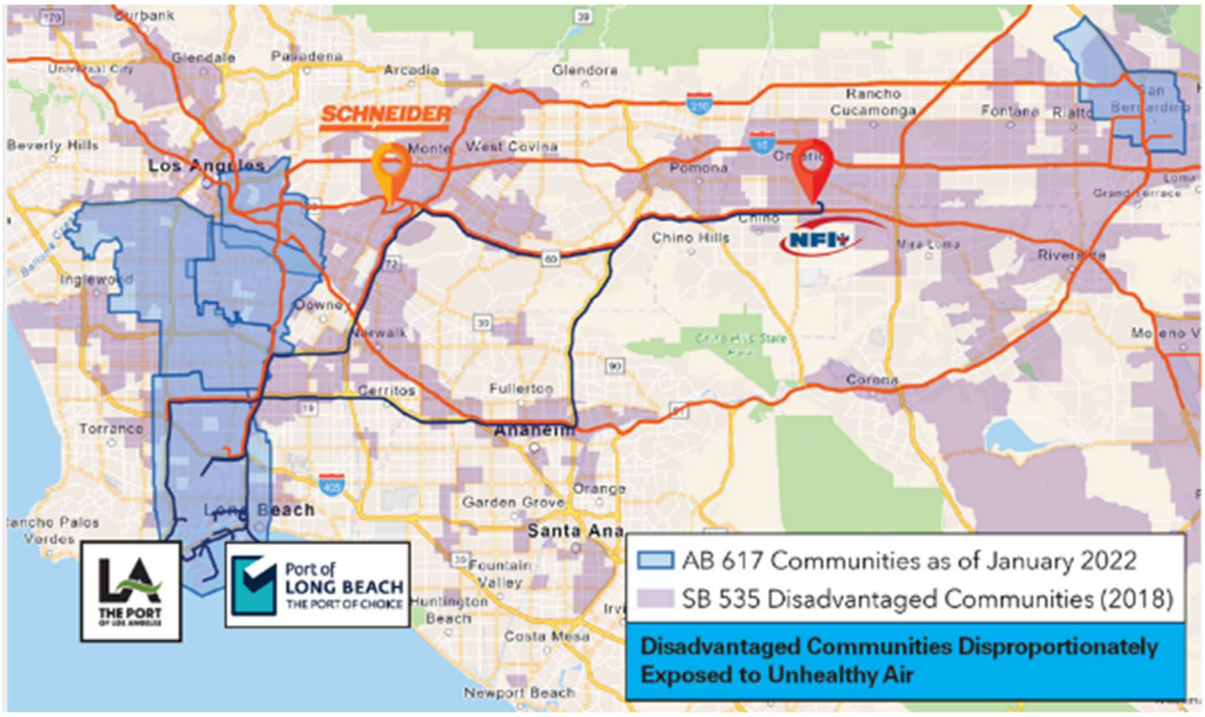


Figure 8: JETSI Truck Routes - NFI Drayage Routes Shown in Dark Blue and Schneider Short Regional Haul Routes Shown in Orange

NFI will operate a mix of 50 Daimler and Volvo Class 8 BETs in drayage operations. NFI will also deploy thirty-eight 350 kW DC fast chargers with SAE standard CCS1 connectors, 1 MW solar, and 5 MWh battery energy storage. This deployment will result in 2.45 tons of weighted criteria pollutant reductions and 440 metric tons of GHG reductions.

Daimler and Volvo truck and infrastructure specifications are shown in Table 3. There will be some variation in Daimler and Volvo BET configurations as fleets take advantage of technology advancements to better serve their needs in later model year trucks.

Table 3: NFI Truck and Infrastructure Specifications

OEM	Battery Pack (kWh)	Infrastructure	Charging Time (hours)	Range (miles)
Daimler	438	350 kW DC (80% charging at 240 kW)	2 hours	220
Volvo	375 565	350 kW DC (80% charging at 250 kW)	1 hours 1.5 hours	180 275

Schneider will operate 50 Daimler Class 8 BETs in short regional haul operations. Schneider will also deploy sixteen 350 kW DC fast chargers with standardized CCS1 connectors. This deployment will result in 2.55 tons of weighted criteria emission reductions and 3,984 metric tons of GHG reductions. Daimler truck and infrastructure specifications for Schneider are similar to NFI and shown in Table 2. Daimler and Volvo trucks to be deployed at NFI and Schneider are shown in Figure 9.

Table 4: Schneider Truck and Infrastructure Specifications

OEM	Battery Pack (kWh)	Infrastructure	Charging Time (hours)	Range (miles)
Daimler	438	350 kW DC (80% charging)	1.5 hours	220

Figure 9: JETSI Trucks at NFI and Schneider – (left to right) Volvo VNR Electric truck to be deployed at NFI in Ontario, and Daimler eCascadia truck deployed at Schneider in South El Monte

Ricardo, CALSTART, and EPRI will collaborate on data collection and analysis for the BETs, infrastructure and DER. Ricardo will perform data logging on a subset of baseline diesel trucks as well as deployed BETs for a 12 – 24 month data collection period, as well as conduct surveys, fleet/driver interviews, analyze data, and provide quarterly and final reports on data collection. CALSTART will focus on charger pricing analysis and fleet case studies including startup and final fleet deployment activities. EPRI will focus on charger performance and utilization analysis, development of a fleet reliability uptime dashboard, and analysis of grid impacts. The fleet reliability uptime dashboard will create a project database from real time BET and charger data to perform automated queries to make determinations and identify issues affecting operations, alert fleet managers, perform remote diagnoses or dispatch service calls to maintain an ideal 90% or higher charger uptime. In addition, University of California Riverside Center for Environmental Research and Technology will analyze data form the first 10 BETs at each fleet to evaluate energy savings potential from energy efficient routing software for BETs.

Los Angeles Cleantech Incubator (LACI) and Gladstein, Neandross and Associates (GNA) will partner on developed a ZEV workforce plan required by CEC which includes performance metrics and collection/ analysis of data on workforce training and job creation and impacts. The ZEV workforce plan will document training efforts by project partners including NFI, Schneider, Daimler, Volvo, Rio Hondo College, and San Bernardino Valley College. LACI will also convene incubator stakeholder roundtable meetings to encourage further dissemination of technologies for JETSI.

Coalition for Clean Air will conduct project stakeholder meetings and community outreach with environmental organizations, community-based organizations, and local government leaders, as well as targeted outreach to stakeholders in disadvantaged communities.

JETSI will result in 5 weighted tons of criteria pollutant emission reductions each year, 5.5 million diesel gallon equivalent of diesel fuel displaced over the eight-year project, 8,200 metric tons of GHG reductions, creation of 239 long-term jobs, and $16.8 million in regional economic activity resulting from site construction. This is in addition to the benefits of learning how to address challenges in large scale deployments, increasing coordination between agencies to deploy BETs and charging infrastructure, and designing incentive programs to enable fleets to transition to BETs earlier than required by the CARB Advanced Clean Fleets regulation by addressing the additional cost for BETs and infrastructure over

conventional fuel trucks.

- **Develop and Demonstrate Hydrogen Fuel Cell Medium-Duty Buses**

As CARB continues to adopt zero emission mandates such as the Innovative Clean Transit (ICT), Zero-Emission Airport Shuttle and Advanced Clean Trucks regulations, there is growing demand for longer range and fast fueling options that meet fleet needs for more vigorous duty-cycles. Ford medium-duty vehicles have significant market share in multiple applications, including local and regional goods movement, municipal fleets, utilities, and transit, shuttle and school bus operations.

A-1 Alternative Fuel Systems (A-1) and its consortium members have formed a public-private technology development program to introduce to California two new zero emission Class 4 medium- duty hydrogen fuel cell paratransit platforms that will provide a minimum 175-250 mile range per fill: a low floor (kneeling) Ford F-53 and a standard floor Ford E-450. A-1 has demonstrated their commercialization strategy as well as aftermarket service and warranty capability from their two decades of alternative fuels industry experience. This project will leverage A-1 and the project team's core capabilities to co-develop and bring to market long-range, fast filling medium-duty zero emission platforms that are not yet commercially available.

The Ford medium-duty vehicle platform plays an important role in California's economy. Ford's innovative design and business model allows fleets to order a factory-built Ford chassis consisting of a cab and chassis from which a wide variety of vehicles can be assembled via Ford's Qualified Vehicle Modifier (QVM) partnerships. Examples of vehicles include: small school buses, airport shuttle vans/buses, delivery trucks, work trucks for water, refuse, utility, aerial, flat bed, dump, and service applications.

Figure 10: Medium-Duty Bus Applications including School Bus and Airport Shuttle Buses

Project team member responsibilities are broken down into seven tasks. US Hybrid will be responsible for hydrogen fuel cell development and chassis electrification development, A-1 and Luxfer Gas Cylinders will be responsible for hydrogen fuel tank system development. Hometown Manufacturing and Turtle Top Bus will be in charge of shuttle bus body development. A-1 will also be leading the work on integration of fuel cell technology, chassis electrification, fuel tank system, and shuttle bus body, as well as CARB and Altoona bus certifications.

SunLine Transit (SunLine), a public transit agency serving the Coachella Valley, has agreed to participate as the demonstration partner for the project. Sunline is at the forefront of zero emission bus technology and has demonstrated fuel cell and battery electric buses in their fleet since 2000, after replacing its entire fleet from diesel to CNG buses in 1994. Their current fleet includes 16 fuel cell electric buses (FCEB) and four battery electric buses (BEB). SunLine's existing FCEB fueling and BEB charging infrastructure was designed to enable future growth of their fleet. In late 2019, Sunline began operating an electrolyzer capable

of producing 900 kg hydrogen/day, fueling 32 buses daily based on average hydrogen fuel consumption of FCEBs operating on SunLine's routes. SunLine intends to continue to deploy both FCEBs and BEBs as their fleet transitions to 100% zero-emission by 2035. SunLine released their Zero Emission Bus Rollout Plan and will transition their paratransit fleet to 100% zero emission by 2032 and their fixed route fleet to 100% zero emission by 2035, five years ahead of ICT regulatory requirements. SunLine has offered to contribute to the project by supplying hydrogen fuel needed to operate the E-450 and/or F53 demonstration buses for a minimum of 1 year demonstration period.

According to data from Ford and industry sources, annual demand for "gaseous fuel prepped" Ford medium-duty engines nationwide exceeds 6,000 buses, with at least 1,200 buses shipped to California for upfit to gaseous fuels. As fuel cell technologies continue to be deployed in larger numbers, there should be an easier transition to zero emission buses for existing fleets currently running on propane and NG. There should also be more high mileage fleets investigating zero emission bus options to serve high mileage routes.

The project is co-funded by South Coast AQMD from the Clean Fuels Fund and SoCalGas as well as in-kind contribution from project partners. The total project cost is $2.1 million.

CLEAN FUELS PROGRAM

2022 Funding & Financial Summary

The Clean Fuels Program supports clean fuels and technologies that appear to offer the most promise in reducing emissions, promoting energy diversity, and in the long-term, providing cost-effective alternatives to current technologies. To address the wide variety of pollution sources in the Basin and the need for reductions now and in the future, using revenue from a $1 motor vehicle registration fee (see Program Funding on page 7), South Coast AQMD seeks to fund a wide variety of projects to establish a diversified technology portfolio to proliferate choices with the potential for different commercial maturity timing. Given the evolving nature of technology and changing market conditions, such a representation is only a "snapshot-in-time," as reflected by the projects approved by the South Coast AQMD Board.

As projects are approved by the South Coast AQMD Governing Board and executed into contracts during the year, finances may change to reflect updated information provided during the contract negotiation process. As such, the following represents the status of the Clean Fuels Fund as of December 31, 2022.

Funding Commitments by Core Technologies

South Coast AQMD continued its successful leveraging of public funds with outside investment to support the development of advanced clean air technologies. During the period from January 1 through December 31, 2022, a total of 26 contracts/agreements, projects or studies that support clean fuels were executed or amended (adding dollars), as shown in Table 5. The major technology areas summarized are listed in order of funding priority. The distribution of funds based on technology area is shown graphically in Figure 11. This wide array of technology support represents South Coast AQMD's commitment to researching, developing, demonstrating and deploying potential near-term and longer-term technology solutions.

The project commitments that were contracted or purchased for the 2022 reporting period are shown below with the total projected project costs:

- South Coast AQMD Clean Fuels Fund Contribution $7,425,646
- Total Cost of Clean Fuels Projects $74,152,921

Traditionally, every year, the South Coast AQMD Governing Board approves funds to be transferred to the General Fund Budget for Clean Fuels administration. However, starting with FY 2017, fund transfer from Clean Fuels Fund to the General Fund was handled through the annual budget process. When the Board approved South Coast AQMD's FY 2022-23 Budget on May 6, 2022, it included $1 million from Clean Fuels Fund recognized in TAO's budget for technical assistance, workshops, conferences, co-sponsorships and outreach activities, as well as postage, supplies and miscellaneous costs. Only the funds committed by December 31, 2022, are included within this report. Any portion of the Clean Fuels Fund not spent by the end of Fiscal Year 2022-23 ending June 30, 2023, will be returned to the Clean Fuels Fund.

Partially included within the South Coast AQMD contribution are supplemental sponsorship revenues from various organizations that support these technology advancement projects. Supplemental revenue for pass-through contracts executed in 2022 totaling approximately $304,000 is listed in Table 6.

For Clean Fuels executed and amended contracts, projects and studies in 2022, the average South Coast AQMD contribution was leveraged with nearly $10 of outside investment. The typical historical leverage amount is $4 for every $1 of the South Coast AQMD Clean Fuels Fund, but from 2016 to 2022 there were several significant contracts in funding and impact that should make tangible progress toward developing and commercializing clean transportation technologies.

During 2022, distribution of funds for South Coast AQMD executed contracts, purchases and contract amendments with additional funding for the Clean Fuels Program totaling approximately $7.4 million are shown in the figure below.

Additionally, South Coast AQMD continued to seek funding opportunities and was awarded an additional $3.3 million in CY 2022 for RD[3] projects as listed in Table 7. As of January 1, 2023, there were 74 open Clean Fuels Fund contracts. Appendix B lists these contracts by core technology.

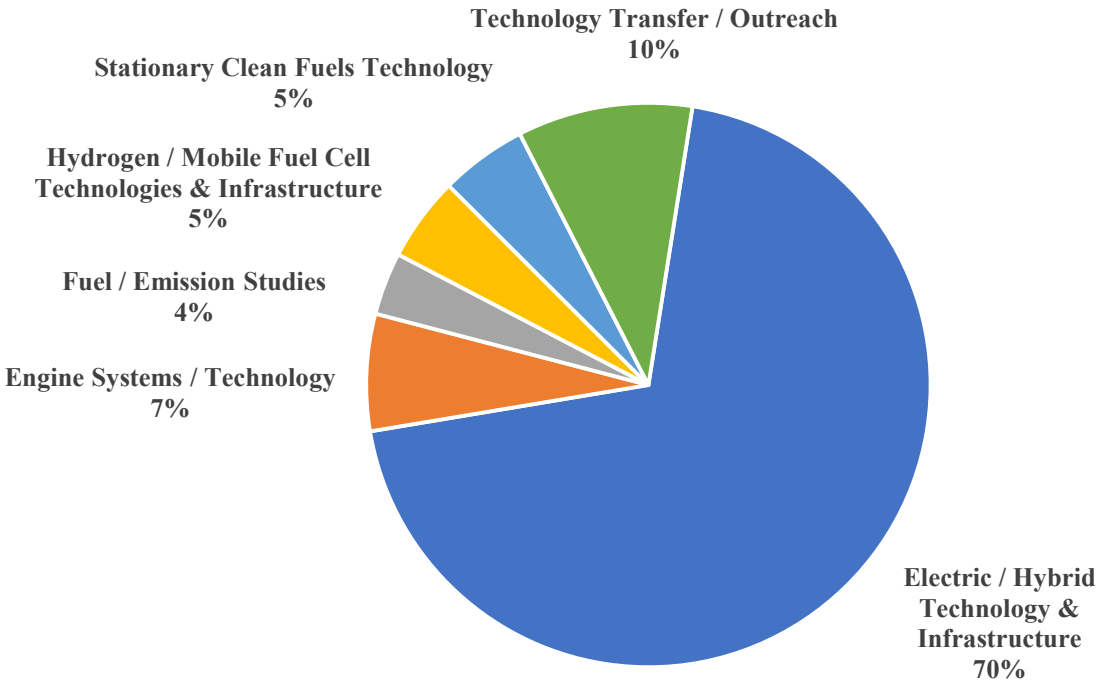


Figure 11: Distribution of Funds for Executed Clean Fuels Projects CY 2022 ($7.4M)

Review of Audit Findings

State law requires an annual financial audit after the closing of each South Coast AQMD fiscal year. The financial audit is performed by an independent Certified Public Accountant selected through a competitive bid process. For the fiscal year which ended June 30, 2022, the firm of BCA Watson Rice, LLP, conducted the financial audit. As a result of this financial audit, an Annual Comprehensive Financial Report (ACFR) was issued. There were no adverse internal control weaknesses regarding South Coast AQMD financial statements, which include the Clean Fuels Program revenue and expenditures. BCA Watson Rice, LLP, gave South Coast AQMD an "unmodified opinion," the highest obtainable. Notably, South Coast AQMD has achieved this rating on all prior annual financial audits.

Project Funding Detail by Core Technologies

The 26 new and continuing contracts/agreements, projects and studies that received South Coast AQMD funding in CY 2022 are summarized in Table 5 (beginning on the next page), together with funding authorized by South Coast AQMD and project partners.

Table 5: Contracts Executed or Amended (w/$) between January 1 & December 31, 2022

Contract	Contractor	Project Title	Start Term	End Term	South Coast AQMD $	Project Total $
Electric / Hybrid Technologies and Infrastructure						
19278	Volvo Group North America LLC	Low Impact Green Heavy Transport Solutions (LIGHTS)- Develop and Demonstrate Zero Emission Heavy-Duty Trucks, Freight Handling Equipment, EV Infrastructure and Renewable Energy	04/17/19	09/30/22	0	1,044,854
22036	University of California Riverside	Energy-Efficient Routing for Electric Trucks	09/06/22	04/30/25	99,500	99,500
22120	Los Angeles Cleantech Incubator	Conduct Stakeholder Outreach and ZEV Workforce Plan	03/24/22	03/31/25	95,000	155,000
22177	Daimler Trucks North America LLC	Deploy Class 8 Battery Electric Trucks and Charging Infrastructure	06/16/22	04/30/25	447,638	27,073,593
22247	NFI Interactive Logistics LLC	Deploy Class 8 Battery Electric Trucks, Charging Infrastructure and Distributed Energy Resource Technologies	12/15/22	4/30/25	4,547,126	35,078,329
Engine Systems / Technologies						
18194	CALSTART	Develop and Demonstrate Near-Zero Emission Opposed Piston Engine	05/30/18	11/30/23	1,413,000	17,413,000
Fuel / Emission Studies						
21083	University of California Riverside	Assess Emissions Impacts of Hydrogen-Natural Gas Fuel Blend on Natural Gas Engines	01/22/22	01/21/23	229,021	583,021
22131	Fresno Council of Governments	Conduct California Inland Port Feasibility Study Phase Two	03/24/22	12/23/22	37,500	250,000
Hydrogen / Mobile Fuel Cell Technologies and Infrastructure						
15150	Air Products and Chemicals Inc	Install/Upgrade Eight Hydrogen Fueling Stations throughout SCAG	10/10/14	04/09/23	(237,500)	(237,500)
20033	Port of Long Beach	Sustainable Terminals Accelerating Regional Transportation (START) Phase I	06/04/21	04/30/24	0	2,049,701
22082	Frontier Energy Inc	High Flow Bus Fueling Protocol Development	03/30/22	08/29/23	25,000	572,500

Table 5: Contracts Executed or Amended (w/$) between January 1 & December 31, 2022 (cont'd)

Contract	Contractor	Project Title	Start Term	End Term	South Coast AQMD $	Project Total $
22084	A-1 Alternative Fuel Systems	Develop and Demonstrate Hydrogen Fuel Cell Medium-Duty Buses	01/19/22	04/18/24	531,166	2,086,608
23071	Frontier Energy Inc	Participate in California Fuel Cell Partnership for Calendar Year 2022	01/01/22	12/31/22	40,000	1,200,000
Stationary Clean Fuels Technologies						
22262	University of California Irvine	Study of Fuel Cell Microgrids for Backup Power and Transit	06/03/22	06/02/24	370,000	510,000
Technology Assessment and Transfer / Outreach						
19078	Green Paradigm Consulting, Inc.	Technical Assistance with Alternative Fuels, Biofuels, Emissions Testing & Zero-Emission Transportation Technology	09/07/18	09/30/24	0	14,000
22273	Green Paradigm Consulting, Inc.	Technical Assistance with Alternative Fuels, EVs, Charging & Infrastructure and Renewable Energy	04/22/22	04/02/24	200,000	200,000
22274	Gladstein, Neandross & Associates LLC	Technical Assistance with Alternative Fuels & Fueling Infrastructure, Emissions Analysis & On-Road Sources	05/05/22	04/02/24	300,000	300,000
Various	Various	Cosponsor 10 Conferences, Workshops & Events plus 3 Memberships	01/01/22	12/31/22	137,630	1,651,680
Direct Pay	Various	Advanced Technology Program Expenses	01/01/22	12/31/22	107,135	107,135
						$74,152,921

Table 6: Supplemental Grants/Revenue Received into the Clean Fuels Fund (31) in CY 2022

Revenue Agreement #	Revenue Source	Project Title	Contractor	SCAQMD Contract #	Award Total $
21070	Southern California Gas Company	Assess Emission Impacts of Hydrogen-Natural Gas Fuel Blend on Natural Gas Engines	University of California, Riverside	21083	304,000
Table 6 lists revenue awarded to South Coast AQMD and received into the Clean Fuels Fund (31) only if the South Coast AQMD pass-through contract was executed during the reporting CY (2022).					**$304,000**

Table 7: Summary of Federal, State and Local Funding Awarded or Recognized in CY 2022

Awarding Entity or Program	Award (*) or Board Date	Purpose	Contractors	Award Total/ Fund
US EPA DERA Grant	05/06/22	Electrification Of Cargo Handling Equipment	Various	$2,349,995 Fund 17
California Air Resources Board	09/02/22	Zero-Emission Drayage Truck and Infrastructure Pilot Project	Gladstein, Neandross & Associates LLC	$220,000 Fund 67
US EPA CATI Grant	09/02/22	Deployment of Zero Emission Mobile Clinics	San Bernardino County, Arrowhead Regional Medical Center	$500,000 Fund 17
US EPA DERA Grant	11/04/22	Electrification Of Cargo Handling Equipment	Various	$219,938 Fund 17
Table 7 provides a comprehensive summary of revenue awarded to South Coast AQMD during the reporting CY (2022) for TAO's RDD&D efforts which falls under the umbrella of the Clean Fuels Program, regardless of whether the revenue will be received into the Clean Fuels Program Fund (31) or the South Coast AQMD pass-through contract has been executed.				**$3,289,933**

Project Summaries by Core Technologies

The following summaries describe the contracts, projects and studies executed, or amended with additional dollars, in CY 2022. They are listed in the order found in Table 5 by category and contract number. As required by H&SC Section 40448.5.1(d), the following project summaries provide the project title; contractors and, if known at the time of writing, key subcontractors or project partners; South Coast AQMD cost-share, cosponsors and their respective contributions; contract term; and a description of the project.

Electric / Hybrid Technologies and Infrastructure

- **19278: Low Impact Green Heavy Transport Solutions (LIGHTS) - Develop and Demonstrate Zero Emissions Heavy-Duty Trucks, Freight Handling Equipment, EV Infrastructure and Renewable Energy**

Contractor: Volvo Group North America	South Coast AQMD Cost-Share	$ 0
	Cosponsors:	
	CARB *(pass-through funds received into Fund 67)*	1,044,854
Term: 04/17/19 – 09/30/22	Total Cost:	$ 1,044,854

Volvo Group North America and South Coast AQMD secured a CARB ZANZEFF grant for the Volvo LIGHTS project to demonstrate 25 Class 8 battery electric trucks at two freight handling facilities, DHE in Ontario and NFI Industries in Chino. The Volvo LIGHTS project also includes the demonstration of 29 battery electric forklifts, yard tractors and support EVs; 58 Level 2 and DC fast chargers; and production of 1.8 million MWh annually of solar. This contract amendment is for deployment of 5 additional Class 8 battery electric trucks utilizing CARB funds.

- **22036: Energy-Efficient Routing for Electric Trucks**

Contractor: University of California Riverside	South Coast AQMD Cost-Share	$ 99,500
Term: 09/06/22 – 04/30/25	Total Cost:	$ 99,500

The work under this Contract is part of the Zero-Emission Drayage Truck and Infrastructure Pilot Project, which is primarily funded by CARB and CEC. South Coast AQMD is providing the funding for this Contract as match share under CEC revenue agreement ARV-21-014. University of California, Riverside, College of Engineering, Center for Environmental Research and Technology (UCR/CE-CERT) will determine energy savings potential from energy-efficient routing for the first 10 BETs at each fleet. Performance specifications of recent electric truck models have improved significantly. However, electric trucks still have shorter driving range and require longer refueling (charging) time than conventional diesel trucks, which can significantly impact how fleets utilize electric trucks. Therefore, any technologies that can improve energy efficiency of electric trucks will help minimize the impact on fleet operations. For example, an increase in the energy efficiency of electric trucks will directly translate to an extended range, which allows the trucks to cover a larger service area. An increase in the energy efficiency of electric trucks will also mean a shorter charging time, which will increase truck utilization and revenue. As energy consumption of an electric truck can vary greatly depending on cargo weight, traffic, road grade, weather,

driver, etc., it is possible to determine a travel route that is most energy efficient. The objective of this project is to determine energy savings potential of energy-efficient routing for electric trucks based on their real-world truck operation data.

- **22120: Conduct Stakeholder Outreach and ZEV Workforce Plan**

Contractor: Los Angeles Cleantech Incubator	South Coast AQMD Cost-Share	$ 95,000
	Cosponsors:	
	CEC *(pass-through funds received into Fund 67)*	60,000
Term: 3/24/22 – 3/31/25	Total Cost:	$ 155,000

Los Angeles Cleantech Incubator (LACI) will host workshops with industry stakeholders, including environmental and public health groups, technology startups, OEMs, service providers, fleets and other regional stakeholders to identify technology, policy, funding and barriers to innovation for scaling battery electric truck adoption for drayage and regional haul applications. This will assist LACI in partnership with GNA in developing a ZEV Workforce Data Collection Plan, draft and final ZEV Workforce Plan, and provide a workforce analysis to include in the California Joint Electric Truck Scaling Initiative (JETSI) final report.

- **22177: Deploy Class 8 Battery Electric Trucks and Charging Infrastructure**

Contractor: Daimler Truck North America LLC	South Coast AQMD Cost-Share	$ 447,638
	Cosponsors	
	CARB *(pass-through funds received into Fund 67)*	7,241,144
	CEC *(pass-through funds received into Fund 67)*	1,729,811
	POLA *(pass-through funds received into Fund 67)*	1,500,000
	MSRC	5,000,000
	Schneider	8,655,000
	SCE	2,500,000
Term: 06/16/22 – 04/30/25	Total Cost:	$ 27,073,593

The work under this Contract is part of the Zero-Emission Drayage Truck and Infrastructure Pilot Project, which is primarily funded by CARB and CEC. CARB will fund the deployment of 100 commercial Class 8 BETs, while CEC will fund other effort including work under this Contract. DTNA will partner with Schneider National Carriers, Inc. and to deploy the 50 Class 8 BETs, and 16 350 kW DC fast chargers at the Schneider site in South El Monte. DTNA will coordinate other aspects of the California JETSI project

including work force training, develop energy management system, as well as support other subcontractors of the JETSI project.

- **22247: Deploy Class 8 Battery Electric Trucks, Charging Infrastructure and Distributed Energy Resource Technologies**

Contractor: NFI Interactive Logistics LLC	South Coast AQMD Cost-Share	$ 4,547,126
	Cosponsors:	
	CARB *(pass-through funds received into Fund 67)*	7,241,144
	CEC *(pass-through funds received into Fund 67)*	6,819,859
	POLB *(pass-through funds received into Fund 67)*	1,500,000
	MSRC	3,000,000
	SCE	2,500,000
	NFI	9,470,200
Term: 12/15/22 – 04/30/25	Total Cost:	$ 35,078,329

The work under this Contract is part of the Zero-Emission Drayage Truck and Infrastructure Pilot Project, which is primarily funded by CARB and CEC. Under this contract, NFI will operate 50 Class 8 BETs trucks in drayage operations. This project will significantly advance market penetration of Class 8 BETs through at-scale manufacturing production. NFI will deploy the following technologies at its fleet in Ontario: up to 50 BETs; up to 34 175 kW or 350 kW DC fast chargers; up to 1 MW solar installation; and up to 5 MWh battery energy storage. BETs under this project shall be commercial vehicles approved for the U.S. market and certified by CARB. DER technologies such as solar and battery energy storage will utilize energy management systems to optimize vehicle charging by balancing requirements of trucks, facility, and the grid. SCE's Charge Ready Transport (CRT) program has committed to fund EVSE and installation services towards make-ready infrastructure at NFI. Infrastructure installed will be UL certified and meet Open Charge Point Protocol and Open Automated Demand Response requirements. It is anticipated that the NFI site will result in 2.45 tons of weighted criteria pollutant reductions for 50 BETs and 440 metric tons of GHG reductions.

Engine Systems / Technologies

- **18194: Develop and Demonstrate Near-Zero Emissions Opposed Piston Engine Contractor:**

Contractor: CALSTART Inc	South Coast AQMD Cost-Share	$ 1,413,000
	Cosponsors:	
	CARB *(pass-through funds received into Fund 67)*	7,690,000

	Achates Power Inc	6,850,000
Term: 05/30/18 – 11/30/23	Total Cost:	$ 17,413,000

In 2018, South Coast AQMD entered into a contract with CALSTART to develop and demonstrate emission opposed piston (OP) engine technology in Class 8 heavy-duty, line-haul trucks that meet a 0.02 g/bhp-hr NOx target, with concurrent reductions in C02 emissions in the amount of $1 million. CARB awarded CALSTART a grant in the amount of $7 million under CARB 's Low Carbon Transportation GHG Reduction Fund Investments towards this project. Other funding was provided by Achates Power, Inc. in the amount of $6.55 million and San Joaquin Valley Air Pollution Control District in the amount of $1 million. In 2022, CARB reallocated previously recognized unused funds of $618,070 from the Zero Emission Drayage Truck Project awarded to South Coast AQMD for additional emissions testing on the opposed piston engine. South Coast AQMD committed $496,430 and Achates committed an additional $300,000 towards the additional emissions testing. Under this contract, total funding of $1,114,500 was added for the additional work.

Fuel / Emissions Studies

- **21083: Assess Emissions Impacts of Hydrogen-Natural Gas Fuel Blend on Natural Gas Engines**

Contractor: University of California Riverside	South Coast AQMD Cost-Share	$ 229,021
	Cosponsors	
	SoCalGas *(pass-through funds received into Fund 31)*	304,000
	Cummins Inc	50,000
Term: 01/22/22 – 01/21/23	Total Cost:	$ 583,021

Past studies by South Coast AQMD and others have demonstrated that the addition of hydrogen in compressed natural gas (HCNG) could potentially lower emissions with optimal engine calibration and HCNG blend ratio. Recent low carbon and renewable fuel initiatives have renewed interest in further decarbonization of NG, providing a source of lower carbon content fuel for the transportation sector. However, the recent rapid commercialization of NZE NOx NG engines have warranted additional investigation of the effects of HCNG blends on both criteria and GHG emissions for recently certified NZE NG engines. The University of California, Riverside (UCR)/CE-CERT is partnering with SoCalGas and CWI to evaluate the impact of different HCNG blends on emissions and performance of the Cummins L9N NZE NG engine. UCR/CE-CERT will design and build an HCNG blending apparatus as part of the study and vary hydrogen content from zero to five percent by volume. The proposed first phase study will be focused on the emissions impacts of HCNG blends compared to the baseline on regulated engine test duty cycles. CWI will provide the test engine and aftertreatment systems, as well as engineering and data analysis support including oil sample analysis. Depending on the outcome of the first phase study, staff may choose to seek Board approval to fund a second phase 500-hour durability study to assess the deterioration effects of the HCNG fuel.

- **22131: Conduct California Inland Port Feasibility Study Phase Two**

Contractor: Fresno Council of Governments	South Coast AQMD Cost-Share	$ 37,500
	Cosponsors	
	POLA, POLB, SJVAPCD, Sacramento AQMD, Sacramento County	212,500
Term: 03/24/22 – 12/31/22	Total Cost:	$ 250,000

An Inland Port along freight transportation corridors from the San Pedro Bay Ports to the San Joaquin Valley would help establish an efficient and competitive logistics system in California. Currently, nearly all containers transported between the POLA and POLB through San Joaquin Valley are moved by heavy-duty diesel trucks. By shifting a majority of the cargo truck traffic off of the highway and roadway system onto a rail system, an inland port system has the potential to reduce air pollution associated with heavy-duty trucking in the South Coast Air Basin and surrounding regions. In early 2019, the first phase of the California Inland Port Feasibility Study was initiated through a joint effort funded by SJVAPCD, POLA, POLB, and several San Joaquin Valley Cities and counties. Phase one found the container on-truck methods currently being used to transport goods between San Joaquin Valley consumption and production centers is highly inefficient, resulting in increased costs and air pollution from increased truck trips. The phase one study showed there is potential for a strong business case to utilize intermodal rail service which would yield substantial transportation cost savings as well as significant environmental benefits for the surrounding regions over use of heavy-duty trucks. South Coast AQMD issued this Contract with Fresno Council of Governments to conduct phase two of the study. Key objectives include developing market readiness and acceptance, estimating costs, developing a partnership with one or both Class One railroads, reviewing the economic competitiveness impact to the region, and understanding the environmental process to move forward. The project is also planning a future phase and considering federal funding.

Hydrogen / Mobile Fuel Cell Technologies and Infrastructure

- **15150: Install/Upgrade Eight Hydrogen Fueling Stations**

Contractor: Air Products and Chemicals Inc	South Coast AQMD Cost-Share	$ (237,500)
Term: 10/10/2014– 04/09/2023	Total Cost:	$ (237,500)

Air Products was originally awarded funding for $1 million from South Coast AQMD to help cost-share this project with the California Energy Commission (CEC; PON-09-608) and offset higher than-anticipated initial equipment costs and investment for the production and distribution of hydrogen. Other funding was provided by CEC in the amount of $8,484,871 and by Air Products in the amount of $3,826,386 towards this $13,073,757 project. The hydrogen fueling stations are new (or upgraded), publicly accessible, next-generation (35 MPa and 70 MPa) located throughout Southern California, including the construction and upgrade of the existing station at South Coast AQMD headquarters in Diamond Bar. Six light-duty stations were built and operated under this contract. The West LA station was operated for three years as required, but the property is being redeveloped, the lease ended, and the equipment was removed. Air Products continues to operate the Diamond Bar, UC Irvine, Santa Monica, Beverly Blvd., and Lawndale stations. The Santa Clarita and Rancho Palos Verdes stations were removed from the statement work of this contract due to several operational issues. As such, CEC descoped these stations from the CEC Grant Agreement,

and $237,500 ($118,750 per station) of Clean Fuels Program funds were de-obligated. Total Clean Fuels Program funds towards this project are $762,500.

- **20033: Sustainable Terminals Accelerating Regional Transportation (START) Phase I**

Contractor: Port of Long Beach	South Coast AQMD Cost-Share	$ 0
Term: 6/4/21 – 4/30/24	Total Cost:	$ 2,049,701

In June 2021, South Coast AQMD executed a contract with POLB for the POLB START project develop and demonstrate 102 zero and near-zero emission vehicles, vessels, cargo handling equipment, and charging infrastructure. In January 2022, CARB provided a two year no cost time extension to complete work for this project due to supply chain disruptions from the pandemic. There were also minor changes in partner match share as follows: CARB $50,000,000; POLB $7,285,200; SCE $3,000,000; Port of Stockton $2,000,000; Port of Oakland $1,250,000; Other Partners $33,873,114 cash and $7,105,451 in-kind; and South Coast AQMD $500,000. Total project costs increased by $2,049,701 for a total of $105,013,765.

- **22082: High Flow Bus Fueling Protocol Development**

Contractor: Frontier Energy Inc	South Coast AQMD Cost-Share	$ 25,000
	Cosponsors:	
	U.S. DOE	422,000
	SoCalGas	80,000
	Shell	20,000
	Sunline Transit Agency	25,500
Term: 03/30/22 – 03/30/24	Total Cost:	$ 572,500

The High Flow Bus Fueling Protocol Development project was awarded to Frontier Energy and project partners as a result of a competitive US DOE H2@Scale Cooperative Research and Development Agreement (CRADA) call. Frontier Energy, with the support of SoCalGas, Shell, South Coast AQMD, the Gas Technology Institute, and SunLine Transit, is partnering with NREL to develop a 35 MPa high flow hydrogen vehicle fueling protocol constructed from the existing J2601 mass compensated (MC) Formula approach. The project's goal is to develop, characterize, and deliver the necessary data for standards development organizations to implement the strategy for the target fueling applications. This Contract is co-funded separately with South Coast AQMD Clean Fuels Program funds, in coordination with the U.S. DOE CRADA.

- **22084: Develop and Demonstrate Hydrogen Fuel Cell Medium-Duty Buses**

Contractor: A-1 Alternative Fuel Systems	South Coast AQMD Cost-Share	$ 531,166
	Cosponsors	
	SoCalGas, A-1, Ford, Turtle Top Bus, US Hybrid, Luxfer Gas Cylinders, Hometown Manufacturing	1,555,442

Term: 01/19/22 – 04/18/24	Total Cost:	$ 2,086,608

As CARB continues to adopt zero emission mandates such as the Innovative Clean Transit (ICT), Zero-Emission Airport Shuttle and Advanced Clean Trucks regulations, there is growing demand for longer range and fast fueling options that meet fleets needs for more vigorous duty-cycles. Ford Motor Company (Ford) medium-duty vehicles have significant market share in multiple applications, including local and regional goods movement, municipal fleets, utilities, and a variety of transit, shuttle and school bus operations. A-1 Alternative Fuel Systems and consortium partners will develop two new zero emission hydrogen fuel cell powered Ford platforms for medium-duty commercial trucks and buses. This project will leverage A-1 consortium partner's core capability to co-develop and bring to market long-range, fast filling medium-duty zero emission platforms that are currently not commercially available. A-1 and its consortium partners Ford, US Hybrid Corporation (US Hybrid), Turtle Top Bus (TT), Hometown Manufacturing, Inc (Hometown) and Luxfer Gas Cylinders (Luxfer) shall develop, demonstrate, and commercialize two hydrogen fuel cell Class 4 medium-duty buses on Ford platforms that are capable of 175-300 miles of range.

- **23071: Participate in California Fuel Cell Partnership for Calendar Year 2022**

Contractor: Frontier Energy Inc	South Coast AQMD Cost-Share	$ 40,000
	Cosponsors:	
	7 automakers, 3 public agencies, 7 industry stakeholders, 35 Full & Associate Members	1,160,000
Term: 01/01/22 – 12/31/22	Total Cost:	$ 1,200,000

In April 1999, the California Fuel Cell Partnership (CaFCP) was formed with eight members; South Coast AQMD joined and has participated since 2000. The CaFCP and its members are demonstrating and deploying fuel cell passenger cars and transit buses with associated hydrogen fueling infrastructure in California. Since the CaFCP is a voluntary collaboration, each participant contracts with Frontier Energy Inc for their portion of the CaFCP's administration. In 2022, South Coast AQMD contributed $40,000 for Executive membership. CaFCP transitioned to H2FCP in 2022 to focus on expanding the fuel cell vehicle technologies and hydrogen infrastructure on a national level. The main focus of this organization will still be California.

Stationary Clean Fuels Technologies

- **22262: Study of Fuel Cell Microgrids for Backup Power and Transit**

Contractor: University of California Irvine	South Coast AQMD Cost-Share	$ 370,000
	Cosponsors:	
	UCI Anteater Express	70,000
	POLB	40,000
	U.S. DOE	30,000
Term: 06/03/22 – 06/02/24	Total Cost:	$ 510,000

The deployment of hydrogen infrastructure is gaining more demand to support increasing fuel cell vehicles and secure the resiliency and reliability of the electricity system. A microgrid is comprised of not only loads, but also the generation of power, and least one point of connection to the grid, and the capability to island from the grid in the event of a grid outage. As an increasing important and desired attribute, the islanding capability brings both enhanced reliability and resiliency to the community served and, rather than diesel backup generators powering critical loads, the microgrid can serve all the loads (not just the critical loads) with clean sources of power such as solar panels, batteries, and fuel cells. In the proposed project, two targets for emission mitigation are backup generators with the seamless islanding afforded by microgrids powered by fuel cells, and the charging and fueling of battery and fuel cell electric buses at fleet microgrid hubs. This project will study: replacing backup generators through microgrid deployment; and zero-emission battery and fuel cell electric bus microgrid hubs.

Technology Assessment and Transfer / Outreach

- **19078: Technical Assistance with Alternative Fuels, EVs, Charging and Infrastructure, and Renewable Energy**

Contractor: Green Paradigm Consulting Inc	South Coast AQMD Cost-Share	$ 0
	Cosponsors:	
	CARB *(pass-through funds received into Fund 67)*	14,000
Term: 09/07/18 – 09/30/24	Total Cost:	$ 14,000

The South Coast AQMD relies on expert input, consultation and support to manage various efforts conducted under the Clean Fuels Program and TAO's many incentive programs. Green Paradigm Consulting, Inc., (GPCI) is providing technical assistance with alternative fuels, renewable energy and electric vehicles as well as outreach activities to promote, assess, expedite and deploy the development and demonstration of advanced, low and zero emissions mobile and stationary technologies. This contract amendment is for technical and administrative support to enable the range of activities involved in implementing the Clean Fuels Program which includes assistance in implementing complementary programs such as CARB's GGRF ZEDT project and ZANZEFF Volvo LIGHTS project as well as others. This assistance consists of executing contracts, processing invoices, disbursement requests, quarterly progress reports, final reports, and audit recordkeeping. The Volvo LIGHTS project started in February 2019 and ended in September 2022.

- **22273: Technical Assistance with Alternative Fuels, EVs, Charging and Infrastructure, and Renewable Energy**

Contractor: Green Paradigm Consulting Inc	South Coast AQMD Cost-Share	$ 200,000
Term: 04/22/22 – 04/03/24	Total Cost:	$ 200,000

The South Coast AQMD relies on expert input, consultation and support to manage various efforts conducted under the Clean Fuels Program and TAO's many incentive programs. GPCI is providing technical expertise and program implementation support in alternative fuels, alternative fuel vehicles and

charging/fueling infrastructure. GPCI has provided expertise on alternative fuel technologies since the late 1990s. This includes evaluation of zero and near-zero emission technologies for LD, MD and HDVs for on- and off-road applications and infrastructure; evaluation of renewable technologies including photovoltaic and battery storage; support for advanced technology mobile source implementation; and program implementation support on Clean Fuels and grant funded programs.

- **22274: Technical Assistance with Alternative Fuels and Fueling Infrastructure, Emissions Analysis and On-Road Sources**

Contractor: Gladstein, Neandross & Associates LLC	South Coast AQMD Cost-Share	$ 300,000
Term: 05/05/22 – 04/02/24	Total Cost:	$ 300,000

This contract leverages staff resources with specialized outside expertise. GNA has previously assisted South Coast AQMD with implementing a wide-array of incentive programs to deploy lower-emitting HDVs and advanced transportation technologies. Under this contract, GNA will provide technical expertise across a broad spectrum of emission reduction technologies, including alternative and renewable fuels and fueling infrastructure, emissions analysis and heavy-duty on-road sources on an-as-needed basis.

- **Various: Cosponsor 10 Conferences, Workshops and Events plus 3 Memberships**

Contractor: Various	South Coast AQMD Cost-Share	$ 137,630
	Cosponsors:	
	Various	1,514,050
Term: 01/01/22 – 12/31/22	Total Cost:	$ 1,651,680

The South Coast AQMD regularly participates in and hosts or cosponsors conferences, workshops and miscellaneous events. In CY 2022, South Coast AQMD provided funding for 10 conferences, workshops and events and 3 memberships in key stakeholder organizations, as follows: Clean Fuels Advisory Group Retreat in February and September 2022; the PEMS Conference in March 2022; the 31st Real World Emissions Workshop in March 2022; CE-CERT's 30th Anniversary Event in April 2022; the ACT Conference and Expo in May 2022; the California Hydrogen Leadership Summit in June 2022; the 15th Annual VerdeXchange Conference in June 2022; the Driving Mobility 9 Symposium in June 2022; the AltCar Expo & Conference in October 2022; and the International Colloquium on Environmentally Preferred Advanced Generation (ICEPAG) in December 2022. Additionally, for 2022, three memberships were renewed for participation in Veloz, a nonprofit organization comprised of high-powered, diverse board members uniquely qualified to accelerate the shift to electric vehicles through public-private collaboration, public engagement and policy education innovation; CALSTART, a nonprofit organization working nationally and internationally with businesses and governments to develop clean, efficient transportation solutions; and the California Natural Gas Vehicle Partnership (CNGVP), an alliance of air quality, transportation and energy agencies, vehicle and engine manufacturers, fuel providers, transit and refuse hauler associations, and other stakeholders interested in increasing and strengthening the deployment of low-emission natural gas vehicles throughout California.

- **Direct Pay: Advanced Technology Program Expenses**

Contractor: Various	South Coast AQMD Cost-Share	$ 107,135
Term: 01/01/22 – 12/31/22	Total Cost:	$ 107,135

The South Coast AQMD advanced technology program showcases new clean-fuel technologies to public and private organizations so that potential purchasers may familiarize themselves with available low-emission technologies and to push the development of even cleaner technologies. This direct pay covers cost of annual EV charging fees, the lease of two BEVs for three years; EVSE installation, FC, EVSE and CNG equipment maintenance and various miscellaneous program expenses that were incurred in 2022.

[This Page Intentionally Left Blank]

CLEAN FUELS PROGRAM

Progress and Results in 2022

Key Projects Completed

Given the large number and diversity of emission sources contributing to the air quality problems in the Basin, there is no single technology or "silver bullet" that can solve all the region's problems. Only a portfolio of different technologies can successfully achieve the required emission reductions needed to meet the upcoming 2023 and 2032 air quality standards as well as the state's 2050 climate goals. Therefore, the South Coast AQMD continues to support a wide range of advanced technologies, addressing not only the diversity of emission sources, but also the time frame to commercialization of these technologies. Projects cofunded by the South Coast AQMD's Clean Fuels Program include emission reduction demonstrations for both mobile and stationary sources, although legislative requirements limit the use of available Clean Fuels funds primarily to on-road mobile sources. The projects funded not only expedite the development, demonstration and commercialization of zero and near-zero emission technologies and fuels, but also demonstrate the technical viability to technology providers, end-users and policymakers.

In the early years, the mobile source projects funded by the Clean Fuels Program targeted low emissions technology developments in automobiles, transit buses, medium- and heavy-duty trucks and off-road applications. Over the last several years, the focus has largely shifted to zero emission technologies for medium- and heavy-duty trucks, especially those in the goods movement and freight handling industry.

Table 15 provides a list of 57 projects and contracts completed in 2022. Summaries of the completed technical projects are included in Appendix C. Selected projects completed in 2022 which represent a range of key technologies from near-term to long-term are highlighted below: (a) Battery Electric Excavator and Wheel Loader Development and Demonstration Project; (b) Zero Emission Truck Innovation Fleet Project; (c) Zero Emission Drayage Truck Project; (d) Volvo Low Impact Green Heavy Transport Solutions (LIGHTS); and (e) 200 Vehicle In-Use Emissions Study.

- **Battery Electric Excavator and Wheel Loader Development and Demonstration Project**

The South Coast AQMD 2022 AQMP identified the need for an additional 83 percent in NOx emission reductions from the 2018 level and 67 percent in NOx reductions beyond already adopted regulations and programs to meet the 2015 8-hour ozone standard by 2037. This level of required NOx reductions cannot come from only on-road vehicles. The AQMP proposes economy-wide transition to zero emission technologies where cost-effective and feasible, and low NOx technologies in other applications. Current and future state and federal efforts in developing regulations for on- and off-road vehicles and equipment are expected to significantly reduce NOx emissions, but are insufficient to achieve the 2023, 2031, and 2037 ozone attainment deadlines. Furthermore, technology development for zero emission off-road equipment is currently lagging significantly behind on-road heavy-duty vehicles. The 2022 AQMP projects that off-road equipment inventory will exceed heavy-duty diesel trucks by 2037 and contributes 41% of total NOx emissions in the 2018 emissions inventory and grows to 58% in the 2037 emission inventory. Off-road equipment (23 tons/day) is the third highest contributor of NOx in 2037. Since NOx emissions also lead to the formation of PM2.5, the NOx reductions needed to meet the ozone standards will also lead to attainment of the NAAQS for PM2.5.

The purpose of this project was to accelerate deployment of zero emission technologies for off-road mobile equipment and reduce harmful diesel emissions, petroleum consumption, and greenhouse gases within the South Coast Air Basin. This was to be accomplished by developing a battery electric compact wheeled loader and battery electric compact tracked excavator and deploying them in the South Coast Air Basin for application testing and feedback with local construction contractors. During this project, a battery electric compact wheeled loader (L25) in the 1.2yd³ bucket class was demonstrated along with a battery electric compact tracked excavator (ECR25) in the 2-3 ton class (both shown above in Figure 1). The L25 utilizes a 48V lithium-ion battery system with 40kWh of energy storage and one 22kW electric induction motor for the driveline system and a 14kW permanent magnet synchronous motor for the hydraulic motors. The L25 can operate for up to six hours of active work per full charge, depending on the environment and tasks performed. This unit can be charged via DC fast charging in two hours and Level 2 AC charging in six hours and Level 1 AC charging in 24 hours. Other mechanical specifications for the L25 are the same as or better than the diesel equivalent model being replaced. The ECR25 utilizes a 48V lithium-ion battery system with 20kWh of energy storage and one 14.7kW permanent magnet synchronous motor for the hydraulic system. The ECR25 can operate for up to six hours of active work per full charge, depending on the environment and tasks performed. This unit can be charged via DC fast charging in approximately one hour, Level 2 AC charging in approximately six hours and Level 1 AC charging in approximately 12 hours. The other mechanical specifications for the ECR25 are the same as or better than the diesel equivalent model being replaced.

Figure 12: L25 and ECR25

Figure 13: Diesel vs Electric Machine Specifications

The project started in September 2019 and testing commenced in September 2020 with the ECR25. Testing on the L25 followed in December 2020 and was successfully completed in August 2021. A press conference in September 2021 at the Mildred E. Mathias Botanical Garden at University of California Los Angeles (UCLA) discussed results and lessons learned. The project continued through September 2022 and the final project reporting will be submitted in early 2023.

Figure 14: L25 and ECR25 Tree Planting Ceremony at UCLA

The L25 and ECR25 were tested in a wide variety of applications during this project by three main customers and their crews – Baltic Sands, Casper Company, and Caltrans. The applications ranged from residential house construction, clearing remote access trails, utility repair and construction, and demolition. Environmental conditions during testing ranged from moderate to high temperatures, dust, rain, and even inside buildings.

The two machines accumulated approximately 400 operating hours during testing. Hours recorded as part of testing are different from traditional construction equipment measurement of engine hours because engine hours increase whether the machine is working or idling. Volvo calculated engine hours on this equipment so that approximately 40% of the engine hours are attributed to idling. The 400 hours of testing are only for direct work since the machine is essentially in a sleep state when it is on but not working.

Testing feedback was overwhelmingly positive, with customers impressed with the performance of the equipment. There was a small adjustment period when a new piece of equipment was introduced to a crew where they needed to learn how to optimize their usage. The first few days generally resulted in lower runtimes than predicted but after some minor adjustments to how they worked, the crews could significantly increase their uptime.

The L25 and ECR25 were both tested under various charging scenarios for this project. The primary methods of charging were Level 1 and Level 2 AC charging. Level 1 charging worked as expected but due to the lower amount of power transferred during this process, customers would not choose to use this method if there were alternative charging options. Level 2 charging also worked as expected and provided the expected 50% reduction in charging time. The downside during testing was that the onboard charging network was not configured to take advantage of all available power provided by 240V infrastructure. In addition, portable and non-grid connected solutions were tested through a mobile battery bank and solar powered charger. The solar charger worked well, especially in remote locations where grid access was not possible. Customers were very excited about the mobile battery bank, but some technical limitations

Figure 15: L25 Being Charged by Mobile Battery Bank

Figure 16: L25 Charging on Solar Charger

reduced its effectiveness. The battery bank was large and required a dedicated trailer for transportation so there was a need for an additional truck or trip. The battery bank also required a lengthy recharge time. There is a benefit and interest in this type of solution, if a cost-effective battery bank can be provided for opportunity charging between jobs or shifts and it can easily transported without additional equipment.

The positive impacts of using battery electric equipment such as noise and vibration reductions were significant benefits that all customers commented on during testing. The ECR25 had a measured 9dBA drop in sound pressure around the machine compared to an equivalent diesel machine. This was verified through empirical testing measurements and informal operator feedback. Direct feedback indicated that operators no longer felt fatigued at the end of their shift. With diesel equipment, they were constantly exposed to vibration and noise throughout the day, but electric equipment significantly reduced those exposures by not having an internal combustion engine inducing vibration into the operator and significantly lowering noise pollution. The operators no longer had to yell over the engine of the machine to the surrounding crew.

General maintenance costs of the equipment have dropped significantly. There are still hydraulic filters, but there are no longer engine air filters, oil filters, or oil changes required. The only general maintenance required on the equipment is standard lubrication for moving mechanical joints. One of the operators even commented that the lubrication needs were decreased because the equipment was so quiet they could determine the need for lubrication by hearing the equipment in operation as opposed to providing lubrication on a time based schedule, which commonly led to an excess of grease being applied.

Total project cost was $3.15 million, with $2 million funded by a U.S. EPA Targeted Airshed grant. Volvo Construction Equipment (CE) invested an additional $1.155 million in match share.

The L25 and ECR25 are both commercially available in North America, as well as Europe and other select countries around the world. The L25 is a versatile machine that can be used in a range of applications from material transfer and loading to lifting, digging, and transporting. The ECR25 can be equipped with various attachments such as different buckets for specific digging and trenching applications or tools such as breakers.

Project learnings have continued to strengthen the Volvo viewpoint that battery electric machines are an excellent fit for reducing NOx emissions in the compact construction equipment sector while also providing positive health impacts to the operators, crews and communities in which this equipment operates. Feedback from the crews who have used this equipment is used in continued refinement of these products and in the planning and development of future products. While the work completed as part of this project clearly demonstrated that this equipment works as well or better than diesel equivalents, there are still some applications where heavy-duty cycles require increased runtime. Recharge time and access to charging infrastructure could pose a barrier to entry for some customers. As a result, Volvo will continue to investigate ways to enhance the runtime of this equipment, optimize on-board charging to efficiently use available power where they operate, and explore alternate methods of charging. Since testing conducted for this project, enhancements have been made to the L25 to decrease the AC charging time by 50%. The L25 is now capable of Level 2 charging in six hours. Volvo intends to continue evolving its product portfolio with additional compact construction equipment models as well pursue larger equipment of various types. One example of this commitment has been the public introduction of a 22-ton electric excavator, the EC230.

In May 2022, Volvo participated in the annual Advanced Clean Transportation (ACT) Expo, which is North America's largest event dedicated to fleet sustainability. Volvo announced the expansion of its battery

electric compact equipment offerings. The announcement introduced the L20 Electric compact wheel loader, and EC18 and ECR18 Electric compactor excavators, bringing the Volvo CE electric lineup to an industry-leading five pieces of equipment. In addition, Volvo also announced that the 20-ton EC230 Electric excavator, which is not yet commercially available, will be coming to North America for future demonstration projects. "Off-road equipment is the next frontier in electric vehicles, and Volvo CE is proud to lead the way in the construction industry's sustainability journey," said Stephen Roy, president, Region North America at Volvo CE. "Fleets need cleaner solutions to meet growing regulations and societal demand, and now we have five electric compact models for our customers to choose from."

Figure 17: Expanded Volvo Zero Emission Equipment Line Up

- **Zero Emission Truck Innovation Fleet Project**

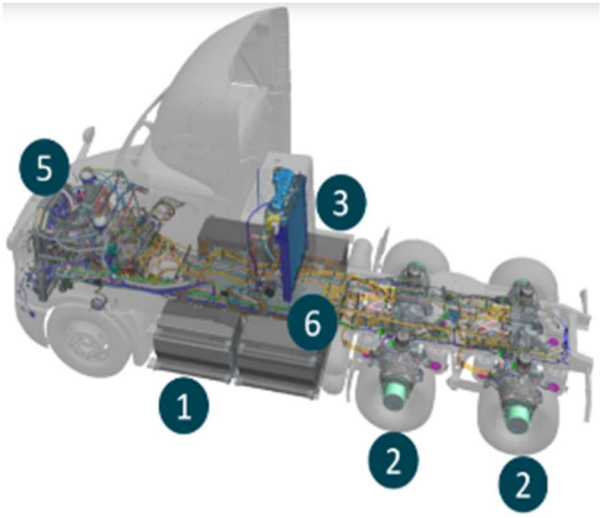
Along with co-funding from U.S. EPA, POLA, and POLB, South Coast AQMD supported development and deployment of 20 Daimler (Freightliner) battery electric trucks (BETs) and fast charging infrastructure. The Innovation Fleet Project was the single largest investment that South Coast AQMD has made in the development of Class 8 BETs and infrastructure at that time. It allowed DTNA, the parent company of the Freightliner Truck brand, to scale a pilot prototype battery electric truck concept to full commercialization. The intention and larger vision for this deployment was to gain knowledge and testing with customers in real world applications of BET technology. The project was initiated in early 2019 and completed in December 2022. This project spun a series of follow up BET and infrastructure projects with additional demonstration partners.

The main objective is to identify a range of applications where the transportation industry sector is the best fit for heavy-duty battery electric technologies and identify the locations where it is most needed to reduce emissions associated with diesel truck use. The project aimed to capture a variety of adoption burdens, duty cycles, and operational schedules to provide a comprehensive knowledge base of BET charging and operation. Penske Trucking Leasing (Penske) and NFI were selected as the fleet partners for the deployment

and demonstration of these BETs. Through NFI's Port drayage activity and Penske's rental, leasing, and logistics operations, a variety of heavy-duty BET applications were demonstrated in the South Coast region. Penske was able to lease the BETs to various fleets including UPS, Costco, and Iron Mountain to gain additional real-world experience in a wide variety of operations.

Fifteen Class 8 eCascadia and five Class 6 eM2 BETs were deployed in this project. The eCascadia (see Figure 18) deployed in this project had the following main specifications. These are first generation prototypes meant for use as a proof of concept. The final series production specifications are significantly improved from the prototypes.

Range	160 miles	**Battery**	410 kWh
Charging Time	160 min (80% soc)	**Max Charge Power**	150 kW
Charging Type	CCS Type 1	**Power (peak/continuous)**	500 kW / 240 kW
Top Speed	65 mph / 105 kmph	**Cab Type**	Day Cab
Curb Weight	23,500 lbs. / 10,660 kg	**GVWR**	80,000 lbs.
Startability	18% grade	**Gradeability**	2% grade at 50 mph



1. Battery, 2. E-Axle, 3. Power Distribution Unit, 4. Inverter, 5. Vehicle Control Unit, 6. Brake Resistor

Figure 18: Exterior Look of Class 8 eCascadia Truck Specifications and Main Components

The eM2 (see Figure 19) had the following main specifications:

Range	*50-100 miles*	**Battery**	*220 kWh – 330 kWh*
Charging Type	CCS Type 1	**Power (peak)**	*440 kW Allison / 180 kW Meritor*
Top Speed	*65 mph*	**GVWR**	*26,000 lbs.*
Curb Weight	*~ 17,500 lbs.*	**Gradeability**	*20% at 25 mph at GVWR*
Startability	*25% grade at GVWR*		

Ten eCascadia and five eM2 BETs were demonstrated by multiple leasing customers of Penske for local pick-up and delivery as well as first/last mile services. These duty cycles generally have lower daily mileage compared with long-haul and typically return to an established depot to be domiciled overnight. Five eCascadia BETs were demonstrated by NFI. They were operated out of its inland warehouse facility for drayage activities. A total of over half a million miles were traveled among the 20 BETs, with emission reductions of 0.92 tons of NOx, 0.07 tons of PM2.5, and 912 metric tons of GHG emissions.0.92 tons for NOx, 0.07 tons for PM2.5, and 912 metric tons of GHG reductions.

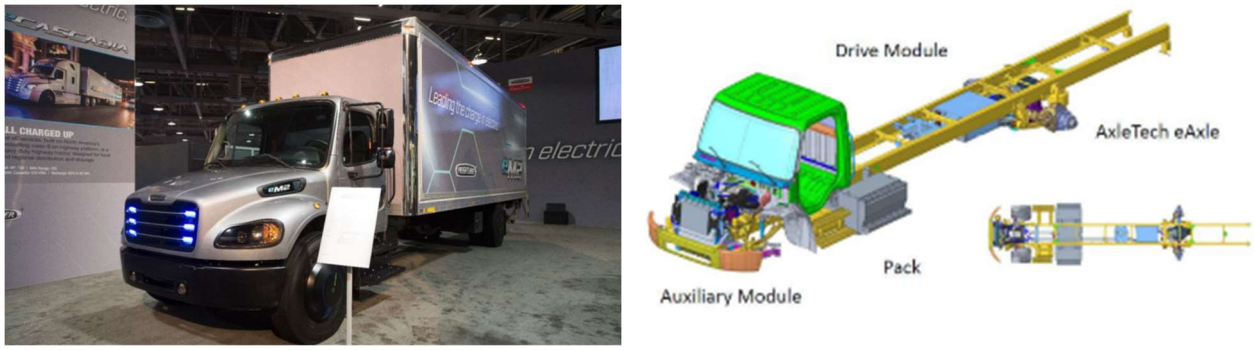


Figure 19: Exterior Look of Class 6 eM2 Truck and the Main Components

The operation activities among the 20 BETs are summarized in Table 8 below. Trucks typically operated 6 to 9 hours a day with a daily charging time of 3 to 4 hours. eCascadia BETs traveled 100 to 150 miles per day on average with an average energy consumption of approximately 2 kWh/mile. eM2 BETs traveled 85 miles per day with an average energy consumption of 1.4 kWh/mile.

Table 8: Telematics Truck Operation Data (Oct 2019 - Jun 2021)

Fleet	Vehicle	Total Miles	Miles/Day			kWh/Mile			Driving Hrs/Day			Charging Hrs/Day		
			Avg.	Min	Max	Avg.	Min	Max	Avg.	Min	Max	Avg.	Min	Max
Penske	eCas	228,857	104	16	196	2.1	0.9	3.7	5.5	0.8	15.3	3.5	0.2	8.9
Penske	eM2	55,702	85	11	135	1.4	1.0	2.0	8.9	1.0	12.5	2.7	2.3	2.8
NFI	eCas	236,836	151	78	246	2.0	1.2	3.5	7.6	2.7	11.6	3.9	1.0	9.0

Sixteen chargers (mostly 150 kW DC fast chargers) and one battery energy storage system (BESS) across seven sites were deployed to charge the 20 BETs (see Figure 3 for examples). Data for the Penske fleets at its six sites reflected that the chargers had 62% to 100% uptime during the demonstration period. The majority of charging took place during off-peak hours, which helped with cost savings.

Figure 20: Examples of BET Chargers

Fleets surveyed during the demonstration BETs showed support for BET adoption with feedback for improvement in some areas. According to the survey responses, the BETs provided exceptional driver comfort due to the elimination of engine noise and vibration inside the cab. Power and torque availability allowed smoother operation during high traffic conditions. Additionally, the BETs provided rig stability and outperformed diesel powertrains in acceleration, power, and ease of driving.

On the other hand, BET uptime was not always satisfactory. Both eCascadia and eM2 BETs experienced eAxle failure, requiring repairs. Charging sessions were sometimes unsuccessful or interrupted due to charger interoperability issues. Problems originated at the charger hardware, network service, and vehicle software level. Fixing chargers was always time consuming and involved hundreds of tests. At the time of the demonstration, the charging network was still in its infancy for medium- and heavy-duty high-power applications. More advanced features, such as automated fleet scheduling, load management, reporting, and data analysis were not fully functional for the project.

The Innovation Fleet project proved that BETs are competitive for short-haul use cases along with the benefits of emissions reductions. The project indicates that significant coordination is needed among charger hardware manufacturers, network service providers, and vehicle hardware team. A charger validation process is critical for future BET deployments. A protocol should be established to specify coordination, responsibilities, and duties among the hardware and software providers to ensure uptime of BETs and chargers. While COVID-19 caused numerous delays on parts, permits, and software, supply chain issues and overwhelming demand is expected to continue as more OEMs deploy BET offerings. The industry has raised concerns that the strong power and torque of battery-electric powertrains combined with the greater total vehicle weight of a battery-electric tractor will tax today's standard tires beyond the current standard. While not assessed quantitatively in the project, tire durability may be worthy of future study.

The Innovation Fleet project to deploy 20 BETs in the goods movement and logistic sectors has been a critical step for future deployments and further market penetration. Technology improvements to increase

mileage and lower costs will support a wider variety of use cases for BETs. Issues identified in the project are informative for the industry and fleets.

- **Zero Emission Drayage Truck Project**

The California Zero Emission Drayage Truck (ZEDT) Demonstration project was funded by a CARB grant from the Greenhouse Gas Reduction Fund, South Coast AQMD Clean Fuels Fund, and match share from OEMs, including BYD, Kenworth, Peterbilt/Meritor/TransPower, and Volvo. The GGRF ZEDT project is part of California Climate Investments (CCI), a statewide initiative that puts billions of Cap-and-Trade dollars to work reducing greenhouse gas emissions, strengthening the economy, and improving public health and the environment – particularly in disadvantaged communities.

The GGRF ZEDT project deployed 44 pre-commercial Class 8 battery electric, CNG, and diesel hybrid electric drayage trucks, including 25 BYD battery electric trucks, 12 Peterbilt/ Meritor/TransPower battery electric trucks, two Kenworth CNG series hybrid trucks, three Volvo diesel parallel plug-in hybrid trucks, and two Volvo battery electric trucks, along with supporting infrastructure. These trucks were operated in revenue service at the Ports of Los Angeles, Long Beach, San Diego, and Oakland traveling the state of California, including the areas under South Coast AQMD, Bay Area AQMD, SJVAPCD, and San Diego APCD jurisdictions.

The GGRF ZEDT project was funded to demonstrate the feasibility of multiple zero and near-zero emission technology pathways for Class 8 drayage trucks. These technologies included zero emission battery electric trucks as well as near-zero emission CNG hybrid electric and diesel hybrid electric trucks. At the time that the GGRF ZEDT project was funded in 2016, it was not known when battery electric trucks would become CARB certified commercial trucks and whether there would continue to be a need for near-zero technology alternatives such as CNG and diesel hybrid electric trucks as interim technologies. The intent of this project was to demonstrate feasibility of multiple truck technologies to enable lessons learned and more choices for fleet adoption to transition to cleaner truck technologies to meet GHG and criteria pollutant emission reduction goals.

BYD demonstrated and deployed two phases of the BYD Class 8 Model 8TT battery electric trucks. The 8TT is an over-the-road tractor which was still in design phase at the beginning of the project, built upon prototypes and experience from manufacturing Class 2 - 5 buses and municipal trucks. Phase 1 trucks included a 207 kWh battery. Phase 2 trucks had a larger battery of 435 kWh. The use of higher power DC fast charging reduced charging times while enabling higher vehicle range. BYD truck and infrastructure specifications are shown in Table 9.

Table 9: BYD Truck and Infrastructure Specifications

Phases	Battery (kWh)		Infrastructure	Charging Time (hours)	Range (miles)
Phase 1	207		80 kW AC	3 hours	100
Phase 2	435		40 kW AC 120 kW DC	11 hours 3.5 hours	125

Peterbilt/Meritor/TransPower demonstrated and deployed two phases of Class 8 Model 579 battery electric trucks. Phase 1 trucks had three battery sizes ranging from 264 kWh – 352 kWh. Phase 2 trucks had a 396

kWh battery. Phase 2 trucks used higher power DC fast charging to have a longer vehicle range without increasing charging time. Peterbilt/Meritor/TransPower truck and infrastructure specifications are shown in Table 10.

Table 10: Peterbilt/Meritor/TransPower Truck and Infrastructure Specifications

Phases	Battery (kWh)	Infrastructure	Charging Time (hours)	Range (miles)
Phase 1	264	70 kW AC	3 – 4 hours	110
	308	70 kW AC		130
	352	70 kW AC		150
Phase 2	396	180 kW DC CCS1	3.5 hours	130

Kenworth demonstrated and deployed two Class 8 CNG hybrid electric truck tractors. This was intended to determine technical and economic feasibility of replacing mechanical systems used on diesel engine technology for Class 8 truck tractors with an engine and generator set fueled by NG. The truck also has a large high voltage battery bank for zero emission operations and to supplement engine output to the electric drive system. Kenworth truck specifications are shown in Table 11 below.

Table 11: Kenworth Truck Specifications

Item	Specification	Comments
GVWR	>33,000 lbs.	GVWR for Class 8 trucks
GCWR	80,000 lbs. max	61,000 lbs average
Engine type/Rating	Stock Cummins L9N engine/320 hp	Un-modified production engine
Engine fuel	CNG	
Fuel tank capacity	150–200 US DGE	Agility Fuel Tank Assembly
Hybrid motor rating	300 kW	Fully integrated electric motor-transmission and inverter assembly
Transmission Type	Automated manual	
Power assist Steering	Electric over hydraulic	Custom
Tire specs	Smart Way Certified	
Acceleration	Equal to or better than conventional vehicle	
Interior noise	Per FMCSA Part 393.94	
Exterior noise	Comply with federal, state & local noise ordinances (FMCSA Part 325.7)	
Fuel economy	20% or greater	

Based on simulation models and data from customer routes in southern California near the Ports of Los Angeles and Long Beach, the model predicted the performance of various hybrid and battery configurations and components to assist in truck design. A series hybrid electric vehicle was designed around the Kenworth T680 day cab, with the trucks modified, assembled and tested. Sourcing components for the truck proved to be more challenging than anticipated due to supply chain issues during the pandemic. The hybrid genset with large capacity high voltage batteries was shown to be technically feasible in these applications but not reliable enough for mass production. Continued development of the genset hybrid vehicle design would need to focus on improving reliability, reducing complexity, and lowering the truck cost. Selected

performance metrics for the Kenworth CNG hybrid electric truck based on their T680 day cab platform are shown in Table 12.

Table 12: Kenworth Truck Performance Metrics

Parameter	Expected Performance
Max battery charge	~100 kwh
Max torque	2000 Nm total (1475 ft-lb)
Range	150 miles
Top Speed	62 mph
Grade ability	6.5% Grade at 20 mph 5.0% grade at 30 mph
EV mode (electric only) Range	30-40 miles or 1 hour of operation depending on duty cycle and trailer load
Operating temperatures	16F (-9C) to 135F (57C)

*All performance parameters tested with a vehicle GVWR of 65,000 lbs.

Volvo developed and refined a plug-in hybrid EV (PHEV) drivetrain and tested an emission aftertreatment system in the form of a mini-burner which was to maintain the catalyst temperature to improve hybrid emissions performance. The first PHEV truck was from a prior U.S. DOE funded project and used as an engineering mule by Volvo during the first half of the project. The second PHEV truck with the same technologies as the first one was deployed and completed revenue service in 2017. For the third PHEV truck, real world testing on three prescribed test routes including extended stop and go activities was used while CO2, NOx, CO and total hydrocarbon emissions were quantified using portable emission measurement system (PEMS). The third PHEV truck had the mini-burner and EcoDrive technology and was tested at Volvo's engineering campuses before the mini-burner aftertreatment system was tested extensively at West Virginia University (WVU) Center for Alternative Fuels Engines and Emissions (CAFEE) using a combination of chassis dynamometer and local road cycles. Emissions data was collected using typical CAFEE equipment and methods and compared with baseline tests performed on the first PHEV to quantify NOx and GHG emission reductions. Four different routes were used to evaluate operation of the third PHEV with two combined weight configurations for the truck and trailer at 31,900 lbs and 64,300 lbs. After the third PHEV was transported to California, WVU CAFEE also tested the truck using their Transportable Emissions Measurement System (TEMS) on three different drayage routes between the San Pedro Bay Ports and Inland Empire warehouses and railyards. The third PHEV was then tested at University of California Riverside to confirm performance and robustness of the connected intelligent transportation system (C-ITS) EcoDrive technology while operating on connected freight corridors before the five month deployment at Intermodal Bridge Transport (IBT) ended in 2021.

In late 2021, Volvo deployed two Class 8 VNR Electric trucks at Producers Dairy in Fresno, located in an AB 617 disadvantaged community. Producers Dairy has a fleet of over 80 tractor trucks and does short and long-range deliveries throughout the state; it also deployed two 150 kW DC fast chargers in Fresno.

Table 13: Volvo Truck and Infrastructure Specifications

Battery (kWh)	Infrastructure	Charging Time (hours)	Range (miles)
375	150 kW DC	2.5 hours	150

Battery electric, CNG hybrid electric, and diesel hybrid electric trucks from the four OEMs are shown in Figure 21.

Top to bottom, left to right:
BYD Phase 1 8TT in service at GSC Logistics in Oakland;
Peterbilt/ Meritor/TransPower Model 579 in service at Biagi Brothers in Napa;
Kenworth CNG hybrid truck at TTSI in Compton;
Volvo diesel plug-in hybrid truck at IBT in Wilmington; and
Volvo VNR Electric truck at Producers Dairy in Fresno, CA.

Figure 21: ZEDT Trucks Deployed at Various Fleets

OEMs installed different types of infrastructure to support their trucks. BYD deployed their proprietary 80 kW AC and 40 kW AC chargers with a GB/T connector (standardized connector used in China) in both phases. AC Chargers for Phase 2 trucks had lower power than Phase 1 trucks since BYD changed the charging platform to meet the demands and trends of the medium- and heavy-duty truck market. BYD later switched to 150 kW DC fast charging with an SAE standard CCS1 connector at the request of fleets with BETs from multiple OEMs who wanted their trucks to have the ability to utilize the same charger/connector. Peterbilt/Meritor/TransPower utilized 70 kW AC charging using proprietary marine grade connectors but switched to DC fast charging to increase range without increasing charging time. Shifts from proprietary to

standardized connectors and from AC to DC fast charging reflected fleets' preferences for increased vehicle range, less charging time, and ability for trucks to utilize any charger at their site.

For the Kenworth CNG hybrid electric trucks, TTSI was able to take advantage of a nearby CNG public fueling station hosted by Clean Energy for fueling as needed. The Volvo diesel plug-in hybrid truck also utilized existing diesel fueling infrastructure. The two Volvo battery electric trucks at Producers Dairy in Fresno had two 150 kW DC fast chargers installed since there were no other fast chargers in Fresno.

Figure 22: Charging and Fueling Infrastructure for ZEDT Trucks

Detailed operational data, including vehicle performance data, were obtained using HEM data loggers which were stored, collected, and analyzed by Ricardo. Data were collected from June 2019 to October 2021 by Ricardo. Mileage data for the 44 Class 8 trucks are shown in Table 14.

Table 14: Truck Mileage

OEM	Battery Electric	CNG Hybrid Electric	Diesel Hybrid Electric
BYD	329,429		
Peterbilt	137,565		
Kenworth		8,240	
Volvo			23,091
TOTAL	**466,994**	**8,240**	**23,091**

Since the ZEDT project started in 2016, Class 8 battery electric trucks have become CARB certified and commercialized from the OEMs, including BYD, Peterbilt, Volvo, Kenworth, and Daimler. The ZEDT project enabled four OEMs to work towards developing, demonstrating and deploying Class 8 trucks on multiple fuel platforms, at a time when the future zero and near-zero emission pathways for these trucks were not certain. While CNG trucks ended up using engines capable of ultralow emissions such as 0.02 g/bhp-hr and diesel hybrid electric trucks capable of operating in zero emission mode for a limited range did not follow a commercial pathway, deploying these trucks enabled the four OEMs to garner valuable lessons learned and an opportunity to work with 22 fleets in deploying trucks at different stages of development.

Ricardo conducted surveys and interviews with project participants near the end of the project on the truck and infrastructure deployment process and lessons learned. Eighteen of the 22 fleets in the project indicated

they would consider the addition of advanced technology drayage trucks in their fleets subject to the following key improvements:

- Total cost of ownership must be competitive with conventional drayage trucks
- Increased vehicle range so that trucks could be assigned to all routes operated by drayage companies
- Reliability similar to conventional drayage trucks which typically do not exceed 10% downtime
- Service and maintenance and parts availability comparable to conventional trucks with fleets preferring to perform most maintenance at their in-house facilities

Fleets also suggested that advanced technology trucks should be 1:1 replacement for conventional diesel drayage trucks and that the following should be in place:

- Ensure vehicle certifications are in place prior to deployment
- Minimum vehicle range of 150 miles. Some fleets suggested that 200 miles or as much as 350 miles would be the minimum vehicle range, since limited range meant that trucks could only be assigned to up to 50% of existing routes.
- Reduced charging time to 90 minutes or less to allow charging at the end of longer routes
- Capital costs similar to conventional diesel trucks
- Assistance in obtaining full coverage for vehicle insurance for advanced technology trucks
- Tractor weights similar to conventional diesel trucks
- Tractor safety improvements including warning sounds when underway, adjustable side view mirrors inside the cab, and better acceleration at highway speeds
- Standardization of charging hardware
- Viable options to reduce electricity costs while allowing opportunity charging
- Reliable vehicles and good technical support
- Better coordination between fleets, OEMs, and utilities to better understand vehicle and infrastructure technologies to reduce costs, maintenance and repair options, safety requirements and vehicle features
- Improved training programs for fleet operators, managers, drivers, maintenance technicians and first responders

Near-zero truck technologies such as the Kenworth CNG hybrid electric and Volvo diesel hybrid electric trucks were successfully demonstrated at two fleets, TTSI and IBT, and were able to be utilized for drayage service. However, both technologies are not ones which Kenworth and Volvo plan to further develop and commercialize.

Kenworth used the chassis from a previous project for field demonstration and encountered issues with obtaining components during the pandemic due to supply chain issues. This resulted in a delay in the deployment of their two trucks. The other challenge is that by the time the ZEDT project was completed in April 2022, the regulatory climate at CARB had transitioned to become more supportive of zero emission technologies and residents in disadvantaged communities began to increasingly demand deployment of zero emission trucks in their communities. Fuel cell technologies using hydrogen fuel became more technically feasible and are being demonstrated, with a future pathway towards commercialization as another viable zero emission truck technology. CARB regulations such as the Advanced Clean Trucks and upcoming Advanced Clean Fleets regulations have increasingly stringent requirements for OEMs to produce zero emission trucks and for fleets to deploy 100% zero emission trucks by 2035.

Volvo intended for the ZEDT project to accelerate deployment of zero and near-zero emission truck technologies. For its diesel hybrid electric truck, Volvo implemented geo-fencing, driver information,

hybrid controls featured and advanced aftertreatment temperature management through a post-turbo mini-burner. These combined technologies targeted very levels NOx emissions levels when in operated in near-zero emission operational modes. The mini-burner reduced NOx emissions across all test routes and combined vehicle test weights by 50% -90% compared to traditional diesel only operation. However, when the hybrid operation was combined with use of the mini-burner, there were reduced NOx emissions for light-load and cold-start conditions but these were increased for higher load and warm operation as additional thermal management challenges were introduced by hybrid operation and affected the conversion efficiency of the mini-burner. Through rigorous simulation modeling, EcoDrive was shown to help the vehicle consume 6% - 18% les energy when traveling on arterial freight corridors with connected intersections and to reduce tailpipe NOx emission by 3% - 5% based on modeling results from conventional trucks. However, the impact of EcoDrive was minimal with PHEV trucks which already had lower NOx emissions. Additional research would be needed to characterize the level of energy savings and emission reductions that EcoDrive could provide under a variety of settings.

Battery electric trucks were able to prove themselves from a commercial standpoint and are currently the main commercially available and certified zero emission truck technology. BYD and Peterbilt/Meritor/TransPower have deployed commercial versions of their Class 8 battery electric trucks from the development and demonstration work in the ZEDT project. Between Phase 1 and Phase 2 versions of their trucks, they increased battery size and switched to DC fast charging with CCS1 connectors to keep the charging time about the same for the larger batteries. Towards the end of the project, Volvo deployed two Class 8 battery electric trucks which they had developed and demonstrated on another CARB funded GGRF project Volvo LIGHTS. This project resulted in the commercialization and certification of Volvo's battery electric truck in December 2020. The Volvo battery electric truck has roughly an equivalent battery size and vehicle range as the Phase 2 BYD and Peterbilt/Meritor/TransPower trucks and were among the first Class 8 battery electric trucks deployed in Fresno.

- **Volvo Low Impact Green Heavy Transport Solutions (LIGHTS)**

The Volvo LIGHTS project was a unique collaboration between Volvo, South Coast AQMD, and 12 other organizations that each contributed critical expertise, capital, and commitment to achieve the goal of successful widescale deployment of commercial battery electric trucks. Prior to commercialization of the battery electric trucks, two Southern California fleets - NFI and DHE piloted Volvo Class 8 VNR Electric demonstration trucks in their daily routes and provided real-world feedback to Volvo. TEC Equipment Fontana, Volvo Trucks' largest West Coast dealership, was trained and equipped to provide local maintenance and technical support on repairs for the demonstration trucks and provided access to high-power 150 kW DC fast chargers prior to installation of their own charging infrastructure.

The project ran from February 2019 to September 2022. In 2020, Volvo deployed its first pilot VNR Electric trucks to fleets in the South Coast Air Basin. The first demonstration trucks were delivered to TEC Equipment in Fontana for local parts distribution, as well as NFI and DHE for freight transport throughout the region. Starting in 2021, TEC Equipment also provided the opportunity for local fleets with different types of revenue service — including Albertsons, Penske Truck Leasing, Medline, SAIA, Quality Custom Distribution (QCD), 10 Roads Express, and SCE — to lease Volvo VNR Electric trucks to gain hands-on experience and determine where battery electric trucks might best fit their routes. With supplemental funding through a U.S. EPA Clean Air Technology Initiative Grant, 30 battery electric trucks were deployed through the Volvo LIGHTS project. Fourteen fleets utilized Volvo VNR Electric trucks in commercial operation during the Volvo LIGHTS project, hauling freight 80-150 miles per day.

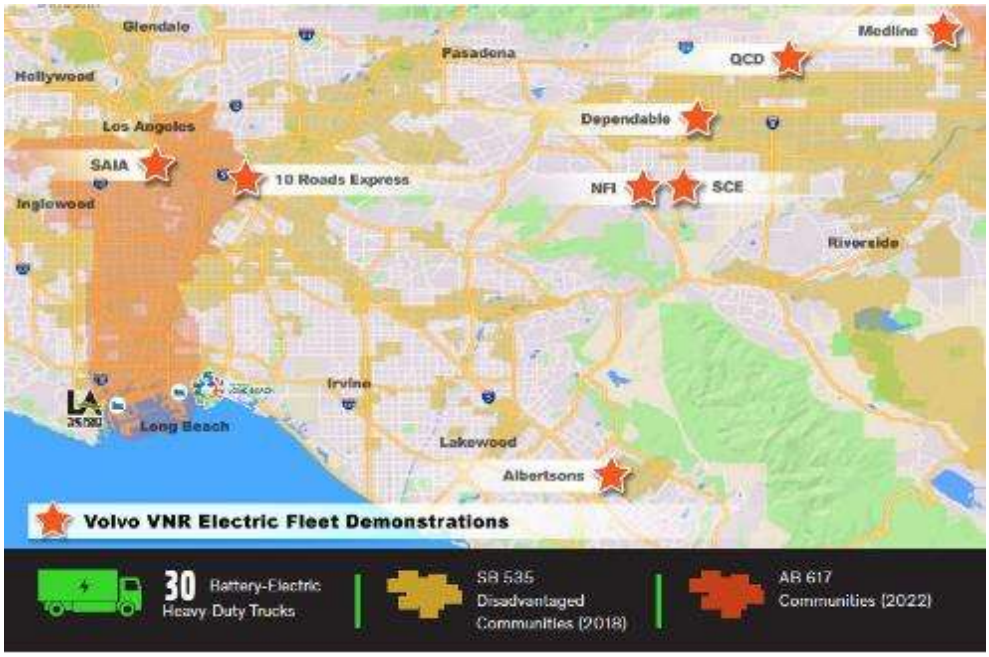


Figure 23: Locations of fleets with VNR Electric Trucks in SB 535 and AB 617 Communities

Shell Recharge Solutions (formerly Greenlots) supported DHE, NFI, and TEC Equipment with installation of private chargers for the battery electric trucks, yard tractors, forklifts, and light-duty vehicles. Level 2 chargers for light-duty vehicles, AC chargers for the forklifts, 50 kW DC fast chargers for the yard tractors, and 150 kW DC fast chargers for the trucks were on the SKY networking software, which integrated with Volvo's truck telematics, to balance the needs of the trucks and cargo handling equipment, facility, and utility grid. The Ports of Los Angeles and Long Beach also provided infrastructure planning support to facilitate early adoption of battery electric trucks for Port drayage service, while SCE analyzed the grid impacts of charging.

Figure 24: Three Volvo VNR Trucks Charging at DHE in Ontario

As part of the Volvo LIGHTS project, DHE and NFI installed 1.5 MW of rooftop and canopy solar at its facilities. Annually, solar at both sites will generate 1.86 GWh of renewable electricity. Solar at DHE is

more than enough to power its facility; Volvo VNR Electric, yard tractor, and forklift fleet; and Level 2 light-duty vehicle chargers. DHE's investment in onsite solar panels, energy storage, and battery electric vehicles and equipment enables DHE to save more than $100,000 annually on fuel and energy costs.

Volvo LIGHTS project partner, University of California, Riverside – Bourns College of Engineering Center for Environmental Research & Technology (UCR CE-CERT) used project data to develop algorithms to improve battery electric truck routing and reduce impacts on local communities. Early simulations evaluated the performance of the Volvo VNR Electric using a heavy-duty chassis dynamometer and performed an environmental life cycle assessment (LCA) of its well-to-wheel impact. Results showed that the Volvo VNR Electric saves 65% in total energy, 81% in fossil energy, and provides an emissions benefit of more than 80% reduction in GHG emissions and criteria pollutants/toxics compared to baseline vehicles evaluated in this study.

Battery electric trucks have highly specialized components, such as battery systems, advanced power management software and computing systems, regenerative braking systems, and high-voltage electrical systems, requiring development and implementation of appropriate training modules for the safety of service technicians. Rio Hondo College and San Bernardino Valley College both launched heavy-duty battery electric truck technician training and first/second responder safety programs, which offered a blend of in-person hands-on and online coursework. Volvo provided the colleges with battery electric drivetrains and components from the Volvo VNR Electric, enabling the students to have valuable hands-on learning opportunities. More than 45 students completed these training programs at the two colleges in 2021 and 2022.

Yard tractors and forklifts typically only operate within the proximity of a warehouse facility, thereby impacting the local air quality in the vicinity of the warehouses. During their lifetime, it is estimated that each battery electric forklift and yard tractor is equivalent to removing 30 and 100 gasoline-powered cars from roads for a year, respectively. Battery electric forklifts and yard tractors at DHE and NFI were widely accepted by the equipment operators. Among the many benefits they noted, equipment operators appreciated the quieter, smoother operations. In addition, battery electric forklifts and yard tractors demonstrated lower operating costs and maintenance costs relative to diesel and propane equipment (76% -100% in lower fueling costs and 50-64% in lower maintenance costs).

Figure 25: DHE Replaced 100% of Forklifts at its Ontario Facility with Battery Electric Forklifts

Over the course of the project, the Volvo LIGHTS project won five awards. These included the following: Breathe Southern California 2020 Innovation Award, CALSTART 2020 Blue Sky Award, 2021 Climate Leadership Award – Innovative Partnership, South Coast AQMD's 32nd Annual Clean Air Award for Innovative Clean Air Technology, and Southern California Association of Governments 2022 Sustainability Award for Outstanding Achievement in Sustainability. This is the highest honor category in the program and recognizes projects that best exemplify the core principles of sustainability.

In January 2022, Volvo announced production of an enhanced VNR Electric model, including new vehicle configurations, with an operating range of up to 275 miles, and ability to achieve an 80% charge in 90 minutes for the six-battery truck configuration and 60 minutes for the four-battery truck configuration.

Over the three-year project, the Volvo LIGHTS partners designed and implemented a blueprint for the complete ecosystem needed to successfully deploy commercial battery electric freight trucks. While the Volvo LIGHTS project took place entirely in the South Coast Air Basin, lessons learned from the project can be replicated in any region to support fleets with the transition to zero emission electromobility solutions.

- **200 Vehicle In-Use Emissions Study**

On-road HDVs, primarily consisting of freight trucks, transit buses, school buses and refuse trucks, are major sources of criteria pollutant and GHG emissions in the State of California and in the South Coast Air Basin. The South Coast Air Basin is one of only two air basins in the U.S. categorized as being in "extreme nonattainment" of national ambient air quality standards for ozone. Mobile sources including HDVs emit more than 80 percent of the inventory for NOx, which is the primary precursor of ozone. Rapid NOx reduction from HDVs is therefore a critical step towards achieving health-based ozone standards. Over the last 30 years, major progress has been made to reduce HDV emissions of NOx, as well as PM. This has resulted in improved ambient air quality in the South Coast Air Basin and throughout California. In particular, new emission standards for on-road HDVs that took effect in 2007 and 2010, respectively, led to widespread implementation of vehicles equipped with diesel particle filters (DPFs) to control PM emissions, and SCR to control NOx emissions. Moreover, alternative fueled engines certifying to the 0.02 g/bhp-hr have been deployed in the South Coast Air Basin. Even-more-stringent emissions standards will apply to new and in-use heavy-duty diesel engines starting in 2024 and 2027.

To improve understanding of this phenomenon and expand the knowledge base of how in-use HDVs emit in real-world use, CEC, CARB, South Coast AQMD, and SoCalGas cosponsored this 200 Heavy-Duty Vehicle In-Use Emissions Testing Program (Program). Two academic institutions, University of California at Riverside (UCR) and West Virginia University (WVU), were chosen to conduct all testing and analysis under the Program. Collectively, these cosponsors and the two universities designed and implemented one of the world's largest emissions testing programs for HDVs.

The Program's goal was to collect robust and empirical information that better characterizes and helps understand the real-world vehicle activity data, emissions, and fuel usage profiles of HDVs powered by common diesel engine types and technologies, as well as advanced/alternative fuel technologies. The Program aimed to assess emissions reduction efficacy of HDV technologies (engines, drivetrains, fuels and aftertreatment systems) under commonly encountered driving and operational conditions in the South Coast Air Basin. Additionally, vehicle emission measurements collected under this Program provide important new data to improve air quality planning.

The Program was conducted using a phased approach designed to initially collect vehicle operating data across a large pool of test HDVs using portable instruments. This enabled emissions measurements and other types of testing using more reliable and accurate laboratory-grade instruments across a smaller subset of test HDVs. Specifically, the HDV testing was conducted in the following four sequential phases:

1) On-road data gathering with Portable Activity Measurement Systems (PAMS) ~227
2) On-road emissions testing with Portable Emissions Measurement Systems (PEMS) ~100
3) In laboratory (stationary) emissions testing with a chassis dynamometer ~55
4) On-road emissions testing with mobile emissions laboratory trailer ~ 10

To comparatively assess emissions from different HDV fuel-technology types while being operated over representative driving cycles, data collected during PAMS testing was used to develop test cycles needed for phase 3 (HDV chassis dynamometer testing) and phase 4 (real-world HDV testing using mobile emissions laboratories on the roads of Southern California).

PAMS data collected by the two university teams represent real-world activity characteristics of the 217 tested HDVs. First, the PAMS activity data collected for each vocation were directly compared to the corresponding existing vocational chassis dynamometer test cycles for various statistical parameters. After initial cycle comparisons, summary cycle statistics such as average speeds, idle periods, average load/power were compared. Differences were observed between known standard test cycles and PAMS data for three HDV vocations: school buses, goods movement trucks, and delivery trucks. To test these HDV types under more representative conditions, new chassis dynamometer test cycles specific to these three categories were developed using a Markov-Chain Drive Cycle Generation Tool developed by WVU.

Using the vehicle test matrix from the PAMS test phase, a subset of 100 HDVs were selected for PEMS testing based on availability, vehicle type, and consideration for the later test phases. The PEMS results are considered "daily" averaged emissions where the HDV was put into revenue service as intended, regardless of the duty cycle. The analysis for Not-to-Exceed (NTE) emissions compliance, based on the provisions in Title 40 Code of Federal Regulations (CFR) Part 1065. was performed. However, the percent activity within the NTE zone was relatively limited. In general, PEMS testing incorporated a diverse set of HDVs, fleet operators, and operating conditions/duty-cycles. The PEMS results showed high variability in NOx emission levels between vocations and technology categories. For example, for all HDVs excluding non-SCR equipped diesel vehicles, daily averaged NOx emissions ranged from 0.009 to 3.616 g/bhp-hr. Furthermore, as can be seen in Figure 1 below, the observed spread varied by vocation with transit bus categories having the lowest variability and delivery trucks the highest. The same variability was observed within each technology category. The high variance observed in the data was expected, given that the emissions were measured with PEMS and averaged over the entire test day, regardless of the vocation and the duty cycle.

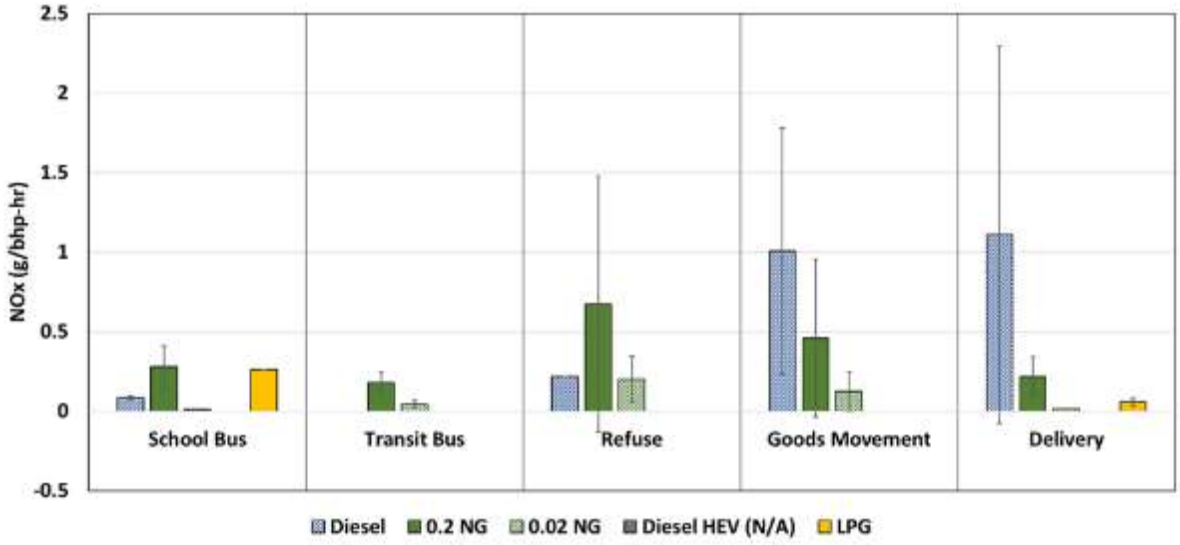


Figure 26: Brake-Specific PEMS NOx Daily Averaged Emission Rates; Source: UCR and WVU

CARB staff also analyzed PEMS data for the NG vehicles (29 0.2g NG and 17 0.02g NG vehicles) to inform updates to the NG emission rate assumptions in Emission Factors (EMFAC) 2021. Prior to this study, EMFAC only modeled NG emissions from refuse trucks and transit buses due to the lack of NG data for other truck categories. This provided a more accurate picture of emissions from NG trucks and buses operating in California.

A total of 52 unique HDVs were tested by the two universities on a chassis dynamometer under the Urban Dynamometer Driving Schedule (UDDS) and their respective vocational cycles. As shown in Figure 27, UDDS cycle-averaged results were similar across different HDV categories. This is a markedly different result than the "daily" averages presented in the PEMS section. The UDDS cycle, although not identical, closely resembles the Federal Test Procedure (FTP) certification test cycle, over which an HDV engine's emissions certification value is derived. Therefore, these UDDS data provide good comparison points to understand the NOx emissions in this context. The 0.02g NG transit bus, 0.2g NG school bus, three fuel types of refuse haulers (0.2g diesel, 0.2g renewable diesel (RD), and 0.2g NG), three fuel types of delivery trucks (0.2g diesel, 0.2g RD, and 0.2g NG), and two fuel types of goods movement trucks (0.2g diesel and 0.2g RD) had NOx emission rates higher than the respective certification standards while the remaining categories were at or below their respective levels.

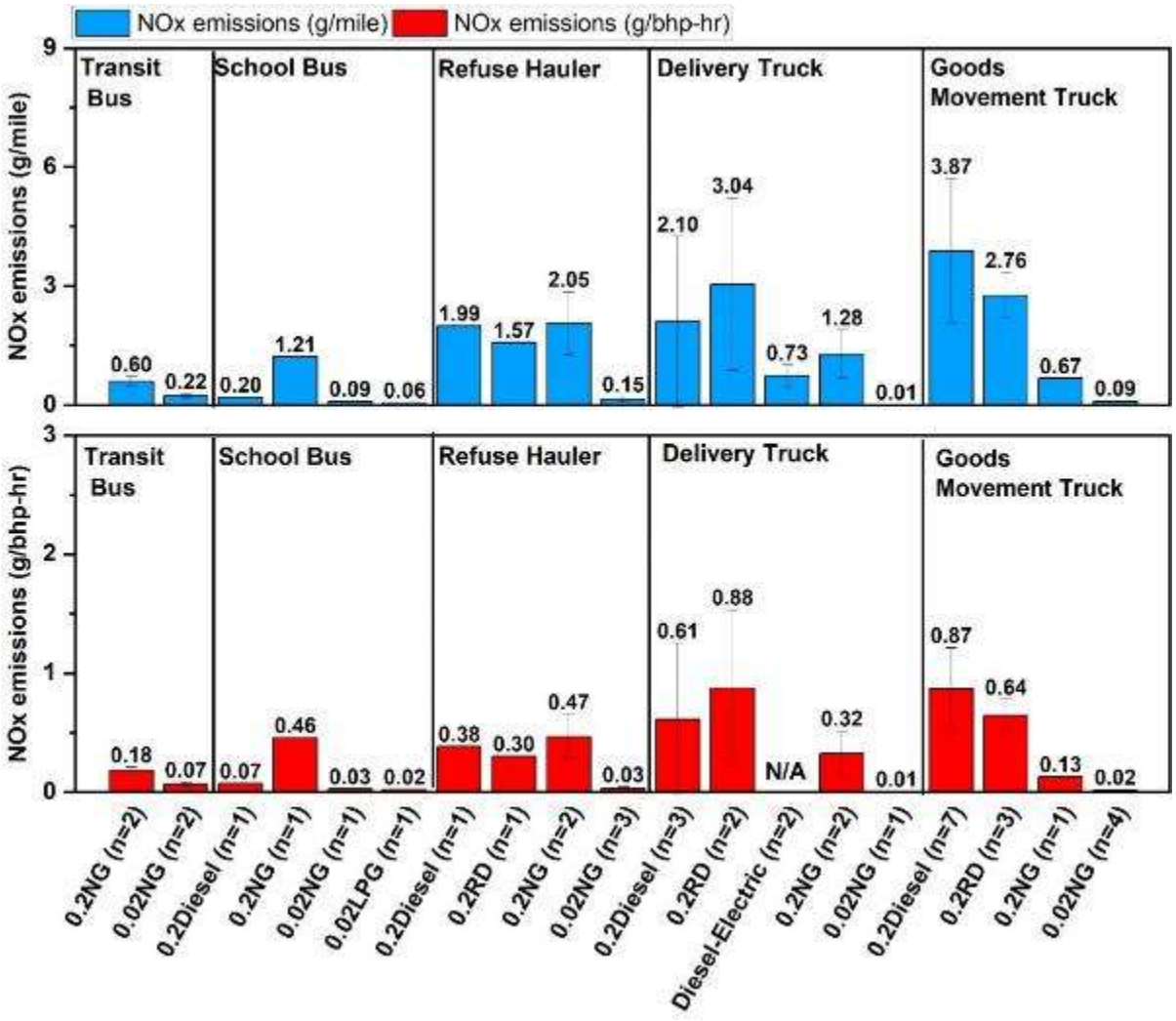


Figure 27: Cycle Average Chassis Dyno NOx Emission Rates under UDDS; Source: UCR and WVU

For vocations with well-established diesel baselines, such as delivery and goods movement categories, the NG HDVs showed significantly lower NOx emissions. The reductions were 26 to 78 percent lower for 0.2g NG HDVs and 97 to 99 percent lower for 0.02g NG HDVs relative to the diesel baselines.

A systemic error of elevated NOx emissions during idle was observed for the 0.02g NG transit bus category in the chassis dynamometer testing. Further analysis found that similar issues also impacted other 0.2g NG and 0.02g NG HDVs. The root cause is related to measurement and reported in detail in the final report. The affected data is removed from the overall data and lessons learned were documented in the final report. Overall, approximately 25 percent of NG HDVs in this study (during both PEMS and Chassis testing) were impacted by this systemic issue.

A total of 10 HDVs were tested on the roads of Southern California. The HDVs in this phase were exclusively Class 8 goods movement trucks capable of legally towing the specially designed mobile emissions lab weighing about 62,000 to 65,000 lbs. Tests were done on four different routes representing typical goods movement driving routes in Southern California. Compared to the emissions data presented

in PEMS and chassis dynamometer testing, NOx and fuel economy were averaged over the entire-test route. Distance- and work-specific NOx emission results are summarized in Figure 28 below.

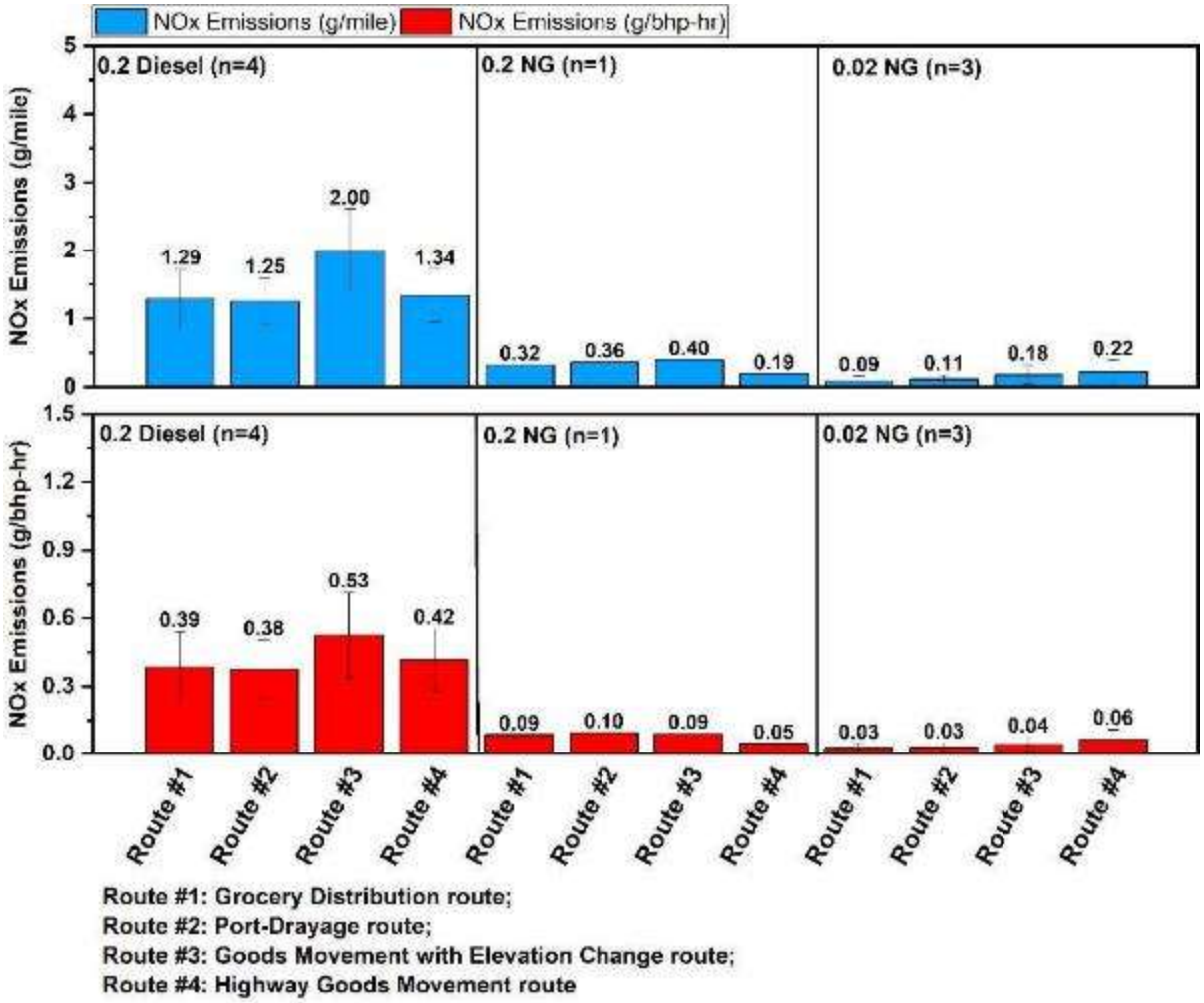


Figure 28: Route Averaged Emission Rates by Fuel Types and Routes; Source: UCR and WVU

In contrast to the larger variability during PEMS and chassis testing, route-averaged NOx emissions trends and lower variability of the on-road testing were largely expected. In part, this can be attributed to the smaller data sample as well as the single vocation. Furthermore, fixed routes reduce duty-cycle variability which has a significant impact on the daily-averaged NOx emissions in the PEMS testing. Lastly, the mobile reference lab offers better instrumentation compared to PEMS and provided a fixed curb weight throughout the route.

The Program observed many incidents where HDVs emitted NOx (and other key air pollutants) at higher-than-designed levels during real-world operation. The two test teams classified the likely causes for these HDV NOx emission "outliers" into three distinct categories: 1) Systemic, 2) Rare/Random, or 3) Duty Cycle Related. More details are documented in the final report.

All four co-sponsoring agencies have already conducted knowledge transfer activity for the Program. Specifically:

- CEC leveraged activity data from this study to support development of the Medium- & Heavy-Duty Electric Vehicle Load, Operations, and Deployment Tool (HEVI-LOAD). The inaugural Assembly Bill 2127 Electric Vehicle Charging Infrastructure Assessment report included results from HEVI-LOAD to help characterize load profiles and charging infrastructure needs for on-road medium- and heavy-duty electric vehicles.
- South Coast AQMD is using study data as a key input for its latest 2022 AQMP, which is the regional blueprint for achieving air quality standards in the South Coast Air Basin.
- CARB has published literature highlighting this Program and has incorporated study data into its latest EMFAC2021 model. In parallel, CARB has initiated efforts to further test and study in-use NG HDVs using 0.02g certified engines.
- SoCalGas has conducted various follow up activities, including participating in a maintenance cost study jointly funded by SoCalGas, U.S. Department of Energy, and South Coast AQMD.

The two universities continue to engage in activities to transfer knowledge gained through the Program. As one key example, UCR presented a summary of Program results at the Coordinating Research Council's 32nd annual "Real World Emissions Workshop" (San Diego, March 2022). Additionally, UCR and WVU team members have disseminated Program results through various other key venues that are specifically focused on reducing in-use mobile source emissions and development of emissions factors.

This study builds on these past efforts by investigating in-use emission levels of these NG HDVs in the context of the 0.02 g/bhp-hr NOx certification standard, legacy 0.2 NG HDVs, multiple HDV vocations, and other fuel types. By identifying technology impacts and shortfalls potentially causing higher than expected in-use emissions, as well as areas of exceptional in-use emissions performance, the project is informing further technology development and research opportunities to maximize emission reduction benefits from deploying 0.02 NG HDVs.

Additionally, the comprehensive dataset (and models leveraging the data) can help policymakers better understand real world emissions from California's in-use fleet (approximately one million medium- and heavy-duty vehicles). Decision makers can leverage the study results to determine the best pathways forward for meeting transportation decarbonization and air quality goals. For the on-road fleet, most of those reductions will need to come from HDVs, including newly manufactured units and those already in use. To prepare these new control measures, it is critical that the agency's planners, modelers and rule-development staff have a strong, accurate, up-to-date characterization of NOx emissions from the in-use HDV fleet operated in real-world conditions.

Table 15: Projects Completed between January 1 & December 31, 2022

Contract	Contractor	Project Title	Date
Electric / Hybrid Electric Technologies and Infrastructure			
16081	Broadband Telcom Power Inc	Provide EV Hardware and Control System at SCAQMD Headquarters Including Installation Support, Warranty and Networking	Apr 2022
17225	Volvo Technology of America LLC	Development and Demonstration of up to 2 Class 8 Battery Electric Drayage Trucks	Apr 2022
17244	Kenworth Truck Company	Development & Demonstration of four Class 8 CNG Hybrid Electric Drayage Trucks	Jun 2022
18277	Velocity Vehicle Group DBA Los Angeles Truck Centers LLC	Southern California Advanced Sustainable Freight Demonstration	Mar 2022
19182†	Los Angeles County	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Jan 2022
19183†	Southern California Public Power Authority (SCPPA)	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Jan 2022
19190	Daimler Trucks North America LLC	Zero Emission Trucks and EV Infrastructure Project	Jun 2022
19202†	City of Compton	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Apr 2022
19250†	Baldemar Caraveo	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Apr 2022
19251†	Gary Brotz	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Mar 2022
19252†	Hui Min Li Chang	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Mar 2022
19253†	Jennifer Chin	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Apr 2022
19254†	Liping Huang	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Apr 2022
19255†	Ramona Manning	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Apr 2022
19256†	Tony Chu	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Apr 2022
19278	Volvo Group North America, LLC	Low Impact Green Heavy Transport Solutions (LIGHTS) -Develop and Demonstrate Zero Emissions Heavy-Duty Trucks, Freight Handling Equipment, EV Infrastructure and Renewable Energy	Sept 2022
19279†	Douglas Harold Boehm	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Mar 2022
19280†	Emile I. Guirguis	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Apr 2022
19281†	Helen Chi	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Mar 2022

Table 15: Projects Completed between January 1 & December 31, 2022 (cont'd)

Contract	Contractor	Project Title	Date
Electric / Hybrid Electric Technologies and Infrastructure (cont'd)			
19282†	Hosneara Ahmed	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Apr 2022
19283†	Hsuan Hu	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Mar 2022
19284†	Jyi Sy Chiu	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Apr 2022
19285†	Mercedes Manning	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Apr 2022
19286†	Monica Sii	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Apr 2022
19287†	Quei-Wen P Yen	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Mar 2022
19288†	Rae Marie Johnson	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Apr 2022
19289†	Yilong Yang	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Apr 2022
19295†	Ivan Garcia	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Apr 2022
19296†	Jamei Kun	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Apr 2022
19297†	Laizheng Wei	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Apr 2022
19438†	Puente Hills Hyundai LLC	Lease Two 2019 Hyundai Kona Evs for Three Years	Jun 2022
20054†	Puente Hills Hyundai LLC	Lease One 2019 Hyundai Kona EV for Three Years	Aug 2022
20124	Volvo Technology of America LLC	Develop & Demonstrate Battery-Electric Excavator & Wheel Loader	Sept 2022
20125	Roush Cleantech LLC	Develop and Demonstrate Battery Electric Medium-Duty Truck	Mar 2022
20129†	San Bernardino County	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	Feb 2022
Engine Systems / Technologies			
20158	University of California Riverside	OnBoard Nox and PM Measurement Method	Dec 2022
Fuel / Emission Studies			
17276	University of California Riverside	Development of ECO-ITS Strategies for Cargo Containers	Jan 2022

Table 15: Projects Completed between January 1 & December 31, 2022 (cont'd)

Contract	Contractor	Project Title	Date
Fuel / Emission Studies (cont'd)			
17286	University of California Riverside	In-Use Emissions Testing and Fuel Usage Profile of On-Road Heavy-Duty Vehicles	Mar 2022
22131	Fresno Council of Governments	Conduct California Inland Port Feasibility Study Phase Two	Dec 2022
Hydrogen / Mobile Fuel Cell Technologies and Infrastructure			
17059	CALSTART Inc	Develop and Demonstrate Fuel Cell Extended Range Powertrain for Parcel Delivery Trucks	May 2022
18150†	California Department of Food and Agriculture, Division of Measurement Standards	Conduct Hydrogen Station Site Evaluations for Hydrogen Station Equipment Performance	Feb 2022
19248†	Tustin Hyundai	Three Year Lease of 2019 Fuel Cell Hyundai Nexo	Mar 2022
20169†	Port of Los Angeles	Develop and Demonstrate Near-Zero and Zero Emissions Vehicles and Equipment at the Ports	Nov 2022
23071	Frontier Energy Inc	Participate in California Fuel Cell Partnership (CaFCP) for Calendar Year 2022	Dec 2022
Fueling Infrastructure and Deployment (NG / RNG)			
21099†	CR & R INC	Renewable Natural Gas Production and Vehicle Demonstration Project	Sept 2022
Technology Assessment and Transfer / Outreach			
16262	University of California Davis	Support Sustainable Transportation Energy Pathways (STEPs) 2015-2018 Program	Jan 2022
17097†	Gladstein, Neandross & Associates LLC	Technical Assistance with Alt Fuels and Fueling Infrastructure, Emissions Analysis and On-Road Sources	Jun 2022
22032†	Southern California Chinese-American Environmental Protection Association	Cosponsor the 2021 Southern California Chinese-American Environmental Protection Association 30-Year Anniversary and Annual Convention	May 2022
22128†	University of California Riverside	Cosponsor the 2022 Portable Emissions Measurement Systems Conference	Aug 2022
22134†	Coordinating Research Council Inc	Cosponsor the 31st CRC Real World Emissions Workshop	Jun 2022
22282†	University of California Riverside	Cosponsor CE-CERT's 30th Anniversary	Sept 2022
22286†	Gladstein, Neandross & Associates LLC	Cosponsor ACT Expo 2022	May 2022
22288†	Gladstein, Neandross & Associates LLC	Cosponsor 2022 California Hydrogen Leadership Summit	Jun 2022
22373†	Community Partners for the VerdeXchange Institute Project	Cosponsor 15th Annual VerdeXchange Conference	Oct 2022
22388†	Sustain SoCal	Cosponsor 2022 Driving Mobility 9	Jul 2022

Table 15: Projects Completed between January 1 & December 31, 2022 (cont'd)

Contract	Contractor	Project Title	Date
Technology Assessment and Transfer / Outreach (cont'd)			
23092†	Platia Productions	Cosponsor the 2022 AltCar Expo and Conference	Nov 2022

†Two-page summary reports (as provided in Appendix C) are not required for level-of-effort technical assistance contracts, leases or cosponsorships; or it was unavailable at time of printing this report.

[This Page Intentionally Left Blank]

CLEAN FUELS PROGRAM

2023 Plan Update

In 1988, SB 2297 (Rosenthal) was signed into law (Chapter 1546) establishing South Coast AQMD's Clean Fuels Program and reaffirming the existence of the TAO to administer the Clean Fuels Program. The funding source for the Clean Fuels Program is a $1 motor vehicle registration surcharge that was originally approved for a limited five-year period, but legislation eventually extended both the Program and surcharge indefinitely. The Clean Fuels Program has evolved over the years but continues to fund a broad array of technologies spanning near- and long-term implementation. Similarly, planning will remain an ongoing activity for the Clean Fuels Program, which must remain flexible to address evolving technologies as well capitalize on the latest progress in technologies, research areas and data.

Every year, South Coast AQMD re-evaluates the Clean Fuels Program to develop a Plan Update based on reassessment of clean fuel technologies and direction of the South Coast AQMD Board. This Plan Update for CY 2023 targets several projects to achieve near-term emission reductions needed for the South Coast to meet health-based NAAQS.

Overall Strategy

The overall strategy of TAO's Clean Fuels Program is based on emission reduction technology needs identified through the AQMP process and South Coast AQMD Board directives to protect the health of the approximately 18 million residents (nearly half the population of California) in the Basin. The 2022 AQMP, which was released in May 2022 and adopted in December 2022 by the South Coast AQMD Board, is the long-term regional "blueprint" that relies on fair-share emission reductions from all jurisdictional levels (e.g., federal, state and local). The 2022 AQMP is composed of stationary and mobile source emission reductions from traditional regulatory control measures, incentive-based programs, projected co-benefits from climate change programs, mobile source strategies and reductions from federally regulated sources (e.g., aircraft, locomotives and ocean-going vessels). CARB's Proposed 2022 State SIP Strategy included a revised mobile source strategy required for the Basin to meet the 2015 8-hour ozone standard of 70 ppb by 2037. The Proposed 2022 State SIP Strategy for both mobile and stationary sources require rapid deployment of zero emission technologies to achieve air quality targets.

The emission reductions and control measures in the 2022 AQMP rely on commercial adoption of a mix of currently available technologies as well as the expedited development and commercialization of clean fuel mobile and stationary advanced technologies in the Basin to achieve air quality standards. The 2022 AQMP identifies that 83 percent NOx emission reductions from the 2018 level and 67 percent additional reductions in 2037 beyond already adopted regulations and programs are necessary to meet the 2015 8-hour ozone standard by 2037. The majority of NOx reductions must come from mobile sources, including both on- and off-road sources. Notably, South Coast AQMD is currently only one of two regions in the nation designated as an extreme nonattainment area of the 2015 8-hour ozone NAAQS (the other region is California's San Joaquin Valley).

The 2022 AQMP shows the need for economy-wide transition to zero emission technologies where feasible, and low NOx emission technologies in other applications.

Current state efforts in developing regulations for on- and off-road vehicles and stationary equipment are expected to significantly reduce NOx emissions, but additional measures are needed to achieve the 2023, 2031, and 2037 ozone attainment deadlines. To support fleet turnover the Clean Fuels Program continues to emphasize commercialization and deployment of HD low NOx engines with alternative fuel sources and

large scale deployment of zero emission HD trucks like the Joint Electric Truck Scaling Initiative (JETSI) Pilot Project.[1]

While zero emission technologies, battery and fuel cell electric vehicles are making progress or becoming commercialized, the number of zero emission trucks needed to be deployed in time to meet the 2031 and 2037 ozone standards will be difficult to achieve. To enable widespread deployments of battery electric trucks and achieve the needed decline in prices from scale production, several challenges need to be addressed. These challenges include providing an easier process for fleets and independent owner operators to purchase battery electric trucks and not have to worry about difficulties with installing charging infrastructure, charging dwell times, and ability to match duty cycles with diesel trucks. Projects such as the JETSI 100 BET deployment and EPRI Electric Truck Research and Utilization Center (eTRUC) project to development and demonstrate large battery electric truck deployment with higher powered chargers. These projects will implement two 500 kW and up to 1 MW charging sites and will focus on addressing the complexity of integrating 50 battery electric trucks.

Within the South Coast Basin, large fleets are starting to purchase BETs with near term delivery dates. Several fleets have trucks being delivered in 2023 but unfortunately the installation of infrastructure lags the delivery of the trucks. This difficulty of adding infrastructure to charge BETs is often a hindrance that many fleets have chosen not to tackle and simply have reverted to purchasing new diesel trucks. The infrastructure challenge is something that public truck charging stations alongside technology solutions will help mitigate the frustrations with purchasing BETs. Unfortunately in the South Coast Air Basin the infrastructure for public truck charging does not exist but many companies have efforts in place to install infrastructure. The best design and business practices for installing public infrastructure will be something that South Coast AQMD staff will closely monitor.

Diesel truck emissions are the largest NOx emission category in the South Coast Air Basin. While CARB has the proposed Advanced Clean Fleets regulation and existing truck regulations there is a need to tackle interstate truck emissions. On June 3, 2016, South Coast AQMD petitioned U.S. EPA to initiate rulemaking for a lower national NOx standard for on-road HD engines to achieve additional mobile source emission reductions. The national NOx standard for on-road HD vehicles is estimated to result in 70 to 90 percent NOx emission reductions from this source category in 14 to 25 years, respectively. CARB estimates that 60 percent of total on-road HD vehicle miles traveled in the Basin are from vehicles purchased outside of California, which points to the need for a more stringent federal as well as state standard for on-road HD vehicles.

U.S. EPA has acknowledged the need for additional NOx reductions through a harmonized and comprehensive national NOx reduction program for HD on-highway engines and vehicles. On November 13, 2018, U.S. EPA announced the Cleaner Truck Initiative, and on January 6, 2020, they issued an Advance Notice of Proposed Rule to reduce NOx emissions from on-road HD trucks. After some delay, in March 2022, U.S. EPA issued the Notice of Proposed Rule Making (NPRM) and finalized the rule in December 2022. Numerous organizations, including South Coast AQMD, submitted comments to U.S. EPA urging the adoption of the most stringent rule as fast as feasible. South Coast AQMD comments suggested that U.S. EPA should align with the already adopted CARB Omnibus regulation. The CARB regulation imposes two-phase NOx standards starting in model year 2024 with the ultimate standard of 0.02 g/bhp-hr in 2027, 90% below today's NOx standard, while the U.S. EPA proposal considers three NOx options of 0.05, 0.035 and 0.02 g/bhp-hr in 2027. Despite these efforts, the implementation and effectiveness of U.S. EPA and CARB regulations are unable to help South Coast AQMD meet its 2023 federal ozone attainment deadline

[1] The project, known as Joint Electric Truck Scaling Initiative, or JETSI, will be one the largest commercial deployment of battery-electric trucks in North America to date, helping to significantly increase the number of zero-emission HD trucks available for goods movement while achieving necessary emission reductions. This is the first battery-electric truck project jointly financed by CARB and the CEC, and the largest investment of its kind.

of 80ppb ozone. Given that the Basin must attain the 70-ppb ozone NAAQS by 2037, a new on-road HD engine NOx emission standard is critical given the time needed for OEMs to develop and produce compliant vehicles, and for national fleet turnover to occur.

Figure 29 shows the difference in NOx reductions in the Basin from on-road HD trucks under three scenarios: baseline (no change in the NOx standard) in blue, a 0.02 g/bhp-hr NOx standard adopted only in California in yellow, and lastly, a federal 0.02 g/bhp-hr NOx standard in orange. Although a single 0.02 g/bhp-hr standard no longer reflects the current adopted and proposed options of NOx standards, Figure 29 is still relevant because it shows the significant contribution by federally regulated trucks to the Basin NOx inventory as well as the relatively long turnover time from when the regulation is first adopted. (e.g. 10 years for 50% NOx reduction and 20 years for 80% NOx reduction). These two facts support the urgency for the Basin to have a more stringent nationwide NOx regulation as soon as feasible.

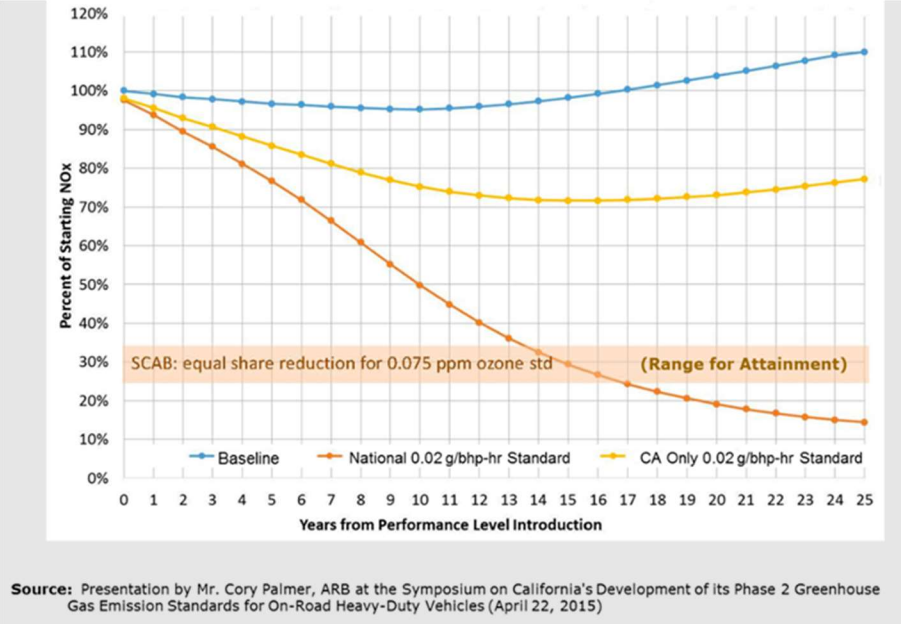


Figure 29: NOx Reduction Comparison:
No New Regulations vs Low NOx Standard in California only vs National Standard

South Coast AQMD completed MATES V in August 2021 to update the emissions inventory of toxic air contaminants, as well as modeling to characterize risks, including measurements and analysis of ultrafine particle concentrations typically emitted or subsequently formed from vehicle exhaust. Findings from the MATES V report showed that air toxics cancer risk based on modeling data has decreased by over 50% since MATES IV, with an average multi-pathway air toxics cancer risk at 454-in-a-million. The highest risk locations are at LAX, the Ports, and along goods movement and transportation corridors. Diesel PM continues to be the major contributor accounting for over 60% of the overall air toxics cancer risk. For the first time, chronic non-cancer risk was estimated with a chronic hazard index of 5.9 across the 10 stations in the MATES V study. U.S. EPA approved the use of the CARB EMFAC 2017 model for on-road vehicles for use in the State Implementation Plan and transportation conformity analyses, which assesses emissions from on-road vehicles including cars, trucks and buses. The off-road model, which assesses emissions from off-road equipment such as yard tractors, top handlers, and rubber tire gantry cranes, is being replaced by category-specific methods and inventory models developed for specific regulatory support projects.

A key strategy of the Clean Fuels Program, which allows significant leveraging of Clean Fuels funding (historically $4 to every $1 of Clean Fuels funds), is its public-private partnerships with private industry, technology developers, academic institutions, research institutions and government agencies. Since 1988, the Clean Fuels Program provided more than $250 million toward projects nearing $1.6 billion. Leveraging of the Clean Fuels Fund is based on actual executed contracts and total project costs from the prior year's Clean Fuels Annual Report and Plan Update. In 1998, South Coast AQMD's Carl Moyer Program was launched. The two programs produce a unique synergy, with the Carl Moyer Program (and other subsequent incentive programs) providing the necessary funding to push market penetration of commercial technologies partially developed and demonstrated by the Clean Fuels Program. This synergy enables South Coast AQMD to act as a leader in technology development and commercialization efforts targeting reduction of criteria pollutants. Since the Carl Moyer Program began, South Coast AQMD has begun implemented other incentive programs (i.e., Volkswagen Mitigation, Proposition 1B-Goods Movement, and Community Air Protection Program), with cumulative funding of over $200 million in 2022. There is $15.6 million in Year 3 AB 617 Community Air Protection Program (CAPP) incentive funding reserved for zero emission trucks in the East Los Angeles/Boyle Heights/West Commerce, Southeast Los Angeles, San Bernardino/Muscoy, and Wilmington/Carson/West Long Beach AB 617 communities, all of which identified zero emission trucks as a funding priority in their CERPs. The 2022 AQMP also included control measures to develop an indirect source regulation for the San Pedro Ports and strengthen fleet rules to take advantage of incentives to further accelerate emission reductions.

Despite several current California incentive programs to deploy cleaner technologies and offset the higher procurement costs of cleaner technologies, significant additional resources and technology development is needed to achieve the NAAQS for this region. There are several emerging key technologies that are discussed in detail later that will provide NOx and GHG co-benefits while requiring less vehicle purchase incentives.

As technologies move towards commercialization, such as HD fuel cell trucks, the Clean Fuels Program has partnered with large OEMs, such as Daimler and Volvo to deploy these vehicles. These OEM partnerships allow the Clean Fuels Program to leverage their research, design, engineering, manufacturing, sales and service, and financial resources to move advanced technologies from the laboratories to the field and into customers' hands. The OEMs have the resources to develop advanced technology vehicles such as battery electric and fuel cell powertrains, manufacture in large quantities, and utilize their distribution networks to support sales across the state.

Figure 30 outlines a developmental progression for technology demonstration and deployment projects funded by the Clean Fuels Program and the relationship incentive programs administered by TAO play in that progression. The Clean Fuels Program funds various stages of technology projects, typically ranging from Technology Readiness Levels 3-8, to provide a portfolio of technology choices and achieve near-term and long-term emission reduction benefits.

Figure 30: Stages of Clean Fuels Program Funding

Many technologies that address the Basin's needed NOx reductions align with the state's GHG reduction efforts. U.S. EPA (2022)[2] noted that the transportation sector contributed 36 percent of overall GHG emissions. Due to these co-benefits, South Coast AQMD has been successful in partnering with the state and public/private partnerships to leverage its Clean Fuels funding extensively.

Program and Funding Scope

This Draft 2023 Plan Update includes projects to research, develop, demonstrate and advance deployment a variety of technologies, from near-term to long-term, that are intended to address the following challenges:

1) implementation of new and changing federal requirements, such as the more stringent federal 8-hour ozone standard of 70 ppb promulgated by U.S. EPA in late 2015;
2) implementation of new technology measures including accelerated development of technologies nearing commercialization and deployment of commercially ready technologies; and
3) continued development of near-term cost-effective approaches and long-term technology development.

The overall scope of projects in the Draft 2023 Plan Update remains sufficiently flexible to address new technologies and control measures identified in the 2022 AQMP, dynamically evolving technologies, and new research and data. The latter includes findings from MATES V and revised emission inventories from EMFAC 2017.

Within the core technology areas defined later in this section, project objectives range from near term to long term. The Clean Fuels Program concentrates on supporting development, demonstration and technology commercialization and deployment efforts rather than fundamental research. The nature and typical time-to-product for Clean Fuels Program projects are described below, from near term to long term.

- *Deployment* or technology *commercialization* efforts focus on increasing utilization of clean technologies in conventional applications, promising immediate and growing emission reduction benefits. These are expected to result in commercially available products as early as 2022, including obtaining required certifications from CARB and EPA. It is often difficult to transition users to non-traditional technologies or fuels due to higher incremental costs or required changes to user behavior, even if these technologies or fuels offer significant benefits. In addition to the government's role to reduce risk by funding technology development and testing, it is also necessary to offset incremental costs through incentives to accelerate the use of cleaner technologies. The increased use of these clean fuel technologies also depends on efforts to increase stakeholder confidence that these technologies are viable and cost-effective in the long term.
- Several technologies ready to begin field *demonstration* in 2023 are expected to result in commercially available products in the 2024-2027 timeframe, and technologies being demonstrated generally are in the process of being verified or certified by CARB and EPA. Field demonstrations provide a controlled environment for manufacturers to gain real-world experience and address end-user issues that arise prior to the commercial introduction of technologies. Field demonstrations provide real-world evidence of performance to allay any concerns by early adopters as well as preliminary emissions reduction potential.
- Finally, successful technology *development* projects are expected to begin as early as late 2023 with durations of two or more years. Additionally, field demonstrations to gain long term verification of performance may also be needed prior to commercialization. Certification and

[2] *U.S. Greenhouse Gas Emissions and Sinks 1990-2020*. 2022. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

commercialization would be expected to follow. Projects may involve the development of emerging technologies that are considered long-term and higher risk, but with significant emission reductions potential. Commercial introduction of such long-term technologies would not be expected until 2028 or later.

Core Technologies

The following technologies have been identified as having the greatest potential to enable the emission reductions needed to achieve the NAAQS and thus form the core of the Clean Fuels Program.

The goal is to fund viable projects in all categories. However, not all project categories will be funded in 2023 due to funding limitations, and the focus will remain on control measures identified in the 2022 AQMP, with consideration for availability of suitable projects. The project categories identified below are appropriate within the context of the current air quality challenges and opportunities for technology advancement.

Within these areas, there is significant opportunity for South Coast AQMD to leverage its funds with other funding partners to expedite the demonstration and deployment of clean technologies in the Basin. A concerted effort is continually made to form public private partnerships to maximize leveraging of Clean Fuels funds.

Several of the core technologies discussed below are synergistic. For example, a HD vehicle such as a transit bus or drayage truck, may utilize a hybrid electric drive train with a fuel cell operating on hydrogen fuel or an internal combustion engine (ICE) operating on an alternative fuel as a range extender. Elements of the core hybrid electric system may overlap. Similarly, a hydrogen powered engine may utilize a natural gas HD vehicle that also combusts gaseous fuel and requires a compressed tank storage system; elements of the similar combustion and fuel storage may overlap.

Priorities may shift during the year in keeping with the diverse and flexible technology portfolio approach or to leverage opportunities such as cost-sharing by the state or federal government or other entities. Priorities may also shift to address specific technology issues which affect residents within the South Coast AQMD's jurisdiction. For example, AB 617, signed by the Governor in 2017, implements actions and provides incentive funding for priorities designated in CERPs by six AB 617 communities within the South Coast region, and additional flexibility will be needed to develop new strategies and technologies for those disadvantaged communities.

The following ten core technology areas are listed by current South Coast AQMD priorities based on the goals for 2023.

Hydrogen / Mobile Fuel Cell Technologies

South Coast AQMD supports hydrogen fuel cell technologies as one option in the technology portfolio; the agency is dedicated to assisting federal and state government programs to deploy LD, medium, and HD fuel cell electric vehicles (FCV).

Calendar Years 2015-2019 were a critical timeframe for the introduction of LD hydrogen FCVs. In 2014, Hyundai introduced the Tucson FCV for lease. In 2015, Toyota commercialized the Mirai, the first FCV available to consumers for purchase. In December 2016, Honda started commercial lease of its 2017 Honda Clarity FCV. The 2019 Hyundai Nexo was the second FCV offered for sale and lease in California. In the past, Clean Fuels funding has gone towards leases for LD FCVs as part of its technology outreach efforts for conferences and events in disadvantaged communities.

Fuel cells can play a role in MD and HD applications where battery recharge time and vehicle range, although improving, is insufficient to meet fleet operational requirements. The California Fuel Cell Partnership's (CaFCP's) *2030 Vision*[3] released in July 2018 provides a broader framework for the earlier *MD and HD Fuel Cell Electric Truck Action Plan* completed in October 2016, which focused on Class 4 parcel delivery trucks and Class 8 drayage trucks with infrastructure development and established metrics for measuring progress. The CaFCP's *HD Vision* released in July 2021 describes 70,000 fuel cell electric trucks supported by 200 HD hydrogen stations operating in California and beyond.

Another player in the HD fuel cell truck space is Cummins (CWI) who recently purchased Hydrogenics and Efficient Drivetrains, Inc. (EDI) to develop fuel cell power trains. CWI is currently working on the ZECT 2 and a CEC/South Coast AQMD project to develop and demonstrate fuel cell drayage trucks with next generation fuel cell module - easy to package system design and other innovative integration strategies. In 2022, Volvo and Daimler also announced a joint venture to develop fuel cell powered trucks. South Coast AQMD has created many alliances with large OEMs and will continue to fund projects with these OEMs over the next year to develop HD fuel cell trucks. In June 2021, South Coast AQMD recognized $500k from U.S. EPA to demonstrate two Hyundai Class 8 fuel cell trucks with a range of up to 500 miles for regional and long-haul operations.

The CaFCP *Fuel Cell Electric Bus Road Map* released in September 2019 supports implementation of CARB's Innovative Clean Transit and Zero Emission Airport Shuttle regulations. As part of the $46 million Fuel Cell Electric Bus Commercialization Consortium project, for which the Clean Fuels Fund contributed $1 million, Center for Transportation and the Environment (CTE), in partnership with New Flyer, Trillium, and OCTA, wrapped up its deployment of ten 40-foot New Flyer XHE40 fuel cell transit buses and installed a liquid storage hydrogen station capable of fueling up to 50 fuel cell transit buses at OCTA in February 2021. This project also deployed 10 fuel cell transit buses and a hydrogen station upgrade at Alameda-Contra Costa Transit District (AC Transit). The ten fuel cell buses at OCTA accumulated almost 300,000 miles of revenue service during the demonstration with an overall uptime of 67%.

SunLine Transit Agency (SunLine) received a U.S. EPA Targeted Airshed grant in June 2020 to deploy five fuel cell transit buses, in addition to their existing fleet of 26 fuel cell and four battery electric transit buses as well as a recently upgraded 900 kg/day hydrogen station capable of supporting up to 30 fuel cell transit buses. SunLine has accepted and commissioned one of the buses into its fleet. In August 2021, the Clean Fuels Program committed $531,166 to a $2 million project to develop and demonstrate two MD fuel cell transit buses at SunLine. Additional outlets for hydrogen fueling infrastructure for these buses will also be developed.

In March 2021, Frontier Energy was awarded $25,000 to perform a high-flow bus fueling protocol development project as a part of the DOE H2@Scale program with partners including SoCalGas, Shell, and NREL. NREL was also awarded $25,000 for California HD Infrastructure Research, and UC Davis was awarded $50,000 for California Hydrogen Systems Analysis. These projects aim to fill in the gaps between LD and HD hydrogen fueling infrastructure to encourage the expansion of hydrogen fueling infrastructure as more state and federal policies are developed or passed. In addition, as more fuel cell MHDVs are commercialized, this research becomes more pivotal to ensuring sufficient hydrogen fueling stations are available.

The Draft 2023 Plan Update identifies key opportunities while clearly leading the way for pre-commercial demonstrations of OEM FCVs. Future projects may include the following:

[3] CaFCP's *The California Fuel Cell Revolution, A Vision For Advancing Economic, Social, and Environmental Priorities* (Vision 2030), September 4, 2018.

- development and demonstration of cross-cutting fuel cell applications (e.g. scalable and cost-effective fuel cell powertrain components);
- development and demonstration of fuel cells in off-road, locomotive and commercial harbor craft applications such as port cargo handling equipment, switcher locomotives and tugs;
- demonstration of FCVs in controlled fleet applications in the Air Basin;
- coordination with FCV OEMs to develop an understanding of their progress in overcoming barriers to economically competitive FCVs and develop realistic scenarios for large scale introduction;
- development and implementation of strategies with government and industry to build increasing scale and renewable content in the hydrogen market including certification and testing of hydrogen as a commercial fuel to create a business case for investments as well as critical assessments of market risks to guide and protect these investments; and
- repurposing fuel cells and hydrogen tanks for other secondary energy production and storage uses, as well as reusing fuel cells and hydrogen tanks, and approaches to recycle catalysts and other metals.

Electric / Hybrid Technologies

To meet the NAAQS, a primary focus continues to be on zero and near-zero emission technologies. A key strategy to achieve these goals is wide-scale transportation electrification. South Coast AQMD supports projects to address concerns regarding cost, battery life, all-electric range, and OEM commitment. Integrated transportation systems can encourage further emission reductions by matching EVs to typical consumer and fleet duty cycles and demands including drayage, short regional haul, and last mile delivery. Class 8 battery electric trucks from Daimler and Volvo are now CARB and U.S. EPA certified, commercially available, and eligible for incentives from Hybrid and Zero Emission Truck and Bus Voucher Incentive Project (HVIP), Carl Moyer, Prop 1B, VW Settlement, Voucher Incentive Program, and CAPP funds.

Development and deployment of zero emission goods movement and freight handling technologies remains one of the top priorities for the South Coast AQMD to support balanced and sustainable growth at the San Pedro Bay Ports as well as freight/logistics facilities throughout the Basin. The South Coast AQMD continues to work with our regional partners, including the San Pedro Bay Ports, Southern California Association of Governments (SCAG) and Los Angeles County Metropolitan Transportation Authority (Metro) to demonstrate and deploy technologies that are technically feasible, cost-effective with the assistance of incentives and/or grant funding, and beneficial to all stakeholders. Specific technologies include zero emission trucks/freight handling equipment (battery and/or fuel cell), or plug-in hybrid powertrains, locomotives with hydrogen fuel cells, hybrid and battery electric technologies, and linear synchronous motors for locomotives and trucks. Additionally, the California Sustainable Freight Action Plan outlines a blueprint to transition the state's freight system to an environmentally cleaner, more efficient and economical system, including a call for a zero and near-zero emission vehicle pilot project in Southern California. The City of Los Angeles *Zero Emission 2028 Roadmap 2.0* in preparation for the 2028 Olympics corroborates this effort, calling for an additional 25% each in GHG and criteria pollutant reductions. The San Pedro Bay Ports *Clean Air Action Plan* Update (2022) calls for zero emissions cargo handling equipment by 2030 and zero emission drayage trucks by 2035, respectively.

HD hybrid vehicles have historically been optimized for fuel economy, new generation hybrid powertrains that use a systems approach for co-optimizing both criteria emissions and fuel economy could provide another technology pathway to meet the air quality goals of the Basin. These hybrid systems in both plug-in and non-plug-in configurations, focus on electrifying key engine subsystems and energy recovery to provide engine assistance during transient operations. Furthermore, the availability of additional electrical

power such as 48-volt systems could allow for electric aftertreatment heaters for better transient control through thermo-management and therefore better NOx control at a reduced cost compared to traditional aftertreatment systems. South Coast AQMD views these next generation hybrid powertrains as capable of being deployed without the need for incentives, by providing fuel economy benefits which could provide another potential cost-effective pathway for near term NOx emission reductions. Furthermore, CARB's Advanced Clean Trucks (passed June 2020) and Advanced Clean Fleets (Board consideration October 2022) regulations allow sales of plug-in hybrid vehicles capable of zero-emission operation as a compliance pathway for meeting the manufacturer and fleet zero emission vehicle mandate.

New, ongoing, and recently completed zero emission battery electric technology projects include: 1) Joint Electric Truck Scaling Initiative (JETSI) Pilot Project with deployment of 100 Daimler and Volvo Class 8 battery electric trucks for drayage and regional haul at NFI and Schneider funded by $16 million from CARB, $11 million from CEC, $8 million from Mobile Source Air Pollution Reduction Review Committee (MSRC), $5.5 million from the Clean Fuels Fund, $5 million from SCE, and $3 million from the San Pedro Bay Ports; 2) Switch-On Project with deployment of 70 Volvo Class 8 battery electric drayage/freight trucks at eight fleets funded with $20 million from the U.S .EPA Targeted Airshed grant; 3) deployment of two additional Class 8 battery electric drayage trucks as part of the CARB Volvo LIGHTS project through a $500,000 U.S. EPA Clean Air Technology Initiative grant; 4) deployment of two Volvo Class 8 battery electric trucks at Producers Dairy in Fresno as part of the CARB Greenhouse Gas Reduction Fund Zero Emission Drayage Truck Project; 5) Daimler Customer Experience project to demonstrate eight Class 6 and 8 battery electric trucks and fast charging infrastructure funded with $1 million by the Clean Fuels Fund; and 6) commercial deployment of 35 Daimler Class 6 and Class 8 battery electric trucks funded by $4 million from the U.S. EPA Targeted Airshed grant.

Opportunities to develop and demonstrate technologies that could enable expedited widespread use of pre-commercial and commercial battery electric and hybrid-electric vehicles in the Basin include the following:

- demonstration of battery electric and fuel cell electric technologies for cargo handling and container transport operations, e.g., HD battery electric or plug-in electric drayage trucks with all electric range;
- large scale deployments of commercial battery electric vehicles (i.e. 50 or more vehicles) to prove feasibility and development of fleet tools to assist in successful operation for drayage and short regional haul operations;
- demonstration of MD battery electric and fuel cell electric vehicles in package delivery or last mile operations, e.g., battery electric walk-in vans with fuel cell or plug-in hybrid range extender;
- development and demonstration of battery and fuel cell electric off-road equipment; e.g. battery electric off-road construction equipment, yard tractors, or top-handler with wireless charger;
- development and demonstration of hybrid and plug-in hybrid vehicle technology;
- development of hybrid vehicles and technologies for off-road equipment;
- demonstration of niche application battery and fuel cell electric MD and HD vehicles, including school and transit buses and refuse trucks with short-distance fixed service routes;
- demonstration of integrated programs that make best use of electric drive vehicles through interconnectivity between fleets of shared electric vehicles and mass transit, and rideshare services that cater to multiple users and residents in disadvantaged communities;
- development of eco-friendly intelligent transportation system (ITS), geofencing, and Eco-Drive strategies to maximize emission reductions and energy consumption by operating in zero emission mode when driving in disadvantaged communities; demonstrations that encourage electric drive

vehicle deployment in autonomous applications; optimized load-balancing strategies and improved characterization of in-duty drayage cycles and modeling/simulations for cargo freight and market analysis for zero emission HD trucks;

- development of higher density battery technologies for use in HD vehicles;
- repurposing EV batteries for other or second life energy storage uses, as well as reusing battery packs and approaches to recycle lithium, cobalt and other metals; and
- development of a methodology to increase capability to accept fast-charging and resultant life cycle and demonstration of effects of fast-charging on battery life and vehicle performance.

Zero Emission Infrastructure

Significant demonstration and commercialization efforts for zero emission infrastructure are funded by the Clean Fuels Program as well as other local, state and federal programs. Zero emission infrastructure has become an increasing focus of the Clean Fuels Program in order to support large scale demonstration and deployment of hydrogen fuel cell and battery electric vehicles and equipment. This category is being presented separately from Hydrogen/Fuel Cell and Electric/Hybrid Technologies for the first time in the Draft 2023 Plan Update.

Hydrogen Infrastructure

With lead times on retail level hydrogen fueling stations requiring 18-36 months for permitting, construction and commissioning, plans for future stations need to be implemented. While coordination with the California Division of Measurement Standards (DMS) to establish standardized measurements for hydrogen fueling started in 2014, additional efforts to offer hydrogen for sale in higher volumes are still needed specifically with upcoming ZE vehicle and infrastructure policy deadlines on a national and state level. Moreover, CARB's Low Carbon Fuel Standard (LCFS) regulation provides incentives for producing and dispensing the low carbon intensity (CI) hydrogen for FCVs, enabling station operators to remain solvent and cover part of their operational cost and consequently reducing the dollar per kilogram cost of hydrogen for consumers. Lastly, a deliberate and coordinated effort is necessary to ensure that hydrogen stations are developed with design flexibility to address specific location limitations, robust hydrogen supply, and fueling reliability matching those of existing gasoline and diesel fueling stations. The current network of hydrogen fueling stations to support the current number of LD FCVs on the road and future MHD FCVs is insufficient, and supply of hydrogen and additional hydrogen production, specifically the carbon-neutral hydrogen, continue to be challenges that need to be addressed.

In 2019, the Clean Fuels Program awarded $1.2 million to Equilon (Shell) as part of the H2Freight project for a new 1,000 kg/day HD hydrogen fueling station using hydrogen produced by a new tri-generation fuel cell on POLB property leased by Toyota. The station was commissioned in 2021 and continues its soft open operation with ongoing data collection and analysis. As part of the $83 million Shore-to-Store project led by the POLA, for which the Clean Fuels Program committed $1 million, Toyota and Kenworth deployed 10 Class 8 fuel cell trucks and Equilon (Shell) built two large capacity hydrogen fueling stations in Wilmington and Ontario. Kenworth leveraged the development on the fuel cell truck demonstrated in South Coast AQMD's ZECT 2 project and integrated Toyota's fuel cells into the Kenworth trucks. These fuel cell trucks are deployed at fleets including UPS, Total Transportation Services, Southern Counties Express, and Toyota Logistics Services at the Ports of Los Angeles and Port Hueneme, as well as other fleets in Riverside County. Most of the fuel cell trucks completed the demonstration phase. Also, the Ontario and Wilmington stations are commissioned and NREL continues to collect and analyze the data.

New, ongoing, and recently completed hydrogen infrastructure projects include: 1) POLA Shore to Store project with deployment of two 400 kg/day hydrogen fueling stations in Wilmington and Ontario for HD

fuel cell trucks and 2) retrofit of existing hydrogen infrastructure stations to accommodate HD fuel cell trucks by First Element to demonstration Hyundai Class 8 fuel cell trucks.

Electric Charging Infrastructure

The challenges of installing charging infrastructure include costs, permitting, UL certification of equipment, utility interconnection requirements and the ability of utilities to upgrade power to specific fleet sites, all of which need to be better understood and streamlined.

Continued technology advancements in LD infrastructure have facilitated development of corresponding codes and standards for MD and HD infrastructure including UL certification of the CCS2 connector for the Volvo LIGHTS battery electric truck demonstration project. Additionally, SCE's Charge Ready Transport Program and Los Angeles Department of Water and Power's (LADWP) Commercial EV Charging Station Rebate Program includes funding for MD and HD vehicles and infrastructure.

LD EV charging infrastructure is commercially available and MD and HD charging infrastructure is becoming commercially available. The CCS1 connector continues to be the standard connector for MD and HD charging up to 350 kW direct current (DC). Charging Interface Initiative (CharIN) released a Megawatt Charging System (MCS) connector in June 2022 for Class 6 -8 EVs designed for a maximum current of 3,000 A at up to 1,250V for charging up to 3.75 MW DC. Currently there are no MD or HD EVs capable of accepting charging above 350 kW DC. There is also an agreed upon SAE J3068 connector standard for single-phase and three-phase AC charging. Challenges and costs of installing MD and HD charging infrastructure increase exponentially compared to LD infrastructure. Each year there are more commercially available options for MD and HD charging infrastructure.

South Coast AQMD is seeking DOE funding to lead a regional collaborative to create a MD/HD charging and hydrogen fueling infrastructure plan for the South Coast Air Basin. This will supplement SCAG's existing effort to create a six county regional MD/HD charging and hydrogen fueling infrastructure plan as part of a CEC eTRUC project to develop and demonstrate high power DC fast charging for HD battery electric trucks. A detailed plan for the San Pedro Bay Ports and the I-710 corridor will be created using advanced modeling and additional data sources. In a related effort, Metro has committed $50 million of its funding to deploy charging for HD battery electric trucks between the San Pedro Bay Ports and along the I-710 south corridor.

New, ongoing, and recently completed electric charging infrastructure projects include: 1) Joint Electric Truck Scaling Initiative (JETSI) Pilot Project with installation of 350 kW DC fast chargers to support 100 Daimler and Volvo Class 8 battery electric trucks at NFI and Schneider; 2) Switch-On Project with installation of multiple DC fast chargers to support 70 Volvo Class 8 battery electric drayage/freight trucks at eight fleets; and 3) deployment of two 150 kW DC fast chargers at Producers Dairy in Fresno as part of the CARB Greenhouse Gas Reduction Fund Zero Emission Drayage Truck Project.

The Draft 2023 Plan Update identifies key opportunities while clearly leading the way for demonstration and deployment of hydrogen fueling and charging infrastructure. Future projects may include the following:

- continued development and demonstration of distributed hydrogen production and fueling stations from multiple providers, including energy stations with electricity and renewable hydrogen co-production and higher pressure (10,000 psi) hydrogen dispensing and scalable/higher throughput;
- development of additional sources of hydrogen production and local generation of hydrogen for fueling stations far from local production sources to better meet demand of FCVs;
- development of carbon-natural (or low carbon intensity) hydrogen production, distribution, and infrastructure network through a partnership with regional hydrogen hub projects;

- large scale deployments of commercial large fleet and public charging infrastructure to meet needs for owner operators/small fleets/large fleets for various segments (drayage, last mile delivery, short regional haul);
- development of fleet tools to assist in successful operation for drayage, last mile delivery, and short regional haul operations;
- demonstration and installation of infrastructure to support battery electric and fuel cell electric LD, MD and HD fleets, and ways to reduce cost and incentivize incremental costs over conventionally fueled vehicles, meet fleet operational needs, improve reliability, and integrate with battery energy storage, renewable energy and energy management strategies (e.g., vehicle-to-grid or vehicle-to-building functionality, demand response, load management);
- creation of MD/HD charging and hydrogen fueling regional infrastructure planning efforts; and
- deployment of infrastructure corresponding to codes and standards specific to LD, MD and HD vehicles, including standardized connectors, fuel quality, communication protocols, and open standards and demand response protocols for EV chargers to communicate across charging networks.

Engine Systems/Technologies

To achieve the emission reductions required for the Basin, ICEs used in the HD sector will require widespread implementation of zero emission technologies as outlined in CARB's 2020 Mobile Source Strategy. The path to 100% zero emission trucking sector will take time and the CARB HD On-Road "Omnibus" Low NOx regulation and EPA's proposed Cleaner Trucks Initiative (CTI) shows the need for ultra-low NOx ICE engines.

In 2016, CWI achieved a new ultra-low NOx threshold by commercializing the first on-road HD engine to be certified to CARB's optional low NOx standard of 0.02g NOx/bhp-hr. The 8.9 liter (8.9L) ISL-G natural gas engine demonstrated that an ICE could achieve NOx exhaust emission levels 90 percent cleaner than the existing federal standard. Powering these vehicles with low Carbon Intensity renewable fuels or biomethane, to help address GHG objectives, became a game changer for the HD transportation sector. The 8.9L engine works well in refuse and other vocational trucks as well as transit and school buses.

In 2017, CWI, with South Coast AQMD and other project partners, achieved certification of the 12L natural gas engine. The 12L engine in Class 8 drayage trucks and 60-foot articulated transit buses expanded the scope of this near-zero technology. Both CARB and U.S. EPA certified the 12L engine at 0.02 g/bhp-hr for NOx. New for 2020, CWI certified its 6.7L natural gas engine to 0.02 g/bhp-hr NOx for the first time, further ensuring the viability of near-zero engine options for all market segments.

Although no near-zero emission diesel technology is commercially available today, development and demonstration efforts have proven low NOx diesel technology is viable. South Coast AQMD has been working closely with CARB, U.S .EPA and others on defining low NOx diesel technology pathways via several projects, including the Ultra-Low Emissions Diesel Engine Program at Southwest Research Institute (SwRI), opposed piston engine development with Achates Power Inc., and Thermal Management using Cylinder Deactivation (CDA) with West Virginia University.

More recently, CWI announced a hydrogen powered ICE with near –zero NOx capabilities ready for implementation in the 2027 timeframe. As a result, the Draft 2023 Plan Update includes on-road truck demonstrations using hydrogen as a fuel for internal combustion. These demonstration efforts are considered key milestones in driving up the TRL level toward full commercialization as a bridge and complementary technology toward zero emission technology, especially for high horsepower and long-haul applications where zero emission technologies and supporting infrastructure will take longer to become commercially available.

The Draft 2023 Plan Update continues to incorporate pursuit of cleaner engines and hybrid powertrains for the HD sector but is starting to transition to large scale pre-commercial demonstration and deployment efforts as current near-zero NOx ICE technologies are becoming readily available. Future projects will continue to support the development, demonstration and emissions verification/certification of engines and powertrains that can achieve needed near-term emission reductions. At the same time, aggressive GHG emission reduction targets set forth by both CARB and U.S. EPA have invigorated interest in revisiting low- and zero carbon alternative fuels for those high power/torque applications. While the GHG benefit is relatively easy to assess by fuel source, it is also important to understand the criteria emissions impact under real-world conditions and over its useful lifetime to ensure reduction of both criteria and GHGs are fully realized.

The Draft 2023 Plan Update includes potential projects that the South Coast AQMD might participate with federal, state, and other private companies towards these efforts. Specifically, these projects are expected to target the following:

- development of ultra-low emissions and improved higher efficiency gaseous and liquid fuel powered engines for HD vehicles and high horsepower applications projects that move these technologies to a higher technology readiness level and commercialization;
- development and demonstration of gaseous and liquid fuel powered engines to support hybrid and plug-in hybrid vehicle technology;
- development and demonstration of alternative fuel engines for on- and off-road applications;
- development and demonstration of engine systems that employ advanced engine design features, CDA, improved exhaust or recirculation systems, and aftertreatment devices; and
- further development of robust aftertreatment systems which can maintain certified emissions levels under a wide variety of duty-cycles and throughout the vehicle's useful life.

EPA's recent proposal to create a new national low NOx standard for on-highway HD engines starting in 2027 will further motivate manufacturers to develop lower-NOx emitting technologies expected to result in greater NOx emission reductions than a "California only" low NOx standard for on-road HD engines. Low- and zero carbon alternative fuels for new low emitting engines will continue to emerge as timelines for GHG reductions approach.

RNG Infrastructure (RNG and Renewable Fuels)

Significant demonstration and commercialization efforts funded by the Clean Fuels Program as well as other local, state and federal agencies are underway to: 1) support the upgrade and buildup of public and private infrastructure projects, 2) expand the network of public-access and fleet fueling stations based on the population of existing and anticipated vehicles, 3) put in place infrastructure that will ultimately be needed to accommodate transportation fuels with very low gaseous and GHG emissions, and 4) support local production of clean, low carbon intensity, renewable transportation fuels.

Hydrogen fueling stations continue to be positioned to support both public and private fleet applications. Funding has been applied to provide fueling at key points for all classes of vehicles, with an emphasis on HD vehicle users travelling on major goods movement corridors, including local ports, and along I-15 and The Greater Interstate Clean Transportation Corridor (ICTC) Network. Upgrades and expansions are also needed on RNG stations to refurbish or increase capacity for some of the stations installed five or more years ago as well as standardize fueling station design, especially to ensure growth of alternative fuels throughout the Basin and beyond. There is also a continuing and growing interest for complete transition to renewable fuels, particularly natural gas delivered through existing natural gas pipelines. Future funding will be needed to support local production and use of renewable natural gas and electricity to produce green

hydrogen for light and HD vehicles. The growing interest in low carbon, renewable transportation fuels that also power ultra-low to zero emission vehicles will expand the scope of this category to provide support of local production and distribution of such fuels and help accelerate fleet turnover. SB 350 (De León) further established a target to double the energy efficiency in electricity and renewable natural gas end uses by 2030.

Projects expected to be developed and co-funded for infrastructure development are:

- development and demonstration of low carbon intensity renewable transportation fuels including renewable natural gas, renewable hydrogen, renewable methanol, and renewable electricity from zero emission sources and from renewable feedstocks, such as biomass and biowaste;
- development and demonstration of advanced, cost-effective methods for manufacturing synthesis gas for conversion to renewable natural gas and renewable (biomass-based) hydrogen;
- enhancement of safety and emission reductions from existing natural gas fueling equipment;
- technology solutions to help with the expansion of fueling infrastructure, fueling stations, and equipment, with an emphasis on renewable energy sources; and
- technology solutions to help with the expansion of infrastructure connected with existing fleets, public transit, and transportation corridors, including demonstration and deployment of closed loop systems for dispensing and storage.

Stationary Clean Fuel Technologies

Although stationary source NOx emissions are small compared to mobile sources in the Basin, there are applications where cleaner fuel technologies or processes can be applied to reduce NOx, VOC and PM emissions. A demonstration project funded in part by the South Coast AQMD at a local sanitation district consisted of retrofitting an existing biogas engine with a digester gas cleanup system and catalytic exhaust emission control. The retrofit system resulted in significant reductions in NOx, VOC and CO emissions. This project demonstrated that cleaner, more robust renewable distributed generation technologies exist that not only improve air quality but enhance power quality and reduce electricity distribution congestion.

SCR has been used as aftertreatment for combustion equipment for NOx reduction. SCR requires the injection of ammonia or urea that is reacted over a catalyst bed to reduce the NOx formation during the combustion process. Challenges arise if ammonia distribution within the flue gas or operating temperature is not optimal resulting in ammonia emissions leaving the SCR in a process referred to as “ammonia slip.” The ammonia slip may also lead to the formation of secondary particulate matter in the form of ammonium sulfate and ammonia nitrate. As discussed in engine systems, the use of low and zero carbon fuels could also be used in stationary applications; it is easier to develop optimized engine systems and stationary sources typically operate in steady-state modes.

Additionally, alternative energy storage could be achieved through vehicle-to-grid or vehicle-to-building technologies, as well as power-to-gas that could allow curtailed renewable electricity to be stored as hydrogen fuel. Microgrid demonstration and deployment projects to support large scale deployment of zero emission vehicles and equipment could also be incorporated into new or existing deployment projects to facilitate installation of infrastructure. UCR’s Sustainable Integrated Grid Initiative and UCI’s Advanced Energy and Power Program, funded in part by the South Coast AQMD, for example, could assist in evaluation of these technologies.

Projects conducted under this category may include:

- development and demonstration of reliable, low emission stationary technologies and fuels (e.g., new innovative low NOx burners and fuel cells);
- exploration of renewables, waste gas and produced gas sources for cleaner stationary technologies;
- evaluation, development and demonstration of advanced control technologies for stationary sources;
- vehicle-to-grid, vehicle-to-building, or other stationary energy demonstration projects to develop sustainable, low emission energy storage alternatives and reduce total cost of ownership (TCO); and
- development and demonstration of microgrids with photovoltaic/fuel cell/battery storage/EV chargers and energy management to support large scale deployment of zero emission vehicles and equipment.

The development, demonstration, deployment and commercialization of advanced stationary clean fuel technologies will support control measures in the 2022 AQMP that reduce emissions of NOx and VOCs from traditional combustion sources by replacement or retrofits with zero and near-zero emission technologies.

Fuel and Emissions Studies

Monitoring of pollutants in the Basin is extremely important, especially when linked to a particular sector of the emissions inventory. This information highlights the need for further emission studies to identify emissions from high polluting sectors resulting from these technologies.

Over the past few years, the South Coast AQMD has funded emission studies to evaluate the impact of tailpipe emissions of biodiesel, renewable diesel, and ethanol fueled vehicles mainly focusing on criteria pollutants and GHG emissions. These studies showed that biofuels, especially biodiesel in some applications and duty cycles, can contribute to higher NOx emissions while reducing other criteria pollutant emissions. South Coast AQMD has participated in several renewable diesel and ethanol-blend gasoline studies led by CARB to approve these renewable fuels in California.

In addition, as the market share for gasoline direct injection (GDI) vehicles has rapidly increased from 4 percent of all vehicle sales in the U.S. to an estimated 60 percent between 2009 and 2016, it is important to understand air quality impacts from these vehicles. South Coast AQMD has funded studies to investigate both physical and chemical composition of tailpipe emissions, focusing on PM from GDI vehicles as well as secondary organic aerosol formation formed by the reaction of gaseous and particulate emissions from natural gas and diesel HD vehicles. The results from these studies suggest the addition of a particulate filter for controlling particulate emissions from GDI vehicles.

In 2017, South Coast AQMD initiated a basin wide in-use real-world emissions study, including fuel usage profile characterization and an assessment of the impacts of current technology and alternative fuels. Preliminary results suggest real-world emissions vary greatly between applications and fuel types; but alternative fueled technologies such as natural gas fueled vehicles, especially ones certified to near-zero emission levels, are significantly lower in emissions compared to diesel baseline. The results of the study also contributed to the new EMFAC 2021 emissions model.

In 2020, CARB adopted the Omnibus regulation to the next lower-level NOx standard, particularly highlighting the need to address the gap between certification values and in-use emissions. The new regulation included a new low-load cycle, new in-use emissions testing metric based on 3-Bin Moving Average Windows (3B-MAW), as well as a new concept to assess NOx across the entire vehicle population via onboard emission sensors. The 3B-MAW will be a game changer for future combustion technologies,

as it addresses the shortfalls of previous in-use testing methods and should address the gap between in-use emissions and the certification standard, an issue commonly seen in the Basin where low-speed, low load operations are more common. It is important to continue conducting real-world emissions studies on existing and new technologies to help stakeholders better understand the impacts of emissions in real time to a specific geographic area, as well as ensuring emissions are low throughout the useful life of the vehicle.

To assess issues with legacy fleets, SB 210 was signed into law in 2019 and directs CARB to develop and implement a new comprehensive HD inspection and maintenance (HD I/M) program to support higher emitter issues due to mal-maintenance/deterioration to ensure trucks maintain their emissions for their intended useful life. The HD I/M program includes an emissions measurement campaign from a large population of a current fleet of trucks which is critical for the success of this program. Mass screening methods such as remote sensing technology, which can be setup near roadsides and on freeway overpasses has gained the spotlight for enabling a new suite of technology for assessing emissions in-use when compared to traditional measurements. In August 2021, CARB staff shared findings and recommendations from the pilot program. CARB suggested that on-board diagnostics (OBD) and Roadside Emissions Monitoring Device (REMD) testing would likely be the best combination of technologies for a future statewide vehicle compliance and enforcement program. Together with Automated License Plate Recognition (ALPR) camera technologies that are able to capture 80% of license plates, this can be another tool to assist in any enforcement efforts. A statewide vehicle compliance program is being phased in with vehicle screening starting in 2023, enforcement of compliance certificate requirements starting in July 2023, and periodic testing and certified devices for OBD submissions in 2024. The newly adopted HD I/M rule should address the concerns of high emitters in the legacy fleets which are expected to remain in service well into the 2030s, further reducing emissions in our region. South Coast AQMD also recognizes HD I/M is one of the few regulations that can provide much needed immediate emission reductions.

In recent years, there has also been an increased interest at the state and federal level in the use of alternative fuels to reduce petroleum oil dependency, GHG emissions and air pollution. To sustain and increase biofuel utilization, it is essential to identify feedstocks that can be processed in a more efficient, cost-effective and sustainable manner. More recently, various low and zero carbon initiatives have stirred up a new round of interest in alternative fuel combinations such as ethanol, hydrogen and other engineered bio/renewable fuels. In 2019, South Coast AQMD, SoCalGas, and UCR/CE-CERT launched a study to assess emission impacts of hydrogen-natural gas blends on near-zero emission natural gas engines. Test results will be available in late 2022. Similar emissions work is being considered to support the use of zero-carbon fuels. Based on higher average summer temperatures over the past few years, there is interest on how higher temperatures impact ozone formation. A project was launched in 2019 to evaluate meteorological factors and trends contributing to recent poor air quality in the Basin. These types of studies may be beneficial to support the CERPs developed under AB 617, as well as other programs targeting benefits to residents in disadvantaged communities.

Some areas of focus include:

- demonstration of remote sensing technologies to target different high emission applications and sources;
- studies to identify health risks associated with ultrafine and ambient particulate matter to characterize toxicity and determine specific combustion sources;
- in-use emission studies using biofuels, including renewable diesel and other alternative fuels;
- in-use emission studies to determine impact of new technologies, in particular new near-zero emission engine technologies and hybrids on local air quality as well as the benefit of telematics on emission reduction strategies;

- lifecycle energy and emissions analyses to evaluate conventional and alternative fuels;
- analysis of fleet composition and its associated impacts on criteria pollutants;
- evaluation of emissions impact of low- and zero-carbon fuels/blends on the latest technology engines; and
- evaluation of impact of higher ambient temperatures on emissions of primary and secondary air pollutants.

Emission Control Technologies

Although engine technology and engine systems research are required to reduce emissions at the combustion source, dual fuel technologies and post-combustion cleanup methods are also needed to address on-road and off-road equipment emissions. Existing diesel emissions can be greatly reduced with introduction of RNG, hydrogen, biofuels, synthetic and low carbon fuels into the engine but also via aftertreatment controls such as close coupled catalysts, advanced SCR and DPF catalysts coupled with electrically heated diesel exhaust fluid (DEF) dosers as well as advanced control strategies using cylinder deactivation, which have proven to lower emissions to near-zero and increase efficiency. Gas to Liquid (GTL) fuels formed from natural gas or other hydrocarbons rather than petroleum feedstock and emulsified diesel, provide low emission fuels for use in diesel engines. As emissions from engines become lower, lubricant contributions to VOC and PM emissions become increasingly important. Recently, particulate matter (PM and PN) emissions from GDI fueled LD vehicles, natural gas fueled MD and HD vehicles have gathered attention due to the lack of particulate filters. While relative PM levels are low and below the applicable standard, concerns on ultra-fine emissions needs to be assessed. South Coast AQMD will continue to fund studies to help mitigate emissions concerns for gasoline and natural gas fueled engines. Onboard emissions sensors have been identified by CARB and other agencies as a reliable method for assessing in-use emissions compliance. At the same time, researchers have proposed to use sensors, coupled with GPS, cellular connection, weather, traffic, and other online air quality models together to enable advanced concepts like Geofencing, Eco-routing, and more. Similar strategy have been presented in CARB's latest 2022 SIP Strategy. The most promising of these technologies will be considered for funding, specifically:

- evaluation and demonstration of new emerging liquid fuels, including alternative and renewable diesel and other GTL fuels;
- development and demonstration of renewable-diesel engines and advanced aftertreatment technologies for mobile applications (including heated dosing technologies, close coupled catalysts, electronically heated catalysts and other advanced selective catalytic reduction systems) as well as non-thermal regen technology;
- development and demonstration of low-VOC and PM lubricants for diesel and natural gas engines;
- develop, evaluate, and demonstrate onboard sensor-based emissions monitoring methodology; and
- develop, evaluate, and demonstrate cloud-based emissions and energy management system.

Health Impacts Studies

Assessment of potential health risks linked to exposure to pollution is extremely important. Studies indicate that ultrafine particulate matter (PM) can produce irreversible damage to children's lungs, which highlights the need for further studies to identify health effects resulting from these technologies.

Previous studies of ambient levels of toxic air contaminants, such as the MATES studies, have found that diesel exhaust is the major contributor to health risk from air toxics. South Coast AQMD completed

MATES V in August 2021 to update the emissions inventory of toxic air contaminants, as well as modeling to characterize risks, including measurements and analysis of ultrafine particle concentrations typically emitted or subsequently formed from vehicle exhaust. Findings from the MATES V report showed that air toxics cancer risk based on modeling data has decreased over 50% since MATES IV, with average multi-pathway air toxics cancer risk at 454-in-a-million. The highest risk locations are at LAX and the Ports along goods movement and transportation corridors. Diesel PM continues to be the major contributor accounting for over 60% of the overall air toxics cancer risk. For the first time, chronic non-cancer risk was estimated with a chronic hazard index of 5.9 across the 10 stations in the MATES V study.

Furthermore, despite recent advancements in toxicological research related to air pollution, the relationship between particle chemical composition and health effects is still not completely understood, especially for biofuels, natural gas and other alternative fuels. In 2015, South Coast AQMD funded chamber studies as part of the 200 Vehicle Study to further investigate the toxicological potential of emissions from MD and HD vehicles, such as ultrafine particles and vapor phase substances, and to determine whether substances such as volatile or semi-volatile organic compounds are being emitted in lower mass emissions that could pose harmful health effects, the results are due to be finalized by end of 2022.

Technology Transfer and Outreach

Since the Clean Fuels Program depends on the deployment and adoption of demonstrated technologies, technology transfer and outreach efforts are essential to its success. This core area encompasses assessment of advanced technologies, including retaining outside technical assistance to expedite implementation of low emission and clean fuel technologies, coordinating activities with other organizations and educating end users of these technologies. Technology transfer efforts include supporting various incentive programs that encourage the purchase of cleaner technologies, cosponsoring technology-related conferences, workshops, and other events, and disseminating information on advanced technologies to various audiences (i.e., residents in AB 617 or disadvantaged communities, local governments, funding agencies, technical audiences). South Coast AQMD's AB 617[4] program is designed to reduce emissions in communities disproportionately impacted by air pollution. TAO conducted additional outreach to AB 617 communities regarding available zero and near-zero emission technologies and incentives to accelerate the adoption of cleaner technologies. Incentivizing deployment of zero emission HD trucks has been included in the CERPs and an RFP for zero emission HD truck incentive funding will be released in 2022 for these AB 617 communities.

Target Allocations to Core Technology Areas

Figure 31 presents the potential allocation of available funding, based on South Coast AQMD projected program costs of $19.8 million for all potential projects. The actual project expenditures for 2023 will be less than the total South Coast AQMD projected program costs since not all projects will materialize. Target allocations are based on balancing technology priorities, technical challenges and opportunities discussed previously, and near term versus long term benefits with the constraints on available South Coast AQMD funding. Although the Clean Fuels Program must consider cost effectiveness of emission reductions as one of several factors in determining which technologies to fund the Legislature allows for flexibility in prioritizing technologies with a higher cost effectiveness if it is deemed necessary for South Coast AQMD to meet its NAAQS. The 2022 AQMP specifically calls for accelerated deployment of zero emission technologies wherever feasible to achieve the 2015 8-hour ozone standard and the associated CARB 2020 Mobile Source Strategy shows the need for rapid implementation of zero-emission transportation. Specific contract awards throughout 2023 will be based on this proposed allocation, quality of proposals received, and evaluation of projects against standardized criteria and ultimately South Coast AQMD Board approval.

[4] http://www.aqmd.gov/nav/about/initiatives/environmental-justice/ab617-134

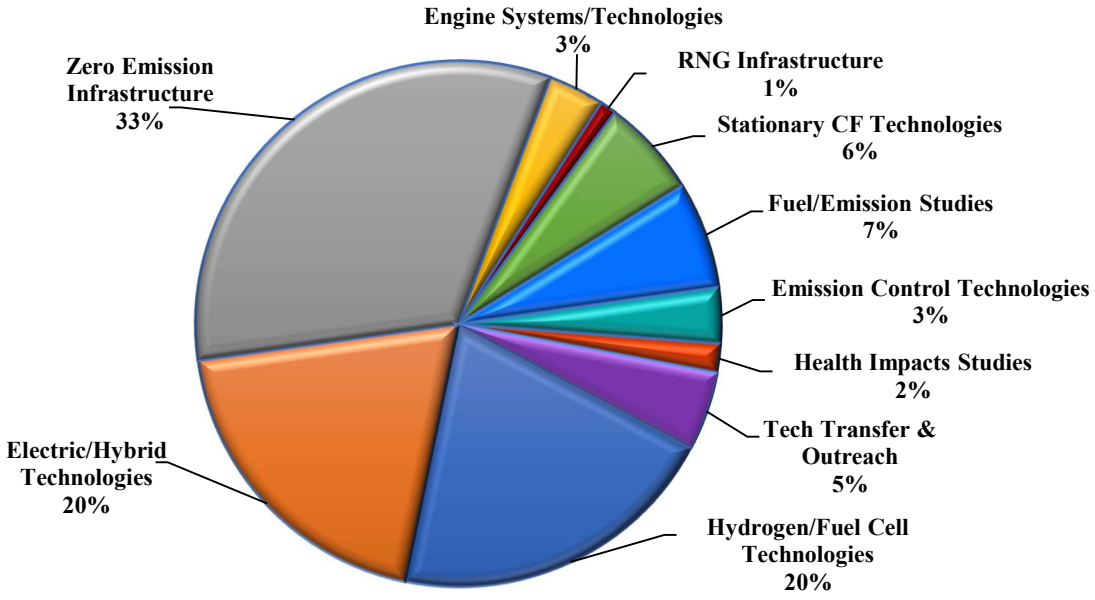


Figure 31: Projected Cost Distribution for Potential South Coast AQMD Projects in 2023 ($19.8M)

[This Page Intentionally Left Blank]

CLEAN FUELS PROGRAM

Program Plan Update for 2023

This section presents the Clean Fuels Program Plan Update for 2023. The proposed projects are organized by program areas and described in further detail, consistent with the South Coast AQMD budget, priorities and the best available information on the state-of-the-technology. Although not required, this Plan also includes proposed projects that may also be funded by revenue sources other than the Clean Fuels Program, through state and federal grants for clean fuel technologies, incentive programs such as AB 617 Community Air Protection Program (CAPP) funding, Volkswagen Mitigation and Carl Moyer, and VOC and NOx mitigation.

Table 16 summarizes potential projects for 2023 as well as the distribution of South Coast AQMD costs in some areas as compared to 2022. The funding allocation continues the focus on development and demonstration of zero and near-zero emission technologies including infrastructure to support vehicles and off-road equipment. For the 2023 Draft Plan Update, there is a continuing focus on zero emission technologies including funding for hydrogen/fuel cell technologies, electric/hybrid technologies, and zero emission infrastructure. Zero emission infrastructure was formerly included within hydrogen/fuel cell and electric/hybrid technologies, but given its increasing importance it is now being presented as a separate category. There are significant decreases in funding for RNG infrastructure and engine systems/ technologies as near-zero engine development has been significantly reduced as funding is increasingly shifted to zero emission technologies and infrastructure for future planned projects in 2023, including:

- HD zero emission battery electric and fuel cell trucks;
- HD zero emission infrastructure development, demonstration, deployment and planning;
- Onboard sensor development for emissions monitoring and improved efficiency;
- Microgrid demonstrations to support zero emission infrastructure;
- Battery and fuel cell electric transit and school bus fleet charging/fueling infrastructure;
- HD diesel truck replacements with zero emission trucks; and
- Fuel and emissions studies, such as conducting airborne measurements and analysis of NOx emissions and assessing emission impacts of hydrogen-natural gas fuel blends on near-zero emission HD natural gas engines.

As in prior years, funding allocations again align well with the South Coast AQMD's FY 2022-23 Goals and Priority Objectives, which includes supporting development of cleaner advanced technologies. Overall, the Clean Fuels Program is designed to ensure a broad portfolio of technologies, complement state and federal efforts, and maximize opportunities to leverage technologies in a synergistic manner.

Each of the proposed projects described in this Plan, once fully developed, will be presented to the South Coast AQMD Governing Board for approval prior to contract initiation. This Plan Update reflects the maturity of the proposed technology and identifies contractors to implement projects, participating host sites and fleets, and securing sufficient cost-sharing to complete projects, and other necessary factors. Recommendations to the South Coast AQMD Governing Board will include descriptions of technologies to be demonstrated or deployed, their applications, proposed scope of work, and capabilities of selected contractor(s) and project teams, in addition to the expected costs and project benefits as required by H&SC 40448.5.1.(a)(1). Based on communications with all organizations specified in H&SC 40448.5.1.(a)(2) and review of their programs, projects proposed in this Plan do not appear to duplicate any past or present projects.

Funding Summary of Potential Projects

The remainder of this section contains the following information for each of the potential projects summarized in Table 16.

Proposed Project: Descriptive title and a designation for future reference.

Expected South Coast AQMD Cost: Estimated proposed South Coast AQMD cost-share as required by H&SC 40448.5.1.(a)(1).

Expected Total Cost: Estimated total project cost including South Coast AQMD cost-share and cost-share of outside organizations expected to be required to complete the proposed project. This is an indication of how much South Coast AQMD public funds are leveraged through its cooperative efforts.

Description of Technology and Application: Brief summary of proposed technology to be developed and demonstrated, including expected vehicles, equipment, fuels, or processes that could benefit.

Potential Air Quality Benefits: Brief discussion of expected benefits of proposed project, including expected contribution towards meeting the goals of the 2022 AQMP, as required by H&SC 40448.5.1.(a)(1). In general, the most important benefits of any technology research, development and demonstration program are not necessarily realized in the near-term. Demonstration projects are generally intended to be proof-of-concept for an advanced technology in a real-world application. While emission benefits, for example, will be achieved from the demonstration, true benefits will be seen over a longer term, as a successfully demonstrated technology is eventually commercialized and implemented on a wide scale.

Table 16: Summary of Potential Projects for 2023

Proposed Project	Expected SCAQMD Cost $	Expected Total Cost $
Hydrogen/Mobile Fuel Cell Technologies		
Develop and Demonstrate Hydrogen Research to Support Innovative Technology Solutions for Fueling Fuel Cell Vehicles	50,000	800,000
Develop and Demonstrate MD and HD Fuel Cell Vehicles	4,000,000	15,000,000
Subtotal	$4,050,000	$15,800,000
Electric/Hybrid Technologies		
Develop and Demonstrate MD and HD On-Road and Off-Road Battery Electric and Hybrid Vehicles and Equipment	3,400,000	26,800,000
Demonstrate Alternative Energy Storage	300,000	1,000,000
Demonstrate Light-Duty Battery Electric Vehicles and Plug-In Hybrid Vehicles	160,000	160,000
Subtotal	$3,860,000	$27,960,000
Zero Emission Infrastructure		
Develop and Demonstrate Hydrogen Production and Fueling Stations	2,000,000	6,500,000
Develop and Demonstrate Electric Charging Infrastructure	4,500,000	47,361,774
Subtotal	$6,500,000	$53,861,774
Engine Systems/Technologies		
Develop and Demonstrate Advanced Gaseous- and Liquid-Fueled MD and HD Engines & Vehicle Technologies to Achieve Ultra-Low Emissions	500,000	2,000,000
Develop and Demonstrate Alternative Fuel and Clean Conventional Fueled Light-Duty Vehicles	0	0
Develop and Demonstrate Low Emission Locomotive Technologies and After Treatment Systems	176,300	1,000,000
Subtotal	$676,300	$3,000,000
RNG Infrastructure (Renewable Natural Gas and Renewable Fuels)		
Demonstrate Near-Zero Emission Hybrid and Hydrogen ICE Vehicles in Various Applications	0	0
Develop, Maintain and Expand Renewable Fuel Infrastructure	200,000	2,100,000
Demonstrate Renewable Transportation Fuel Manufacturing and Distribution Technologies	0	0
Subtotal	$200,000	$2,100,000
Stationary Clean Fuel Technologies		
Develop and Demonstrate Microgrids with Photovoltaic/Fuel Cell/Battery Storage/EV Chargers and Energy Management	1,000,000	4,000,000
Develop and Demonstrate Zero or Near-Zero Emission Energy Generation Alternatives	200,000	1,000,000
Subtotal	$1,200,000	$5,000,000

Table 16: Summary of Potential Projects for 2023 (cont'd)

Proposed Project	Expected SCAQMD Cost $	Expected Total Cost $
Fuel and Emissions Studies		
Conduct In-Use Emission Studies for Advanced Technology Vehicle Demonstrations	500,000	2,000,000
Conduct Emission Studies on Biofuels, Alternative Fuels and Other Related Environmental Impacts	400,000	1,500,000
Identify and Demonstrate In-Use Fleet Emission Reduction Technologies and Opportunities	400,000	1,500,000
Subtotal	$1,300,000	$5,000,000
Emission Control Technologies		
Develop and Demonstrate Advanced Aftertreatment Technologies On-Highway	250,000	1,000,000
Develop Methodology and Evaluate and Demonstrate Onboard Sensors for On-Road HD Vehicles	250,000	1,000,000
Demonstrate On-Road Technologies in Off-Road and Retrofit Applications	176,300	800,000
Subtotal	$676,300	$2,800,000
Health Impacts Studies		
Evaluate Ultrafine Particle Health Effects	88,150	1,000,000
Conduct Monitoring to Assess Environmental Impacts	132,225	500,000
Assess Sources and Health Impacts of Particulate Matter	132,225	300,000
Subtotal	$352,600	$1,800,000
Technology Transfer and Outreach		
Assess and Support Advanced Technologies and Disseminate Information	600,000	1,000,000
Support Implementation of Various Clean Fuels Incentive Programs	350,000	400,000
Subtotal	950,000	$1,400,000
TOTALS FOR POTENTIAL PROJECTS	$19,765,200	$118,721,774

Technical Summaries of Potential Projects

Hydrogen / Mobile Fuel Cell Technologies

Proposed Project: Develop and Demonstrate Hydrogen Research to Support Innovative Technology Solutions for Fueling Fuel Cell Vehicles

Expected South Coast AQMD Cost: $50,000

Expected Total Cost: $800,000

Description of Technology and Application:

California regulations require automakers to place increasing numbers of ZEVs into service every year. By 2050, CARB projects that 87% of LD vehicles on the road will be zero emission battery and FCVs.

Many stakeholders are working on hydrogen and fuel cell products, markets, requirements, mandates and policies. California has been leading the way for hydrogen infrastructure and FCV deployment. This leadership has advanced a hydrogen network that is not duplicated anywhere in the U.S. and is unique in the world for its focus on providing a retail fueling experience. In addition, the advancements have identified many lessons learned for hydrogen infrastructure development, deployment and operation. Other interested states and countries are using California's experience as a model case, making success in California paramount to enabling market acceleration and uptake in the U.S. U.S. leadership for hydrogen technologies is rooted in California, a location for implementing many DOE H2@Scale pathways, such as reducing curtailment and stranded resources, reducing petroleum use and emissions, and developing and creating jobs. The technical research capability of the national laboratories can be used to assist California in decisions and evaluations, as well as to verify solutions to problems impacting the industry. Because these challenges cannot be addressed by one agency or one laboratory, in 2018, a hydrogen research consortium was organized to combine and collaborate. Moreover, in 2022 California announced its intention to develop a renewable hydrogen hub as a part of the DOE announcement for an $8B funding opportunity to establish up to ten regional hydrogen hubs to build self-sustaining hydrogen economies of producers and infrastructure in the nation. The Governor's Office of Business and Economic Development (GO-Biz) established Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES) to unite critical public and private stakeholders to build the framework for a California renewable, clean hydrogen hub as such additional hydrogen research studies and projects are foreseen in 2023.

The California Hydrogen Infrastructure Research Consortium focuses on top research needs and priorities to address near-term problems to support California's continued leadership in innovative hydrogen technology solutions needed for fueling FCVs. These tasks also provide significant contributions to the DOE H2@Scale Initiative. For instance, advances in fueling methods and components can support the development of supply chains and deployments. Tasks completed include data collection from operational stations, component failure fix verification (i.e., nozzle freeze lock), reporting about new fueling methods for MD and HD applications and HD tasks to develop HD reference station design, model HD station capacity with high flowrates and provide near-real-time verification of fuel quality with on-site hydrogen contaminant detectors (HCDs) for use at both LD and HD stations. The tasks are supported by leading researchers at NREL and coordinating national labs and managed in detail (e.g., schedule, budget, roles, milestones, tasks, reporting requirements) in a hydrogen research consortium project management plan. The UC Davis Institute of Transportation study on hydrogen systems analysis in 2021 is intended to evaluate the current hydrogen polices and their impact on a carbon neutral transportation by 2050 with data analysis and modeling support of the current hydrogen resources.

These efforts are complemented by projects undertaken and supported by the HFCP and its members over the last few years such as the *H2 Fuel Cell Electric Trucks, A Vision for Freight Movement in California – and Beyond* document released in July 2021 establishing a vision for 70,000 Class 8 FC trucks supported by 200 hydrogen fueling stations by 2035, including barriers that need to be overcome, CARB's Advanced Clean Truck Regulation adopted in June 2020, and anticipated adoption of the Advanced Clean Fleets Regulation in 2022.

This project area would enable co-funding support for additional or follow on mutually agreed technical tasks with the California Hydrogen Infrastructure Research Consortium members, the HFCP, UC Davis as well as other collaborative efforts that may be undertaken to advance hydrogen infrastructure technologies including the upcoming hydrogen hubs efforts.

Potential Air Quality Benefits:

The 2022 AQMP identifies the use of alternative fuels and zero emission transportation technologies as necessary to lower NOx and VOC emissions to meet federal air quality standards. One of the major advantages of FCVs is the fact that they use hydrogen, a fuel that can be domestically produced from a variety of resources such as natural gas (including biogas), electricity (stationary turbine technology, solar or wind), and biomass. The technology and means to produce hydrogen fuel to support FCVs are available but require optimization to achieve broad market scale. The deployment of large numbers of FCVs, which is one strategy to attain air quality goals, requires a well-planned and robust hydrogen fueling infrastructure network. These South Coast AQMD projects, with significant additional funding from other governmental and private entities, will work towards providing the necessary hydrogen production and fueling infrastructure network for our region.

Proposed Project: Develop and Demonstrate MD and HD Fuel Cell Vehicles

Expected South Coast AQMD Cost: $4,000,000

Expected Total Cost: $15,000,000

Description of Technology and Application:

This proposed project would support evaluation, including demonstrating promising fuel cell technologies for applications using direct hydrogen with proton exchange membrane (PEM) fuel cell technology. Battery dominant fuel cell hybrids are another potential technology to reduce costs and potentially enhance the performance of FCVs.

The California *ZEV Action Plan* specifies actions to help deploy an increasing number of ZEVs, including MD and HD ZEVs. CARB's Advanced Clean Truck and Fleet and Innovative Clean Transit Bus Regulations will also increase deployment of MD and HD FCVs. Fleets are useful demonstration sites because economies of scale exist in central fueling, training skilled personnel to operate and maintain FCVs, monitoring and collecting data on vehicle performance, and OEM technical and customer support. In some cases, MD and HD FCVs could leverage the growing network of hydrogen stations and provide an early base load of fuel consumption until the number of LD FCVs grows. These vehicles could include hybrid-electric vehicles powered by fuel cells and equipped with batteries capable of being charged from the grid and even supplying power to the grid.

In 2012, the DOE awarded South Coast AQMD funds to demonstrate Zero Emission Container Transport (ZECT) technologies. In 2015, the DOE awarded South Coast AQMD additional funds to develop and demonstrate additional fuel cell truck platforms and vehicles under ZECT II. Both ZECT I and ZECT II enabled the largest strides in Technology Readiness Level (TRL) of hybrid, battery electric and fuel cell HD trucks on the overall vehicle design and architecture. Especially, the fuel cell drayage truck's TRL prior to this project was at a strong Level 4 with several proof-of-concept vehicles constructed and it has advanced the TRL to a Level 7 with ZECT II. The Clean Fuels Program cost-shared the demonstration of transit buses at OCTA which was completed in September 2021. In 2020, the U.S. EPA Targeted Airshed Grant Program awarded South Coast AQMD five fuel cell transit buses to be deployed at SunLine Transit which was also cost-shared by the Clean Fuels Program.

This category may include projects in the following applications:

On-Road:	**Off-Road:**
• Transit Buses • Shuttle Buses • MD & HD Trucks	• Vehicle Auxiliary Power Units • Construction Equipment • Lawn and Garden Equipment • Cargo Handling Equipment

Potential Air Quality Benefits:

The 2022 AQMP identifies the need to implement ZEVs. South Coast AQMD adopted fleet regulations require public and some private fleets within the Basin to acquire alternatively fueled vehicles when making new purchases. CARB is revising the Advanced Clean Fleets for adoption in 2022 to impose 100% zero emission vehicle fleet targets for last mile delivery, drayage and public fleets in 2035. In the future, such vehicles could be powered by zero emission fuel cells operating on hydrogen fuel. The proposed projects have the potential to accelerate the commercial viability of FCVs. Expected immediate benefits include the establishment of zero and near-zero emission proof-of-concept vehicles in numerous applications. Over the longer term, the proposed projects could help foster wide-scale implementation of FCVs in the Basin. The

proposed projects could also lead to significant fuel economy improvements, manufacturing innovations and the creation of high-tech jobs in Southern California, besides realizing the air quality benefits projected in the AQMP as well as GHG reductions. Currently, the range of the trucks in the ZECT II project have a targeted range of 150 miles. Future projects would include extending the range of the FCVs up to 400 miles and demonstrate improvements in reliability and durability of powertrain systems and hydrogen storage systems. For fuel cell transit buses, projects are being proposed that reduce the cost of the fuel cell bus to less than $1 million through advanced technologies for the fuel cell stack, higher density and lower cost batteries, and increased production volumes.

Electric / Hybrid Technologies

Proposed Project: Develop and Demonstrate MD and HD On-Road and Off-Road Battery Electric and Hybrid Vehicles and Equipment

Expected South Coast AQMD Cost: $3,400,000

Expected Total Cost: $26,800,000

Description of Technology and Application:

The significance of transportation in overall carbon emissions is increasing as energy utilities move toward cleaner and more sustainable ways to generate electricity. U.S. EPA (2022)[5] estimated that transportation was responsible for 27 percent of the nation's carbon emissions, while the electricity sector emissions accounted for 25 percent.

The South Coast AQMD has long been a leader in promoting early demonstrations of next generation LD vehicle propulsion technologies (and fuels). However, given the commercial availability of LD EVs, priorities have shifted. South Coast AQMD will continue to evaluate market offerings and proposed technologies in LD vehicles to determine if any future support is required.

Meanwhile, MD and HD vehicles make up 5[6] percent of vehicles in the U.S. and drive 11[7] percent of all vehicle miles traveled each year yet are responsible for more than 25[8] percent of all the fuel burned annually. Moreover, the 2022 AQMP identified MD and HD vehicles as the largest source of NOx emissions in the Basin. Electric and hybrid technologies have gained momentum in the LD sector with commercial offerings by most of the automobile manufacturers. Unfortunately, significant emission reductions are needed for MD and HD vehicles and off-road equipment, exacerbated by low turnover of these vehicles by fleets and high incremental costs for battery electric vehicles and equipment compared to conventional-fueled vehicles and equipment.

The South Coast AQMD has investigated the use of electric and hybrid technologies to achieve similar performance as conventional-fueled counterparts while achieving emission reductions and improved fuel economy. Multiple natural gas and diesel hybrid vehicles have been developed and demonstrated under the DOE funded Zero Emissions Cargo Transport (ZECT), CARB Greenhouse Gas Reduction Fund (GGRF) and NREL's Natural Gas Vehicle Consortium. These hybrid trucks all share plug-in capability and ability to operate in zero emission mode, and some leveraging advanced concepts such as geofencing and EcoDrive to maximize emission reductions in disadvantaged communities. CARB's Advanced Clean Trucks (ACT) and Advanced Clean Fleets (ACF) regulations further provided additional compliance flexibility for plug-in hybrids. Vehicle based hybrid systems continue to progress for additional emission reductions and efficiency improvements. Engine powertrain based hybrid systems began to emerge since the introduction of optional hybrid powertrain test procedures.

Vehicle categories to be considered for potential or future demonstration and deployment projects include drayage/freight/regional haul trucks, utility trucks, last mile delivery vans, shuttle buses, transit buses, waste haulers, construction equipment, cranes and other off-road equipment such as yard tractors, forklifts, top

[5] *U.S. Greenhouse Gas Emissions and Sinks 1990-2020*. 2022. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

[6] https://www.bts.gov/content/number-us-aircraft-vehicles-vessels-and-other-conveyances

[7] https://www.bts.gov/content/us-vehicle-miles

8 https://www.bts.gov/content/fuel-consumption-mode-transportation

handlers, and RTG cranes. Innovations that may be considered for demonstration and deployment include advancements in the auxiliary power unit, either ICE or other heat engine; and battery-dominant plug-in hybrid systems utilizing off-peak charging, with advanced battery technologies including alternative chemistries, design, and management systems. Alternative fuels are preferred in these projects, e.g., natural gas, especially from renewable sources, LPG, hydrogen, gas-to-liquid (GTL) and hydrogen-natural gas blends, but conventional fuels such as gasoline, renewable diesel, or even modified biodiesel may be considered if emission benefits can be demonstrated as equivalent or superior to alternative fuels. Both new designs and retrofit technologies and related charging infrastructure will be considered.

Both on-road vehicles and off-road equipment are transitioning increasingly towards zero emission technologies. Off-road equipment includes cargo handling equipment as well as construction equipment. The Volvo LIGHTS project included certification of Volvo's Class 8 battery electric truck, and the demonstration of a zero-emission freight handling system including 30 Class 8 battery electric trucks, 29 battery electric yard tractors and forklifts, 56 chargers and solar/energy storage at fleets DHE and NFI. Volvo Construction Equipment just recently finished demonstrating a small battery electric compact excavator and wheel loader in California that was commercially released in late 2021. Several other manufacturers have released battery electric and hybrid equipment, and more are becoming commercially available. CARB has introduced the Clean Off-Road Equipment Voucher Incentive Project (CORE) which have been seeing great success in deploying zero-emission cargo handling equipment and switch locomotives. The most recent round of funding in 2022 included off-road construction equipment. Since the applications are more diverse in this sector, continued development and incentives are needed to accelerate progress in this sector, especially for large mobile off-road equipment where infrastructure solutions are more difficult.

This project category will develop and demonstrate:

- various electric vehicles and equipment;
- anticipated costs for electric vehicles and equipment;
- customer interest and preferences for these alternatives;
- integration of technologies into prototype vehicles and fleets;
- battery electric and hybrid-electric MD and HD vehicles (e.g., drayage/freight/regional haul trucks, utility trucks, delivery vans, shuttle buses, transit buses, waste haulers);
- development and demonstration of battery electric off-road equipment, (e.g., battery electric off-road cargo handling such as yard tractors, forklifts and top-handlers, and construction equipment;
- development and demonstration of hybrid and plug-in hybrid vehicle technology; and

Potential Air Quality Benefits:

The 2022 AQMP identifies zero or near-zero emission vehicles as a key attainment strategy. Plug-in hybrid electric technologies have the potential to achieve near-zero emission while retaining the range capabilities of conventional-fueled vehicles, a key factor expected to enhance broader consumer acceptance. Given the variety of EV systems under development, it is critical to determine actual emission reductions and performance metrics compared to conventional-fueled vehicles. Successful demonstration of optimized prototypes would promise to enhance the deployment of zero and near-zero emission technologies.

Expected benefits include the establishment of criteria for emission evaluations, performance requirements, and customer acceptability of the technology. This will help both regulatory agencies and OEMs to expedite introduction of zero and near-zero emission vehicles in the Basin, which is a high priority of the 2022 AQMP.

Proposed Project: Demonstrate Alternative Energy Storage

Expected South Coast AQMD Cost: $300,000

Expected Total Cost: $1,000,000

Description of Technology and Application:

The South Coast AQMD has been involved in the development and demonstration of energy storage systems for electric and hybrid-electric vehicles, mainly lithium ion chemistry battery packs. Over the past few years, new technologies, especially lithium-ion batteries have shown robust performance. Other technology manufacturers have also developed energy storage devices including beyond lithium-ion batteries, flywheels, hydraulic systems and ultracapacitors. Energy storage systems optimized to combine the advantages of ultracapacitors and high-energy but low-power advanced batteries could yield benefits. Beyond lithium-ion batteries (e.g., lithium-sulfur, lithium-oxygen, sodium-ion, flow, and solid-state batteries) also have opportunities to achieve higher energy density, longer cycle life, and lower cost.

This project category is to apply these advanced storage technologies in vehicle platforms to identify best fit applications, demonstrate their viability (reliability, maintenance and durability), gauge market preparedness, evaluate costs relative to current lithium-ion batteries and provide a pathway to commercialization. The use of alternative energy storage and generation (i.e. solar) could also be in combination with a large scale deployment of 50 or more battery electric trucks and charging infrastructure at a single fleet location for energy storage optimization for grid reliability and offset electricity demand charges.

The long-term objective of this project is to decrease fuel consumption and resulting emissions without any changes in performance compared to conventional-fueled vehicles. This effort will support several projects for development and demonstration of battery electric and hybrid electric vehicles using advanced energy storage strategies and conventional or alternative fuels. The overall net emissions and fuel consumption of these types of vehicles are expected to be much lower than traditional engine systems. Both new and retrofit technologies will be considered.

Additionally, this project will also assess potential for second life uses of electric vehicle batteries for storage as well as the longer term more cost-effective recycling approaches currently in a nascent “pilot” stage, especially for metals such as lithium and cobalt.

Potential Air Quality Benefits:

Certification of battery electric and hybrid electric vehicles and engines and their integration into the Basin’s transportation sector is a high priority under the 2022 AQMP. This project is expected to further efforts to develop alternative energy storage technologies that could be implemented in MD and HD trucks, buses, off-road equipment, and other applications. Benefits will include proof of concept for new technologies, diversification of transportation fuels and lower emissions of criteria, toxic pollutants and greenhouse gases.

Proposed Project: Demonstrate Light-Duty Battery Electric Vehicles and Plug-In Hybrid Vehicles

Expected South Coast AQMD Cost: $160,000

Expected Total Cost: $160,000

Description of Technology and Application:

This proposed project would support the demonstration of limited production and early commercial LD BEVs and PHEVs using advanced technology, mainly through showcasing this technology. Recent designs of LD BEVs and PHEVs provide increased electric range, improved efficiency and recharge times, and other advanced safety, energy, autonomous and performance features in new platforms and applications that can accelerate EV adoption.

South Coast AQMD has included BEVs and PHEVs as part of its demonstration fleet since the development of early conversion vehicles. South Coast AQMD installed 92 Level 2 EV charging ports in 2017 and a DC fast charger with CHAdeMO and CCS1 connectors in 2018 to support public and workplace charging as a means of education outreach regarding BEV and PHEV technology. Thirty networked Level 2 fleet chargers were added through the Southern California Edison Charge Ready Fleet program in 2020, which will help South Coast AQMD acquire 8,500 GVW and over ZEVs like LD trucks and vans to comply with the upcoming CARB Advanced Clean Fleet regulation.

LD BEVs and PHEVs are available from most established OEMs and several new OEMs. Current legislation extends solo carpool lane access only for MY 2019 and later vehicles, with all Clean Air Vehicle decals expiring between 2023 - 2025, unless legislation is adopted to continue.

Potential Air Quality Benefits:

The 2022 AQMP identifies the need to implement LD EVs. South Coast AQMD adopted fleet regulations require public and some private fleets within the Basin to acquire alternatively fueled vehicles when making new purchases. In the future, such vehicles could be powered by BEVs. The proposed projects have the potential to accelerate commercial viability of BEVs and PHEVs. Expected immediate benefits include the deployment of ZEVs in South Coast AQMD's demonstration fleet. Over the longer term, the proposed projects could help foster wide-scale implementation of ZEVs in the Basin. The proposed projects could also lead to significant fuel economy improvements, manufacturing innovations and the creation of high-tech jobs in Southern California, besides realizing the air quality benefits projected in the 2022 AQMP.

Zero Emission Infrastructure

Proposed Project: Develop and Demonstrate Hydrogen Production and Fueling Stations

Expected South Coast AQMD Cost: $2,000,000

Expected Total Cost: $6,500,000

Description of Technology and Application:

Alternative fuels, such as hydrogen and the use of advanced technologies, such as FCVs, are necessary to meet future clean air standards. A key element in the widespread acceptance and resulting increased use of alternative fuel vehicles is the development of a reliable and robust infrastructure to support the fueling of vehicles, cost-effective production and distribution and clean utilization of these new fuels.

A challenge to the entry and acceptance of direct-hydrogen FCVs is the limited number and scale of hydrogen fueling and production sites. This project would support the development and demonstration of hydrogen fueling technologies with a focus on MD/HD fueling infrastructure. Proposed projects would address:

Fleet and Commercial Fueling Stations: Further expansion of the hydrogen fueling network based on retail models, providing renewable generation, adoption of standardized measurements for hydrogen fueling, other strategic fueling locations, dispensing pressures that support zero emission vehicle deployment and compatibility with existing CNG stations may be considered.

Energy Stations: Multiple-use energy stations that can produce hydrogen for FCVs or stationary power generation are considered an enabling technology and potentially cost-competitive with large-scale reforming. System efficiency, emissions, hydrogen throughput, hydrogen purity and system economics will be monitored to optimize strategies for hydrogen fueling infrastructure deployment and to produce power and hydrogen from renewable feedstocks (e.g., biomass, digester gas) and store hydrogen in larger scale.

Innovative Fueling Appliances: Home or small scale fueling/charging is an attractive advancement for alternative clean fuels for potential applications. This project would evaluate an innovative hydrogen refueler for cost, compactness, performance, durability, emission characteristics, ease of assembly and disassembly, maintenance and operations. Other issues such as setbacks, building permits, building code compliance and UL ratings for safety would also be evaluated.

- CARB projections for on-road FCVs counts are now 30,800 in 2024 and 61,000 in 2027 in California[9] and the majority of these do not include MD and HD vehicles deployed in the Basin. To meet demand, the number of hydrogen fueling infrastructures needs to be significantly increased and become more reliable in terms of uptime and supply. South Coast AQMD will seek additional funding from CEC and CARB to construct and operate hydrogen fueling stations and take advantage of funding opportunities that may arise soon with the California hydrogen hub application and others such as anticipated adoption of the Advanced Clean Fleets Regulation.

Potential Air Quality Benefits:

The 2022 AQMP identifies the use of alternative clean fuels in mobile sources as a key attainment strategy. Pursuant to AQMP goals, the South Coast AQMD has several fleet rules in effect that require public and

[9] California Air Resources Board. *2021 Annual Evaluation of Fuel Cell Vehicle Deployment & Hydrogen Fuel Station Network Development* (AB 8 Report). September 2021.

certain private fleets to purchase clean-burning alternative-fueled vehicles when adding or replacing vehicles to their vehicle fleets. The Warehouse Indirect Source Rule (ISR) also requires certain warehouse owners and operators to comply with the rule by operating clean fuel vehicle technologies. FCVs constitute some of the cleanest alternative-fuel vehicles today. Since hydrogen is a key fuel for FCVs, this project would address some of the barriers faced by hydrogen as a fuel with the focus on MD/HD infrastructure and thus assist in accelerating its acceptance and ultimate commercialization. In addition to supporting the immediate deployment of the demonstration fleet, expanding the hydrogen fuel infrastructure should contribute to the market acceptance of fuel cell technologies in the long run, leading to substantial reductions in NOx, VOC, CO, PM and toxic compound emissions from vehicles.

Proposed Project: Develop and Demonstrate Electric Charging Infrastructure

Expected South Coast AQMD Cost: $4,500,000

Expected Total Cost: $47,361,774

Description of Technology and Application:

There is a critical need to address gaps in EV charging infrastructure availability. Thirty nine percent of the 2,826,923[10] EVs sold in the U.S. since 2010 were in California, and of those sales in California, almost half (46 percent) of CVRP[11] rebates issued as of April 2021 were for vehicles in the South Coast AQMD. In addition, the California *ZEV Action Plan*, which was updated in 2018, calls for 5 million ZEVs and supporting infrastructure by 2030.

There are separate challenges associated with infrastructure for LD EVs vs. MD and HD EVs, which are on opposite ends of the commercialization spectrum. LD EVs and charging infrastructure have long been commercially available with an SAE J1772 connector standard for Level 1 and Level 2 charging. Availability of public fast charging and workplace charging continues to increase and is needed particularly for residents in multi-unit dwellings without easy access to home charging. Availability and costs to deploy infrastructure are the main challenges for LD EVs.

MD and HD EVs are becoming more commercially available, with Daimler and Volvo obtaining CARB certification of their Class 6 and/or 8 battery electric trucks in 2020. Standards for charging infrastructure to support MD and HD EVs has generally been with the CCS1 connector in North America. Although Volvo and ABB obtained UL certification of the CCS2 connector in 2020, which is a connector standard predominantly used in Europe and other parts of the world, the CCS1 connector continues to be the standard connector for charging up to 350 kW DC. A Megawatt Charging System connector is under development by the Charging Interface Initiative (CharIN) for Class 6 -8 EVs for charging up to 4.5 MW DC, although there are no EVs which are currently capable of accepting charging above 350 kW DC. There is also an agreed upon SAE J3068 connector standard for single-phase and three-phase AC charging. The challenges and costs of installing MD and HD charging infrastructure are exponentially increased compared to LD infrastructure. Each year there are more commercially available options for MD and HD on-road EVs and off-road equipment, charging infrastructure to HD EVs, equipment, and infrastructure. As the deployment of MD and HD EVs and off-road equipment has increased, there is an increasing reliance on the use of standardized charging connectors that are UL or Nationally Recognized Testing Laboratory (NRTL) certified charging infrastructure, as opposed to proprietary charging infrastructure and connectors which can only be used with EVs and equipment manufactured by that OEM or equipment manufacturer. Further, for off-road mobile applications where a fixed charging solution is not feasible, innovative solutions must be explored and demonstrated.

The South Coast AQMD is actively pursuing development of intelligent transportation systems, such as Volvo's EcoDrive 2.0 software platform being utilized for the GGRF Zero Emission Drayage Truck (ZEDT) and Volvo LIGHTS projects, to improve traffic efficiency of battery electric and fuel cell electric drayage/freight trucks. This system provides truck drivers real-time vehicle operation feedback based on changing traffic and road conditions where trucks can dynamically change their speed to better flow through intersections. EcoDrive also uses geofencing capabilities to operate in zero emissions mode while traveling through disadvantaged communities. A truck eco-routing system can provide the eco-friendliest travel route based on truck engine/emission control characteristics, loaded weight, road grade and real-time traffic

[10] https://www.veloz.org/ev-market-report/. Q2 2022 data uploaded on 8/23/22.

[11] https://cleanvehiclerebate.org/eng/rebate-statistics

conditions. Integrated programs can interconnect fleets of electric drive vehicles with mass transit via web-based reservation systems that allow multiple users. These integrated programs can match the features of EVs (zero emissions, zero start-up emissions, short range) to typical consumer demands for mobility in a way that significantly reduces emissions of pollutants and greenhouse gases. As part of the demonstration of the Volvo diesel plug-in hybrid electric truck for the ZEDT project, this truck will be demonstrated in California for six months starting in November 2020 and data will be collected on the performance of EcoDrive 2.0 through the connector vehicle corridor in Carson that was set up as part of the CEC funded Eco FRATIS[12] freight transportation connected truck project.

This project category is one of South Coast AQMD's continued efforts to:

- deploy a network of DC fast charging infrastructure (350kW or more) and rapidly expand the existing network of public EV charging stations including energy storage systems;
- deploy DC fast charging infrastructure (500 kW or more) in conjunction with energy storage and/or solar to support large scale deployments of 50 or more battery electric trucks at a single fleet location;
- charging infrastructure and innovative systems (i.e. solar or battery swap) to support MD and HD vehicle and off-road equipment demonstration and deployment projects;
- regional planning for MD/HD charging;
- Develop MD/HD charging infrastructure solutions that provide easier installation through reduced grid reliance and increased resiliency;
- support investigation of fast charging impacts on battery life;
- develop intelligent transportation system strategies for cargo containers; and
- develop freight load-balancing strategies as well as to conduct market analysis for zero emission HD trucks in goods movement.

Potential Air Quality Benefits:

The 2022 AQMP identifies zero emission vehicles as a key attainment strategy. MD/HD infrastructure is currently a limiting factor to deploying battery electric trucks for many fleets. This proposed project category will reduce PM pollution along major roadways through the expansion of the public EV charging infrastructure network by allowing drivers to shift away from conventional-fueled vehicles to battery and fuel cell EVs. In addition, this project will assist in achieving improved fuel economy and lower tailpipe emissions, further helping the region to achieve NAAQS and protect public health. Expected benefits include the establishment of criteria for emission evaluations, performance requirements and customer acceptability of the technology. This will help both regulatory agencies and OEMs to expedite introduction of ZEVs in the Basin, which is a high priority of the 2022 AQMP.

[12] https://www.aapa-ports.org/files/PDFs/ITS%20POLA%204.24.2019.pdf

Engine Systems / Technologies

Proposed Project: Develop and Demonstrate Advanced Gaseous- and Liquid-Fueled MD and HD Engines and Vehicles Technologies to Achieve Ultra-Low Emissions

Expected South Coast AQMD Cost: $500,000

Expected Total Cost: $2,000,000

Description of Technology and Application:

The objective of this proposed project would be to support development and certification of near-commercial prototype low emission MD and HD gaseous- and liquid-fueled engine technologies, as well as integration and demonstration of these technologies in on-road vehicles. The NOx emissions target for this project area is 0.02 g/bhp-hr or lower and the PM emissions target is below 0.01 g/bhp-hr. The recent development of low-NOx diesel or natural gas engine hybrid/plug-in hybrid powertrain has also shown the potential for achieving lower NOx as a combined system. To achieve these targets, an effective emissions control strategy must employ advanced fuel system and engine design features such as CDA, aggressive engine calibration and improved thermal management, improved exhaust gas recirculation (EGR) systems, and aftertreatment devices that are optimized using a system approach. This effort is expected to result in several projects, including:

- development and demonstration of advanced engines in MD and HD vehicles and high horsepower (HP) applications;
- development of durable and reliable retrofit technologies to significantly reduce NOx emissions;
- field demonstrations of advanced technologies in various fleets operating with different classes of vehicles;
- development and demonstration of CNG, propane and diesel hybrid powertrain technology; and
- development and demonstration of optimized engine systems for use with low- and zero carbon alternative fuels such as hydrogen

Anticipated fuels for these projects include but are not limited to alternative fuels (fossil fuel-based and renewable natural gas, propane, hydrogen blends, ethanol, electric and hybrid), conventional and alternative diesel fuels, ultra-low sulfur diesel, renewable diesel, dimethyl ether and gas-to-liquid fuels. There has been significantly more interest as well as a mandate requiring the use of renewable fuels across all sectors due to CARB's Low Carbon Fuel Standard (LCFS). Projects listed under Fuel/Emissions Studies will assess the emissions impact of renewable fuels on past and future optimized combustion technologies. Several key diesel engine development projects that have demonstrated the ability to achieve 0.02 g/bhp-hr NOx under laboratory conditions are near the on-road truck demonstration stage. Truck integration and packaging are another critical step towards commercialization. Prototype trucks are typically placed in revenue service to collect real-world performance data as well as end user feedback for production engines. Furthermore, with the new in-use and low-load emissions requirements within the CARB Omnibus and the U.S. EPA CTI regulations, we expect these new generation of low-emission engines to comply with the low emissions standard for their full useful life.

The use of alternative fuel in HD trucking applications has been demonstrated in certain local fleets within the Basin. These vehicles typically require 200-400 HP engines. Higher HP alternative fuel engines for long-haul applications are beginning to be introduced. However, vehicle range, lack or limited accessible public infrastructure, lack of experience with alternative fuel engine technologies, limited selection of appropriate alternative fuel engine products, and high initial cost have made it difficult for more fleets to

adopt and deploy larger quantity of alternative fuel vehicles. For example, in recent years, several large trucking fleets have expressed interest in using alternative fuels but requires higher horsepower engines that able to fulfill the full range of needs. However, at this time the choice of engines over 400 HP or more was not available. Continued development of cleaner dedicated alternative gaseous- or diesel-fueled engines over 400 HP with low NOx emissions, would increase availability to end-users and provide additional emission reductions for long-haul applications. The applications that require high power/torque levels such as long haul are also the applications where zero emission technologies and supporting infrastructures will take longer to become commercially available. South Coast has been supporting effort for developing high power natural gas engines that address that gap.

Moreover, as incentive funding shifts away as clean combustion technologies reach full commercial readiness, development of cost-effective technologies that do not rely on incentives are key to drive additional market penetration and emissions reduction. South Coast AQMD has investigated the emergence of cost-effective hybrid and plug-in hybrid powertrain technologies to achieve targeted lower-NOx emission standard while with improved fuel economy. Cost-effective hybrid technologies that offer reasonable payback period could potentially offer a faster commercialization pathway for reducing both NOx and GHG in the near term by strategically utilizing the existing ICEs and electric components together to assists engine operation and maintain aftertreatment temperature and efficiency. Manufacturers of Emission Controls Association's (MECA) 2019 low NOx white paper analysis shows that these newly integrated hybrid powertrains could potentially achieve the CARB 2024-2026 NOx standard of 0.05 g/bhp-hr while maintaining reasonable costs and offering a feasible pathway to 0.02 g/bhp-hr. Due to the slow fleet turn over, the legacy 2010+ diesel fleet will remain in service well into the 2030s and beyond, especially for the high powered applications. Thus, continued development of cost-effective low emission engine technologies is key to reduce the impact of legacy fleets in our region.

Potential Air Quality Benefits:

This project is intended to expedite the commercialization of near-zero emission gaseous- and liquid-fueled MD and HD engine technology both in the Basin and in intrastate operation. The emissions reduction benefits of replacing one 4.0 g/bhp-hr HD engine with a 0.02 g/bhp-hr engine in a vehicle that consumes 10,000 gallons of fuel per year is about 1,400 lb/yr of NOx. MD and HD engines between 6L to 12L using natural gas and propane achieving NOx emissions of 0.02 g/bhp-hr have been certified and commercialized, with larger displacement and advanced technology (e.g., opposed piston) engines still undergoing development. Further, renewable or blended alternative fuels can also reduce HD engine particulate emissions by over 90 percent compared to current diesel technology. The key to future engine system project success are emissions, cost-effectiveness and availability of future incentives. This project is expected to lead to increased availability of low emission alternative fuel HD engines. Fleets can use the engines and vehicles emerging from this project to comply with South Coast AQMD fleet regulations and towards compliance of the 2022 AQMP control measures as well as future CARB and U.S. EPA low NOx regulations.

Proposed Project: Develop and Demonstrate Alternative Fuel and Clean Conventional Fueled Light-Duty Vehicles

Expected South Coast AQMD Cost: $0

Expected Total Cost: **$**0

Description of Technology and Application:

Although new conventionally fueled vehicles are much cleaner than their predecessors, not all match the lowest emissions standards often achieved by alternative fuel vehicles. This project would assist in the development, demonstration and certification of both alternative-fueled and conventional-fueled vehicles to meet the strictest emissions requirements by the state, e.g., SULEV for light-duty vehicles. The candidate fuels include CNG, LPG, ethanol, GTL, renewable diesel and hydrogen, and other novel technologies including electric hybrids. The potential vehicle projects may include:

- certification of CNG light-duty sedans and pickup trucks used in fleet services;
- assessment of "clean diesel" vehicles, including hybrids and their ability to attain SULEV standards;
- assessment of other clean technologies; and
- other fuel and technology combinations may also be considered under this category.

Potential Air Quality Benefits:

The 2022 AQMP identifies the use of alternative clean fuels in mobile sources as a key attainment strategy. Pursuant to AQMP goals, South Coast AQMD has in effect several fleet rules that require public and certain private fleets to purchase clean-burning alternative-fueled vehicles when adding or replacing vehicles to their vehicle fleets. This project is expected to lead to increased availability of low emission alternative- and conventional-fueled vehicles for fleets as well as consumer purchase.

Proposed Project: Develop and Demonstrate Low Emission Locomotive Technologies and After Treatment Systems

Expected South Coast AQMD Cost: $176,300

Expected Total Cost: $1,000,000

Description of Technology and Application:

This project aims to support the development and demonstration of gaseous and liquid-fueled locomotive engines. With the upcoming revision of locomotive regulations and the plan to establish Tier 5 or cleaner locomotive emission standards, railroads are exploring the possibility of transitioning from diesel to cleaner fuels or installing aftertreatments to the existing locomotives. The railroad is also considering alternative fuels for its potential economic benefit as compared with diesel fuel. The requirements of locomotive engines as primary generators of electricity to power the locomotive poses serious challenges. From an operational standpoint, there is a significant difference between natural gas and diesel energy density, a fuel tender would need to provide sufficient fuel for an acceptable range. Locomotives operate at a specific duty cycle different than conventional on-road engines. The engines often run at low speed and have extended periods of idle time. The durability requirements also surpass other forms of transportation.

Large displacement gaseous fueled engines are still in early stages of commercialization in the U.S., especially in the marine sector. The development of engines and systems to fill this need is currently on-going in the locomotive sector. Engine emissions are expected to be below the current 0.2g/bhp-hr NOx standard. Adaptation of alternative fueled locomotives in coordination with required infrastructure improvements by leading manufacturers in the industry, shows great potential for further research and cost savings with fewer maintenance costs and better reliability. Depending on the type of combustion strategy, aftertreatments are likely needed to achieve Tier 4 or cleaner emission standards. Urea-based selective catalytic reduction (SCR) or exhaust gas recirculation (EGR) can be used to reduce NOx emissions and methane slip. Similar low and zero carbon fueled engines could migrate as a retrofit option.

Potential Air Quality Benefits:

The 2022 AQMP identifies the use of low emissions technologies for locomotives where zero emission technologies are not yet commercially available. This project is expected to reduce emissions of around 97 tons per year of NOx per locomotive. The reduction of PM and GHG emissions also show great potential mitigation in environmental justice communities.

RNG Infrastructure (Renewable Natural Gas and Renewable Fuels)

Proposed Project: Demonstrate Near-Zero Emission Hybrid and Hydrogen ICE Vehicles in Various Applications

Expected South Coast AQMD Cost: $0

Expected Total Cost: $0

Description of Technology and Application:

Natural gas vehicles (NGVs) have been very successful in reducing emissions in the Basin due to the deployment by fleet owners and operators of HD vehicles utilizing this fuel. Currently, an increasing number of on-road HD natural gas engines are being certified to CARB's optional low-NOx standards which are significantly lower in NOx emissions than the current on-road HD standard. This technology category seeks to support the expansion of OEMs producing engines or systems certified to the lowest optional NOx standard or near-zero emission and useable in a wide variety of MD and HD applications, including Class 6 vehicles such as school buses and in passenger and goods delivery vans, Class 7 vehicles such as transit buses, waste haulers, street sweepers, sewer-vector trucks, dump trucks, concrete mixers, commercial box trucks, Class 8 tractors used in goods movement and drayage operations, and off-road equipment such as construction vehicles and yard hostlers. This category can also include advancing engine technologies to improve engine efficiencies that will help attract HD vehicle consumers to NGVs. Under Engine Systems, South Coast AQMD supports efforts for development of high-powered NGVs to support long-haul applications. Increasing natural gas engine availability for the full range of applications would increase NGV deployment in long-haul applications where diesel engines have been the only feasible option.

Potential Air Quality Benefits:

NGVs have inherently lower engine criteria pollutant emissions relative to conventionally fueled vehicles, especially older diesel-powered vehicles. Recently, on-road HD engines have been certified to near-zero emission levels that are 90% lower in NOx than the current on-road HDV standard. California's On-Road Truck and Bus Regulation requires all on-road HDVs to meet the current standard by January 1, 2023. The deployment of near-zero emission vehicles would significantly further emission reductions relative to the state's current regulatory requirements. Incentivizing the development and demonstration of near-zero emission NGVs in private and public fleets, goods movement applications, and transit buses will help reduce local emissions and emissions exposure to nearby residents. NGVs can also have lower GHG emissions and increase energy diversity, help address national energy security objectives, and reduce biomass waste produced from such feedstocks. Deployment of additional NGVs is consistent with the 2022 AQMP goal to reduce criteria pollutants. When fueled by RNG, it supports California's objectives of reducing GHGs and carbon intensity of the state's transportation fuel supply, as well as the federal government's objective of increasing domestically produced alternative transportation fuels.

Proposed Project: Develop, Maintain & Expand Renewable Fuel Infrastructure

Expected South Coast AQMD Cost: $200,000

Expected Total Cost: $2,100,000

Description of Technology and Application:

This project supports the development, maintenance and expansion of natural gas fueling infrastructure in strategic locations throughout the Basin, including the Ports, and advancing technologies and station design to improve fueling and fueling efficiencies of HD NGVs. This category supports broader deployment of near-zero emission HD vehicles and implementation of South Coast AQMD's fleet rules. In addition, as natural gas fueling infrastructure begins to age or has been placed in demanding usage, components will deteriorate. This project offers facilities the opportunity to replace worn-out equipment or to upgrade existing fueling and/or garage and maintenance equipment to provide increased fueling capacity to public agencies, private fleets and school districts.

Potential Air Quality Benefits:

The 2022 AQMP identifies the use of alternative clean fuels in mobile sources as a key attainment strategy. HD NGVs have significantly lower emissions than their diesel counterparts and represent one of the cleanest ICE-powered vehicles available today. The project has the potential to significantly reduce the installation and operating costs of NGV fueling infrastructure and improve vehicle fueling times through improved fueling system designs and high-flow nozzles. New or improved NGV infrastructure helps facilitate near-zero emission NGVs in private and public fleets. It is expected that the lower fuel cost of natural gas relative to diesel and added financial incentives of RNG under the state's Low Carbon Fuel Standard (LCFS) program attract fleets and consumers to this technology. Increased exposure and fleet and consumer acceptance of NGVs will lead to significant and direct reductions in NOx, VOC, CO, PM and toxic compound mobile source emissions. Such increased penetration of NGVs will provide direct emission reductions of NOx, VOC, CO, PM and air toxic compounds throughout the Basin.

Proposed Project: Demonstrate Renewable Transportation Fuel Manufacturing and Distribution Technologies

Expected South Coast AQMD Cost: $0

Expected Total Cost: $0

Description of Technology and Application:

The transportation sector represents a significant source of criteria pollution in the Basin. Clean, alternative fuel-powered transportation is a necessary component for this region to meet NAAQS. Alternative fuels produced from renewable sources such as waste biomass help further efforts associated with landfill and waste diversion, GHG reduction, energy diversity and petroleum dependency. Locally produced renewable fuels further reduce concerns associated with out-of-state production and transmission of fuel and help support the local economy. Renewable fuels recognized as a transportation fuel under the state's LCFS program and the federal government's Renewable Fuel Standard program can provide financial incentives, including reduced fuel price and operational costs, which act as incentives to purchase and deploy alternative or renewable energy powered vehicles.

This project category will consider development and demonstration of technologies for the production and use of renewable transportation fuels such as RNG, renewable diesel (RD), and renewable hydrogen (RH). These renewable fuels can be converted from various waste biomass feed stocks, including municipal solid wastes, green waste, and biosolids produced at wastewater treatment facilities generated from anaerobic digestion, gasification, and pyrolysis.

The main objectives of this project are to investigate, develop and demonstrate:

- commercially viable methods for converting renewable feed stocks into CNG, LNG, hydrogen or diesel (e.g., production from biomass);
- economic small-scale natural gas liquefaction technologies;
- utilization of various gaseous feed stocks locally available;
- commercialize incentives for fleets to site, install and use RNG refueling facilities; and
- pipeline interconnection in the local gas grid to supply users.

Potential Air Quality Benefits:

The 2022 AQMP relies on a significant increase in the penetration of zero and near-zero emission vehicles in the Basin to attain the NAAQS by 2037. This project would help develop renewable transportation fuel production and distribution facilities to improve local production and use of renewable fuels to help reduce transportation costs and losses as well as reduce total operating costs of zero and near-zero emission vehicles to be competitive with comparable diesel fueled vehicles. Such advances in production and use are expected to lead to greater infrastructure development. Additionally, this project could support the state's goal of redirecting biomass waste for local fuel production and reduce GHGs associated with these waste biomass feedstocks.

Stationary Clean Fuel Technologies

Proposed Project: Develop and Demonstrate Microgrids with Photovoltaic/Fuel Cell/Battery Storage/EV Chargers and Energy Management

Expected South Coast AQMD Cost: $1,000,000

Expected Total Cost: $4,000,000

Description of Technology and Application:

CARB has proposed the Advanced Clean Truck Regulation which is part of a holistic approach to accelerate a large-scale transition of zero emission MD and HD vehicles from Class 2B to Class 8. Manufacturers who certify Class 2B-8 chassis or complete vehicles with combustion engines would be required to sell zero emission trucks as an increasing percentage of their annual California sales from 2024 to 2030. By 2030, zero emission truck/chassis sales would need to be 50% of Class 4–8 straight trucks sales and 15% of all other truck sales.

The commercialization of zero emission HD trucks is currently under way with two of the largest manufacturers offering commercial products in California. Both Daimler and Volvo obtained CARB certification of their Class 6 and/or 8 battery electric trucks in 2020, with these trucks eligible for HVIP and other incentives and commercially available for sale. South Coast AQMD also received $16M in CARB and $11M in CEC funding, as well as $34M in co-funding from project partners for the deployment of 100 Daimler and Volvo Class 8 battery electric trucks, solar, and energy storage for the JETSI Pilot Project for drayage and regional haul applications. Ever larger deployments of zero emission trucks will be needed for the technology to have an impact on air quality.

Large deployments of zero emission Class 8 battery electric trucks (BETs) each carrying 300+ kWh of battery-stored energy or fuel cell trucks (FCTs) carrying 30-50 kg of hydrogen will require costly infrastructure that creates a barrier for some fleets to adopt zero emission technologies. Many fleet operators lease their facilities making the capital expenditure of EV or hydrogen infrastructure impossible to recoup in a short period of time. In order to comply with existing and upcoming regulatory requirements, fleets are having to navigate challenges in installing and maintaining charging and/or fueling infrastructure. Microgrids can be instrumental in meeting the challenge of providing large amounts of energy cost-effectively for EV charging or hydrogen generation to support zero emission vehicle charging and fueling. Additionally, if the microgrid equipment is owned by a third party and energy is sold to the fleet through a power purchase agreement, the financial challenge of large capital investment can be avoided by the fleets.

A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected and island-mode. Microgrids can work synergistically with the utility grid to provide power for zero emission vehicle fueling by managing when energy from the grid is used–during off-peak hours when it is the least expensive. Then during peak demand periods, the microgrid would use energy from battery storage or onsite generation. Most technologies that make up microgrids include photovoltaic, fuel cells, battery storage, along with hardware and software for the energy management system (EMS). When grid service is interrupted, the microgrid can disconnect from and continue to operate as an energy island independent from the grid. Having assurance of an uninterrupted power source is an important consideration for fleets. If the microgrid is connected to the fleet's logistics and telematics systems, additional benefits in terms of infrastructure cost and battery life for BETs can be realized. If the EMS is fed information on the route a truck is planning to travel, it can charge the vehicle with enough energy for the trip so the truck will operate within the desired 20-80% state of charge (SOC) of the battery having the least amount of impact to battery life. Additionally,

if the EMS is connected to the logistics system, it can plan charging schedules with 150 kW or lower power chargers which will have less impact on battery life than 350+ kW chargers and lower charging costs.

Electricity demand of electric and fuel cell HD trucks is substantial. For a 100-vehicle fleet of BETs with 300 kWh batteries, 30 MW hours/day of electricity would be required to charge these BETs. For a 100-vehicle fleet of FCTs the hydrogen requirement is 2,000 kg/day. Microgrids can provide energy for EV and hydrogen infrastructure to enable large zero emission vehicle deployments and make charging and fueling economical and reliable. Staff has demonstrated several microgrid projects with University of California Irvine and has toured the microgrid at University of California San Diego. Currently, several pilot projects are being discussed with microgrid developers and fleets that involve various configurations of microgrid technologies and different business models. Proposed projects would include development and demonstration of microgrids utilizing various types of renewable and zero emitting onsite generation (fuel cell tri-generation, power to gas, photovoltaic, wind), energy storage, connectivity to logistics systems, vehicle-to-grid and vehicle-to-building technologies. Projects that demonstrate different business models will be considered, such as projects involving a separate entity owning some or all the microgrid equipment and engaging in a power purchase agreement to provide energy to fleets transitioning to zero emission trucks. Proposed projects would partner with truck OEMs and their major customers, such as large- and medium-sized fleets looking at microgrid solutions for their operations in the Basin.

Potential Air Quality Benefits:

Microgrids can provide grid resilience and potentially support large deployments of zero emission MD and HD trucks that are necessary to meet the AQMP target of 83 percent NOx emission reductions from the 2018 level and 67 percent additional reductions in 2037 beyond already adopted regulations and programs by 2037. Both renewable and zero emitting power generation technologies that make up a microgrid can provide a well-to-wheel zero emission pathway for transporting goods. Projects could potentially reduce a significant class of NOx and CO emissions in excess of the assumptions in the 2022 AQMP and further enhance South Coast AQMD’s ability to enforce full-time compliance.

Proposed Project: Develop and Demonstrate Zero or Near-Zero Emission Energy Generation Alternatives

Expected South Coast AQMD Cost: $200,000

Expected Total Cost: $1,000,000

Description of Technology and Application:

The objective of this project is to support development and demonstration of clean energy, renewable alternatives in stationary applications. The technologies to be considered include thermal, photovoltaic and other solar energy technologies; wind energy systems; energy storage potentially including vehicle to grid or vehicle to building functionalities for alternative energy storage; biomass conversion; and other renewable energy and recycling technologies. Innovative solar technologies, such as solar thermal air conditioning and photovoltaic-integrated roof shingles, are of particular interest. Also, in the agricultural sections of the Basin, wind technologies could potentially be applied to drive large electric motor-driven pumps to replace highly polluting diesel pumps. Besides renewable technologies, electrolyzer technology could be used to generate hydrogen as a clean fuel. Hydrogen, when used in ICEs, can potentially reduce tail-pipe emissions of NOx, while in fuel cells emissions are reduced to zero.

This project is expected to result in pilot-scale production demonstrations, scale-up process design and cost analysis, overall environmental impact analysis and projections for ultimate clean fuel costs and availability. This project is expected to result in several projects addressing technological advancements in these technologies that may improve performance and efficiency, potentially reduce capital and operating costs, enhance the quality of natural gas generated from renewable sources for injection into natural gas pipelines, improve reliability and identify markets that could expedite implementation of successful technologies.

Potential Air Quality Benefits:

The 2022 AQMP identifies that the development and implementation of non-polluting power generation could gain maximum air quality benefits. Polluting fossil fuel-fired electric power generation needs to be replaced with clean, renewable energy resources or other advanced zero emission technologies, such as hydrogen fuel cells, particularly in a distributed generation context to help provide grid resiliency as the transportation sector becomes more reliant on electricity.

This project is expected to accelerate implementation of advanced zero emission energy sources. Expected benefits include directly reducing emissions by displacement of fossil generation; proof-of-concept and potential viability for zero emission power generation systems; increased exposure and user acceptance of the new technology; reduced fossil fuel usage; and potential for increased use, once successfully demonstrated, with resulting emission benefits, through expedited implementation. These technologies would also have a substantial influence in reducing GHG emissions.

Fuel and Emissions Studies

Proposed Project: Conduct In-Use Emission Studies for Advanced Technology Vehicle Demonstrations

Expected South Coast AQMD Cost: $500,000

Expected Total Cost: $2,000,000

Description of Technology and Application:

Hybrid electric, hybrid hydraulic, plug-in electric hybrid and battery-electric and fuel cell electric vehicles will all play a role in the future of transportation. Each of these transportation technologies has attributes that could provide unique benefits to different transportation sectors. Identifying optimal placement of each transportation technology will provide the co-benefits of maximizing environmental benefit and return on investment.

South Coast AQMD has been supporting rapid deployment of near-zero emission natural gas technologies since the first HD engine became commercially available in 2015. As more near-zero emission natural gas, propane and other alternative fuel technologies penetrate different segments, in-use assessment of real-world benefit is needed especially as CARB and U.S. EPA have introduced a new in-use testing metric.

The CARB EMFAC 2017 model that the 2022 AQMP is based on uses emissions data from in-use emissions studies for calculating emission factors for HD trucks rather than certification data which has a relatively limited data set for alternative fuel vehicles. For the recently released EMFAC 2021, more complete natural gas engine modules have been included for the first time with emissions data gathered from the currently funded South Coast AQMD in-use emissions characterization effort. CARB and U.S. EPA low-NOx regulations focus on addressing the gap of in-use and certification values by introducing a new methodology that includes emissions from all operations. While staff expects the in-use emissions from new engines to perform closer to certification values, there is still a significant population of the MY 2010+ legacy fleet expected to remain in service well into the 2030s. There is always a need to better assess real world truck emissions, fuel economy, and activity from engines, hybrid powertrain and zero emission technologies for continued technology improvements and verification of emission reductions.

Environmental benefits for each technology class are duty-cycle and application specific. Identifying attributes of a specific application or drive cycle that would take best advantage of a specific transportation technology would speed adoption and make optimal use of financial resources in the demonstration and deployment of a technology. Adoption rates would be accelerated since intelligent deployment of a certain technology would ensure that a high percentage of demonstration vehicles showed positive results, which would spur adoption of this technology in similar applications, as opposed to negative results derailing further development or deployment of a certain technology.

This project would review and potentially coordinate application specific drive cycles for specific applications. Potential emission reductions and fossil fuel displacement for each technology in a specific application would be quantified on a full-cycle basis. This information could be used to develop a theoretical database of potential environmental benefits of different transportation technologies when deployed in specific applications. This duty-cycle requirement, often based on traditional vehicles, is used for planning purposes for building MD and HD public fueling stations. Furthermore, some of the standardized test cycles, like the chassis dyno-based cycle, can be used to evaluate efficiency of zero-emissions vehicles and direct comparisons with diesel and natural gas vehicles.

Another project would be characterization of intermediate volatility organic compound (IVOC) emissions, which is critical in assessing ozone and secondary organic aerosol (SOA) precursor production rates. Diesel

vehicle exhaust and unburned diesel fuel are major sources and contribute to formation of urban ozone and SOA, which is an important component of PM2.5. NGVs are also a concern due to lack of particulate filters, however the actual impact based on current and projected vehicle populations needs to be further studied.

While early developments in autonomous and vehicle-to-vehicle controls are focused on LD vehicles, early application of this technology to HD, drayage and container transport technologies is more likely. Impacts on efficiency and emissions could be substantial. A project to examine this technology to assess its effect on goods movement and emissions associated with goods movement could be beneficial at this time.

Potential Air Quality Benefits:

Development of an emissions reduction database for various application specific transportation technologies would assist in targeted deployment of new transportation technologies. This database coupled with application specific vehicle miles traveled and population data would assist in intelligently deploying advanced technology vehicles to attain the maximum environmental benefit. These two data streams would allow vehicle technologies to be matched to an application that is best suited to the specific technology, as well as selecting applications that are substantial enough to provide significant environmental benefits. Demonstration of a quantifiable reduction in operating cost through intelligent deployment of vehicles will also accelerate commercial adoption of various technologies. Accelerated adoption of lower emitting vehicles will further assist goals in the 2022 AQMP.

Proposed Project: Conduct Emission Studies on Biofuels, Alternative Fuels and Other Related Environmental Impacts

Expected South Coast AQMD Cost: $400,000

Expected Total Cost: $1,500,000

Description of Technology and Application:

The use of renewable fuels such as biofuels can be an important strategy to reduce petroleum dependency, air pollution and greenhouse gas emissions and help with California's aggressive GHG reduction goals. Biofuels are receiving increased attention due to national support and state activities resulting from SB 32, AB 1007 and the Low-Carbon Fuel Standard. With an anticipated increase in renewable fuel use, it is the objective of this project to further analyze these fuels to better understand their benefits and impacts not only on GHGs but also air pollution and associated health effects.

In various diesel engine studies, replacement of petroleum diesel fuel with renewable fuel has demonstrated reduced PM, CO and air toxics emissions. Renewable fuel also has the potential to reduce GHG emissions if made from renewable feedstocks such as soy and canola. However, certain blends of biodiesel can increase NOx emissions for some engines and duty cycles, which exacerbates ozone and PM2.5 challenges faced in the Basin. In addition, despite recent advancements in toxicological research in the air pollution field, the relationship between biodiesel particle composition and associated health effects is still not completely understood.

Ethanol is another biofuel that is gaining increased national media and state regulatory attention. CARB's reformulated gasoline regulation increases ethanol content to 10% as a means to increase the amount of renewable fuels in the state. As in the case of biodiesel, ethanol has demonstrated in various emission studies to reduce PM, CO and toxic emissions. However, the relationship between particle composition and associated health effects from the combustion of ethanol is not well understood either. In 2019, U.S. EPA approved 15% ethanol (E15) blends for year-round use and CARB, along with South Coast AQMD and other agencies, launched an emissions study of E15 to assess the emissions impact of the current fleet of California light duty vehicles. South Coast AQMD also has been monitoring efforts in using ethanol as a primary fuel for MD and HD applications in optimized engine systems that allows both criteria and GHG reductions which could be another pathway for reducing emissions due to abundance of ethanol from the light duty sector.

CARB recently proposed a regulation on commercialization of alternative diesel fuels, including biodiesel and renewable diesel, while noting that biodiesel in older HD vehicles can increase NOx. The need for emerging alternative diesel fuels for HD trucks and transit buses is also being studied. Researchers have proposed evaluating the emissions impact of RNG and other natural gas blends such as renewable hydrogen or pure hydrogen.

To address these concerns on potential health effects associated with biofuels, namely biodiesel and ethanol blends, this project will investigate physical and chemical composition and associated health effects of tailpipe PM emissions from LD to HD vehicles burning biofuels to ensure public health is not adversely impacted by broader use of these fuels. This project also supports future studies to identify mitigation measures to reduce NOx emissions from biofuels. Additionally, a study of well-to-wheel emissions from for the extraction and use of shale gas might be considered.

The Power-to-Gas concept has renewed interest in hydrogen-fossil fuel blends, and its emissions impact on the latest ICE technologies needs to be reassessed. Hydrogen fueled ICEs were studied heavily in the early 2000s and results have shown significant possible criteria emission reductions with optimized engine

calibration. Since then, ICE technologies have been fitted with advanced aftertreatment technologies to allow engines to be certified to today's lower NOx standards. Therefore, emissions impact assessment is needed on the latest ICE technologies.

In an effort to evaluate contribution of meteorological factors to high ozone and PM2.5 episodes occurring in the Basin, mainly as a result of higher summer temperatures and increased air stagnation following droughts, a comprehensive study is necessary to evaluate trends of meteorological factors that may adversely impact air quality in the Basin. The study will assist in better understanding potential impact of recent weather trends on criteria pollutant emissions and developing more effective strategies for improving air quality in the future.

Potential Air Quality Benefits:

If renewable diesel, biodiesel and biodiesel blends can be demonstrated to reduce air pollutant emissions with the ability to mitigate NOx impacts, this technology will become a viable strategy in meeting air pollutant standards as well as the goals of SB 32 and the Low-Carbon Fuel Standard. The use of biodiesel is an important effort for a sustainable energy future. Emission studies are critical to understanding emission benefits and any tradeoffs (NOx impacts) that may result from using this alternative fuel. With reliable information on the emissions from using biodiesel and biodiesel blends, this can ensure the use of biodiesel without creating additional NOx emissions. Additionally, understanding meteorological factors on criteria pollutant emissions may help identify mitigation strategies, possibly through targeted advanced transportation deployment.

Proposed Project: Identify and Demonstrate In-Use Fleet Emission Reduction Technologies and Opportunities

Expected South Coast AQMD Cost: $400,000

Expected Total Cost: $1,500,000

Description of Technology and Application:

New technologies, such as alternative fueled HD engines, are extremely effective at reducing emissions because they are designed to meet the most stringent emissions standards while maintaining vehicle performance. In addition, many new vehicles are now equipped with telematics enabling motorists to obtain transportation information such as road conditions to avoid excessive idling and track information about vehicle maintenance needs, repair history, tire pressure and fuel economy. Telematics have been shown to reduce emissions from new vehicles through various vehicle usage optimization strategies. Unfortunately, many in-use fleets lack telematic systems, particularly HD engines in trucks, buses, construction equipment, locomotives, commercial harbor craft and cargo handling equipment, and have fairly long working lifetimes (up to 20 years due to remanufacturing in some cases). Even LD vehicles routinely have lifetimes exceeding 200,000 miles and 10 years. The in-use fleet, especially the oldest vehicles, are responsible for the majority of emissions. In the last few years, real-time emissions and fuel economy data reporting along with telematics has been demonstrated with large fleets as fleet management tools to identify high emitters and increase operational efficiency. Similar efforts have already been proposed by CARB as part of the HD I/M regulation. Moreover, the same telematic systems are being installed on zero emission trucks where fleet and charging management are important. Cloud based fleet management concepts are being proposed by researchers to maximize range and air quality benefits of zero emission trucks.

This project category is to investigate near-term emission control technologies that can be cost-effectively applied to reduce emissions from the in-use fleet. The first part of the project is to identify and conduct proof-of-concept demonstrations of feasible candidate technologies, such as:

- remote sensing for HD vehicles including license plate recognition systems;
- annual testing for high mileage vehicles (>100,000 miles);
- replace or upgrade emission control systems at 100,000-mile intervals;
- on-board emission diagnostics with remote notification;
- low-cost test equipment for monitoring and identifying high emitters;
- test cycle development for different class vehicles (e.g. four-wheel drive SUVs);
- electrical auxiliary power unit replacements;
- development, deployment and demonstration of smart vehicle telematic systems;
- fleet and charger management concepts; and
- low cost NOx sensor development.

Potential Air Quality Benefits:

Many of the technologies identified can be applied to LD and HD vehicles to identify and subsequently remedy high-emitting vehicles in the current fleet inventory. Estimates suggest that 5 percent of existing fleets account for up to 80 percent of the emissions. Identification of higher emitting vehicles would assist with demand-side strategies, where higher emitting vehicles have correspondingly higher registration charges. Identification and replacement of high-emitting vehicles has been identified in the Community

Emission Reduction Plans (CERPs) from multiple AB 617 communities as a high priority for residents living in these communities, particularly as HD trucks frequently travel on residential streets to bypass traffic on freeways surrounding these disadvantaged communities.

Emission Control Technologies

Proposed Project: Develop and Demonstrate Advanced Aftertreatment Technologies for On-Highway

Expected South Coast AQMD Cost: $250,000

Expected Total Cost: $1,000,000

Description of Technology and Application:

There are several aftertreatment technologies which have shown substantial emission reductions in diesel engines. These technologies include zoned catalyst soot filters, early light -off catalysts, dual SCR systems, pre-NOx absorbers, and ammonia slip catalysts. Additional heating technologies enabled by availability of a 48 volt battery system or plug-in hybrid system can be used to keep desired catalyst temperatures using heated dosing and heated catalysts which are part of the complete aftertreatment system design for near-zero emission NOx engines. This project category is to develop and demonstrate these aftertreatment technologies alone or in tandem with an alternative fuel to produce the lowest possible PM, ultrafine PM, nanoparticles, NOx, CO, carbonyl and hydrocarbon emissions in retrofit and new applications. With increasing focus on zero and near-zero emission goods movement technologies, this category should examine idle reduction concepts and technologies that can be employed at Ports and airports. The proposed Clean Truck Initiative by U.S. EPA as well as the adopted CARB Omnibus Regulation will require aftertreatment systems to maintain certification levels to a much longer useful life via new in-use testing performance metrics. Technology durability and in-use performance will need to be further studied.

Possible projects include advancing technologies for on-road truck demonstrations beyond lab based testing, retrofit applications such as HD line-haul and other large displacement diesel engines, street sweepers, and waste haulers. Applications for off-road may include construction equipment, yard hostlers, gantry cranes, locomotives, commercial harbor craft, ground support equipment and other similar industrial applications. Potential fuels to be considered in tandem are low-sulfur diesel, emulsified diesel, biodiesel, gas-to-liquids, hydrogen and natural gas. This project category will also explore performance, economic feasibility, viability (reliability, maintainability and durability) and ease-of-use to ensure a pathway to commercialization.

Potential Air Quality Benefits:

Transfer of mature emission control technologies, such as DPFs and oxidation catalysts, to the off-road sector is a potentially low-risk endeavor that can have immediate emission reductions. Further development and demonstration of other technologies, such as early light –off SCR and heated dosing, could also have NOx reductions of up to 90%.

Proposed Project: Develop Methodology and Evaluate and Demonstrate Onboard Sensors for On-Road HD Vehicles

Expected South Coast AQMD Cost: $250,000

Expected Total Cost: $1,000,000

Description of Technology and Application:

New HD on-road vehicles represent one of the largest categories in the NOx emissions inventory in the Basin. The 2022 AQMP identifies that 83 percent NOx emission reductions from the 2018 level and 67 percent additional reductions beyond already adopted regulations and programs are necessary to meet the 2015 8-hour ozone standard by 2037. Previous in-use emission studies, including studies funded by the South Coast AQMD, have shown significantly higher NOx emissions from on-road HD vehicles than the certification limit under certain in-use operations, such as low power duty cycles. In CARB's adopted HD On-Road "Omnibus" Low NOx regulation, in addition to the lower certification values, there is a low load test cycle and revisions to the not-to-exceed compliance tests. NOx sensor data reporting is also introduced where the vehicle computer is required to store a past period of emissions data to ensure real-world emission reductions are realized over various duty cycles, especially those low power duty cycles in urban areas. An alternative proposed new methodology is to continuously measure real-time emissions from trucks with onboard sensors. Both industry, government and regulators are looking to use sensors to better monitor emissions compliance and leverage the real-time data from sensors to enable advances concepts such as geofencing. CARB's newly adopted HD I/M rules addresses in-use emissions from the older legacy fleets and also has onboard sensors as one of the emission testing methods.

This project category is to investigate near term and long-term benefits from onboard sensors to understand in-use emissions better and reduce emissions from the advanced management concept. The first part of the project is to identify and conduct proof-of-concept demonstrations of feasible candidate technologies, such as:

- laboratory evaluation/verification of new and baseline sensors;
- development and evaluation of next generation sensors;
- development of algorithms to extract sensor information into mass-based metric;
- demonstrate feasibility to monitor emissions compliance using sensors;
- identify low cost option for cost and benefit analysis;
- demonstrate sensors on natural gas and other mobile sources such as LD, off-highway and commercial harbor craft; and
- development, deployment and demonstration of smart energy/emissions management systems.

Potential Air Quality Benefits:

The proposed research projects will assist the trucking industry to monitor emissions, using sensors as one of the design platform options and identify freight routes which result in lower emissions. Reduction of NOx and PM emissions from mobile sources is imperative for the Basin to achieve NAAQS and protect public health.

Proposed Project: Demonstrate On-Road Technologies in Off-Road and Retrofit Applications

Expected South Coast AQMD Cost: $176,300

Expected Total Cost: $800,000

Description of Technology and Application:

On-road HD engines have demonstrated progress in meeting increasingly stringent federal and state requirements. New HD engines have progressed from 2 g/bhp-hr NOx in 2004 to 0.2 g/bhp-hr NOx in 2010, which is an order of magnitude decrease in just six years. Off-road engines, however, have considerably higher emissions limits depending on engine size. For example, Tier 3 standards for HD engines require only 3 g/bhp-hr NOx. There are apparent opportunities to implement cleaner on-road technologies in off-road applications. There is also an opportunity to replace existing engines in both on-road and off-road applications with the cleanest available technology. Current regulations don't usually require repowering (engine replacement) or remanufacturing to meet cleaner emission standards as engines are retired. Unfortunately, this does not take advantage of recently developed clean technologies.

Exhaust gas cleanup strategies, such as EGR, SCR, DPF, electrostatic precipitators, baghouses and scrubbers, have been used successfully for many years on stationary sources. The exhaust from the combustion source is routed to the cleaning technology, which typically requires a large footprint for implementation. This large footprint has made installation of such technologies on some mobile sources prohibitive. However, in cases where the mobile source is required to idle for long periods of time, it may be more effective to route emissions from the mobile source to a stationary device to clean the exhaust stream.

Projects in this category will include utilizing proven clean technologies in novel applications, such as:

- demonstrating certified LNG and CNG on-road engines as well as other clean alternative fuels in off-road applications including yard hostlers, locomotives, commercial harbor craft, gantry cranes, waste haulers and construction equipment;
- implementing lower emission engines requirement in repower applications for both on-road and off-road applications; and
- applying stationary best available control technologies, such as EGR, SCR, scrubbers, DPF, baghouses and electrostatic precipitators, to appropriate on- and off-road applications, such as idling locomotives, commercial harbor craft at dock and HD line-haul trucks at weigh stations.

Potential Air Quality Benefits:

Transfer of mature emission control technologies, such as certified engines and SCR, to the off-road and retrofit sectors offers high potential for immediate emission reductions. Further development and demonstration of these technologies will assist in regulatory efforts which could require such technologies and retrofits.

Health Impacts Studies

Proposed Project: Evaluate Ultrafine Particle Health Effects

Expected South Coast AQMD Cost: $88,150

Expected Total Cost: $1,000,000

Description of Technology and Application:

Reducing diesel exhaust from vehicles has become a high priority in the Basin since CARB identified the particulate phase of diesel exhaust as a surrogate for all toxic air contaminants emitted from diesel exhaust. Additionally, health studies indicate that ultrafine particulate matter (UPM) may be more toxic on a per-mass basis than other fractions. Several control technologies have been introduced and others are under development. Recent studies have shown that control technologies applied to mobile sources have been effective in reducing the mass of particulates emitted. However, there is also evidence that UPM on and near roadways has increased, even while the mass of particulates has decreased. To have a better understanding of changes in ultrafine particulate emissions from the application of new technologies and health effects of these emissions, an evaluation and comparison of UPM and potential impacts on community exposure, particularly in disadvantaged communities, is needed.

In this project, measurements and chemical composition of UPM will be done, as well as studies conducted from HD vehicles to measure, evaluate and compare UPM, PAH and other relevant toxic emissions from different types of fuels such as gasoline, CNG, low-sulfur diesel, biofuels and others. This project needs to be closely coordinated with development of technologies for alternative fuels, aftertreatment technologies, and new engine development to determine health benefits of such technologies.

Furthermore, gasoline direct injection (GDI) vehicles are known for higher efficiency and power output but the PM emissions profile is not well understood especially on secondary organic aerosol (SOA) formation potential. As manufacturers introduce more GDI models in the market to meet new fuel economy standards, it is important to understand SOA potential from these vehicles as it could further impact ambient PM concentration in our region. In 2015 a project with UCR CE-CERT to investigate the physical and chemical composition of aerosols from GDI vehicles using a mobile environmental chamber was designed and constructed to characterize secondary emissions. Based on initial results indicating an increase in particle numbers, follow-up in-use studies to assess PM emissions including with and without particle filters will be beneficial. Similar studies should also be conducted on natural gas MD and HD vehicles to understand potential emissions impacts are being considered.

Potential Air Quality Benefits:

The 2022 AQMP for the Basin relies on significant penetration of low emission vehicles to attain federal clean air standards. Reduction of PM emissions from combustion of diesel and other fuels is a major priority in achieving these standards. This project would help to better understand the nature and number of UPM generated by different types of fuels and advanced control technologies as well as provide information on potential health effects of UPM. Such an understanding is important to assess the emission reduction potentials and health benefits of these technologies. In turn, this will have a direct effect on the policy and regulatory actions for commercial implementation of alternative fuel vehicles in the Basin.

Proposed Project: Conduct Monitoring to Assess Environmental Impacts

Expected South Coast AQMD Cost: $132,225

Expected Total Cost: $500,000

Description of Technology and Application:

Facilities, buildings, structures, or highways which attract mobile sources of pollution are considered "indirect" sources. Ambient and saturation air monitoring near sources such as ports, airports, rail yards, freight/logistics distribution centers and freeways is important to identify emissions exposure to surrounding communities and provide data to assess health impacts. This could include the study of indirect sources such as warehouses which are impacted by South Coast AQMD's Indirect Source Regulations. This project category would identify areas of interest and conduct ambient air monitoring, emissions monitoring, analyze data and assess potential health impacts from mobile sources. These projects would need to be at least one year in duration in order to properly assess air quality impacts in surrounding communities.

Potential Air Quality Benefits:

The proposed project will assist in evaluation of adverse public health impacts associated with mobile sources. The information will be useful in (a) determining whether indirect sources have a relatively higher impact on residents living in close proximity, particularly in disadvantaged communities; and (b) providing guidance to develop some area-specific control strategies in the future should it be necessary.

Proposed Project: Assess Sources and Health Impacts of Particulate Matter

Expected South Coast AQMD Cost: $132,225

Expected Total Cost: $300,000

Description of Technology and Application:

Previous studies of ambient levels of toxic air contaminants, such as the MATES studies, have found that diesel exhaust is the major contributor to health risk from air toxics. Analyses of diesel particulate matter (DPM) in ambient samples have been based on measurements of elemental carbon. While the bulk of particulate elemental carbon in the Basin is thought to be from combustion of diesel fuels, it is not a unique tracer for diesel exhaust.

The MATES III study collected particulate samples at ten locations in the Basin. Analysis of particulate bound organic compounds was utilized as tracers to estimate levels of ambient DPM as well as estimate levels of PM from other major sources. Other major sources that were taken into consideration include automobile exhaust, meat charbroiling, road dust, wood smoke and fuel oil combustion. Analyzing for organic compounds and metals in conjunction with elemental carbon upon collected particulate samples was used to determine contributing sources.

MATES IV, completed in 2015, included an air monitoring program and updated emissions inventory of toxic air contaminants. MATES IV also measured UPM concentrations and black carbon at monitoring sites as well as near sources such as airports, freeways, rail yards, busy intersections and freight/logistics warehouse operations.

South Coast AQMD completed MATES V in August 2021 to update the emissions inventory of toxic air contaminants, as well as modeling to characterize risks, including measurements and analysis of ultrafine particle concentrations typically emitted or subsequently formed from vehicle exhaust. Findings from the MATES V report showed that air toxics cancer risk based on modeling data has decreased by about 50% since MATES IV, with average multi-pathway air toxics cancer risk at 454-in-a-million. The highest risk locations are at LAX and the Ports along goods movement and transportation corridors. Diesel PM continues to be the major contributor accounting for over 60% of the overall air toxics cancer risk. For the first time, chronic non-cancer risk was estimated with a chronic hazard index of 5.9 across the 10 stations in the MATES V study.

This project category would include other related factors, such as toxicity assessment based on age, source (HD, LD engines) and composition (semi-volatile or non-volatile fractions) to better understand health effects and potential community exposure, particularly in disadvantaged communities. Additionally, early identification of new health issues could be of considerable value and could be undertaken in this project category.

Potential Air Quality Benefits:

Results of this work will provide a more robust, scientifically sound estimate of ambient levels of DPM as well as levels of PM from other significant combustion sources, including gasoline and diesel generated VOCs. This will allow a better estimation of potential exposure and health effects from toxic air contaminants from diesel exhaust in the Basin. This information in turn can be used to determine health benefits of promoting clean fuel technologies.

Technology Transfer and Outreach

Proposed Project: Assess and Support Advanced Technologies and Disseminate Information

Expected South Coast AQMD Cost: $600,000

Expected Total Cost: $1,000,000

Description of Project:

This project supports assessment of clean fuels and advanced technologies, progress towards commercialization and dissemination of information on demonstrated technologies. The objective of this project is to expedite transfer of technology developed from Technology Advancement Office projects to the public domain, industry, regulatory agencies and the scientific community. This project is a fundamental element in South Coast AQMD's outreach efforts by coordinating activities with other organizations to expedite implementation of advanced engines and clean fuels technologies.

This project may include the following:

- technical review and assessment of technologies, projects and proposals;
- support for alternative and zero emission charging and fueling infrastructure;
- advanced technology curriculum development, mentoring and outreach to local schools;
- emission studies and assessments of near-zero and zero emission alternatives;
- preparation of reports, presentations at conferences, improving public relations and public communications of successful clean technology demonstration projects;
- participation in and coordination of workshops and various meetings;
- support for training programs related to fleet operation, maintenance and fueling of alternative fuel vehicles and equipment;
- publication of technical papers as well as reports and bulletins; and
- dissemination of information, including websites development and updates.

These objectives will be achieved by consulting with industry, scientific, health, medical and regulatory experts and co-sponsoring related conferences and organizations, resulting in multiple contracts. In addition, an ongoing outreach campaign will be conducted to encourage decision-makers to voluntarily switch to alternatively fueled vehicles and train operators to purchase, operate and maintain these vehicles/equipment and associated infrastructure.

Potential Air Quality Benefits:

As the Clean Fuels Program transitions increasingly to zero emission vehicle, equipment and infrastructure technologies, there will continue to be challenges in assisting fleets and others to successfully make this transition. The benefits of highlighting challenges, lessons learned, and success stories in the use of zero emission and near-zero emission vehicles, equipment and infrastructure can expedite acceptance and commercialization of these technologies. The emission reduction benefits will contribute to the goals of the 2022 AQMP.

Proposed Project: Support Implementation of Various Clean Fuels Incentive Programs

Expected South Coast AQMD Cost: $350,000

Expected Total Cost: $400,000

Description of Project:

This project supports implementation of incentive programs, including state and federal grant programs, Carl Moyer, Prop 1B, VW, VIP, CAPP, lower emission school bus, Replace Your Ride, and South Coast AQMD residential EV charger rebate program. Implementation support includes application review, funds allocation, equipment owner reports collection, documentation to CARB, verification of vehicle operation, and other support as needed. Information dissemination is critical to successfully implementing coordinated and comprehensive incentive programs. Outreach will be directed to vehicle OEMs, dealers, individuals and fleets.

Potential Air Quality Benefits:

South Coast AQMD will provide matching funds to implement several key incentive programs to reduce emissions in the Basin. The benefit of highlighting zero emission vehicle, equipment and infrastructure incentives is to expedite acceptance and commercialization of advanced technologies. Future emission reduction benefits will contribute to the goals of the 2022 AQMP. Carl Moyer, Prop 1B, VW, VIP, CAPP, and lower emission school bus incentive programs can reduce large amounts of NOx and PM emissions, and toxic air contaminants in the Basin.

Appendix A

South Coast AQMD Advisory Groups

[This Page Intentionally Left Blank]

Technology Advancement Advisory Group[1]

Dr. Aaron Katzenstein, Chair	South Coast AQMD
Don Anair	Union of Concerned Scientists
Chris Cannon	Port of Los Angeles
Dr. Bill Robertson	California Air Resources Board
Dr. Michael Kleinman	University of California Irvine
Yuri Freedman	Southern California Gas Company
George Payba	Los Angeles Department of Water and Power
Phil Heirigs	Western States Petroleum Association
Vic La Rosa	Total Transportation Solutions Inc.
*Elizabeth John	California Energy Commission
David Pettit	Natural Resources Defense Council
Dr. Sunita Satyapal	Department of Energy
Heather Tomley	Port of Long Beach
*Rosalie Barinas	Southern California Edison

*Newly appointed member

[1] Members as of February 17, 2023

SB 98 Clean Fuels Advisory Group[2]

Dr. Aaron Katzenstein, Chair	South Coast AQMD
Keith Brandis	Volvo Group
Dr. John Budroe	California Environmental Protection Agency, Office of Environmental Health Hazard Assessment
Dr. John Wall	Independent Consultant in Combustion Technology
*Marcus Alexander	Electric Power Research Institute
Dr. Mridul Gautam	West Virginia University, Adjunct Professor, & University of Nevada-Reno
Dr. Wayne Miller	University of California, Riverside, College of Engineering, Center for Environmental Research and Technology
Dr. Petros Ioannou	University of Southern California Director of the Center for Advanced Transportation Technologies
Dr. Scott Samuelsen	University of California, Irvine, Combustion Laboratory/National Fuel Cell Research Center
*David Park	Hydrogen Fuel Cell Partnership
Dr. Andreas Truckenbrodt	Independent Consultant in Fuel Cell Technologies
Ken Kelly	National Renewable Energy Laboratory
Dwight Robinson	Mortimer & Wallace, Inc.

*Newly appointed member

[2] Members as of March 3, 2023

Appendix B

Open Clean Fuels Contracts as of January 1, 2023

[This Page Intentionally Left Blank]

Contract	Contractor	Project Title	Start Term	End Term	South Coast AQMD $	Project Total $
Electric / Hybrid Electric Technologies and Infrastructure						
14184	Clean Fuel Connection, Inc.	DC Fast Charging Network Provider	04/04/14	06/30/23	390,000	1,210,000
17105	BYD Motors Inc	Development and Demonstration of up to 25 Class 8 Battery Electric Drayage Trucks	04/14/17	10/13/23	794,436	9,450,400
17207	Peterbilt Motors	Development and Demonstration of up to 12 Class 8 Battery Electric Drayage Trucks	04/07/17	10/06/23	2,342,436	11,082,340
18129	Electric Power Research Institute	Versatile Plug-In Auxilary Power System Demonstration	06/28/18	04/30/23	125,000	273,000
18232	Hyster-Yale Group Inc	Electric Top-Pick Development, Integration & Demonstration	09/14/18	06/30/23	367,801	3,678,008
18287	Evgo Services LLC	Charging Station and Premises Agreement for Installation of One DCFC at SCAQMD Headquarters	06/27/18	06/26/28	0	0
19166	Phoenix Cars LLC dba Phoenix Motorcars	Battery Electric Shuttle Bus Replacement Project	01/31/19	07/31/23	0	7,311,456
20097	Zeco Systems, Inc. DBA Greenlots	Operate, Maintain and Network the EV Chargers	02/14/20	02/13/23	155,664	155,664
20168	OMNITRANS	Disburse donated Mercedes-Benz USA, LLC Electric Vehicle Chargers	02/28/20	02/27/23	0	0
20296	Daimler Trucks North America LLC	Deploy Zero Emission Electric Delivery Trucks	05/27/21	12/31/24	0	12,310,000
21077	Daimler Trucks North America LLC	Develop and Demonstrate up to 8 Heavy-Duty Battery Electric Trucks and Transportable Fast-Charging	03/11/21	03/31/23	1,000,000	6,742,000
21153	Volvo Group North America, LLC	Switch-On: Develop and Deploy Seventy Heavy-Duty Battery Electric Vehicles	06/10/21	09/30/24	2,000,000	31,540,000
22036	University of California Riverside	Energy-Efficient Routing for Electric Trucks	09/06/22	04/30/25	99,500	99,500
22120	Los Angeles Cleantech Incubator	Conduct Stakeholder Outreach and ZEV Workforce Plan	03/24/22	03/31/25	95,000	155,000
22177	Daimler Trucks North America LLC	Deploy Class 8 Battery Electric Trucks and Charging Infrastructure	06/16/22	04/30/25	447,638	27,073,593
22247	NFI Interactive Logistics LLC	Deploy Class 8 Battery Electric Trucks, Charging Infrastructure and Distributed Energy Resource Technologies	12/15/22	04/30/25	4,547,126	35,078,329
Engine Systems and Technologies						
17353	Odyne Systems, LLC	Develop and Demo Medium-Heavy Duty (Class 5-7) Plug-In Hybrid Electric Vehicles for Work Truck Applications	06/09/17	03/31/23	900,000	6,955,281

Contract	Contractor	Project Title	Start Term	End Term	South Coast AQMD $	Project Total $
Engine Systems and Technologies (cont'd)						
18194	CALSTART	Develop and Demonstrate Near-Zero Emission Opposed Piston Engine	05/30/18	11/30/23	2,114,500	17,413,000
19439	Cummins, Inc.	Natural Gas Engine and Vehicles Research and Development - Natural Gas Specific Combustion Design	08/30/19	08/29/23	250,000	10,996,626
20092	Southwest Research Institute	Natural Gas Engine and Vehicles Research and Development - Pent-Roof Medium Duty Natural Gas Engine	10/14/20	04/13/24	475,000	6,000,000
20199	Agility Fuel Solutions LLC	Develop a Near-Zero Natural Gas and Propane Conversion System for On-Road Medium-Duty Vehicles	07/01/21	03/31/23	453,500	1,834,000
20316	US Hybrid	Natural Gas Engine & Vehicles Research & Development - Plug-In Hybrid CNG Drayage Truck (PHET)	06/02/20	06/02/24	500,000	2,853,006
Fuel / Emission Studies						
21083	University of California Riverside	Assess Emissions Impacts of Hydrogen-Natural Gas fuel Blend on Natural Gas Engines	01/22/22	01/21/23	229,021	583,021
21103	University of California Riverside	Perform Investigation Study of E15 Gasoline Fuel Effects	03/09/21	03/08/23	200,000	1,300,000
21169	West Virginia University Research Corp	Evaluation of Vehicle Maintenance Costs Between NG and Diesel Fueled On-Road Heavy-Duty Vehicles	09/29/21	03/28/24	100,000	250,000
Fueling Infrastructure and Deployment (NG / RNG)						
18336	ABC Unified School District	FY2017-18 Alternative Fuel School Bus Replacement Program (3 CNG Buses)	10/05/18	11/30/34	117,900	676,500
18337	Alta Loma School District	FY 2017-18 Alternative Fuel School Bus Replacement Program (2 CNG Buses)	10/05/18	11/30/34	78,600	423,000
18344	Bellflower Unified School District	FY 2017-18 Alternative Fuel School Bus Replacement Program (1 CNG Bus)	09/07/18	11/30/34	39,300	225,500
18346	Chaffey Joint Union High School District	FY 2017-18 Alternative Fuel School Bus Replacement Program (6 CNG Buses)	10/05/18	11/30/34	235,800	1,269,000
18348	Cypress School District	FY 2017-18 Alternative Fuel School Bus Replacement Program (1 CNG Bus)	09/07/18	11/30/34	39,300	211,500
18349	Downey Unified School District	FY 2017-18 alternative Fuel School Bus Replacement Program (4 CNG Buses)	09/14/18	11/30/36	157,200	902,000
18350	Fountain Valley School District	FY2017-18 Alternative Fuel School Bus Replacement Program (1 CNG Bus)	09/07/18	11/30/34	39,300	211,500

Contract	Contractor	Project Title	Start Term	End Term	South Coast AQMD $	Project Total $
Fueling Infrastructure and Deployment (NG / RNG) (cont'd)						
18351	Fullerton Joint Union High School District	FY2017-18 Alternative Fuel School Bus Replacement Program (4 CNG Buses)	10/05/18	11/30/34	157,200	846,000
18354	Hemet Unified School District	FY2017-18 Alternative Fuel School Bus Replacement Program (5 CNG Buses)	10/05/18	11/30/34	196,500	1,127,500
18355	Huntington Beach Union High School District	FY2017-18 Alternative Fuel School Bus Replacement Program (15 CNG Buses)	10/05/18	11/30/34	589,500	3,382,500
18363	Orange Unified School District	FY 2017-18 Alternative Fuel School Bus Replacement Program (1 CNG Bus)	09/14/18	11/30/34	39,300	225,500
18364	Placentia-Yorba Linda Unified School District	FY2017-18 Alternative Fuel School Bus Replacement Program (6 CNG Buses)	10/05/18	11/30/34	235,800	1,353,000
18365	Pupil Transportation Cooperative	FY 2017-18 Alternative Fuel School Bus Replacement Program (5 CNG Buses)	10/05/18	11/30/34	196,500	1,127,500
18367	Rialto Unified School District	FY 2017-18 Alternative Fuel School Bus Replacement Program (13 CNG Buses)	10/05/18	11/30/34	510,900	2,931,500
18368	Rim Of The World Unified School District	FY2017-18 Alternative Fuel School Bus Replacement Program (3 CNG Buses)	10/05/18	11/30/34	117,900	676,500
18369	Rowland Unified School District	FY 2017-18 Alternative Fuel School Bus Replacement Program (3 CNG Buses & 1 Propane Bus)	11/02/18	11/30/34	117,900	770,000
18370	San Jacinto Unified School District	FY 2017-18 Alternative Fuel School Bus Replacement Program (2 CNG Buses)	09/14/18	11/30/34	78,600	451,000
18374	Upland Unified School District	FY 2017-18 Alternative Fuel School Bus Replacement Program (4 CNG Buses)	10/12/18	11/30/34	157,200	902,000
20178	Whittier Union High School District	FY 2017-18 Alternative Fuel School Bus Replacement Program	02/21/20	11/30/34	196,500	1,052,500
21140	Inland Kenworth (US) Inc	SCAQMD Approved Participating Dealership in TRUCK TRADE DOWN PROGRAM	01/07/21	12/31/23	0	0
21142	TEC of California, Inc.	SCAQMD Approved Participating Dealership in TRUCK TRADE DOWN PROGRAM	04/15/21	12/31/23	0	0
Hydrogen and Mobile Fuel Cell Technologies and Infrastructure						
15150	Air Products and Chemicals, Inc.	Install/Upgrade Eight H2 Fueling Stations throughout SCAG (including SCAQMD's HQs H2 station)	10/10/14	04/09/23	762,500	17,097,939
15366	Engineering, Procurement & Construction, LLC.	Operate and Maitain Publicly Accessible Hydrogen Fueling Station at SCAQMD's Diamond Bar HQs	10/10/14	04/09/22	0	0
15611	Ontario CNG Station, Inc.	Installation of Ontario Renewable Hydrogen Fueling Station	07/10/15	07/09/22	200,000	2,510,000

Contract	Contractor	Project Title	Start Term	End Term	South Coast AQMD $	Project Total $
Hydrogen and Mobile Fuel Cell Technologies and Infrastructure (cont'd)						
16025	Center for Transportation and the Environment	Develop & Demonstrate Fuel Cell Hybrid Electric Medium-Duty Trucks	02/05/16	11/30/23	980,000	7,014,050
19313	Equilon Enterprises LLC DBA Shell Oil Products	Construct & Operate Renewable Hydrogen Refueling Station	06/30/20	04/01/23	1,200,000	12,000,000
20033	Port of Long Beach	Sustainable Terminals Accelerating Regional Transportation (START) Phase I	06/04/21	04/30/24	500,000	105,013,765
20038	University of California Irvine	Expansion of the UCI Hydrogen Refueling Station	10/18/19	02/17/27	400,000	1,800,000
20244	Cummins Electrified Power NA Inc	Demonstrate Fuel Cell Range-Extended Drayage Trucks	12/16/19	06/30/23	582,305	4,985,665
21313	Sunline Transit Agency	Deployment of 5 Zero-Emission Fuel Cell Transit Buses	08/27/21	09/30/25	204,921	6,761,125
21386	National Renewable Energy Laboratory	CA Hydrogen Heavy-Duty Infrastructure Research Consortium H2@Scale Initiative	09/03/21	09/02/23	25,000	1,171,000
22082	Frontier Energy Inc	High Flow Bus Fueling Protocol Development	03/3022	08/29/23	25,000	572,500
22084	A-1 Alternative Fuel Systems	Develop and Demonstrate Hydrogen Fuel Cell Medium-Duty Buses	01/19/22	04/18/24	531,166	2,086,608
Stationary Sources - Clean Fuels						
21266	University of California Irvine	Develop Model for Connected Network of Microgrids	08/17/21	02/16/24	290,000	370,000
22262	University of California Irvine	Study of Fuel Cell Microgrids for Backup Power and Transit	06/03/22	06/02/24	370,000	510,000
Technology Assessments and Transfer / Outreach						
08210	Sawyer Associates	Technical Assistance on Mobile Source Control Measures and Future Consultation on TAO Activities	02/22/08	02/28/24	50,000	50,000
09252	JWM Consulting Service	Technical Assistance with Review and Assessment of Advanced Technologies, Heavy-Duty Engines and Conventional and Alternative Fuels	12/20/08	06/30/24	30,000	30,000
12376	University of California Riverside	Technical Assistance with Alternative Fuels, Biofuels, Emissions Testing, and Zero-Emission Transportation Technology	06/01/14	05/31/24	300,000	300,000
15380	ICF Resources LLC	Technical Assistance with Goods Movement, Alternative Fuels and Zero-Emission Transportation Technologies	12/12/14	12/11/24	30,000	30,000

Contract	Contractor	Project Title	Start Term	End Term	South Coast AQMD $	Project Total $
Technology Assessments and Transfer / Outreach (cont'd)						
19078	Green Paradigm Consulting Inc	Technical Assistance with Alternative Fuels, Evs, Charging & Infrastructure and Renewable Energy	09/07/18	09/30/24	200,000	871,236
19227	Gladstein, Neandross & Associates LLC	Technical Assistance with Alternative Fuels & Fueling Infrastructure, Emissions Analysis & On-Road Sources	02/01/19	01/31/23	300,000	300,000
19302	Jerald Cole	Technical Assistance with Hydrogen Infrastructure and Related Projects	04/24/19	04/23/23	50,0000	50,000
20085	CALSTART Inc	Technical Assistance for Development & Demonstration of Infrastructure and Mobile Source Applications	11/08/19	11/07/23	250,000	250,000
20265	Eastern Research Group	Technical Assistance with Heavy-Duty Vehicle Emissions Testing, Analyses & Engine Development & Applications	06/17/20	06/30/24	50,000	50,000
21260	Fred Minassian	Technical Assistance with Incentive and Research and Development Programs	04/13/21	10/12/24	75,000	75,000
22096	AEE Solutions LLC	Technical Assistance with Heavy-Duty Vehicle Emission Testing, Test Methods and Analysis of Real-World Activity Data	11/08/21	11/07/23	100,000	100,000
22273	Green Paradigm Consulting Inc	Technical Assistance with Alternative Fuels, Evs, Charging & Infrastructure and Renewable Energy	04/22/22	04/02/24	200,000	200,000
22274	Gladstein, Neandross & Associates LLC	Technical Assistance with Alternative Fuels & Fueling Infrastructure, Emissions Analysis & On-Road Sources	05/05/22	04/02/22	300,000	300,000
23114	University of California Irvine	Cosponsor ICEPAG 2022	12/22/22	03/31/23	8,000	80,000

[This Page Intentionally Left Blank]

Appendix C

Final Reports for 2022

[This Page Intentionally Left Blank]

South Coast AQMD Contract #16081 **April 2022**

Provide EV Hardware and Control System at South Coast AQMD Headquarters including Installation Support, Warranty and Networking

Contractor

Broadband Telecom Power, Inc.

Cosponsors

South Coast AQMD

Project Officer

Patricia Kwon

Background

In May 2014, the Board approved the release of a Request for Proposal (RFP) to expand and upgrade electric vehicle (EV) charging infrastructure at South Coast AQMD headquarters. At that time, South Coast AQMD had installed 28 Level 2 chargers and one 50 kW DC fast charger for light-duty vehicles. Charging infrastructure was installed in 2011 and 2012 under two grants administered by the U.S. Department of Energy and California Energy Commission to promote light-duty public charging infrastructure to facilitate early adoption of battery electric and plug-in electric vehicles. Initially, the charging infrastructure installed under these grant funded programs was adequate to supply EV charging requirements of South Coast AQMD staff, its vehicle fleet, public, and Board members. However, since the initial installation of this charging infrastructure, national EV sales have increased 600% and it is estimated that 70 electric vehicles are present during business hours.

Project Objective

The large number of EVs requires drivers to closely monitor their vehicle state of charge and rotate vehicles between charging and regular parking spaces. Even with vehicle rotations, many EV drivers have difficulty gaining access to charging during working hours. This has also resulted in visitors not being able to charge their EVs since employees arrive earlier in the day. Installation of additional charging infrastructure and designation of a charging area for visitors will help alleviate this problem. Due to the difference in dwell time at South Coast AQMD between visitors and employees, charging requirements for these types of users are quite different.

RFP #P2014-24 was issued in May 2014 to solicit proposals to expand and upgrade South Coast AQMD charging infrastructure from qualified third-party vendors. South Coast AQMD, with assistance from Electric Power Research Institute (EPRI), reviewed and identified power requirements and infrastructure upgrades needed to support the electric vehicle supply equipment (EVSE) and review any necessary infrastructure upgrades with potential bidders at the mandatory bidders conference/site walk.

The RFP identified four areas in South Coast AQMD's main parking lot for the expansion and upgrade of EVSE to install 92 Level 2 charging ports. In September 2015, the Board approved the selection of Broadband Telecom Power, Inc. (BTC) as the hardware provider for Level 2 charging ports from a total of 14 proposals which were submitted and 36 vendors participating at the mandatory bidders conference/site walk.

Technology Description

New charging infrastructure and networking software would include additional capabilities such as access control, cost recovery, and energy management capabilities. This included the ability to manage power loads to the EVSE to help with demand charges and other energy management needs of the building as well as a five-year maintenance period.

Installation of new charging infrastructure would replace previously installed and outdated Level 2 charging infrastructure, which included multiple hardware vendors and networking software providers. The intent was to provide a single hardware provider and a networking software platform which was fully integrated with the

hardware and capable of providing upgraded features to make charging easier for EV drivers.

In the first phase, BTC would replace existing charging infrastructure and provide chargers with access control, cost recovery options, and demand response capability. In the second phase, BTC would provide additional charging infrastructure once the expanded electrical infrastructure was in place, which included the installation of four transformers and seven electrical panels covering the four areas of the parking lot. Included in BTC's scope of work was a five-year warranty with five years of onsite service support, software, power management capabilities, installation support and five years of networking fees. BTC also provided technical assistance to help establish desirable power management schedules to reduce electricity costs during the electrical infrastructure upgrade. Construction documents were prepared by Goss Engineering based on the technical specifications of the BTC hardware, which served as a blueprint for the installation.

Status

The first phase of installation of charging infrastructure was completed on December 31, 2016, including replacement of chargers under the solar carport of the upper parking structure. This was followed by installation of chargers along the perimeter of the upper parking structure, six American with Disabilities Act (ADA) accessible chargers by the employee entrance and to conference room GB and by the front lobby entrance, parking area behind conference room CC8, and front lobby parking area. Installation of 92 charging ports was completed in April 2017.

After the installation was completed and the Greenlots (now Shell Recharge Solutions) networking software for the chargers was commissioned, BTC and Greenlots continued to maintain the chargers for five years.

Level 2 Chargers Under Solar Carport

Level 2 Chargers on Upper Parking Structure

Results

Since April 2017, the 92 charging ports have resulted in 15,000 – 28,000 kWh of electricity per month and 1,500 – 2,600 sessions per month between May 2017 to March 2020. Since March 18, 2020, when the office closed due to the pandemic, kWh of electricity dispensed, and the number of charging sessions decreased significantly. From April 2020 to January 2023, charging averaged about 5,000 kWh per month and about 500 sessions per month.

Benefits

Since April 2017, the 92 charging ports have resulted in 82,926 charging sessions, 898,386 kWh of energy dispensed, 1,759,938 lbs. of greenhouse gas (GHG) reductions, and 89,839 gallons of gasoline saved.

82,926	898,385.98	63,230.29	1,759,938.13	89,838.60
SESSIONS CHARGED	kWh CHARGED	USD EARNED	lbs OF CO_2 SAVED	Gallons OF GAS SAVED

Project Costs

The cost for BTC hardware for the 92 Level 2 charging ports at South Coast AQMD is $322,425 from the Clean Fuels Fund (31).

Commercialization and Applications

Installation of charging at South Coast AQMD headquarters enabled EV drivers including staff and visitors to utilize charging, at a time when public charging was not widely available. It also tested capabilities of networking software platforms to manage charging at a large site. The hardware and networking software continue to be utilized in commercial applications for public charging for light-, medium-, and heavy-duty vehicles.

South Coast AQMD Contract #17225 **April 2022**

Development and Demonstration of Up to Three (3) Class 8 Battery Electric Drayage Trucks

Contractor

Volvo Trucks North America

Cosponsors

California Air Resources Board (CARB)
San Joaquin Valley Air Pollution Control District (SJVAPCD)

Project Officer

Patricia Kwon

Background

This project started in 2017 in recognition of the need to pursue multiple zero and near-zero emission drayage trucks in goods movement areas around the Port of Los Angeles and the Port of Long Beach.

Project Objective

This project was to continue development of a Class-8 heavy-duty plug-in diesel hybrid electric vehicle (PHEV) drayage truck to demonstrate reductions in fuel consumption, greenhouse gas, and criteria emissions in real world usage patterns. Phase 1 of the project utilized PHEV#1 as the basis for improvements in PHEV#2. Phase 2 of the project further developed the PHEV technology in the form of PHEV#3 and tested additional technologies. Deployment of two Class 8 tractor battery electric trucks (BETs) was added to the project in 2021.

Technology Description

This project included three PHEV Class 8 daycab tractors. Each was a refinement of the prior vehicle, and there were improvements in efficiency and the addition of a connected intelligent transportation system (C-ITS) known as EcoDrive. Software for controlling the electric systems and drivelines was improved across the three trucks, contributing to the BET design deployed in the last phase of the project. The PHEV system had the ability to dynamically create electric mode zones based on operating conditions. A mini-burner emissions aftertreatment system (EATS) was tested for improved hybrid emissions control.

Status

Phase 1 and Phase 2 of the project were completed in April 2022. Completion of the BET deployment at Producers Dairy in Fresno in the San Joaquin Valley Air Pollution Control District (SJVAPCD) was delayed due to supply chain issues and city bureaucracy in obtaining an approved permit to install two 150 kW DC fast chargers. Phase 1 PHEV work was completed in December 2021. Phase 2 BETs were deployed in December 2021 with the plan to utilize a 50 kW DC fast charger until the two 150 kW DC fast chargers were operational at the end of April 2022.

PHEV #1

PHEV #2

PHEV #3

BET

Results

The multiple elements and length of this project preclude a short summary of results. Individual reports on the various project components summarize the many steps and deliverables in the total program. Overall, the study found that the mini burner EATS was effective in reducing emissions but required frequent operation that largely negated the benefits. Each iteration of the PHEV system had better efficiency and performance. PHEV drivetrains were found to be efficient but advances in battery and electric machine technology led to a focus on pure battery electric solutions. The EcoDrive technology showed notable efficiency gains in controlled conditions and benefits in real-life operations. The BET deployment at Producers Dairy in Fresno is expected to be highly successful and lead to further BET adoption.

Benefits

Each stage of the project provided benefits that were taken forward into future projects. The PHEV software development aided all electrified solutions in managing electric air compressors and battery packs. The C-ITS element led to improved efficiency by providing traffic signal data to the driver and evidence of the cost-effectiveness in reducing emissions. The BET deployment will provide important feedback on the process fleets must go through to transition from diesel to battery electric trucks. The transition to BETs will result in significant emissions reductions, and this project will help define the steps needed.

Project Costs

The project will utilize the budgeted amounts, with an expected overpayment of match funding from Volvo and some other partners.
Budgeted amounts were:

Partners	Amount
CARB	$7,265,055
South Coast AQMD	$2,341,184
San Joaquin APCD	$1,000,000
Volvo	$1,459,698
Total	**$11,065,937**

Additional funding was provided by Amply Power, Producers Dairy, West Virginia University and UC Riverside.

Commercialization and Applications

The work under this project provided the initial base for the Volvo Low Impact Green Heavy Transport Solutions (LIGHTS) project, and important learning for the development of the electric VNR production truck that was deployed in the last phase. The refinement of software and BET components under this project were essential. The EcoDrive system showed great potential for future use. The software solutions developed by Amply, GeoTab and Volvo for the Producers Dairy BET deployment will have significant future commercialization potential. The need for fleet management, dispatch, and telematics systems that accommodate BETs is clear but largely unaddressed.

South Coast AQMD Contract #17244 **April 2022**

Near Zero Emission Drayage Truck Demonstration Project

Contractor

Kenworth Truck Company

Cosponsors

California Air Resources Board (CARB)
South Coast Air Quality Management District (South Coast AQMD)

Project Officer

Seungbum Ha

Background

In response to the challenge and goal of reducing emissions in the ports of Los Angeles and Long Beach by CARB and South Coast AQMD, this project was proposed to demonstrate two Class 8 plug-in hybrid electric trucks with zero emission operation capability in revenue drayage service. Kenworth believed that a natural gas series hybrid could be a cost-effective bridge vehicle to the eventual implementation of full electric or zero emission hybrid electric vehicles in drayage applications. Kenworth proposed the development of four natural gas series hybrids to prove this possibility.

Project Objective

The goal of this project was to determine the technical and economic feasibility of replacing mechanical systems used on diesel engine technology for Class 8 truck tractors with an engine and generator set (genset) fueled by natural gas in a hybrid electric vehicle (HEV). The vehicle also had a large high voltage (HV) battery bank for zero emission operations and to supplement engine output to the electric drive system.

Technology Description

The Kenworth T680 hybrid-electric vehicle used the Cummins Westport L9N Near Zero (NZ) emission engine fueled by compressed natural gas (CNG) driving a generator to extend the truck's battery range. The truck used lithium-ion batteries to achieve its zero emissions range and to supplement power from the generator when climbing grades.

Figure 1: Kenworth's Hybrid Electric Vehicle

The system's energy management and control capabilities ensured that energy generated by the engine and regenerative braking system was appropriately applied through the electric motor, resulting in lower fuel consumption.

Status

The project was completed April 15, 2022, and the final report is on file with complete technical details of the project. Unplanned and unpredicted issues were exposed and resolved as they appeared. Technical gaps were identified, design steps were taken to mitigate the risk, and repairs were implemented to maintain operational conditions. During the demonstration, driver, fleet manager, service technicians and first responder feedback were incorporated into the product when possible or were logged in the lessons learned and will be incorporated into future generations of battery electric vehicle (BEV), HEV and fuel cell electric vehicle (FCEV) projects.

Results

Tests comparing the Range Extended Electric truck to a truck using a conventional natural gas powertrain showed a 23 percent improvement in fuel economy and an 18 percent reduction in carbon dioxide (CO2) emissions.

The data suggests that the product designed for this project generated a significant improvement over the previous project results. The independent consultant analysis results were significantly better than the internal results. Kenworth took time to share analysis techniques that reduced the consultant's performance results to something closer to company results.

	Baseline Vehicle	Demonstration Chassis
Type/Description	CNG Hybrid	CNG Hybrid
Make	Kenworth	Kenworth
Model	T680	T680
Model Year	2017	2019
VIN	1NKYD29X5JJ176832	1NKYD29X1KR359051
Engine Displacement	8.9L	8.9L
Rated Horsepower	320	320
Valid Registration and DOT inspections	Yes	Yes
License Plate	9F95777 CA	9F95779 CA
Common Test and Fuel Economy Run (Seattle-Vancouver)		
Fuel Economy (MPGE)	3.28	4.95
Fuel Economy Improvement (%)	51%	
CO2 & NOx reductions (%)	25%	

Table 1: Performance Improvement of Kenworth CNG Hybrid Truck in GGRF ZEDT Project

Iterative improvements to the hybrid hardware and a restructuring of the relationship between the vehicle state and power management strategies easily yielded a fifty percent improvement in fuel economy. Depending on which calculation tool was used, at a minimum, this equates to a twenty five percent reduction in greenhouse gas (GHG) emissions.

Benefits

Despite the challenges, conversion of drayage fleets to zero-emission propulsion will provide immeasurable benefits to local communities, while significantly reducing GHG emissions. However, making this transition faces two serious challenges. The first challenge is a combination of meeting operational needs and proving technology readiness, and the second challenge is manufacturability and serviceability of a commercially affordable vehicle. Additional testing is recommended to further evaluate the environmental benefits of this truck design. Development of the genset hybrid vehicle design should continue, with a focus on improving reliability, reducing complexity, and lowering cost.

Project Costs

The project budget is shown in Table 2 with match funding from Kenworth.

Table 2: Budget for Kenworth GGRF ZEDT Project

Partners	Amount
CARB	$2,575,232
South Coast AQMD	$2,239,106
Kenworth	$303,000
Total	**$5,117,338**

Commercialization and Applications

When hybrid vehicles compete from a cost, weight and performance measure, the market will be completely disrupted. Any deviation from the above will deter the acceptance of commercial electric vehicle products. Today's technical limits suggest that Class 8 heavy duty zero-emission trucks are found to perform best when operating in the Short Haul/ Regional Haul truck categories. These two specific commercial category applications are most likely to first adopt near zero-emission technology, pick-up-and-delivery and regional haul.

However, regulations are such that fossil fuel hybrids do not meet zero emission standards. Therefore, Kenworth has elected to pursue development of battery electric and fuel cell electric Class 5-8 vehicles for all applications. Many of the components tested in this demonstration project will be carried forward albeit modified to resolve issues noted in the lessons learned. Kenworth has Class 7 & 8 vehicles ready for production and sale at the close of this project. Kenworth projects to have fuel cell electrics ready for production before 2030.

Education and training are the next issues that require priority and resolution. Should resource, vehicle and infrastructure growth and development plans not align, this may become a constraint to economic opportunities for resources, facilities, and products.

South Coast AQMD Contract #19190 **December 2022**

Zero Emission Trucks and EV Infrastructure Project

Contractor

Daimler Trucks North America LLC
Penske Truck Leasing Co., L.P.
NFI Industries Inc.
Gladstein, Neandross & Associates

Cosponsors

South Coast Air Quality Management District (South Coast AQMD)
Port of Long Beach (POLB)
Port of Los Angeles (POLA)
U.S. Environmental Protection Agency (EPA)

Project Officer

Sam Cao

Background

Funding from the South Coast Air Quality Management District (South Coast AQMD) and cosponsors, Daimler Trucks North America (DTNA) helped in the development of petroleum-free zero-emission battery electric trucks, providing immediate NOx and greenhouse gas (GHG) emission reductions that support the South Coast AQMD in achieving its alternative fuel use, petroleum displacement and criteria pollutant reduction goals. This project demonstrated real emission reductions by deploying new zero-emission on-road medium duty- and heavy-duty (M&HD) truck technology with supporting infrastructure that replaced M&HD diesel trucks in real world fleet operations including port drayage and local delivery.

Project Objective

The objective of this project was to deploy twenty (20) M&HD battery electric trucks and supportive infrastructure in the South Coast Air Basin, demonstrating the "bridge phase" of battery electric vehicle (BEV) technology going from the proof-of-concept pilot prototype to a "commercial sales" product that is capable of 150-mile range in order to accelerate the market for M&HD EVs and help achieve California's emission reduction goals. The project was designed to provide critical operational data for both vehicles and infrastructure, informing total cost of ownership (TCO) analysis as well as charging interoperability and availability to enable DTNA to scale up productions for increasing market demand and establish best practices for broader market acceleration across a number of OEMs.

Technology Description

The Class 8 eCascadia and Class 6 eM2 were designed to be integrated into a range of freight duty cycles to obtain varied operational data for drayage, delivery, and logistics operations, supported by a comprehensive network of high-powered 150kW rated charging infrastructure throughout the South Coast Air Basin. The vehicle specification targets for both the eCascadia and the eM2 are detailed in the table below.

	eCascadia	eM2
GVWR	80,000 lbs.	26,000 lbs.
Horsepower	455 hp	220 hp
Axle Configuration	6x4	4x2
Battery Capacity	400-600 kWh	225-300 kWh
Connector Type	CCS-1	CCS-1

Status

The project demonstration was completed on June 18, 2022, with the Draft-Final Report submitted on August 24, 2022. The South Coast AQMD has reviewed the draft report and has provided comments for final submission.

Results

Despite initial production delays associated with global supply chain issues and the COVID-19 pandemic, all project deliverables were achieved, including all major vehicle specification targets for vehicle range, horsepower, and efficiency. Achieving the vehicle design targets were critical

for realizing DTNA's objective of gaining a working knowledge of real-world applications of BEV technology and the long-term goal of informing critical technology advancements for the next generations of the eCascadia and the eM2.

The pilot demonstration was overwhelmingly successful, generating key data on vehicle efficiency, charging capabilities and operational costs to inform technology advancement and the business case for MHD zero-emission vehicles. These trucks replaced and operated the same duty cycles as conventional diesel-powered trucks, resulting in direct emissions reductions through a like-for-like replacement, with a product performance and operational cost that is comparable to diesel baseline counterparts. The project deployed advanced energy management strategies, including a battery energy storage system (BESS), collecting data on energy usage, time-of-use (TOU) utility rate structures, and overall costs to inform TCO and ultimate return on investment (ROI) compared to operating/maintaining diesel baseline counterparts. Tables summarizing results related to total vehicle miles traveled (VMT), vehicle efficiency, energy usage and cost are below.

Fleet	Vehicle	Total Miles	Average Miles/Day	Average kWh/Mile
NFI	eCas	236,836	150.77	2.01
Penske	eCas	228,857	104.33	2.05
Penske	eM2	55,702	84.81	1.42
TOTAL		**521,395**	**113.30**	**1.83**

Charging Usage/Cost		
Fleet	**Avg. Utility Rate/kWh**	**Total kWh**
NFI	$ 0.19	917,837
Penske	$ 0.34	482,994
TOTAL/Weighted Average	**$ 0.23**	**1,400,831**

Benefits

Total emission reductions over the 521,000 combined fleet miles traveled during the demonstration period were 0.92 tons of oxides of nitrogen (NOx), 0.07 tons of particulate matter (PM2.5), and 912 metric tons of GHG emissions.

Project Costs

The grant funding for this project was jointly supported by South Coast AQMD, the Port of Long Beach (POLB), The Port of Los Angeles (POLA). US EPA. DTNA, NFI Industries, and Penske provided the remaining cash and in-kind cost-share for this work.

Project Cost Share	
South Coast AQMD	$12,670,072
POLB	$1,000,000
POLA	$1,000,000
EPA	$1,000,000
DTNA & Partners	$23,495,561

Contract Share	Total Budget	Actual Costs Incurred
$15,670,072	$31,340,144	$39,165,633

Commercialization and Applications

The success of this project yielded an extraordinarily important outcome. For the first time in North America a traditional heavy-duty truck manufacturer (OEM) will be able to offer a Class 6 and Class 8 fully electric heavy-duty trucks to end use commercial fleet customers. It also provided a critical model for M&HD electric vehicle supply equipment (EVSE) infrastructure deployment to understand challenges and best practices to remove barriers to adoption and accelerate the market for zero-emission technologies.

The commercial series will demonstrate improved range and efficiency by simplifying/consolidating vehicle components, reengineering the battery structure, and developing proprietary control software to improve overall power and enable peak performance. Specific vehicle design innovations include lighter battery packaging and curb-weight, increased battery capacity, reduced wheelbase, improved thermal efficiency and aerodynamics, as well as upgraded telematics, weatherization, and diagnostic systems.

This approach to commercialization is key to achieving the increased range, overall performance, and cost-savings to accommodate regional haul routes of up to 220 miles per day, covering a wider array of use cases and making up 70% of freight routes in the United States.

South Coast AQMD Contract #19278 **September 2022**

Low Impact Green Heavy Transport Solutions (LIGHTS)-Develop and Demonstrate Zero Emissions Heavy-Duty Trucks, Freight Handling Equipment, EV Infrastructure and Renewable Energy

Contractor

Volvo Group North America

Cosponsors

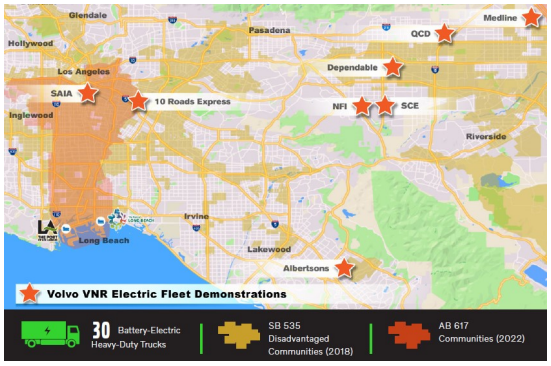
California Air Resources Board (CARB)
South Coast Air Quality Management District (South Coast AQMD)

Project Officer

Patricia Kwon

Background

Volvo Low Impact Heavy Green Transport Solution (LIGHTS) project, a public/private partnership in Southern California, provides early insights and a model for successful fleet adoption of heavy-duty battery electric trucks.



Project Objective

Volvo LIGHTS was launched in 2019 to test critical innovations in vehicle technologies, install charging infrastructure, and establish the groundwork for an electric truck sales and service network. A project team was established to pioneer research and development of heavy-duty battery electric trucks in demanding applications, initiate industrialization to scale, develop the aftersales infrastructure, and install EV charging and energy management at customer sites. A comprehensive project approach was necessary, including coordination with the Ports, local municipalities, and stakeholders in the South Coast Air Basin.

Technology Description

Volvo had previously industrialized zero emission battery electric solutions in Europe for Intercity passenger transit busses and European medium-duty trucks. The LIGHTS project included necessary adaptation to North American duty cycles, U.S. federal and state motor vehicle regulations, 12-volt vehicle requirements, and local customer demands.

Status

Volvo LIGHTS was completed on September 30, 2022. The final report with complete technical details will be posted on the CARB and South Coast AQMD websites.

Volvo Class 8 VNR Electric Trucks from Participating Fleets at Closing Event, Ontario Convention Center, August 23, 2022

Results

Key accomplishments of the Volvo LIGHTS project include:

- 30 battery electric trucks in-service at 13 fleets
- 56 public and private heavy-duty DC fast chargers installed
- 29 pieces battery electric freight handling equipment (yard tractors, forklifts)
- Two community colleges providing new medium- and heavy-duty electric truck technician training curricula
- 45+ graduates from Rio Hondo and San Bernadino Community Colleges (2022)
- Various trucking applications demonstrations included e-commerce, last mile delivery, postal, refrigerated food, drayage, less-than-truckload, medical supplies, and retail stores.

Benefits

The LIGHTS project resulted in annual emission reductions of 3.57 tons of NOx, reactive organic gasses, and particulate matter and 3,020 metric tons of annual greenhouse gas reductions. DHE and NFI installed 1.5 MW of solar with 1.86 million kWh of electricity generated for EV charging and displacement of 207,000 diesel gallons equivalent of fossil fuel annually.

The combined fleet mileage for this project was over 325,000 miles.

Project Costs

Included in the list of Project Partners noted in this chart below are Fleets for NFI and DHE, Southern California Edison (SCE), TEC Equipment, Rio Hondo and San Bernardino Community Colleges, Shell Recharge, the Ports of Los Angeles, and Long Beach, CALSTART, the University of California, Riverside CE-CERT and Reach Out.

Partner	Amount
Volvo	$32,949,552
Project Partners	$10,000,000
U.S. EPA	$500,000
CARB	$43,233,409
South Coast AQMD	$4,000,000
TOTAL	$90,682,961

*Actual total investment by Volvo in the LIGHTS project exceeded required match share.

Commercialization and Applications

Volvo made several major business decisions following the success of the LIGHTS project**.** Specifically, the industrialization of battery electric trucks utilizing already proven architecture resulted in both the MACK LR Electric refuse truck and the VNR Electric series (VNR42, VNR64, VNR42T, VNR62T and VNR64T)**.** On January 13, 2022, Volvo announced the launch of the New Generation VNR Electric with 85% increased range, faster charging, and more configurations covering additional highway applications**.**

Battery electric trucks are here, and this project has identified ways to help accelerate their penetration into the marketplace. First and foremost, fleets make decisions on the lifetime costs of buying and operating trucks. Battery electric trucks require more expensive, high-power charging infrastructure than light-duty vehicles, and this requires greater lead time, cost and planning for fleets. Governments and public agencies can help alleviate the risk through financial incentives and policies that require greater coordination and transparency among key stakeholders. Several major truck manufacturers agree that battery electric trucks are central to the industry's future viability. Stakeholders need to work together proactively and adjust their frame of reference to make this paradigm shift a reality. The transition to electric powertrains will be very different from the introduction of emissions control technology in 2004, 2007, or even 2010, when diesel exhaust fluid became part of the fuelling protocol. Change can be difficult, but Volvo LIGHTS is proving that education and communication, through earnest collaboration, will pave the way for electromobility solutions in the commercial trucking sector.

South Coast AQMD Contract #20124 **September 2022**

Develop and Demonstrate Battery Electric Excavator and Wheel Loader

Contractor
Volvo Technology of America, LLC

Cosponsors
South Coast Air Quality Management District
U.S. Environmental Protection Agency

Project Officer
Sam Cao

Background
In 2016 South Coast Air Quality Management District (South Coast AQMD) identified the need for nitrogen oxide (NOx) emissions reductions as the most significant air quality challenge in meeting the upcoming ozone standard deadlines. On-road diesel trucks and off-road mobile equipment are major contributors to NOx emissions in the South Coast Air Basin (Basin). Significant increases in NOx, particulate matter (PM) and greenhouse gas (GHG) emissions from these sources are expected to increase due to demand in goods movement and construction activities. A proven emissions control strategy to reduce NOx and PM emissions and associated public health risks is to accelerate vehicle and equipment replacement with either battery-electric or near-zero emission vehicles and equipment.

Project Objective
This project was to accelerate the deployment of zero emission technologies for off-road mobile equipment and to reduce harmful diesel emissions, petroleum consumption, and greenhouse gases within the Basin. This was to be accomplished by developing a model of battery electric compact wheeled loader and a model of battery electric compact tracked excavator and subsequently deploying them in and around the Basin area for application testing and feedback with local construction contractors.

Technology Description
During this project, a battery electric compact wheeled loader (L25) in the 1.2yd³ bucket class was completed along with a battery electric compact tracked excavator (ECR25) in the 3-ton class. The L25 utilizes a 48V lithium-ion battery system with 40kWh of energy storage and one 22kW electric induction motor for the driveline system and a 14kW permanent magnet synchronous motor for the hydraulic system. The L25 can operate for up to 6 hours of active work, per full charge depending on the environment and task at hand. This unit was capable of recharging via a DC fast charger in approximately 2 hours, an AC Level 2 charger in approximately 12 hours and an AC Level 1 charger in approximately 24 hours. The ECR25 utilizes a 48V lithium-ion battery system with 20kWh of energy storage and one 14.7kW permanent magnet synchronous motor for the hydraulic system. The ECR25 can operate for up to 6 hours of active work, per full charge depending on the environment and task at hand. This unit can be recharged via a DC fast charger in approximately 1 hour, an AC Level 2 charger in approximately 6 hours and an AC Level 1 charger in approximately 12 hours. The other mechanical specifications for both the L25 and ECR25 are the same as, or better than, their equivalent diesel models.

Status
The project contract was signed in September 2019 and testing commenced in September 2020 when the ECR25 started work. The L25 followed in December 2020 and the testing phase successfully concluded in August 2021. A public press conference was held in September 2021 on the grounds of the Mildred E. Mathias Botanical Garden on the UCLA campus in Los Angeles to discuss the results and learnings from the project. The project contract ran through September 2022 and the final project documentation and reporting is being completed and will be submitted during the early portion of 2023.

Figure 1 – L25 and ECR25 Planting Tree at Press Conference in California

Results

The L25 and ECR25 were tested in a wide variety of applications during this project by three main customers and their crews. The customers were Baltic Sands, Casper Company, and Caltrans. The applications included residential house construction, clearing remote access trails, utility repair, construction, and demolition. The environmental conditions during testing ranged from moderate to high temperatures, dust, rain, and even indoors. The two machines combined, accumulated approximately 400 operating hours over the testing period. The testing feedback was overwhelmingly positive with customers being impressed with the performance of the machines.

The L25 and ECR25 were both tested under various charging scenarios during the project. The primary methods of charging were Level 1 and Level 2 AC charging. The downside during testing was that the onboard chargers were not configured to take advantage of all available power provided by the US 240V infrastructure. In addition, portable and non-grid connected solutions were also tested in the form of a mobile battery bank and a solar powered charging station. The solar charging station worked well, especially in remote locations where grid access was not possible. The customers were very excited about the mobile battery bank, but some technical limitations reduced the effectiveness. The battery bank was large and required a dedicated trailer for transportation so the need for an additional truck or trip was introduced.

Figure 2 – L25 Being charged by Mobile Battery Bank

Benefits

One of the significant benefits expressed by all testing customers was the increase in operator comfort. The positive effect on human factors such as noise and vibration reductions were major improvements where the ECR25 had a measured 9dB drop in sound pressure around the machine, when compared to the equivalent diesel model. The operators no longer had to yell over the engine which reduced employee fatigue.

The total cost of ownership for these electric machines has decreased by not only the savings in diesel fuel but also the significant drop in general maintenance costs. There are still hydraulic oil and filters on the units, but there are no longer engine air and oil filters, or engine oil changes required. The only general maintenance required on these machines is lubrication for moving mechanical joints.

Project Costs

The total project cost was $3,155,000. The U.S. Environmental Protection Agency's Targeted Air Shed Grant Program provided $2 million as pass-through revenue to South Coast AQMD for this project. Volvo CE invested $1,155,000 as in-kind cost share.

Commercialization and Applications

The L25 and ECR25 are both currently commercially available in North America and Europe. The first units delivered to end customers in the US were in December 2022 for the L25 and July 2022 for the ECR25.

The results of this project continue to strengthen the Volvo viewpoint that battery electric machines are an excellent fit for reducing NOx emissions in the compact construction equipment sector while also providing positive health impacts to the operators, crews, and communities in which these machines operate. The feedback from the crews who have used these machines has been and will continue to be used in the continued refinement of these products and in the planning and development of future products. While the work completed as part of this project clearly demonstrated that these machines are equivalent, or better, than the comparable diesel models, there are still some applications where heavy usage requires increased runtime. The time required to recharge and the access to charging infrastructure are also issues that could pose a barrier to entry for some customers. As a result, Volvo has and will continue to investigate ways to enhance the runtime of these machines, optimize on-board charging to make use of the available power more efficiently where they operate, and explore alternate methods of charging. Volvo intends to continue evolving the product portfolio with additional electric compact and mid-size construction equipment models as well pursuing larger machines of various types.

South Coast AQMD Contract #20125 **March 2022**

Develop and Demonstrate Battery Electric Medium-Duty Truck

Contractor

Roush CleanTech, LLC

Cosponsors

Penske Truck Leasing
South Coast Air Quality Management District

Project Officer

Seungbum Ha

Background

Roush CleanTech, LLC, (Roush) received support from the South Coast Air Quality Management District (South Coast AQMD) in the amount of $937,500 to develop a new all-electric platform for medium-duty commercial trucks and school buses. These battery electric vehicles (BEVs) were designed to have a unique powertrain technology for use in Ford F650/750 medium-duty (Class 6-7) commercial vehicles and Class C and D school buses. With support from the South Coast AQMD, Roush was able to complete the technical development, initial prototyping, and in-fleet demonstration of the new powertrain with Penske Truck Leasing (Penske) and other local commercial fleets in Q2 2022.

Project Objective

The project objective was to develop and demonstrate battery electric medium-duty trucks in partnership with Penske and its local fleet partners as well as South Coast AQMD.

Technology Description

While many in the transportation industry focused on heavy-duty long-haul all-electric trucking technologies, Roush believes that the developed battery electric drivetrain fills a significant gap in the zero-emission engine market for heavy-duty fleets operating shorter daily routes with many stop-and-go events. Roush developed a robust future manufacturing strategy that draws upon its decade's old partnership with Ford, engaging partners such as Penske in ongoing evaluation and customer engagement.

Figure 1: ROUSH's Battery-Electric Vehicle Funded by South Coast AQMD, Operated Through Penske Trucking Leasing

Status

The active components of the project were completed in Q2 2022, with administrative wrap-up in Q3 2022. The project has a final report on file with complete technical details of the project

The vehicles built through this project were subject to significant vehicle performance testing for design validation, control validation, and computer aided engineering (CAE) correlation to ensure that vehicles met the key performance targets. Vehicle technology effectiveness was assessed by tests including but not limited to vehicle acceleration, level road performance, weight/ center of gravity testing, battery range verification, cabin climate control and accessories, powertrain cooling and heat management, vehicle stability and traction control.

The COVID-19 global pandemic did present Roush with unanticipated challenges to the global and local supply chain, staffing, and

manufacturing processes. Fortunately, the Roush team was able to overcome these hurdles without significant impact to the development of the two demonstration units. As a result of the COVID-19 global pandemic, Roush delivered the two demonstration units in Q4 2020 rather than Q2 2020.

Roush demonstrated two units in Penske Truck Leasing's fleet in the South Coast Air Basin from December 2020 through May 2022. The EV demonstration schedule included periods at numerous Penske fleet partners, including Costco, Nestle Waters, Iron Mountain, Bimbo Bakeries, and Nike.

Drivers provided positive feedback about the units, especially noting the vehicles' acceleration, regenerative braking, smooth, stable, and quiet ride, safety merging in traffic, battery range, and ease of charging vs. diesel refueling. Through this feedback, Roush was also able to identify and resolve minor vehicle challenges. These included low voltage battery drain caused from drivers leaving vehicles on when not in use, causing battery drain and subsequent dead batteries.

Results

Over the demonstration period, unit "Penske 1" was driven over 10,200 miles, and unit "Penske 2" was driven over 9,300 miles. Telematics data was collected via the vehicles' onboard data collection systems.

One large barrier to new zero emission vehicle technology coming to market is the financial cost of establishing new manufacturing processes, especially at scale. Roush believes the BEV manufacturing capabilities refined through this project will best serve future vehicle manufacturing partnerships with other technology startups as well as established OEMs. Technology companies are rapidly developing incredibly innovative EV architecture, software, and sensing technology, but commercialization requires integrating those technologies, packaging them into a vehicle, and understanding what's required to validate and certify that vehicle to government standards.

Benefits

Deployment of this technology on real fleet routes operating throughout the South Coast Air Basin led to immediate oxides of nitrogen (NOx), diesel particulate matter, and greenhouse gas tailpipe emission reductions, particularly in densely populated urban centers common for municipal fleet routes. In addition to these immediate public health benefits, the project bolstered the adoption of zero emission technology by improving market competition and providing more BEV options to meet a variety of fleet needs. Participating fleets benefited from a low-risk path for testing BEVs in their real fleet operations, building their capabilities to fully transition to zero emission solutions moving forward. This project will help reduce future vehicle emissions and have an impact beyond the immediate project emissions reductions themselves.

Project Costs

Project costs are as follows:

Project Partner	Total
South Coast AQMD	$937,500
Roush Cost Share	$2,062,500
Penske Cost Share	$200,000
Total Project Cost	**$3,200,000**

Commercialization and Applications

This project provided a low-risk path for fleets to gain hands on experience running BEVs in their current fleet operations. The demonstration resulted not only in a learning experience for Roush and the vehicle engineers, but also a transfer of knowledge to world class fleets such as Penske, Costco, Nestle, etc. This type of partnership means that South Coast AQMD funding benefits not only Roush, but also participating fleets who through this project have built their capabilities and interest in adopting BEV technology going forward.

This effort also strengthened collaboration and built networks within the rapidly changing transportation industry. By facilitating open dialogue between vehicle OEMs, leasing fleets, and end user fleets, this project ensured that feedback from drivers and fleet managers are incorporated into engineering best practices. Likewise, fleets gained knowledge on their abilities to successfully transition to new technologies.

South Coast AQMD Contract #20158 **December 2022**

Onboard NOx and PM Measurement Method

Contractor

University of California, Riverside, College of Engineering, Center for Environmental Research and Technology (UCR-CE-CERT)

Cosponsors

California Air Resources Board (CARB)
U.S. Environmental Protection Agency (EPA)
Center for Advancing Research in Transportation Emissions, Energy and Health (CARTEEH)

Project Officer

Sam Cao

Background

Heavy-duty vehicles represent one of the most important contributions to the emissions inventory for both nitrogen oxides (NOx) and particulate matter (PM) emissions. While diesel particulate filters (DPFs) and selective catalytic reduction (SCR) aftertreatment systems have provided significant reductions in PM and NOx emissions, respectively, it is important to verify that these systems are operating optimally under the full range of in-use conditions to ensure that air quality standards can be met. The advancement of sensor technology has provided the potential to measure all trucks at all times and validate compliance from the in-use fleet under the conditions where they produce emissions. The importance of this methodology is underscored by CARB's recent Real Emissions Assessment Logging (REAL) amendments to its OBD (On-board Diagnostic) Regulations.

Project Objective

The goal of this Phase 1 Onboard Sensoring and Reporting (OSAR) project is to develop a low-cost NOx and PM sensor-based emissions measurement system designed for heavy duty engines. This low-cost system was designed to allow for expanded applications going into the future, such as dynamic engine calibration control, in-use policy enforcement, and a data driven exposure model specific to the South Coast Air Basin. A total of 8 OSAR systems were developed under this project. The OSAR units were set up on 9 trucks at two fleets for a period of up to 2 months.

Technology Description

The OSAR system developed for this project included a NOx and PM sensor, a global positioning system (GPS), an engine control module (ECM) logger, and a cellular connection for real-time data reporting. The NOx sensors used for this system was a prototype advanced low temperature capable NOx sensor based on an original equipment manufacturer (OEM) product used for engine control and OBD of SCR systems. The data loggers used for this set up were "EmTrac-6 Onboard Telemetry System Rev. 1" data loggers developed by Emisense Technologies specifically for this program. It is an Advanced RISC [reduced instruction set computer] machine (ARM)-based unit with two controller area networks (CAN) buses, four analog inputs, an onboard K-type thermocouple amplifier, and a global navigation satellite system (GNSS) for location information. The ECM data was logged via OBD or J1939 connection to the OSAR system.

Status

This project was successfully completed, and the final report was submitted in December of 2022.

Results

Average NOx emissions for the different test trucks ranged from 0.14 to 1.35 g/bhp-hr. The D1119 vehicle showed the highest average

emissions, which is more than six times higher than the certification limit. D0214 showed the lowest average emissions on a g/bhp-hr basis, which is near the level of the certification standard of 0.2 g/bhp-hr. These differences in average NOx emissions appear to be attributed to differences in duty cycles and not the engine certification. D1119 was generally idling, or its driving patterns indicated slow, stop-heavy motion. The driving patterns for D0214 also showed a significant amount of operation with multitude of stops, but with less idling behavior. The higher in-use NOx results agree with earlier studies that have reported higher in-use NOx emissions from diesel trucks compared to certification levels, particularly under low load operation.

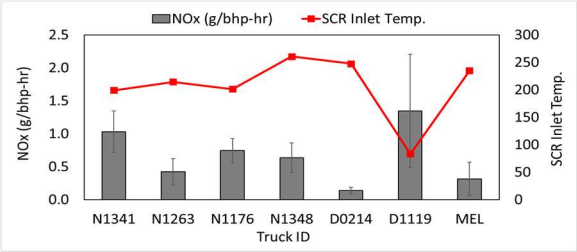


Fig. 1: NOx Emissions for the Different Test Trucks (g/bhp-hr)

Similar trends were seen for the NOx emissions on a g/mile basis. NOx emissions ranged from 0.018 to 11.38 g/mile, with the D1012 showing the highest emissions, and the MEL/MA truck showing the lowest emissions. NOx emissions showed different trends on a g/hour and g/gal basis. NOx emissions ranged from 0.756 to 62.94 g/hour, and 0.013 to 22.71 g/gal. D1119 showed the highest NOx emissions on a g/gal basis, while N1341 showed the highest NOx emissions on g/hour. The MEL/MA truck showed the lowest NOx emissions on both a g/hour and g/gal basis.

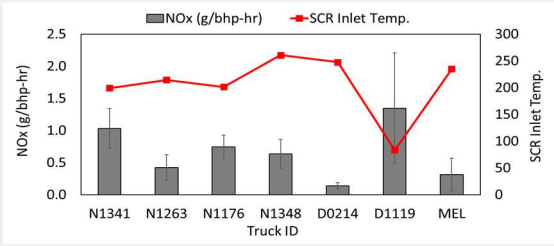


Fig. 2: NOx Emissions for the Different Test Trucks (g/mi)

From an activity standpoint, the trucks operated from 4.4 to 10.6 hours per day. The average speed for the different vehicles ranged from 6.2 to 39.7 mph. The average distance for the different vehicles/pieces of equipment ranged from 59.8 to 234.8 miles. The daily fuel consumption for the different vehicles/pieces of equipment ranged from 8.7 to 33.0 gallon/day. In general, the long-haul trucks showed higher average speeds, longer days of operation, higher average distances per day, and higher fuel usage per day, while the box truck showed the lowest values for these metrics.

Benefits

The OSAR systems developed as part of this project show the potential to measure all trucks at all times and validate compliance from the in-use fleet under various emissions producing conditions. The goal of this Phase 1 OSAR project was to develop and demonstrate a low-cost NOx and PM sensor-based emissions measurement designed for heavy duty vehicles. The results show these low cost OBD sensors are capable of determining emissions at and below the 0.2 g/bhp-hr level. The development of these systems provides the potential for enhanced monitoring of heavy-duty vehicle emissions, which could provide benefits to the South Coast AQMD in meeting the 2023 and 2031 ozone standards.

Project Costs

This $688,587 project was funded as follows:

South Coast AQMD	$201,087
Engine Manufacturers Association	$200,000
EmiSense Technologies LLC	$115,000
CARTEEH	$80,000
CARB / EPA	$50,000
NGK Spark Plug	$42,500

Commercialization and Applications

It is expected that this research will help guide industry into a sustainable path of emissions control for their vehicles using the real world as the design platform. The funds provided by the South Coast AQMD will leverage larger dollars from other agencies and industries and will support the development of regulations to focus more on in-use emissions. It is believed this seed funding will spur industry into a solution that includes instrumenting all new heavy-duty trucks with the potential for retrofitting older ones depending on feedback from the agencies. It is believed this effort will be supported by industry and fleet owners, as it benefits everyone with a fair and practical solution for emissions regulations. Eventually, this solution could be integrated into other mobile sources including non-road and light-duty passenger cars.

South Coast AQMD Contract #17276 **January 2022**

Development of ECO-ITS Strategies for Cargo Containers

Contractor

University of California, Riverside
University of Southern California

Cosponsors

National Center for Sustainable Transportation (NCST)
California Energy Commission (CEC)
California Air Resources Board (CARB)
Los Angeles County Metropolitan Transportation Authority
South Coast Air Quality Management District (South Coast AQMD)

Project Officer

Seungbum Ha

Background

In the last few decades, efforts to reduce emissions from heavy-duty diesel trucks (HDDTs) and their health impacts have focused on imposing increasingly stringent emissions standards. This has led to significant advancements in emission control technologies and alternative fuel vehicle technologies. While these technologies are effective at reducing emissions from HDDTs, the turnover of the existing HDDT population to these advanced technologies would require a large amount of investment and time. In the near term, other efforts to reduce emissions of the existing HDDTs and mitigate their impacts on communities are needed. Many studies have shown the promise of intelligent transportation systems (ITS) technologies in reducing the energy consumption and environmental footprint of people and goods movement through various means.

Project Objective

This research is aimed at developing and evaluating eco-friendly ITS strategies for freight vehicles and traffic, with a focus on strategies that are applicable to the transportation systems in the South Coast Air Basin. Four specific strategies were examined in this research, including: 1) connected eco-driving, 2) truck eco-routing, 3) integrated traffic control, and 4) intelligent parking assist.

Technology Description

Connected eco-driving uses signal phase and timing (SPaT) information from the upcoming traffic signal along with the information about the state of the host vehicle and preceding traffic to determine the best course of action for the vehicle to pass through the intersection.

User Interface of Connected Eco-driving Application

Truck eco-routing is aimed at finding the travel route that would minimize vehicle energy consumption and/or emissions for the trip.

Integrated traffic control coordinates the variable speed limit (VSL), ramp metering (RM), and lane change (LC) control strategies to stabilize traffic flow and mitigate traffic congestion around highway bottlenecks.

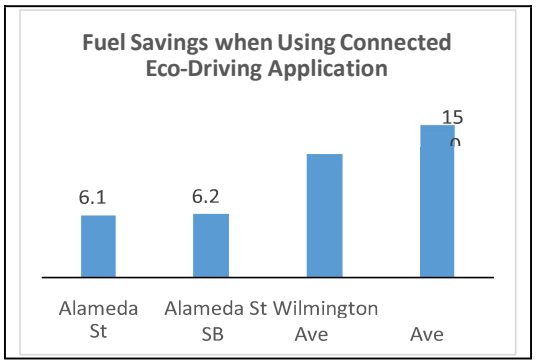
Intelligent parking assist integrates parking availability information into the planning process for long-haul trucks.

Status

This project was completed in January 2022. The final report is on file with South Coast AQMD.

Results

The results from the performance evaluation of the connected eco-driving application in real world show that driving with the application resulted in less fuel consumption, and less carbon dioxide (CO2) emissions, than driving without it by 6% to 15%.



For the truck eco-routing strategy, based on the results of 456 trips made by 48 trucks in a typical day, it was found that for 52% of the trips the fastest route is already the most fuel-efficient route. For another 23% of the trips, the eco route would take up to one minute (1% to 8%) longer travel time than the fastest route, on average, but would result in 5% to 7% fuel savings. For another 11% of the trips, the eco route would take up to 3.5 minutes (12% to 17%) longer travel time, on average, but would result in 7% to 8% fuel savings.

For the integrated traffic control strategy, both macroscopic and microscopic simulation results demonstrate that the proposed control scheme can stabilize the density of the highway section at the desired density, and, as a result, improve the discharging flow rate by 33%, compared to the case of no control action.

For the intelligent parking assist strategy, simulation results illustrate that schedules calculated without accounting for parking availability are often infeasible. Although parking constraints increased trip duration in some scenarios, these scenarios also showed lower feasibility rates when ignoring parking information. Also, computational experiments showed that parking conditions could significantly affect the route choice, illustrating the importance of accounting for parking availability information early in the planning process. Furthermore, when parking availability is limited, the performance gap (in terms of trip duration) between battery electric trucks and diesel trucks is greatly reduced in scenarios with 50 kW chargers, and further reduced when 100 kW chargers are considered.

Benefits

The connected eco-driving application was proven to provide significant reductions in fuel consumption and CO2 emission for HDDT traveling on signalized corridors. If adopted widely, it has a potential to reduce emission inventory of HDDTs, especially those operating in the drayage application, throughout the South Coast Air Basin. Likewise, there is a potential for the truck eco-routing application to help HDDTs with similar trip patterns to those of the trucks studied in this project in reducing fuel consumption and CO2 emission on about a third of their trips.

The ability to better control traffic flow at highway bottlenecks would also result in reductions in traffic emissions including those from HDDTs. Finally, the provision of parking availability information to long-haul truck drivers could lead to more efficient scheduling and routing of their trips, which reduces unnecessary fuel consumption and emissions.

Project Costs

South Coast AQMD's funding contribution to this project is $543,000, which was leveraged in other related research projects totaling $1,647,233.

Commercialization and Applications

The connected eco-driving technology is mature, although its prospect for commercialization depends on the ability to access real-time traffic signal data from public agencies that operate traffic signals. On the other hand, commercial eco- routing applications have already existed for passenger cars. Therefore, it should be possible to commercialize eco-routing applications designed specifically for HDDTs in the near future. Finally, the integrated traffic control strategy and the intelligent parking assist strategy are also ready for deployment by relevant public agencies.

South Coast AQMD Contract #17286 **March 2022**

In-Use Emissions Testing and Fuel Usage Profiles for On-Road Heavy-Duty Vehicles

Contractor

University of California, Riverside (UCR)
West Virginia University (WVU)

Cosponsors

California Energy Commission (CEC)
Southern California Gas Company (SoCalGas)
California Air Resources Board (CARB)
South Coast Air Quality Management District (South Coast AQMD)

Project Officer

Sam Cao

Background

While past studies have shown oxides of nitrogen (NOx) and particulate matter (PM) emissions are reduced from heavy-duty vehicles (HDVs) powered by modern-technology engines, emissions from HDVs still dominate the total basin-wide NOx and PM emissions. Therefore, additional assessment of in-use vehicle emissions remains a critical component for measuring the effectiveness of engine, fuel and aftertreatment technologies and improving emission inventories for air quality modeling and planning as well as developing effective strategies toward achieving the federal ambient air quality standards.

Project Objective

The objective of this project was to conduct in-use emissions testing, characterize fuel usage profiles, develop new or improve existing heavy-duty vehicle drive cycles, and assess the impact of current technology and alternative fuels on fuel consumption and in-use emissions from on-road HDVs with gross Vehicle Weight Rating (GVWR) greater than 14,000 lb. Additionally, the vehicle emission measurements collected under this Program provide important new data to improve air quality planning.

Technology Description

UCR and WVU collectively conducted the exhaust emission tests for over 200 heavy duty trucks with different technologies recruited in Southern California along with data collection for daily vehicle activities and fuel usage profiles. Specifically, the testing was conducted in the following four sequential phases: 1) On-road operation data gathering with Portable Activity Measurement Systems (PAMS) on 227 vehicles, 2) On-road emissions testing with Portable Emissions Measurement Systems (PEMS) on 100 vehicles, 3) In laboratory (stationary) emissions testing with a chassis dynamometer on 55 vehicles, 4) On-road emissions testing with mobile emissions laboratory trailer on 10 vehicles

Figure 1. UCR On-Road Mobile Laboratories

Status

UCR and WVU has completed the data collection and prepared the final reports summarizing their respective research work. A combined draft final report with complete technical details has been prepared as of August 2022 and currently under agency review, the finalized report will be published on the CEC website.

Results

For the four-phase testing and data collection, there were 227 PAMS tests, 100 PEMS tests, 55 chassis dynamometer tests, and 1 on-road tests with a mobile emissions trailer. The vehicle population covered 5 vocations, including Transit Bus (TB), School Bus (SB), Refuse Hauler (RH), Delivery Truck (DT), and Goods Movement (GM), and a range of conventional and cleaner heavy-duty technologies.

To test these HDV types under more representative conditions, new chassis dynamometer test cycles specific to these three categories were developed using a Markov-Chain Drive Cycle Generation Tool developed by WVU from the PAMS data. Further, such PAMS data were included in CARB's

EMFAC2021 development, CEC's Medium- and Heavy-Duty Electric Vehicle Infrastructure Load, Operations and Deployment (HEVI-LOAD) model.

The PEMS testing incorporated a diverse set of HDVs, fleet operators, and operating conditions/duty-cycles. As expected, the PEMS results showed high variability in NOx emission levels between vocations and technology categories. As can be seen in Figure 2, the same high variability was observed within each technology category while all engines were certified to the same emissions standard. The high variance observed in the data was expected; given the emissions were measured with PEMS and were averaged over the entire test day, regardless of the vocation and the duty cycle.

Different than the "daily" averages presented in the PEMS data, the chassis urban dynamometer driving schedule (UDDS) "cycle" averaged results were similar across different vehicle categories. As shown in Figure 3, the UDDS cycle-averaged results were similar across different HDV categories; this is a markedly different result than the "daily" averages presented in the PEMS section. The UDDS cycle, although not identical, closely resembles the Federal Test Procedure (FTP) certification test cycle, over which an HDV engine's emissions certification value is derived. Therefore, these UDDS data provide good comparison points to understand the NOx emissions in this context.

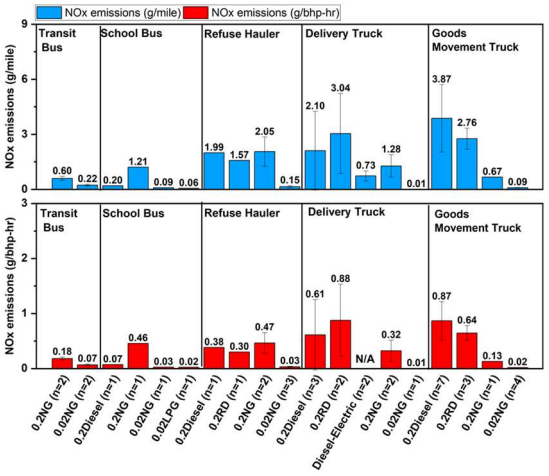


Figure 2. Cycle Averaged Chassis Dyno NOx Emission Rates under UDDS cycle.

A total of 10 HDVs were tested on the roads of Southern California. The HDVs in this phase were exclusively Class 8 goods movement trucks. Compared to the emissions data presented in PEMS and chassis dynamometer testing, the NOx and fuel economy were averaged over the entire-test route. The data trends are as expected due to smaller dataset and single vocation (goods movement). Distance- and work-specific NOx emission results are summarized in Report.

Benefits

This study builds on these past efforts by investigating in-use emission levels of these natural gas (NG) HDVs in the context of the 0.02 g/bhp-hr NOx certification standard, legacy 0.2 NG HDVs, multiple HDV vocations, and other fuel types. By identifying technology impacts and shortfalls potentially causing higher than expected in-use emissions, as well as areas of exceptional in-use emissions performance, the project is informing further technology development and research opportunities to maximize emission reduction benefits from deploying 0.02 NG HDVs.

Additionally, the comprehensive dataset (and the models leveraging the data) can help policymakers better understand real world emissions from California's in-use fleet (approximately one million medium- and heavy-duty vehicles). Decision makers can leverage the study results to determine the best pathways forward for meeting transportation decarbonization and air quality goals. For the on-road fleet, most of those reductions will need to come from HDVs, including newly manufactured units as well as those already in use.

Project Costs

The project cost to WVU and UCR was $1,625,000 each for a total project cost of $3,250,000. CEC, SoCalGas, CARB, and South Coast AQMD's cost-share for the project was $2,000,000, $500,000, $150,000, and $600,000, respectively.

Commercialization and Applications

The 200 HDV Testing Program represents an important milestone for CARB, CEC, the South Coast AQMD, SoCalGas and the U.S. EPA. The results from the program are very instrumental in ongoing efforts to shape, improve and implement policies designed to attain ambient air quality standards, mitigate climate change, and displace fossil-derived diesel with low-carbon alternative transportation fuels.

South Coast AQMD Contract #22131 **December 2022**

Conduct California Inland Port Feasibility Study Phase Two

Contractor

Fresno Council of Governments (Fresno COG)
Global Logistics Development Partners (GLD Partners)

Cosponsors

Port of Los Angeles (POLA)
Port of Long Beach (POLB)
Port of Stockton (POS)
San Joaquin Valley Air Pollution Control District (SJVAPCD)
South Coast Air Quality Management District (South Coast AQMD)
Sacramento Metropolitan Air Quality Management District (SMAQMD)
County of Sacramento

Project Officer

Sam Cao

Background

The California Inland Port System Feasibility Study (FS) Phase II is the second of three feasibility study phases for the project. Project development and planning will begin concurrently with the last feasibility study phase. Phase One looked at the core feasibility test, Phase Two looked at the market, costs, and began the business model development, while Phase Three will detail sites, further define the business model, and detail the rail component. The California Inland Port System Project aims to create the largest, cleanest, and most efficient goods movement system in the nation.

Project Objective

The California Inland Port System FS is a transformational project that will have significant positive implications for improving national and statewide supply chain efficiency, while also improving air quality, economic opportunity, and other public policy objectives. In partnership with the State's major seaports, the California Inland Port System FS will be a public-private platform to transform much of the California logistics system.

Specific objectives include: 1) Significantly reduce vehicle miles travelled, congestion, air pollution, and greenhouse gas emissions by reducing the number of truck trips from the seaports complex in the Los Angeles region to the San Joaquin Valley, the Sacramento region, and the Bay Area. 2) Create tangible new supply chain efficiencies and reduce shipping costs for shippers that manage global supply chains through direct intermodal rail service to/from the San Pedro seaports. 3) Analyze significant private sector investment and new job creation by fundamentally repositioning the economic competitiveness of the San Joaquin Valley Region. 4) Create a more robust and efficient intra-state distribution system with a specific focus on supporting the agriculture sector while spurring new high-value manufacturing and e-commerce investments. 5) Reduce highway road congestion, with a parallel reduction in the requirement for road maintenance; accident-avoidance savings; all reducing cost.

Technology Description

The California Inland Port System will be a multi-modal network of integrated clean and highly efficient truck, rail, air, and cargo facilities that will underpin a next-generation ecosystem of goods movement. The system is being built from the ground up around zero-emission cargo handling equipment. Additionally, using customized technology and integration with port-supply chain data, the system will play a strategic role in increasing supply chain competitiveness and will be a major California contribution to solving the national supply chain crisis.

Status

The project has gained support from a range of interests and is entering a critical period. The overall structure of the project has been formed with identification of key elements, infrastructure, and costs. Due to circumstances, there may be an opportunity to fast-track early portions of the

project, so the next six months will be a critical period in the project's development. While public funding is pursued, work will continue for certain business strategy, planning, engineering, and community engagement aspects of the project. Over the next year, it will become clear if the State will agree to fund Fresno COG's budget request for $60M. This in turn will be important in determining if a corresponding federal funding request may be successful. If State and federal funding were in-place, the foundation would be set to develop the TradePorts with extensive private investment.

Meanwhile, work on Phase Three of the project continues and will soon be underway with U.S. Department of Transportation (U.S. DOT) related to the Regional Infrastructure Accelerator/P3 elements. Phase Three will also begin the environmental analysis process and create advance plans, develop specifications for key infrastructure projects and corresponding project finance and public-private partnership structures. Finally, the project will begin site planning, design, and engineering for the first fast-track project elements and develop a Joint Powers Authority to deliver the first phases of the project.

Results

Phase Two follows the completion of the Core Feasibility Assessment that was competed in the initial phase. This phase was designed to refine the product offer, clarify the likely market, produce infrastructure cost estimates, and define new potential economic development. During this phase of the project, several key objectives were accomplished: 1) Shipper requirements and interest were more clearly defined and clarified , 2) Capital costs for key infrastructure cost estimates were produced, 3) TradePort plans were developed, 4) Competitiveness modelling was performed to demonstrate the extent and type of economic development that would be enabled due to increased logistics connectivity to key supply chain points, 5) Sought and won U.S. DOT Regional Accelerator designation, and 6) Developed a proposal for an initial launch phase for development of the first elements of Truck Mobility Complexes.

During this phase, interactions with a range of additional work was undertaken to communicate and coordinate with ports, railroads, truck manufacturers, and fleet operators. Additional interactions are planned with each as the project proceeds into Phase Three.

Benefits

In terms of the California Inland Port System, strategic public and private investments will directly lead to an economic development system that will generate approximately 100,000 new high-quality and high-wage jobs in a range of manufacturing and logistics sectors, including automotive, agricultural processing and food production, medical products, industrial machinery, and ecommerce. Most of these new jobs will benefit the stat's most disadvantaged region, which is the Central Valley. The private investment in buildings and equipment will produce up to $30 billion in overall gross investment. Finally, the California Inland Port System would be one of the largest, cleanest, and most efficient logistics and investment systems in the world. It would be the flagship model for the nation and would dramatically support improvements to air quality, climate resiliency, economic development and competitiveness, and the national supply chain system.

Project Costs

Phase Two FS cost $250,000 to conduct, with South Coast AQMD's contribution being $37,500, or 15% of the overall cost. Phase One FS cost $250,000 while Phase Three FS will cost $468,000. South Coast AQMD is only contributing to Phase Two and the project team does not expect South Coast AQMD to further contribute to any phase. Phase Three and beyond is/will be funded by State and federal funding. Project development is anticipated to cost upwards of $4 million. Fresno COG has applied for U.S. DOT RAISE Planning grant funds and Governor's budget funds for the remaining portion.

Commercialization and Applications

The project team aims to have the first Truck Mobility Complexes operational by 2025, with full buildout of the system to happen in the years following, subject to various factors.

SCAQMD Contract #17059 **May 2022**

UPS Fuel Cell Extended Range Delivery Truck Demonstration

Contractor
CALSTART Inc

Subcontractor
United Parcel Service (UPS)
Unique Electric Solution, LCC (UES)
Ballard Power System
South Coast Air Quality Management District (South Coast AQMD)

Project Officer
Maryam Hajbabaei

Background
Parcel delivery trucks have a vital role in the modern economy, especially with the onset of the COVID-19 pandemic. Diesel-powered parcel delivery vehicles have become a significant contributor to poor air quality in the South Coast Air Basin. This project aims to demonstrate a fuel-cell-powered parcel delivery vehicle for the purpose of removing the harmful emissions the vehicles emit while driving in local communities and to help meet South Coast AQMD emissions reduction goals.

Project Objective
This project aimed to develop and demonstrate a hybrid electric powertrain with a fuel-cell range extender integrated into a UPS delivery truck as a scalable, innovative, cost-effective alternative to diesel-powered parcel delivery vehicles. The project aimed to assess both the technology's performance viability and commercial viability

Technology Description
The Fuel Cell Extended Range Delivery Truck (FCXRDT) is a hybrid-electric fuel cell vehicle on a standard UPS chassis. The vehicle was a retrofitted UPS vehicle with the new technology mounted on it. The drive train consisted of a 120 kW electric motor and a 50kWh Lithium Iron Phosphate battery, with an estimated range of 120 miles. Additionally, a fuel cell range extender was attached, with 10 kg of hydrogen (H2) storage and a power rating of 30 kW. It is one of the first parcel delivery vehicles to be demonstrated with this type of propulsion system. The vehicle operates with zero emissions.

Status
The project was completed in May 2022. Both the final project report and the accompanying commercialization report are available on file. These reports describe the technical details of the project in-depth.

The vehicle's development and assembly began in 2018 and were completed in February 2019. After assembly completion, several delays prevented demonstration from beginning immediately, including difficulty supplying hydrogen, length repair times, and the onset of the COVID-19 pandemic. The vehicle was operated, and data was collected for 11 months from September 2020 to September 2021. The project was successfully completed during this demonstration period.

Results
The vehicle conducted 11 months of on-road performance testing from September 2020 to September 2021. The following table breaks down

the critical vehicle essential key performance and efficiency metrics.

Parameter	Value
Total Days of Operation	143
Average Distance Driven per day (mi)	24.07
Average Fuel Efficiency (mi/kg)	13.80
Average Energy Efficiency (kWh/mi)	0.99
Average Total Efficiency (mi/DGE)	9.07

The vehicle drove a total of 143 days throughout the testing period and averaged 24.07 miles per day. The vehicle proved to be very fuel-efficient, averaging 9.07 miles per diesel gallon equivalents (DGE) throughout the duration of the data collection period. The following table summarizes the total maintenance and service that was required on the FCXRDT throughout the project.

Parameter	Value
Vehicle Service Events	18
Vehicle Break Down Events	8
Total Days Out of Service (Days)	106
Average days out Service per Event	5.89
Maintenance Cost ($/mi)	0.59

The vehicle had several issues with maintenance and service events throughout the period, being out of service for a total of 106 business days throughout the demonstration period. Maintenance issues, while not extremely expensive ($0.59 per mile) proved to be reasonably common, costing a large amount of unfortunate downtime.

Benefits

The project showed the vehicle and technology were more than capable of completing the duty cycle of a package delivery vehicle. The FCXDRT was able to meet the anticipated range, charging, and power predictions stated at the project's onset. The vehicle is zero-emission and therefore provides significant reductions over a traditional package delivery vehicle. As this project was slated to demonstrate and test the viability of the fuel-cell range extender technology, these results show that the vehicle technology is viable in on-route, real-world conditions.

Project Costs

The project obtained a total funding/cost share of $1,574,250.00 from several partners to evaluate the overall truck's performance. The UPS and South Coast AQMD supplied the most substantial sums. All additional funding sources are mentioned in the table below.

Parties Name	Amount
UPS	$749,500.00
South Coast AQMD	$589,750.00
UES	$165,000.00
CALSTART	$70,000.00
Total	**$1,574,250.00**

Commercialization and Applications

This demonstration represents a significant step forward for the fuel cell industry as it able to successfully deploy a fuel cell parcel delivery truck. This demonstration provided many lessons for the industry. Hydrogen fuel cell technology has the ability to function in a variety of settings and can meet the duty cycle of the parcel delivery sector. To successfully deploy fuel cell vehicles, a fleet needs access to a well-established fueling infrastructure network.

While fuel cell technology has improved and become cheaper, there are some additional barriers to commercialization. While these barriers do not necessarily directly relate to the vehicle technology itself, they can deter customers from adopting fuel cell vehicle technology. These considerations include the availability of hydrogen infrastructure, the cost of hydrogen, hydrogen filling speeds, fuel cell technological expertise, maintenance, and the availability of parts and technician training. Nevertheless, as fuel cell technology advances, all of the concerns will be addressed to make fuel cell technology more appealing to fleets.

South Coast AQMD Contract #23071 **December 2022**

Participate in California Fuel Cell Partnership for CY 2022

Contractor

Frontier Energy Inc

Cosponsors

Automakers, energy companies, local, state and federal public agencies, technology companies, universities, transit agencies and others.

Project Officer

Maryam Hajbabaei

Background

Established with eight members in 1999, the California Fuel Cell Partnership (CaFCP) is a collaboration in which private and public entities are independent participants. It is not a joint venture, legal partnership, or unincorporated association. Therefore, each participant contracts with Frontier Energy (previously Bevilacqua-Knight, Inc./BKi) for their portion of CaFCP administration. South Coast AQMD joined the CaFCP in April 2000. The CaFCP currently includes 16 board members, 12 steering team members, and 44 associate members with a focus on furthering commercialization of fuel cell vehicles, fueling infrastructure technologies and renewable and decarbonized hydrogen production to address climate change and emission reduction challenges.

In 2022 CaFCP began transitioning to a national public-private partnership called the Hydrogen Fuel Cell Partnership (H2FCP). The purpose was to expand progress beyond California. California remains the primary geographic objective, serving as a national leader. While the organization has formally launched as a new legal entity and has applied for 501c3 status, the transition is expected to be fully implemented in 2023. Until then, the current relationship with Frontier Energy and approach is in place.

Project Objectives

The goals for 2022 include the following:

- Identify technology challenges and information gaps within the state's hydrogen station network, and work collaboratively with members to advance the market
- Coordinate and collaborate on approaches to achieving an initial 200 light duty hydrogen stations, expanding to a state-wide sustainable infrastructure network of at least 1,000 stations in California. Build support for the FCET Vision, highlighting the need for 200 heavy duty stations to support 70,000 HD fuel cell trucks, to enable heavy duty hydrogen fuel cell truck adoption
- Identify new concepts and approaches to initiate exponential station network growth for light- and heavy-duty applications
- Communicate progress of fuel cell electric vehicles (light and heavy duty) and hydrogen to current and new stakeholder audiences
- Increase awareness and market participation of fuel cell electric trucks and buses, including supporting the deployment of pilot projects
- Coordinate nationally and internationally to share and align approaches

Status

The members of the CaFCP/H2FCP intend to continue their cooperative efforts within California and have plans to expand activities in 2023 to advance the ZEV technology benefits in-state and nationally. This contract was completed on schedule.

Technology Description

CaFCP/H2FCP members together or individually are operating fuel cell passenger cars, transit buses, drayage trucks and associated fueling infrastructure in California. Passenger cars include Honda's Clarity, Hyundai's Nexo and Toyota's second generation Mirai. Fuel cell bus operators include AC Transit, Sunline Transit, Orange County Transportation Authority, Golden Empire Transit and UC Irvine Student Transportation with more agencies bringing on buses in the coming year or two, including

Foothill Transit, Long Beach Transit, and others. More transit agencies are expected to adopt fuel cell buses over the next 5-10 years as they implement the Innovative Clean Transit regulation. Class 8 fuel cell drayage trucks include a Ballard powered BAE/Kenworth truck, the Cummins fuel cell powered TransPower truck, Hyundai Xcient trucks and Toyota's Portal trucks.

Results

Specific accomplishments include:

- Since 2015, more than 14,000 consumers and fleets have purchased or leased passenger FCEVs
- Transit agencies have 66 fuel cell electric buses in operation and more than 103 on order. Over 2,100 additional fuel cell electric buses anticipated (from recent CARB ACT update)
- 56 plus light-duty retail hydrogen stations in operation in California and 115 in development; 5 bus stations in operation and 3 in development, and 3 truck stations in operation, 1 in development and another 5 funded
- CaFCP/H2FCP staff and members continue to conduct targeted outreach and education throughout California and provide information to non-California requestors
- CaFCP/H2FCP operates and maintains the Station Operational Status System (SOSS) that the 50-plus open retail hydrogen stations use to report status. This data, in turn, feeds real-time information (address, availability, etc.) to FCEV drivers through a CaFCP/H2FCP mobile website and other apps and systems. SOSS data also supports the new ZEV infrastructure credit in the Low Carbon Fuel Standard program
- CaFCP/H2FCP actively engages in medium- & heavy-duty FCEV codes & standards coordination, specifically through sponsoring SAE J2600 (fueling connection) for inclusion of high-flow H35 fueling geometry for fuel cell electric bus (FCEB) fueling and fueling protocol standard development
- Building on the FCET truck vision, CaFCP/H2FCP has initiated development of a national hydrogen mobility strategy. The strategy will develop infrastructure success metrics for heavy- and light-duty vehicles in California (for the ARCHES H2 Hub proposal) and nationally to connect ports, H2 Hubs, and other activities, as well as a public stakeholder engagement strategy

Benefits

Compared to conventional vehicles, fuel cell vehicles offer zero smog-forming emissions, reduced water pollution from oil leaks, higher efficiency and much quieter and smoother operation. When renewable fuels and electricity are used as a source for hydrogen, fuel cell vehicles also encourage greater energy diversity and lower greenhouse gas emissions (CO_2).

By combining efforts, the CaFCP/H2FCP can accelerate and improve the commercialization process for all categories of vehicles: passenger, bus, truck, etc. The members have a shared vision about the potential of fuel cells as a practical solution to many of California's environmental issues and similar issues around the world. The CaFCP/H2FCP provides a unique forum where infrastructure, technical and interface challenges can be identified early, discussed, and potentially resolved through cooperative efforts.

Project Costs

CaFCP/H2FCP's annual operating budget is about $1.4 million, and includes operating costs, program administration, joint studies and public outreach and education. All members make annual contributions towards the common budget with executive government members making an annual contribution of approximately $40,000. Some members contribute additional in-kind products and services to accelerate specific project and program activities.

Commercialization and Applications

CaFCP/H2FCP's goals relate to preparing for and supporting market launch through coordinated individual and collective effort. CaFCP/H2FCP members, individually or in groups:

- Prepare for larger-scale manufacturing, which encompasses cost reduction, supply chain and production
- Reduce costs of station equipment, increase supply of renewable hydrogen at lower cost, and develop new retail station approaches
- Support cost reduction through incentives and targeted research, development, and demonstration projects
- Continue research, development, and demonstration of advanced concepts in renewable and other low-carbon hydrogen
- Provide education and outreach to public and community stakeholders on the role of FCEVs and hydrogen in the evolution to electric drive

South Coast AQMD Contract #16262 **January 2022**

Sustainable Transportation Energy Pathways (STEPS3*)*

Contractor

University of California, Davis - Institute of Transportation Studies

Cosponsors

7 energy providers, 10 automakers, and 6 government agencies, 2 foundations

Project Officer

Lisa Mirisola

Background

STEPS3 (Sustainable Transportation Energy Pathways 3) is a four-year (2015-2018), multidisciplinary research consortium at the UC Davis Institute of Transportation Studies. Our mission is to generate new insights about the transitions to a sustainable transportation energy future and disseminate that knowledge to decision-makers in the private sector and governmental agencies so that they can make informed technology, investment, and policy choices.

Project Objective

STEPS3 researchers develop the theory, tools and methods that allow for self-consistent and transparent comparisons of promising alternative energy and vehicle pathways and development of realistic integrative scenarios toward sustainable transportation goals. The STEPS3 program follows previous ITS-Davis consortium-based research programs on Fuel Cell Vehicle Modeling (1998-2002), Hydrogen Pathways (2003-2006), Sustainable Transportation Energy Pathways (STEPS) (2007-2010), and NextSTEPS (2011-2014).

Program areas continue to include, but are not limited to, consumer behavior, infrastructure system analysis, environmental impact, vehicle technology evaluation and integrative scenarios will be compared and analyzed with reference to the four energy pathways (hydrogen, biofuels, electricity, and fossil fuels including natural gas) best suited to the transportation sector.

Over 220 research publications and reports produced by STEPS3 researchers are currently available to the public at https://its.ucdavis.edu/research/publications/.

The STEPS3 program has input from a team of multi-disciplinary researchers and support from energy companies, automotive manufacturers, and government agencies. STEPS3 analyses will include a focus on Southern California as the early market for alternative fueled vehicles, specifically hydrogen fuel cells, plug-in hybrid, and battery electric vehicles.

Technology Description

Four specific STEPS 2015-2018 program goals that have direct relevance to South Coast AQMD are as follows: 1) optimize scenarios for mass transition to alternative fuels and vehicles in California; 2) model evolving relationships between future sources of mobile energy and the existing oil and gas industry; 3) describe current trends and inform policymakers of strategies for Global Urban Sustainable Transport; and 4) continue development of a wide range of models in order to progress research and improve trend recognition.

There are four (4) specified projects associated with this effort.

The first project looks at initiating transitions for 2015-2030, and asks the question, “What is required for early alternative fuel and vehicle transitions to succeed?”. The key answers included were that to bring a large number of light-duty electric drive vehicles into the U.S market during a 20-year transition period, from 2015–2035, you might require a considerable investment in additional vehicle purchase incentives and refueling infrastructure, relative to an expected amount spent on all U.S. vehicles and fuels during this period. Also, most of the additional costs are for vehicle purchases; the actual subsidies needed

to spur the market to the target levels may be less than these increments.

The second project looks at the future of fuels and the oil and gas industry and asks the question, "How will changing geopolitical landscapes and disruptive technologies in the oil and gas and clean technology industries impact future business models and the competition of fuels?" The key answers to this question were first, that interest in fuel cell electric vehicle (FCV) technologies is growing in the medium-and heavy-duty (MDHD) transportation sector. Compared to battery electric vehicle technologies, FCVs have several advantages, most noticeably their low maintenance, long range and fast refueling, thus offering a promising option for zero-emission MDHD transportation. Also, costs of producing so-called advanced biofuels—those with the lowest greenhouse gas (GHG) and land use impacts—have not decreased in recent years.

The third project asks, "How will a rapidly urbanizing world affect demand for transport and energy? And how can we transition to sustainable transportation in a rapidly urbanizing world with ever-growing need for mobility?"

Key answers to these questions note that three revolutions in urban transportation—vehicle electrification, shared mobility, and automation—could reduce traffic congestion, save over $1 trillion per year, and cut urban travel CO2emissions by over 90% by 2050. Also, fully automated, electric vehicles, without sharing or supporting land use, transit, active mobility and other sustainability pathways, could lead to expensive, highly congested systems.

The fourth project asks the question, "What do improved and cross-compared economic/environmental/transportation/energy models tell us about the future of sustainable transportation?"

The key answers note that in a high ZEV truck sales scenario, STEPS3 choice modeling work suggests that battery electric trucks can eventually compete in most markets, though in long-haul it is fuel cell vehicles that are expected to dominate. Also, across most classes, policy incentives will be needed to reach market share targets, including purchase subsidies. Over time these subsidies can decline as ZEV technologies become more competitive.

Status

The STEPS3 program, including the four projects listed above, was completed on Dec. 31, 2018.

Results

From 2014 to 2018, STEPS3 researchers produced over 220 major publications and journal articles as well as numerous research reports. In addition, the program held 16 symposia, sponsored workshops, and policymaker outreach events. The STEPS website (www.steps.ucdavis.edu) hosts electronic copies of selected publications and other program materials as well as the final report, submitted on January 8, 2020. In addition, a compilation of Summary Papers of STEPS3 research findings can be found at https://stepsplus.ucdavis.edu/steps3-summary-papers.

Project Costs

As budgeted, South Coast AQMD contributed $240,000 toward the STEPS3 program. The STEPS3 program was supported by other industry and government sponsorships and contracts, and the total support was over $6 million over the length of the STEPS3 program (2015-2018).

Commercialization and Applications

The STEPS3 program and especially the four projects highlighted above, focusing on zero emission vehicles and low carbon fuels, have a direct relevance to South Coast AQMD's priorities in evaluating changes to criteria emission levels and vehicle technology options. In addition, outreach and communication of results from the STEPS3 program will broaden the public knowledge base and help expedite introduction of zero and near-zero emitting vehicles in the South Coast Air Basin.

Appendix D

Technology Status

[This Page Intentionally Left Blank]

Technology Status

For each of the core technologies discussed in this report, numerous factors influence the proposed allocation of funds, ranging from overall Environment & Health Benefits, Technology Maturity and Compatibility, and Cost, summarized in the technology status table.

A separate category for zero emission infrastructure is being created. The Fueling Infrastructure & Deployment for natural gas and renewable fuels is being removed since these technologies are largely commercialized. Within the broad factors above, sub-factors for each type of project may be considered, as summarized below:

Environment and Health Benefits

Criteria Pollutant Emission Reduction potential continues to receive the highest priority for projects that facilitate NOx reduction goals outlined in the 2022 AQMP. Technologies that provide co-benefits of GHG and Petroleum Reduction are also weighted favorably, considering the Clean Fuels Program leverages funds available through several state and federal programs, as well as overall health benefits in reducing exposure to Ozone and PM2.5, especially in disadvantaged communities.

Technology Maturity & Compatibility

Numerous approaches are used to evaluate technology maturity and risk given the potential uncertainty in real world operations. This approach can include numerous weighting factors based on the assessed importance of a particular technology. Key metrics considered include Infrastructure Constructability, which evaluates the potential of fuel or energy for the technology and readiness of associated infrastructure, and Technology Readiness, which includes research and development of the technology and large scale deployments that consider ability for near-term implementation and operational compatibility for end users. These combined factors can provide an assessment for market readiness of the technology.

Cost/Incentives

The long-term costs and performance of advanced technologies are highly uncertain, considering continued development of these technologies is likely to involve unforeseen changes in basic design and materials. Additionally, economic sustainability – or market driven – implementation of these technologies is another key factor for technology research, development, demonstration and deployment projects. To accelerate the demonstration and deployment, especially of pre-commercialization technologies, local, state and federal incentive programs are crucial, but may be underfunded to enable large scale deployments.

Staff has developed an approach to evaluating core technologies, especially some of the specific platforms and technologies discussed in the draft plan and annual report. The technology status evaluation below utilizes experience with implementing the Clean Fuels Program for numerous years, as well as understanding the current development and deployment of the technologies and associated infrastructure, and are based on the following measurement:

● Excellent ◓ Good ○ Satisfactory ◒ Poor • Unacceptable

The table below summarizes staff evaluation of the potential projects anticipated in the Plan Update, and technology developers, suppliers and other experts may differ in their approach to ranking these projects. For example, staff ranks Electric/Hybrid Technologies as Excellent or Good for Criteria Pollutant and GHG/Petroleum Reduction, but Satisfactory to Excellent for Technology Readiness, Satisfactory to Excellent for Compatibility, and Satisfactory to Poor for Costs and Incentives to affect large scale deployment. It is further noted that the Clean Fuels Fund's primary focus remains on-road vehicles and fuels, and funds for off-road and stationary sources are limited.

This approach has been reviewed with the Clean Fuels and Technology Advancement Advisory Groups, as well as the Governing Board.

Technologies & Proposed Solutions	Environment & Health			Technology Maturity & Compatibility				Cost	
	Emissions Reduction	GHG/Petroleum Reduction	Health Benefits	Infrastructure Constructability	Technology Readiness	Near-Term Implementation/ Duty Cycle Fulfillment Capability	Operations Compatibility	Relative Cost & Economic Sustainability	Incentives Available
Electric/Hybrid Technologies									
Plug-In Hybrid Heavy-Duty Trucks with Zero-Emission Range	◓	○	◓	●	○	●	●	◒	●
Heavy-Duty Zero-Emission Trucks	●	◓	●	○	○	◓	○	●	◓
Medium-Duty Zero-Emission Trucks	◓	◓	●	◓	◓	◓	◓	●	◓
Medium- and Heavy-Duty Zero-Emission Buses	●	◓	●	◓	◓	◓	○	●	◓
Light-Duty Zero-Emission Vehicles	◓	◓	●	◓	◓	◓	◓	○	◓
Plug-In Hybrid Light-Duty Vehicles with Zero-Emission Range	◓	○	◓	●	●	●	●	◒	◓
Hydrogen & Fuel Cell Technologies									
Heavy-Duty Trucks	●	◓	◓	○	◓	○	◒	●	◓
Heavy-Duty Buses	●	◓	◓	○	●	◓	◓	●	◓
Off-Road – Locomotive/Marine	●	◓	◓	○	○	◒	◒	●	●
Light-Duty Vehicles	●	◓	◓	○	◓	○	○	◒	◓
Zero Emission Infrastructure									
Light-Duty Electric Charging Infrastructure	-	-	-	●	●	●	●	●	◓
Medium- and Heavy-Duty Electric Charging Infrastructure	-	-	-	◓	◓	◓	◓	◒	◓
Light-Duty Hydrogen Fueling Infrastructure	-	-	-	○	●	●	●	◒	◓
Medium- and Heavy-Duty Hydrogen Fueling Infrastructure	-	-	-	○	◓	◓	◓	◒	◓
Infrastructure – Production, Dispensing, Certification	-	-	-	○	○	◒	◒	●	◒
Engine Systems									
Ultra-Low NOx Medium- and Heavy-Duty Renewable Diesel Vehicles	◓	◓	○	●	○	●	●	◓	●
Renewable Gaseous and Alternative Fuel Ultra-Low NOx Medium- and Heavy-Duty Vehicles	◓	◓	○	●	●	●	●	◓	●
Ultra-Low Emission Off-Road Applications	◓	◓	○	◓	○	◓	●	◓	○
Stationary Clean Fuel Technologies									
Low-Emission Stationary & Control Technologies	◓	◓	◓	◓	○	○	◓	○	◒
Renewable Fuels for Stationary Technologies	○	●	◓	◓	○	○	○	○	◒
Vehicle-to-Grid or Vehicle-to-Building/Storage	●	●	◓	○	○	◒	○	◒	◒
Emission Control Technologies									
Alternative/Renewable Liquid Fuels	○	◓	◓	◓	●	●	●	◓	○
Advanced Aftertreatment Technologies	◓	○	◓	○	○	◓	●	○	○

● Excellent ◓ Good ○ Satisfactory ◒ Poor ● Unacceptable

Appendix E

List of Acronyms

[This Page Intentionally Left Blank]

LIST OF ACRONYMS

3B-MAW—3-bin moving average windows
A-1—A-1 Alternative Fuel Systems
AB—Assembly Bill
AC—absorption chiller
ACFR—Annual Comprehensive Financial Report
ACT—advanced clean transportation
ACT—American Clean Truck regulation
ADA—American with Disabilities Act
AER—all-electric range
AFRC—air/fuel ratio control
AFVs—alternative fuel vehicles
AGL—Academy of Global Logistics
ALPR—automated license plate recognition
APCD—Air Pollution Control District
AQMD—Air Quality Management District
AQMP—Air Quality Management Plan
ARB—Air Resources Board
ARM—advanced RISC machine
ARRA—American Recovery & Reinvestment Act
AWMA—Air & Waste Management Association
BACT—best available control technology
BATS—blended aftertreatment system
BEB—battery electric bus
BESS— battery energy storage system
BET—battery electric tractor
BET—battery electric truck
BEV—battery electric vehicle
BMEP—brake mean effective pressure
BMS—battery management system
BSNOx—brake specific NOx
BTC—Broadband Telecom Power, Inc.
CAE— computer aided engineering
CAN—controller area networks
CAP—Clean Air Protection
CAAP—Clean Air Action Plan
CaFCP—California Fuel Cell Partnership
CAPP— Community Air Protection Program
CARB—California Air Resources Board
CATI—Clean Air Technology Initiative
CBD—Central Business District (cycle) - a Dyno test cycle for buses
CCF—California Clean Fuels
CCHP—combined cooling, heat and power
CCI—California Climate Investments
CCV—closed crankcase ventilation
CDA—cylinder deactivation
CDFA/DMS—California Department of Food &Agriculture/Division of Measurement Standards
CE—construction equipment
CEC—California Energy Commission
CE-CERT—College of Engineering – Center for Environmental Research and Technology
CEMS—continuous emission monitoring system
CERP—Community Emission Reduction Plan
CEQA—The California Environmental Quality Act
CFD—computational fluid dynamic
CFR—Code of Federal Regulations
CHBC—California Hydrogen Business Council
CHE—cargo handling equipment
C-ITS—connected intelligent transportation system
CMAQ—community multi-scale air quality
CNG—compressed natural gas
CNGVP—California Natural Gas Vehicle Partnership
CO_2—carbon dioxide
CO—carbon monoxide
COG—council of governments
ComZEV—Commercial Zero-Emission Vehicle
CPA—Certified Public Accountant
C-PORT—Commercialization of POLB Off-Road Technology
CPUC—California Public Utilities Commission
CRADA—Cooperative Research and Development Agreement
CRDS—cavity ring-down spectroscopy
CRT—Charge Ready Program
CRT—continuously regenerating technology
CSC—city suburban cycle
CTE—Center for Transportation and the Environment
CTF—Clean Truck Fund
CVAG—Coachella Valley Association of Governments
CWI—Cummins Westport, Inc.
CY—calendar year
DAC—disadvantaged community
DC—direct connection
DC—direct current
DCFC—direct connection fast charger
DCM—dichloromethane
DEF—diesel exhaust fluid
DEG—diesel equivalent gallons
DER—distributed energy resource
DERA—Diesel Emissions Reduction Act
DGE—diesel gallon equivalents
DF—deterioration factor
DHE—Dependable Highway Express
DME—dimethyl ether
DMS—Division of Measurement Standards
DMV—Department of Motor Vehicles
DOC—diesel oxidation catalysts
DOE—Department of Energy
DOT—Department of Transportation
DPF—diesel particulate filters
D-PMag—dual permanent magnet motor

LIST OF ACRONYMS (cont'd)

DPT3—Local Drayage Port Truck (cycle) - where 3=local (whereas 2=near-dock, etc.)
DRC—Desert Resource Center
DRI—Desert Research Institute
DT—delivery truck
DTNA—Daimler Trucks North America LLC
EATS—emissions aftertreatment system
ECM—emission control monitoring
ECM—engine control module
EDD—electric drayage demonstration
EDTA—Electric Drive Transportation Association
EERE—Energy Efficiency and Renewable Energy
EGR—exhaust gas recirculation
EIA—Energy Information Administration
EIN—Energy Independence Now
EMFAC—Emission FACtors
EPRI—Electric Power Research Institute
E-rEV—extended-range electric vehicles
ESD—emergency shut down
ESS—energy storage system
EV—electric vehicle
EVSE—electric vehicle supply equipment
FCEB—fuel cell electric bus
FCET—fuel cell electric truck
FCEBCC—Fuel Cell Electric Bus Commercialization Consortium
FCEV—fuel cell electric vehicle
FCTO—Fuel Cell Technologies Office
FCV—fuel cell vehicle
FCXRDT—fuel cell extended range delivery truck
FS—feasibility study
FTA—Federal Transit Administration
FTP—federal test procedures
G2V—grid-to-vehicle
g/bhp-hr—grams per brake horsepower per hour
GC/MS—gas chromatography/mass spectrometry
GCW—gross combination weight
GCVW—gross container vehicle weight
GDI—gasoline direct injection
GGE—gasoline gallon equivalents
GGRF—Greenhouse Gas Reduction Relief Fund
GH2—green hydrogen
GHG—greenhouse gas
GM—goods movement
GNA—Gladstein, Neandross & Associates, LLC
GNSS—global navigation satellite system
Go-Biz—Governor's Office of Business and Economic Development
GPCI—Green Paradigm Consulting, Inc.
GPS—global positioning system
GPU—gas processing unit
GREET—Greenhouse Gasses, Regulated Emissions and Energy Use in Transportation
GTI—Gas Technology Institute
GTL—gas to liquid
GVW—gross vehicle weight
GVWR—gross vehicle weight rating
H2—hydrogen
H2NIP—Hydrogen Network Investment Plan
H&SC—California Health and Safety Code
HCCI—Homogeneous Charge Combustion Ignition
HCD—hydrogen contaminant detector
HCHO—formaldehyde
HCNG—hydrogen-compressed natural gas (blend)
HD—heavy duty
HDD—heavy-duty diesel
HDDT—highway dynamometer driving schedule
HD-FTP—Heavy-Duty Federal Test Procedure
HD I/M—heavy-duty inspection and maintenance
HD-OBD—heavy-duty on-board diagnostics
HDV—heavy-duty vehicle
HEV— hybrid electric vehicle
HEVI-LOAD—heavy-duty electric vehicle infrastructure load, operations and deployment
HHDDT—heavy heavy-duty diesel truck schedule
HMI—Human Machine Interface
HPLC—high-performance liquid chromatography
HRSC—heat recovery steam cycle
HT—high throughput
HTFCs—high-temperature fuel cells
HTPH—high throughput pretreatment and enzymatic hydrolysis
HV— high voltage
HyPPO—Hydrogen Progress, Priorities and Opportunities report
Hz—Hertz
IBT—Intermodal Bridge Transport
ICE—internal combustion engine
ICEPAG—International Colloquium on Environmentally Preferred Advanced Generation
ICEV—internal combustion engine vehicle
ICT—Innovative Clean Transit Regulation
ICU—inverter-charger unit
ICTC—Interstate Clean Transportation Corridor
ISX12N—11.9-liter NZE engine
ITS—intelligent transportation system
IVOC—intermediate volatility organic compound
JETSI—Joint Electric Truck Scaling Initiative
kg—kilogram
kWh—kilowatt-hour
L9N—8.9-liter natural gas engine
LADOT—City of Los Angeles Dept. of Transportation
LADWP—Los Angeles Department of Water and Power
LAEDC—Los Angeles Economic Development Corporation

LIST OF ACRONYMS (cont'd)

LA Metro—Los Angeles County Metropolitan Transportation Authority
LBCT—Long Beach Container Terminal
LC—lane change
LCA—life cycle assessment
LCFS—Low Carbon Fuel Standard
LD—light-duty
LED—low emission diesel
LFP—lithium iron phosphate
Li—lithium ion
LIGHTS—Low Impact Green Heavy Transport Solutions
LIMS—Laboratory Information Management System
LLC—low load cycle
LLNL—Lawrence Livermore National Laboratory
LNG—liquefied natural gas
LO-SCR—light-off selective catalytic reduction
LPG—liquefied petroleum gas or propane
LRUSA—Landi Renzo USA Corporation
LSM—linear synchronous motor
LSV—low-speed vehicle
LUV—local-use vehicle
LVP—low vapor pressure
M&HD— medium- and heavy-duty
MATES—Multiple Air Toxics Exposure Study
MC—mass compensated
MCE—multi cylinder engine
MCFC—molten carbonate fuel cells
MD—medium duty
MDHD— medium- and heavy-duty
MECA—Manufacturers of Emission Controls Association
MOA—Memorandum of Agreement
MOVES—Motor Vehicle Emission Simulator
MPa—MegaPascal
MPFI—Multi-Port Fuel Injection
MPG—miles per gallon
MPGde—miles per gallon diesel equivalent
MSRC—Mobile Source Air Pollution Reduction Review Committee
MSW—municipal solid wastes
MY—model year
MTA—Metropolitan Transportation Authority (Los Angeles County "Metro")
NAAQS—national ambient air quality standards
NAFA—National Association of Fleet Administrators
NAICS—North American Industry Classification System
NFPA—National Fire Protection Association
NCP—nonconformance penalty
NEV—neighborhood electric vehicles
NextSTEPS—Next Sustainable Transportation Energy Pathways
NG/NGV—natural gas/natural gas vehicle
NGO—non-governmental organization
NH3—ammonia
Nitro-PAHs—nitrated polycyclic aromatic hydrocarbons
NHTSA—Natural Highway Traffic Safety Administration
NMC—nickel manganese cobalt
NMHC—non-methane hydrocarbon
NO—nitrogen monoxide
NO_2—nitrogen dioxide
$NO + NO_2$—nitrous oxide
NOPA—Notice of Proposed Award
NOx—oxides of nitrogen
NRC—National Research Council
NREL—National Renewables Energy Laboratory
NRTC—non-road-tested cycle
NSPS—new source performance standard
NSR—new source review
NTE—not-to-exceed
NZ—near zero
NZE – near zero emission
O3—ozone
OBD—on-board diagnostics
OCS—overhead catenary system
OCTA—Orange County Transit Authority
OEHHA—Office of Environmental Health Hazard Assessment
OEM—original equipment manufacturer
One-off—industry term for prototype or concept vehicle
OP—opposed piston
OSAR—Onboard Sensoring and Reporting
PAH—polycyclic aromatic hydrocarbons
PAMS—portable activity measurement systems
PbA—lead acid
PCM—powertrain control module
PEMFC—proton exchange membrane fuel cell
PEMS—portable emissions measurement system
PEV—plug-in electric vehicle
PFI—port fuel injection
PHET—plug in hybrid electric tractor
PHET—plug-in hybrid electric truck
PHEV—plug-in hybrid vehicle
PM—particulate matter
PM—permanent magnet
PM2.5—particulate matter ≤ 2.5 microns
PM10—particulate matter ≤ 10 microns
POH—Port of Hueneme
POLA—Port of Los Angeles
POLB—Port of Long Beach
PON—Program Opportunity Notice
POS—point of sale
ppm—parts per million

LIST OF ACRONYMS (cont'd)

ppb—parts per billion
PSI—Power Solutions International
PTR-MS—proton transfer reaction-mass spectrometry
QCD—Quality Custom Distribution
QVM—qualified vehicle modifiers
R&D—research and development
RD&D—research, development and demonstration
RDD&D (or RD3)—research, development, demonstration and deployment
REAL—Real Emissions Assessment Logging
REMD—roadside emissions monitoring device
RFA—Renewable Fuels Association
RFI—Request for Information
RFP—Request for Proposal
RFS—renewable fuel standards
RH—refuse hauler
RI—reactive intermediates
RISC—reduced instruction set computer
RM—ramp metering
RMC—ramped modal cycle
RMC-SET— ramped modal cycle supplemental emissions test
RNG—renewable natural gas
ROG—reactive organic gases
ROI—return on investment
RPS—Rail Propulsion Systems
RTP/SCS—Regional Transportation Plan/Sustainable Communities Strategy
S2S—Shore to Store
SAE—Society of Automotive Engineers
SB—school bus
SB—Senate Bill
SCAB—South Coast Air Basin or "Basin"
SCAG—Southern California Association of Governments
SCAQMD—South Coast Air Quality Management District
SCFM—standard cubic feet per minute
SCE—single cylinder engine
SCE—Southern California Edison Company
SCE—Southern Counties Express
SCR—selective catalytic reduction
SCRT—Selective Catalytic Regenerating Technology
SCCRT—Selective Catalytic Continuously Regenerating Technology
SHR—steam hydrogasification reaction
SI—spark ignited
SI-EGR—spark-ignited, stoichiometric, cooled exhaust gas recirculation
SIP—State Implementation Plan
SJVAPCD—San Joaquin Valley Air Pollution Control District
SMR—steam methane reforming
SNG—synthetic natural gas
SOAs—secondary organic aerosols
SOC—state-of-charge
SoCalGas—Southern California Gas Company (A Sempra Energy Utility)
SOFC—solid oxide fuel cells
SPaT—single phase and timing
START—Sustainable Terminals Accelerating Regional Transportation
STEPS3— Sustainable Transportation Energy Pathways 3
SULEV—super ultra-low emission vehicle
SUV—sports utility vehicle
SwRI—Southwest Research Institute
TAC—toxic air contaminants
TAO—Technology Advancement Office
TAP—(Ports') Technology Advancement Program
TB—transit bus
TC—total carbon
TCO—total cost of ownership
TEMS—transportable emissions measurement system
THC—total hydrocarbons
TLS—Toyota Logistics Services
TO—task order
tpd—tons per day
TRB—Transportation Research Board
TRL—technology readiness level
TSI—Three Squares, Inc.
TOU—time-of-use
TT—Turtle Top Bus
TTSI—Total Transportation Services, Inc.
TWC—three-way catalyst
UCI—University of California, Irvine
UCLA— University of California, Los Angeles
UCR—University of California, Riverside
UCR/CE-CERT—UCR/College of Engineering/Center for Environmental Research & Technology
UCLA—University of California, Los Angeles
UDDS—urban dynamometer driving schedule
µg/m^3—microgram per cubic meter
ULEV—ultra low emission vehicle
ULSD—ultra low sulfur diesel
UPS—United Postal Service
U.S.—United States
U.S. EPA—United States Environmental Protection Agency
USTS—United States Training Ship
V2B—vehicle-to-building
V2G—vehicle-to-grid
V2G/B—vehicle-to-building functionality
VLS—variable speed limit

LIST OF ACRONYMS (cont'd)

VMT—vehicle miles traveled
VOC—volatile organic compounds
V-PER—vessel performance management package
VPP—virtual power plant
WAIRE—Warehouse Actions and Investments to Reduce Emissions Program
WGS—water gas shift
WVU—West Virginia University
ZANZEFF—Zero and Near Zero Emission Freight Facilities
ZE—zero emission
ZEB—zero-emission bus
ZECT—Zero Emission Cargo Transport
ZEDT—Zero Emission Drayage Truck
ZET—zero emission truck
ZEV—zero emissions vehicle

South Coast Air Quality Management District

21865 Copley Drive, Diamond Bar, CA 91765-4178 • Tel 909 396 2000 • 800 CUT SMOG • www.aqmd.gov