South Coast Air Quality Management District

Clean Fuels Program

2021 Annual Report & 2022 Plan Update

Technology Advancement Office

Driving clean technology

Cover Photo Credits

Left to right; top to bottom

- Daimler Truck North America battery-electric Freightliner eCascadia class 8 tractor
- 150 kW DC fast charger installed at TEC Fontana dealership
- Peterbilt/Meritor Class 8 battery electric truck
- FirstElement Fuel Inc's hydrogen station at La Canada Flintridge
- 30 Level 2 chargers installed for South Coast AQMD fleet vehicles
- Kenworth-Toyota Class 8 fuel cell electric truck for Zero Emission Shore to Store Demonstration
- Center for Transportation and the Environment (CTE) Orange County Transportation Authority (OCTA) hydrogen fuel cell electric bus
- Five pilot Class 8 battery electric trucks were developed and demonstrated by Volvo
- Achates truck 10.8–liter near–zero NOx opposed piston diesel engine
- Cummins ISX12N 12L heavy-duty natural gas engine certified to 0.02 g/bhp-hr optional near zero NOx emissions standard
- DHE installed 1 MW of solar as part of the Volvo LIGHTS project

South Coast Air Quality Management District

Governing Board

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Executive Officer: WAYNE NASTRI

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EXECUTIVE SUMMARY

Introduction

The South Coast Air Quality Management District (South Coast AQMD) is the air pollution control agency for all of 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 TAO Clean Fuels Program is an integral part of the South Coast AQMD's effort to achieve the significant nitrogen oxides (NOx) emission reductions called for in the 2016 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 received through a $1 motor vehicle registration fee, the Clean Fuels Program encourages, fosters and supports clean fuels and transportation technologies, such as hydrogen powered fuel cells, advanced natural gas 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 $231.6 million into over $1.14 billion in projects.

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 in larger numbers. 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 needed 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 TAO 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 the 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 the South Coast AQMD continue to make progress toward achieving its clean air goals.

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

Setting the Stage

The overall strategy of TAO's 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 AQMP, which will be updated in 2022, is the long-term regional "blueprint" that identifies the fair-share emission reductions from all jurisdictional levels (e.g., federal, state and local). The 2016 AQMP, which was adopted by the South Coast AQMD Board in March 2017, 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). South Coast AQMD recently initiated efforts for updating the AQMP and is coordinating the efforts with the California Air Resources Board's (CARB) revised 2020 Mobile Source Strategy.

Ground level ozone (a key component of photochemical smog) is created by a chemical reaction between NOx and volatile organic compound (VOC) emissions in sunlight. The primary driver for ozone formation in the Basin is NOx emissions, and mobile sources contribute approximately 88 percent of the NOx emissions in this region, as shown in Figure 1. Furthermore, NOx emissions, along with VOC emissions, also lead to the secondary formation of PM2.5 [particulate matter measuring 2.5 microns or less in size, expressed as micrograms per cubic meter (µg/m3)].

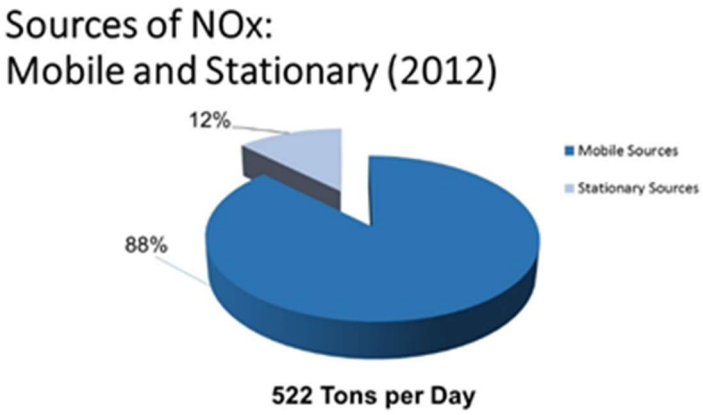
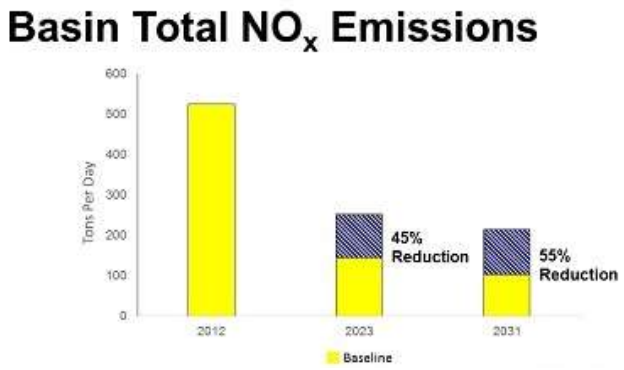


Figure 1: Sources of NOx 2012 Base Year

The emission reductions and control measures in the 2016 AQMP rely on a mix of currently available technologies as well as the expedited development and commercialization of clean fuel mobile and stationary advanced technologies to achieve health-based air quality standards. The 2016 AQMP identifies a 45 percent reduction in NOx is required by 2023 and an additional 55 percent reduction by 2031 to achieve NAAQS for (8-hour) ozone of 80 parts per billion (ppb) and 75 ppb, respectively. Figure 2 illustrates these needed NOx reductions in the Basin. The majority of NOx reductions must come from mobile sources, both on-road and off-road. Notably, the South Coast AQMD is currently

only one of two regions in the nation designated as an extreme nonattainment area (the other region is California's San Joaquin (Central Valley).



8-hour Ozone strategy targeting 2023 will ensure 1-hour attainment in 2022 as well as 24-hour and annual attainment in 2019 and 2025, respectively

Figure 2: Total NOx Reductions Needed

For the first time, the 2016 AQMP identified a means to achieving the NAAQS through regulations and incentives for near-zero and zero emission mobile source technologies that are commercial or nearing commercialization. This strategy requires a significantly lower state and national heavy-duty truck engine emissions standard with the earliest feasible implementation date, significant additional financial resources, and accelerated fleet turnover on a massive scale.

Current 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 and 2031 ozone attainment deadlines.

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 both stationary and transportation 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 not only to provide a portfolio of technology choices but to achieve near-term and long-term emission reduction benefits. South Coast AQMD's Clean Fuels Program typically funds projects in the Technology Readiness Level (TRL) ranging between 3-8.

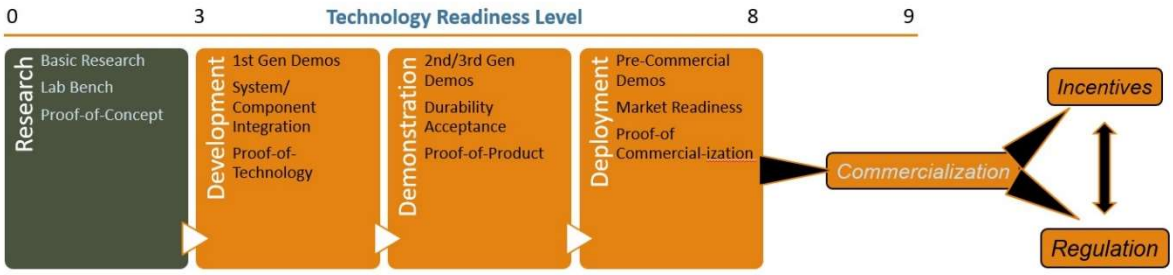


Figure 3: Stages of Clean Fuels Program Funding

Below is a summary of the 2021 Clean Fuels Annual Report and Draft 2022 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.

2021 Annual Report

In CY 2021, the South Coast AQMD Clean Fuels Program executed 19 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 our major funding partners in CY 2021. Table 3 lists the 24 projects or studies, which are further described in this report. The South Coast AQMD Clean Fuels Program contributed over $10.6 million in partnership with other governmental organizations, private industry, academia and research institutes, and interested parties, with total project costs of approximately $253 million. The $10.6 million includes over $4.3 million recognized into the Clean Fuels Fund as pass-through funds from project partners to facilitate project administration by the Clean Fuels Program. Table 4 provides information on this outside funding received into the Clean Fuels Fund. Additionally, in CY 2021, the Clean Fuels Program continued to leverage other outside funding opportunities, securing new awards totaling $48.7 million from federal, state and local funding opportunities. Table 5 provides a comprehensive summary of these federal, state and local revenues awarded to the South Coast AQMD during CY 2021. Like the last several years, the significant project scope of a few key contracts executed in 2021 resulted in higher than average leveraging of Clean Fuels dollars. Typical historical leveraging is $4 for every $1 in Clean Fuels funding. In 2021, South Coast AQMD exceeded this upward trend with nearly $39 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 2016 AQMP to achieve NAAQS.

The projects or studies executed in 2021 included a diverse mix of advanced technologies. The following core areas of technology advancement for 2021 executed contracts (in order of funding percentage) include:

1. Electric and Hybrid Vehicle Technologies and Related Infrastructure (emphasizing battery electric and hybrid electric trucks developed by OEMs and container transport technologies with zero emission operations);
2. Hydrogen and Mobile Fuel Cell Technologies and Infrastructure;
3. Engine Systems/Technologies (emphasizing alternative and renewable fuels for truck and rail applications);
4. Technology Assessment and Transfer/Outreach;
5. Fuel / Emission Studies; and
6. Stationary Clean Fuels Technology

The chart on page 26 shows the distribution by percentage of executed agreements in 2021 across these core technologies.

During CY 2021, the 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 the 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- and heavy-duty vehicles in support of transitioning to near-zero and zero emissions goods movement; development, demonstration and deployment of large displacement natural

gas and ultra-low emissions engines; and demonstration of emissions control technologies for heavy-duty engines; and natural gas and renewable natural gas deployment and support.

In addition to the 24 executed contracts and projects, 24 research, development, demonstration and deployment projects or studies and 7 technology assessment and transfer contracts were completed in 2021, as listed in Table 8. Appendix C includes two-page summaries of the technical projects completed in 2021. As of January 1, 2022, there were 109 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, 2022, after approval by the South Coast AQMD Board.

2022 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 the 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 also 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 extensively.

To identify technology and project opportunities where funding can make a significant difference in deploying cleaner technologies in the Basin, the 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 various 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 Draft 2022 Plan Update. Assembly Bill (AB) 617[1] requires reduced exposure to communities most 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 deployment of cleaner technologies. Cleaner technologies such as near-zero and zero emission heavy-duty trucks are now included in the Community Emission Reduction Plans (CERPs) for these AB 617 communities, and an RFP for zero emission heavy-duty truck program will be released in 2022. CARB adopted two critical milestone regulations for reducing emissions from on-road heavy-duty mobile sources in 2020, the Advanced Clean Truck (ACT) regulation which mandates an increasingly higher percentage of zero emission truck sales starting in 2024 and the Omnibus Low NOx regulation which requires lower exhaust NOx standards on heavy-duty engines starting in 2024. CARB is also working on the Heavy-Duty Vehicle Inspection and Maintenance Program as well as the Advanced Clean Fleets regulation for Board consideration in 2022.

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

Despite these major efforts, NOx emission reductions in the South Coast AQMD are still expected to fall short of the levels necessary to meet ozone attainment target deadlines.

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 near-zero and zero emission drayage trucks and infrastructure;
- developing and demonstrating ultra-low NOx, gaseous and liquid renewable fueled, large displacement/high efficiency engines and heavy-duty zero emission engine technologies;
- developing, demonstrating and deploying advanced, low-NOx natural gas and propane engines as well as near-zero and zero emission technologies for high horsepower applications;
- mitigating criteria pollutant emissions from the production of renewable fuels, such as renewable natural gas, diesel and hydrogen as well as other renewable 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 light-, medium- and heavy-duty platforms;
- establishing large-scale hydrogen refueling and electric vehicle (EV) charging infrastructure to support light-, medium- and heavy-duty zero emission vehicles;
- ultra-fast charging for heavy duty battery electric vehicles; and
- developing and demonstrating zero emission microgrids that utilize electric energy storage systems and onsite clean power generation to support transportation electrification demands associated with goods movement and freight handling activities.

Table 9 (page 75) lists potential projects across nine core technologies by funding priority:

1. Hydrogen/Mobile Fuel Cell Technologies and Infrastructure (especially large-scale refueling and production facilities) and stations that support medium and heavy-duty vehicles;
2. Engine Systems/Technologies (emphasizing alternative and renewable fuels for truck and rail applications);
3. Electric/Hybrid Vehicle Technologies and Infrastructure (emphasizing battery electric and hybrid electric trucks and container transport technologies with zero emission operations);
4. Fueling Infrastructure and Deployment (predominantly renewable natural gas and renewable fuels);
5. Stationary Clean Fuel Technologies (including microgrids that support EV and Hydrogen infrastructure and renewables);
6. Fuel and Emission Studies;
7. Emission Control Technologies that support low emitting diesel engines;
8. Health Impact Studies within disadvantaged communities; and
9. Technology Transfer/Assessment and Outreach.

These potential projects for 2022 total $21.8 million of Clean Fuels funding, with the anticipation of total project costs of $167.5 million, leveraging more than $4 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 Community Air Protection (CAP) funding, Volkswagen Mitigation and Carl Moyer volatile organic compound (VOC), and NOx mitigation funds.

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 the 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 TAO Clean Fuels Program is an integral part of the South Coast AQMD's effort to achieve the significant NOx reductions called for in the 2016 AQMP.

California H&SC section 40448.5(e) calls for the Clean Fuels Program to consider, among other factors, the current and projected economic costs and availability of fuels, the cost-effectiveness of emission reductions associated with clean fuels compared with other pollution control alternatives, the 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 the 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 the 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), the South Coast AQMD must submit to the Legislature, on or before March 31 of each year, an annual report that includes:

1. A description of the core technologies that the 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. An analysis of the impact of the 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 the South Coast AQMD;
3. A description of projects funded by the South Coast AQMD, including a list of recipients, subcontractors, cofunding 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. The title and purpose of all projects undertaken pursuant to the Clean Fuels Program, the names of the contractors and subcontractors involved in each project and the amount of money expended for each project;
5. A summary of the 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 project.

Furthermore, H&SC section 40448.5.1(a)(2) requires the 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, the 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, the scientific community and environmental non-governmental organizations (NGOs). The Technology Advancement Advisory Group serves to:

- Coordinate the South Coast AQMD 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, including consulting with regarding approval of the required annual report prior for submittal to the South Coast AQMD Governing Board. Also, in 1999, considering the formation of the SB 98 Clean Fuels Advisory Group, the South Coast AQMD also 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, the 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 have been integral players and stakeholders in demonstrating near-zero and zero emissions technologies in and around the ports and surrounding environmental justice communities. With the addition of the Port representatives, there are currently 13 members on the Technology Advancement Advisory Group.

As needed, 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. The current 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 the 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) a 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) finally submittal of the Clean Fuels Program Annual Report and Plan Update to the Legislature by March 31 of every year.

The Need for Advanced Technologies & Cleaner Fuels

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

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 88 percent of the NOx emissions in this region, as shown in Figure 1. 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.

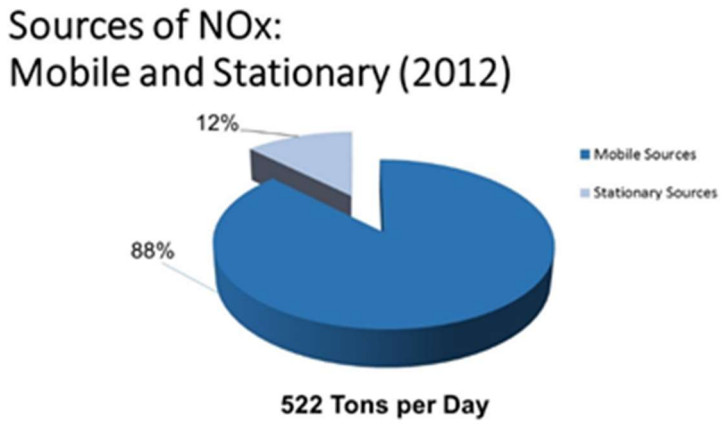
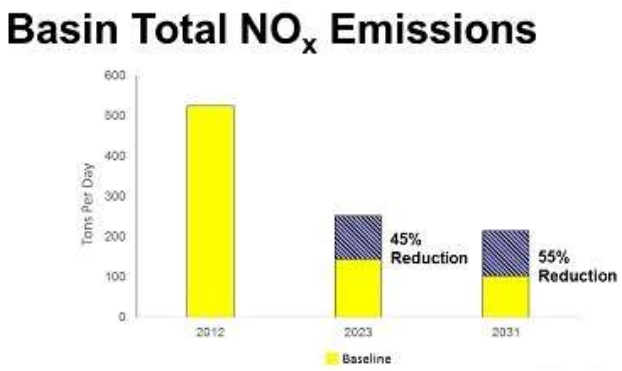


Figure 1: Sources of NOx 2012 Base Year

To fulfill near -and long-term emissions reduction targets, the 2016 AQMP relies on a mix of currently available technology as well as the expedited development and demonstration of advanced technologies that are not yet ready for commercial use. Significant reductions are anticipated from implementation of advanced control technologies for both on-road and off-road mobile sources. In addition, the air quality standards for ozone (70 ppb, 8-hour average) and fine particulate matter, promulgated by the U.S. Environmental Protection Agency (U.S. EPA), are projected to require additional long-term control measures for both NOx and VOC.

The need for advanced mobile source technologies and clean fuels is best illustrated by Figure 2 which



8-hour Ozone strategy targeting 2023 will ensure 1-hour attainment in 2022 as well as 24-hour and annual attainment in 2019 and 2025, respectively

Figure 2: Total NOx Reductions Needed

identifies just how far NOx emissions must be reduced to meet federal standards by 2023 and 2031. The 2016 AQMP's estimate of needed NOx reductions will require the South Coast AQMD Clean Fuels Program to encourage and accelerate advancement of clean transportation technologies that are used as control strategies in the AQMP. Given this contribution, significant cuts in pollution from these sources are needed, therefore proposed AQMP mobile source strategies call for establishing requirements for cleaner technologies (both zero and near-zero) and deploying these technologies into fleets, requiring cleaner and renewable fuels, and ensuring continued clean performance in use. Current state efforts in developing regulations for on- and off-road vehicles and equipment are expected to reduce NOx emissions significantly, but not sufficiently to meet the South Coast AQMD needs, especially in terms of timing.

Health studies also indicate a greater need to reduce NOx emissions and toxic air contaminant emissions. For example, the goal of South Coast AQMD's Multiple Air Toxics Exposure Study (MATES) IV, completed in 2015, like the prior three MATES efforts, was to assess air toxic levels, update risk characterization, and determine gradients from selected sources. However, MATES IV added ultrafine PM and black carbon monitoring components as well. The study found a dramatic decrease in ambient levels of diesel particulate matter and other air toxics. Diesel PM was still the major driver of air toxics health risks. While the levels and exposures decreased, a revision to the methods used to estimate cancer risk from toxics developed by the California Office of Health Hazard Identification increased the calculated risk estimates from these exposures by a factor of up to three. In late 2017, South Coast AQMD initiated MATES V to update the emissions inventory of toxic air contaminants and modeling to characterize risks, including measurements and analysis of ultrafine particle concentrations from major roadways and the regional carcinogenic risk from exposure of air toxics. The MATES V report is expected to be finalized by the end of 2021.

In summary, advanced, energy efficient and renewable technologies are needed not only for attainment, but also to protect the health of those who reside within the South Coast AQMD's jurisdiction, 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 the federal air quality goals. To help 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 has been able to partner with large original equipment manufacturers (OEMs), such as Daimler, Volvo and Kenworth, in order to eventually deploy these vehicles in increasingly large numbers. These partnerships with the OEMs 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 eventually into customers' hands. The OEMs have the resources and abilities to design, engineer, test, manufacture, market, distribute and service quality products under brand names that are trusted. To obtain the emission reductions needed to meet federal and state ambient air quality

standards, large numbers of advanced technology clean-fueled vehicles must be deployed across our region and state.

Once advanced technologies and cleaner fuels are commercial-ready, there needs to be a concerted effort to get them into the marketplace and ono the roads. The South Coast AQMD's Carl Moyer Program, which was launched in 1988, helps achieve these results. The two programs produce a unique synergy, with the Carl Moyer Program (and other incentive programs, such as Proposition 1B-Goods Movement and the Community Air Protection Program[2]) providing incentives to push market penetration of the technologies developed and demonstrated by the Clean Fuels Program. This synergy enables the 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 a concern given the magnitude of additional funding identified in the 2016 AQMP to achieve federal ozone air quality standards.

Emission Reductions Resulting from Clean Fuels Program

The Clean Fuels Program has encouraged projects that increase the utilization of clean-burning fuels over the 33-year lifetime of the program. Many of the technologies that were supported during the early years of the program, are only 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 which all the technologies that the Clean Fuels Program have supported, there are two more recent technologies that have been commercialized and are providing emissions benefits through incentives programs, namely the ultra-low NOx (near-zero emission or NZE) natural gas engines and zero emission (ZE) trucks.

The Clean Fuels Program has been supporting the development of low and near-zero emission heavy-duty natural gas engines since the early 2000's. In 2003, South Coast AQMD conducted a joint project with the California Energy Commission (CEC), the U.S. DOE and the National Renewable Energy Laboratory (NREL) to advance development of heavy-duty natural gas 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 heavy-duty sector, South Coast AQMD, CEC, and SoCalGas issued a joint solicitation to develop and demonstrate a NZE engine for commercial use. CWI won that bid and developed and commercialized the 0.02 g/bhp-hr NOx 8.9-liter natural gas engine (L9N), the first of its kind. 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 of the major truck manufacturers.

The Clean Fuels Program has also been supporting the development of ZE heavy-duty vehicles including battery electric trucks (BETs) and fuel cell electric trucks (FCETs). The DOE funded 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 EV and hybrid truck projects, including ones later funded by CARB's Greenhouse Gas Reduction Fund (GGRF) Zero Emission Drayage Truck (ZEDT) project, which demonstrated more than 40 electric and hybrid drayage trucks across California. In the ZEDT project, TransPower continued their development of their electric truck platform with their OEM partner Peterbilt. More recently, the Clean Fuels Program has co-funded large Daimler and Volvo battery electric truck projects. Daimler has deployed 14 Class 8 eCascadia and six Class 6 eM2 trucks in 2019 and installed seven DC fast charging stations at fleet locations. Volvo is also deploying 23

[2] http://www.aqmd.gov/home/programs/business/business-detail?title=vehicle-engine-upgrades

Class 8 trucks and installing DC fast charging infrastructure as part of their Low Impact Green Heavy Transport Solutions (LIGHTS). Finally, South Coast AQMD was awarded the joint CARB-CEC Pilot project to demonstrate 100 battery electric trucks and charging infrastructure for two fleets, NFI and Schneider. Both the Volvo VNR battery electric truck and DTNA's eCascadia will be widely commercially available in the next few years. Examples of some of the vehicles that South Coast AQMD has helped develop and demonstrated with funding from various partners are show in the figure below. The pathway to cleaner air is clear, for near- and mid- term, near-zero NOx engines, hybrids and clean diesel are expected to provide the greatest reduction where in the long term, battery electric and hydrogen fuel cell will play a dominant role.

Figure 3: Clean Fuel Technology Trucks that South Coast AQMD and Partners have Helped Develop and Demonstrated

To quantify some of the emissions benefit from NZE and ZE truck deployments, Table 1 summarizes the emissions reductions as result of the technologies directly supported by the Clean Fuels Program.

South Coast AQMD staff compiled incentive program data from our Technology Incentives Group to calculate the NOx emissions reductions associated with deployment of NZE and ZE heavy-duty vehicles in the Basin. Note that all that 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: Emissions Benefit from NZE and ZE Truck Deployments

South Coast AQMD Incentive Programs	NZE (# of Trucks)	ZE (# of Trucks)	NOx Reductions (tpy)
VW*	47	93	28
Lower Emission School Bus	280	95	70
Proposition 1B	925	112	444
Carl Moyer	255	10	109
Total	1,507	310	651

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 the South Coast AQMD. This revenue is typically about $13.5 million and $350,000, respectively, every year. For CY 2021, the funds available through each of these mechanisms were as follows:

- Mobile sources (DMV revenues) $13,719,320
- Stationary sources (emission fee surcharge) $279,570

The South Coast AQMD 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, the CEC, the U.S. EPA (including but not limited to their Diesel Emissions Reduction Act or DERA, the Clean Air Technology Initiative or CATI, and Airshed programs), the U.S. Department of Energy (DOE) and the 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 4 lists the supplemental grants and revenues totaling over $4.3 million for contracts executed in CY 2021.

Table 5 lists the federal, state and other revenue totaling $48.7 million awarded to the South Coast AQMD in 2021 for projects that are part of the overall Clean Fuels Program's RD[3] efforts, even if for

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

financial tracking purposes the 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 the South Coast AQMD. This indirect source is the cost-sharing provided by private industry and other public and private organizations. In fact, these 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 Technology Advancement Office 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 $231.6 million into over $1.14 billion in projects. For 2021, the Clean Fuels Program leveraged $1 of Clean Fuels Funds to nearly $39 of outside funding. This atypical leverage was the result of a few key significant project awards in 2021. Specifically, the $31.5 million heavy-duty battery electric truck project, which includes a nearly $20 million award to the South Coast AQMD from US EPA Airshed grant as well as two projects with substantial cofunding of $117 million from CARB and CEC. Through these public-private partnerships, the South Coast AQMD has 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 the demonstration projects and ultimately increased use of clean technologies in the Basin. While the 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 2016 AQMP to achieve federal ozone air quality standards. The South Coast AQMD's 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 2021 are listed in Table 2.

2021 Overview

This report summarizes the progress of the South Coast AQMD Clean Fuels Program for CY 2021. The South Coast AQMD Clean Fuels Program cost-shares projects to develop and demonstrate zero, near-zero and low emissions clean fuels and advanced technologies to push the state-of-the-technology and promote commercialization and deployment of promising or proven technologies not only for the Basin but Southern California and the nation as well. As noted, 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 South Coast AQMD Clean Fuels Program in CY 2021. During the period between January 1 and December 31, 2021, the South Coast AQMD executed 19 new contracts/agreements, projects or studies and modified 5 continuing projects adding dollars during CY 2021 that support clean fuels and advanced zero, near-zero and low emission technologies (see Table 3). The South Coast AQMD Clean Fuels Program contribution for these projects was $10.6 million, inclusive of approximately $4.3 million received into the Clean Fuels Fund as cost-share for contracts executed in this reporting period. Total project costs are almost $253 million. The Clean Fuels contribution and total number of contracts executed in 2021 have been less than previous years largely due the effects of the COVID pandemic that impacted many of our partners business operations. Due to government lockdowns many projects have been delayed or canceled and future projects put on hold. We look forward to 2022 for a resurgence in business activity, more completed projects and newly executed projects.

The projects executed in 2021 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 4), but also funds awarded to the 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 $48.7 million in 2021, see Table 5). For example, in 2021, the South Coast AQMD was awarded nearly $30 million by CARB, CEC and project partners for a zero-emission drayage truck and infrastructure pilot project, $10.7 million from CARB and CEC to develop and demonstrate capture and control system for oil tankers, $4.1 million from US EPA for a zero-emission freight line-haul locomotive and $3.6 million from US EPA for long-range class 8 fuel cell trucks with total project costs of over $103 million. These projects will advance the commercialization of electric and fuel cell trucks, ocean going vessels emission reduction technology. More details on this financial summary can be found later in this report. The South Coast AQMD will continue to pursue federal, state and private funding opportunities in 2022 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 support with a focus on medium and heavy duty vehicles (especially large-scale refueling facilities);
- Engine Systems/Technologies (emphasizing alternative and renewable fuels for truck and rail applications);
- Electric/Hybrid Vehicle Technologies and Related Infrastructure (emphasizing electric and hybrid electric trucks and container transport technologies with zero emission operation);
- Fueling Infrastructure and Deployment (predominantly natural gas 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 2021 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 2022.

The 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.

The 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 cofunding

opportunities. Although the South Coast AQMD program is significant, national and international activities affect the direction of technology trends. As a result, the South Coast AQMD program must be flexible to leverage and accommodate these changes in state, national and international priorities. Nonetheless, while the 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 greenhouse gas (GHG) reductions. Due to these "co-benefits," the South Coast AQMD has been successful in partnering with the state and federal government. Even with the leveraged funds, the challenge for the 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, the 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, medium- and heavy-duty 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., natural gas, propane and hydrogen) including their 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 heavy- and medium-duty 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. The 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 as they relate to goods movement. In the absence of regulatory authority, the 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 2016 AQMP included five Facility-Based Mobile Source Measures, also known as indirect source measures. Since then, 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, indirect source measures for warehouses could focus on reducing emissions from trucks servicing the facility. 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 heavy-duty diesel earth-moving vehicles.

Specific projects are selected for cofunding 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 the South Coast AQMD programs that meet both the funding constraints and 2016 AQMP needs for achieving clean air are briefly described below.

Hydrogen/Mobile Fuel Cell Technologies and Infrastructure

Toyota and Hyundai commercialized light-duty fuel cell vehicles in 2015. Honda started delivering their Fuel Cell Clarity in 2016, and others have plans to commercialize their own soon. 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 the 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 2021, partially funded by South Coast AQMD for those in our region, there is one legacy and 489 retail operational in California. Station development over the past year has been slower than previously projected, partly due to delays in station permitting, construction, and opening caused by the COVID-19 pandemic. CEC and CARB staffs expect that California will exceed the 100-station goal in Assembly Bill 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. However, CARB's 2017 Annual Evaluation projects 37,400 fuel cell electric vehicles (FCEVs) in California by 2023 and 61,000 by the end of 2027, 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, the South Coast AQMD must continue to support infrastructure required to refuel retail fuel cell vehicles and the nexus to medium- and heavy-duty trucks including reducing the cost to deploy heavy-duty hydrogen infrastructure. To that end, South Coast AQMD has cofunded 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) Shore-to-Shore project to deploy 10 heavy-duty fuel cell trucks and install three heavy-duty 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 heavy-duty 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 (phase 2 or ZECT 2), to develop and deploy six heavy-duty fuel cell drayage trucks. Two of the fuel cell drayage trucks are manufactured by Transportation Power Inc. (TransPower), two fuel cell trucks by US Hybrid, one fuel cell truck by Kenworth, and one fuel cell truck by Hydrogenics (a Cummins Inc. company). Six of the seven vehicle designs, and integration, are completed, and four of the fuel cell drayage trucks are in demonstration.

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

The battery and fuel cell dominant fuel cell trucks have a range of 150-200 miles.

Engine Systems/Technologies

Medium- and heavy-duty on-road vehicles contributed approximately 33 percent of the Basin's NOx based on 2016 AQMP data. More importantly, on-road heavy-duty diesel trucks account for 33 percent of the on-road mobile source PM2.5, a known toxic air contaminant (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 heavy-duty sector, to attain the federal clean air standards. Even with the announced rollout of zero emission trucks beginning 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 heavy-duty vehicles can provide significant reductions in NOx and particulate emissions. The current NOx emissions standard for heavy-duty engines is 0.2 g/bhp- hr. The South Coast AQMD, along with various local, state and federal agencies, continues to support the development and demonstration of alternative-fueled low emission heavy-duty engine technologies, using natural gas, renewable natural gas or hydrogen, renewable diesel and potentially other renewable or waste stream fuels, for applications in heavy-duty 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 medium-duty gasoline engine to near-zero NOx level by using natural gas and propane.

In connection with the challenge to develop cleaner engine systems, on June 3, 2016, South Coast AQMD petitioned the U.S. EPA to initiate rulemaking for a lower NOx national standard for heavy-duty engines. The U.S. EPA has since acknowledged a need for additional NOx reductions through a harmonized and comprehensive national NOx reduction program for heavy-duty on-highway engines and vehicles. U.S. EPA announced the Cleaner Truck Initiative on November 13, 2018, and Advance Notice of Proposed Rule on January 6, 2020, to reduce NOx emissions from on-road heavy-duty trucks starting as early as model year 2026. CARB forged ahead, announcing its own Low NOx Omnibus rule, which may be before the CARB Board as early as Spring 2020, proposing a lower NOx standard starting model year 2024. Although both announcements are welcome news, the timing is too late to help the South Coast AQMD meet its 2023 federal attainment deadline. So, despite progress, commercialization and deployment of near-zero engines are still needed.

Electric/Hybrid Vehicle Technologies and Infrastructure

There has been an increased level of activity and attention on electric and hybrid vehicles due to a confluence of factors, including the highly successful commercial introductions of hybrid light-duty passenger vehicles and more recently plug-in electric vehicles (PEVs) by almost all major automakers and increased public attention on global warming, as well as several Executive Orders issued by Former Governor Brown, such as his January 26, 2018 order, calling for 5 million ZEVs by 2030.

EV adoption continues to increase in 2017, selling more than 655,000 cumulative electric vehicles by September 2019 in California, according to Veloz (formerly the PEV Collaborative), with increasingly more announcements by international automakers (e.g., Mercedes-Benz, Volkswagen-Audi-Porsche, Hyundai/Kia, Ford, GM and several growing Chinese brands) on a variety of electrification plans, including some with extended zero emissions range. Joining the trend with longer-range battery electric light-duty passenger vehicles by Tesla, Chevy and several others, multiple manufacturers have announced light-duty electric truck development.

However, technology transfer to the medium- and heavy-duty applications is just beginning, especially in goods movement demonstrations in this region. As with hydrogen and fuel cell technologies, South Coast AQMD is actively pursuing research, development and demonstration projects for medium- and heavy-duty battery electric vehicles and their commercialization. South Coast AQMD is administering the DOE funded ZECT project to develop and demonstrate battery electric and plug-in hybrid drayage trucks: four battery electric trucks from TransPower, two battery electric trucks from US Hybrid, two series plug-in hybrid electric trucks from TransPower, and three parallel plug-in hybrid electric trucks from US Hybrid. Battery electric trucks have an all-electric range of up to 100 miles and plug-in hybrid electric trucks have a range of up to 250 miles. This first ZECT project (ZECT 1), which was completed in 2020, gave birth to many other EV and hybrid truck projects including the GGRF Zero Emission Drayage Truck (ZEDT) project demonstrating more than 40 electric and hybrid drayage trucks across California. In the ZEDT project, TransPower continued their development of their electric truck platform with their OEM partner Peterbilt. In addition, Clean Fuels has cofunded the Daimler and Volvo battery electric trucks. Daimler has deployed 14 Class 8 eCascadia and three Class 6 eM2 trucks in 2019 and installed seven DC fast charging stations at fleet locations. Volvo has deployed two Class 8 rigid trucks and three Class 8 60,000-pound tractors and installed two 50 kW DC fast charging stations at its TEC Fontana dealership in December 2019.

Lastly, the same electric and hybrid technology transfer is beginning to appear on off-road and marine applications. South Coast AQMD is currently in the process of demonstrating a battery electric excavator and wheel loader with Volvo Construction Equipment as part of a FY 18 U.S. EPA Targeted Airshed Grant award. At the same time, a new electric drive, diesel hybrid tugboat is in the process of construction and demonstration by fleet operator Centerline Logistics Cooperation with cofunding from POLB and CARB. These pilot demonstration projects are key to additional emission reductions from the off-road construction 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 natural gas 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 natural gas (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 the 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 is performing a three-year in-use emissions study of 200 next-generation technology heavy-duty vehicles in the Basin. This study, expected to be completed in 2021, is aimed at understanding the activity pattern of different vocations, understanding the real-world emissions emitted from different technologies. Other studies launched in 2020 will evaluate the emissions produced using alternative diesel blends in off-road heavy-duty engines, assess emissions impact of hydrogen-natural gas blend on near-zero emission heavy-duty natural gas engines as well as evaluating emissions produced using higher blend ethanol in light-duty 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 the 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 the U.S. EPA and

CARB, both agencies are currently planning research efforts to aid the next round of rulemaking 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 a number of 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 natural gas, 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 the 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[5], which requires reduced exposure to communities most impacted by air pollution, required TAO to carry out additional outreach in CY 2019 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 Port of Long Beach EV Blueprint, Los Angeles County EV Blueprint, City of Los Angeles Zero Emissions 2028 Roadmap, Electric Power Research Institute (EPRI) study on air quality and GHG impacts of residential electrification, and Los Angeles Cleantech Incubator projects. Technology transfer efforts also include support for various clean fuel vehicle incentive programs (i.e., 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 ACT Conference and Expo and the Renewable Gas 360 Symposium and Webinar Series. While South Coast AQMD's Local Government, 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 40 for a description of the technology assessment and transfer contracts executed in CY 2021 as well as a listing of the 7 conferences, workshops and events funded in CY 2021. Throughout the year, staff also participates in various programmatic outreach for the various incentive programs implemented by TAO, including the Carl Moyer Program, Proposition 1B-Goods Movement, Volkswagen Mitigation Program, Replace Your Ride, a U.S. EPA Airshed-funded Commercial Electric Lawn and Garden Incentive and Exchange Program, and residential lawn mower and EV charger rebate programs, to name a few.

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

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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

- Viable commercialization path
- Technology price/performance parity with convention technology
- Consumer acceptance
- Fuel availability/convenience issues
- Certification, safety and regulatory barriers
- Quantifying emissions benefits
- Sustainability of market and technology

Project-Specific Issues

- Identifying a committed demonstration site
- Overall project cost and cost-share using public monies
- Securing the fuel
- Identifying and resolving real and perceived safety issues
- Quantifying the actual emissions benefits
- Viability of the technology provider

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. The 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 the key stakeholders have become 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, for example, can contribute technology production expertise as well as the experience required for compatibility with process operations. Academic and research institutes bring state-of-the- technology knowledge and testing proficiency. Governmental and regulatory agencies can provide guidance in identifying sources with the greatest potential for emissions reduction, assistance in permitting and compliance issues, coordinating of infrastructure needs and facilitation of standards setting and educational outreach. Often, there is considerable synergy in developing technologies that address multiple goals of public and private bodies regarding the 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, both manufacturers and end-users tend to be discouraged from considering advanced technologies. The Clean Fuels Program addresses these needs by cofunding research, development, demonstration and deployment projects to share the risk of emerging technologies with their developers and eventual users.

Figure 4 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 technology choices but to achieve emission reduction benefits in the nearer as well as over the longer term. The South Coast AQMD Clean Fuels Program funds projects in the Technology Readiness Level ranging between 3-8.

Figure 4: Stages of Clean Fuels Program Projects

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

- Near-zero NOx Engine Development and Demonstrations for Heavy-Duty 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 Heavy-duty diesel engine;
  - Kenworth CNG Hybrid Electric Drayage Truck project;
  - DOE ZECT II project – KW developed one fuel cell truck & one CNG hybrid truck;
  - CARB GGRF project – KW developed advanced CNG hybrid truck by improving ZECT II CNG hybrid; and
  - US Hybrid NZE Plug-In Hybrid demonstration with DOE/NREL/CEC.
- Fuel Cell Development and Demonstrations
  - Kenworth Fuel Cell Range Extended Electric Drayage Truck project;
  - New Flyer Fuel Cell Transit Bus and Air Products Liquid Hydrogen Station at OCTA;
  - Retail light-duty passenger fuel cell vehicles (Toyota Mirai, Hyundai Nexo, Honda Clarity);
  - SunLine Transit Agency Advanced Fuel Cell Bus projects;
  - Commercial stationary fuel cell demonstration with UTC and SoCalGas (first of its kind);
  - UPS demonstration of fuel cell delivery trucks;
  - Fuel cell Class 8 trucks under ZECT II Program; and
  - Kenworth, TransPower, US Hybrid, Cummins developed and demonstrated total 6 fuel cell trucks
- Electric and Hybrid Electric Vehicle Development and Demonstrations
  - Daimler Class 6 and 8 battery electric trucks with Penske and NFI;
  - Volvo LIGHTS Class 8 battery electric trucks demonstration with TEC Fontana, DHE, and NFI;

- Volvo Switch-On Class 8 battery electric truck deployment with multiple fleets;
- Daimler and Volvo Class 8 battery electric truck large scale deployment with NFI and Schneider;
- Hybrid electric delivery trucks with NREL, FedEx and UPS;
- Plug-in hybrid work truck with Odyne Systems;
- DOE funded Develop and Demonstrate Medium- Heavy-Duty Plug-in Hybrid Electric Vehicles for Work Truck Applications;
- BYD battery-electric transit bus and trucks (yard hostlers and drayage);
- LA Metro battery electric buses;
- Blue Bird Electric School Bus with Vehicle to Grid (V2G) capability;
- TransPower Electric school buses, including V2G capability;
- TransPower/US Hybrid battery electric heavy-duty truck and yard hostlers;
- CARB GGRF Class 8 battery electric truck demonstration;
- Peterbilt develop and demonstrated 14 trucks; and
- BYD develop and demonstrated 25 trucks.

➢ Aftertreatment Technologies for Heavy-Duty 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 heavy-duty 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, the 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 South Coast AQMD program with a number of state and federal government organizations, including CARB, CEC, U.S. EPA and DOE/DOT and several of the 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 APCD and San Joaquin Valley APCD, as well as the National Association of Fleet Administrators (NAFA), major local transit districts, local gas and electric utilities, national laboratories, the San Pedro Bay Ports and several universities with research facilities, including but not limited to California State University Los Angeles, Purdue University, Universities of California Berkeley, Davis, Irvine, Los Angeles and Riverside, and University of West Virginia. The list of organizations with which the South Coast AQMD coordinates research and development activities also includes organizations specified in H&SC Section 40448.5.1(a)(2).

In addition, the South Coast AQMD holds periodic meetings with several organizations specifically to review and coordinate program and project plans. For example, the 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 the CaFCP, the California Stationary Fuel Cell Collaborative, the California Natural Gas Vehicle Partnership (CNGVP), EPRI, Veloz (formerly the PEV Collaborative), the Los Angeles Cleantech

Incubator's Regional Transportation Partnership, the California Hydrogen Business Council (CHBC), the SoCalEV Collaborative and the West Coast Collaborative. The coordination efforts with these various stakeholders have resulted in several cosponsored projects.

Descriptions of some of the key contracts executed in CY 2021 are provided in the next section of this report. It is noteworthy that most of the projects are cosponsored by various funding organizations and include the active involvement of original equipment manufacturers (OEMs). Such partnerships are essential to address commercialization barriers and to help expedite the implementation of advanced low emission technologies. Table 2 below lists the 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 participants who make important contributions critical to the success of the South Coast AQMD program. These partners are identified in the more detailed 2021 Project Summaries by Core Technologies contained within this report, as well as Table 5 which lists federal, state and local funding awarded to the South Coast AQMD in CY 2021 for RD^3 projects (which will likely result in executed project contracts in 2022).

Table 2: South Coast AQMD Major Funding Partners in CY 2021

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
	Southern California Gas Company
	Ports of Los Angeles & Long Beach

The following two subsections broadly address the South Coast AQMD's impact and benefits by describing specific examples of accomplishments including commercial or near-commercial products supported by the Clean Fuels Program in CY 2021. Such examples are provided in the following sections on the Technology Advancement Office's Research, Development and Demonstration projects and Technology Deployment and Commercialization efforts.

Research, Development and Demonstration

Important examples of the impact of the South Coast AQMD research and development coordination efforts in 2021 include: (a) Volvo Switch-On: Develop and Deploy Seventy Heavy-Duty Battery Electric Vehicles; (b) Deployment of Five New Flyer Zero-Emission Fuel Cell Buses at Sunline Transit Agency; and (c) Develop and Demonstrate Zero Emission Freight Shore 2 Store with Freightliner and Toyota Fuel Cell Trucks.

Volvo Switch-On: Develop and Deploy Seventy Heavy-Duty Battery Electric Vehicles

The $91 million CARB funded ZANZEFF Volvo Low Impact Green Heavy Transport Solutions (LIGHTS) project developed, demonstrated and deployed 25 pilot and production Class 8 battery electric trucks at two fleets in the Inland Empire, two TEC dealerships in Fontana and La Mirada, and leased trucks at seven additional fleets. The Switch-On project is a $30 million follow-up project deploying 70 certified Volvo VNR Electric Class 8 trucks at seven fleets in disadvantaged communities. U.S. EPA awarded South Coast AQMD $20 million in Targeted Airshed grant funding. South Coast AQMD provided $2 million from the Clean Fuels Fund towards infrastructure. Two of these fleets include DHE and NFI in Ontario, demonstration partners in the Volvo LIGHTS project. Other participating fleets include Performance Team (Santa Fe Springs), CEVA, McLane and Amazon . Each fleet will be replacing Class 8 diesel trucks currently performing drayage service to the San Pedro Bay Ports. The Switch-On project will provide 153 tons of NOx, 1.317 tons of PM 2.5 and 53,160 tons of CO2 over the 10-year lifetime of the trucks.

Figure 5: Volvo VNR Electric Class 8 Truck Deployed at Multiple Fleets in South Coast Air Basin

The trucks are in three configurations including straight trucks and tractors, with Gross Vehicle Weight (GVW) configurations ranging from 32,000 to 60,000 pounds, and axle configurations of 4x2, 6x2, and 6x4. These configurations accommodate various freight sectors and end-user market needs, and target urban, regional distribution, and drayage applications.

The Switch-On project takes advantage of 150 kW direct current (DC) fast charging infrastructure installed at DHE and NFI for the Volvo LIGHTS project, and their prior experience with the Volvo VNR Electric trucks. In addition, DHE and NFI have undergone facility improvements and electrical infrastructure upgrades and installed battery storage and 1 MW and 633 kW of solar respectively. The other participating fleets will install 150 kW or 350 kW DC fast charging infrastructure at their fleets.

The Switch-On project utilizes Volvo's maintenance and customer support and dealer networks at the TEC Fontana and La Mirada dealerships, which were upgraded to handle maintenance of battery electric trucks and have 150 kW DC fast chargers for trucks coming in for service or opportunity charging.

Volvo's Gold Service contract handles all maintenance issues for 72 months and will enable fleets to have a 10 year deployment to assist commercialization of heavy-duty battery electric trucks. In addition, this will assist fleets in complying with CARB's Advanced Clean Fleets regulation, which requires fleets to retain a certain percentage of zero emission trucks starting in 2024. Volvo and the fleets are providing cost share towards each truck which enables the EPA funding to fund additional trucks. South Coast AQMD's Clean Fuels funding is critical to support the installation of 150 kW or higher power charging infrastructure. The cost of installing high power fast charging infrastructure is a significant barrier to enabling fleets to deploy battery electric trucks. The trucks utilize CCS1 for charging infrastructure, which is the North American standard for heavy-duty vehicles. The trucks will be capable of DC fast charging at up to 250 kW.

The VNR Electric trucks for DHE, NFI, and Amazon will have increased vehicle range due to the development of more efficient Gen 3 battery packs. The battery chemistry used in the VNR Electric platform minimizes total cost of ownership by balancing power requirement with charging cycles, with sufficient power density to prevent costly battery replacement from premature degradation and minimal impact on payload capacity. The battery design was optimized to maintain or improve the fleet's productivity and duty cycle applications based on the fleet's operations, routes, and locations of available charging infrastructure.

Having battery electric trucks operating within disadvantaged communities will provide significant health and air quality benefits to residents living in these communities, and support fleets in compliance with South Coast AQMD's Rule 2305 – Warehouse Actions and Investments to Reduce Emissions (WAIRE) Program, which includes compliance and reporting requirement for warehouse owners and operators. Community based organized Reach Out in Upland will create and implement a community engagement strategy to educate residents about battery electric truck technologies and fleet operations. Energetics will collect and analyze fleet data on 1) utilization, 2) energy consumption, and 3) vehicle tailpipe emissions between conventional baseline and battery electric vehicles. Vehicle and fleet-level usage and performance parameters will include mileage, vehicle load, vehicle route, engine hours, idling hours, and energy use. These efforts will ensure that lessons learned and benefits of the Switch-On project will be captured and disseminated to a broad variety of audiences.

Deployment of Five New Flyer Zero-Emission Fuel Cell Buses at Sunline Transit Agency

Despite decades of aggressive efforts to improve air quality within the Basin, this region continues to have some of the nation's worst air quality. Currently, the SCAB and Coachella Valley portion of the Salton Sea Air Basin (SSAB) have areas in non-attainment for ozone and particulate matter (PM2.5). SunLine Transit Agency operates in Riverside County, which, according to the NAAQS, is an ozone "non-attainment" area. In 2020, South Coast AQMD was awarded a $5.9M EPA Targeted Air Shed Grant to replace Sunline fleet of five 2008 model year CNG transit buses with zero emission buses to improve local air quality and assist in achieving NAAQS ozone "attainment" designation for this area. These zero-emission buses produce no criteria emissions of NOx, VOC, CO, and PM2.5 and have significantly reduced GHG emissions, especially with the use of renewable fuels. This project also assists Sunline in complying with CARB Innovative Clean Transit (ICT), requiring all public transit agencies to gradually transition to 100% zero-emission buses by 2030. SunLine has been an early adopter of advanced transit technologies and already operates both fuel cell electric buses (FCEBs) and battery electric buses (BEBs).

New Flyer will build and deliver 5 hydrogen FCEBs equipped with Ballard Power Systems' ("Ballard") HD85 fuel cell system. This latest state-of-the-art technology has been deployed in small volumes to date. The learnings from past deployments position New Flyer to supply robust and reliable zero-emission buses that can be rapidly deployed to generate emission reductions in regular service operations. The project involves procurement, delivery, and commissioning of the buses within a five-year period. Sunline will conduct a minimum of 1-year of data collection after the buses' deployment and will operate the buses on a variety of routes passing through disadvantaged communities to the end of the buses 12-year lifetime. This deployment project also creates a load on Sunline's recently upgraded 900 kg/day hydrogen fueling station. These new FCEBs will bring SunLine's fleet to 21 FCEBs overall, resulting in the station being utilized at more than 65% of its full capacity and creating a reference site for at-scale deployment of FCEBs for other transit agencies. The station can operate more cost-effectively at a broader scale, providing an important reference site to demonstrate the at-scale cost of onsite hydrogen electrolysis. Operation of the station on a larger scale will also uniquely enable SunLine to learn about operational hydrogen fueling considerations. SunLine also plans to provide public access to their hydrogen fueling infrastructure to support other local early adopters of hydrogen fuel cell technology. Integration of the transit fueling operations with public dispensers that share common infrastructure is an additional innovative aspect of SunLine's planned scale-up of their hydrogen fueling operations that this project will be associated with. As public fueling demand grows, SunLine plans to continue to scale its hydrogen supply by adding liquid hydrogen or added electrolyzer capacity, which will provide opportunities to explore multiple integrated fueling technologies.

Figure 6: SunLine Transit Agency Fuel Cell Buses

The total project cost includes a total award of $5,906,601 from the EPA, $806,204 in-kind voluntary cash match in the form of hydrogen fuel, and bus operation and maintenance costs from Sunline, and $204,921 voluntary cost-share for the bus procurement from South Coast AQMD. The budget avoids the costly investment in hydrogen fueling infrastructure by leveraging SunLine's existing hydrogen fueling station. This allows the grant funds to be focused on zero-emission bus procurements, maximizing emission reductions of ozone precursor pollutants and GHGs and directly benefitting the Coachella Valley residents, a disadvantaged community.

Figure 7: SunLine Transit Agency Onsite Hydrogen Fueling Infrastructure

Develop and Demonstrate Zero Emission Freight Shore 2 Store with and Toyota Fuel Cell Trucks

The Port of Los Angeles (POLA) Zero Emissions Freight "Shore To Store" Project (S2S) was awarded $41M CARB ZANZEFF funding to structure operations for future zero emission goods movement, reduce GHG, criteria pollutant, and toxic air contaminant emissions in and around freight facilities; and provide economic, environmental, and public health benefits to disadvantaged communities (DAC).

Funding for this $82.5M project is provided by CARB, CEC (in-kind match), Toyota, Kenworth, Port of Hueneme, Shell, Southern Counties Express, Total Transportation Services (TTSI), UPS and South Coast AQMD.

Ten Kenworth zero-emission Class 8 hydrogen fuel cell electric on-road trucks utilizing the Kenworth T680 platform, integrated with Toyota's fuel cell drive technology will be based in disadvantaged communities and operated in revenue service: three by the United Parcel Services (UPS), two by Total Transportation Services Inc. (TTSI), one by Southern Counties Express (SCE), and four by Toyota Logistics Services (TLS) throughout the Los Angeles basin ports, inland locations such as Riverside County, and the Port of Hueneme (POH). Additionally, POH will demonstrate two electric yard tractors, and TLS will demonstrate two zero-emission forklifts at their facility. All 10 trucks were in service as of October 29, 2021 and will complete the minimum 90-day operation by February 2022. TLS will operate one truck at least one year, through May 2022. The CARB Experimental Permit was renewed through October 2022.

Figure 8: Kenworth – Toyota Class 8 FCET fueling at Shell Ontario Heavy-Duty Hydrogen station July 2021

Two new large-capacity, heavy-duty hydrogen fueling stations built by Equilon Enterprises LLC (d/b/a Shell Oil Products USA) in Ontario and Wilmington plus three additional stations at Toyota facilities around Los Angeles demonstrate an integrated, five-station, heavy-duty hydrogen fueling network. Stations at Toyota Logistics Services in Long Beach and Toyota Technical Center in Gardena serve as important research and development locations. The fifth heavy-duty station on POLB property is leased to Toyota at 785 Edison Ave., Long Beach, CA 90813 (as an in-kind match share by CEC & Shell).

Figure 9: Kenworth – Toyota Class 8 FCET (white/blue)) escorting the US Capital Christmas tree (green truck) from the Rose Bowl to Redlands on November 6, 2021. (Credit: Toyota)

Project partners will also support educational and outreach opportunities during the project that do not interfere with fleet logistics. Since Kenworth's T680 was chosen to convey the US Capital Christmas Tree "Sugar Bear" from the cutting ceremony in Six Rivers National Forest, California to Washington, DC, one of the ten demonstration FCETs was invited to escort the Kenworth truck transporting the tree for the leg of the journey from Pasadena (Rose Bowl) to Redlands, CA.

As heavy-duty hydrogen stations are demonstrated, continued public research is needed to evaluate multiple aspects. Fueling protocols, dispenser design and station throughput and reliability are just some examples that will be evaluated with operating data reported through NREL. Data collected from the ten FCETs will also be collected and evaluated by NREL.

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CLEAN FUELS PROGRAM
2021 Funding & Financial Summary

The South Coast AQMD 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. In order 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), the 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 throughout the year, the 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, 2021.

Funding Commitments by Core Technologies

The 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, 2021, a total of 24 contracts/agreements, projects or studies that support clean fuels were executed or amended (adding dollars), as shown in Table 3. 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 10. This wide array of technology support represents the 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 2021 reporting period are shown below with the total projected project costs:

- South Coast AQMD Clean Fuels Fund Contribution $10,665,745
- Total Cost of Clean Fuels Projects $252,950,852

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, the fund transfer from Clean Fuels to the General Fund was handled through the annual budget process. Thus, when the Board approved the South Coast AQMD's FY 2021-22 Budget on May 7, 2021, it included $1 million from Clean Fuels recognized in TAO's budget for technical assistance, workshops, conferences, co-sponsorships and outreach activities, as well as postage, supplies and miscellaneous costs; another $285,000 is transferred from the Clean Fuels Fund to Capital Outlays for alternative fuel vehicle purchases for TAO's Alternative Fuel Demonstration Program as well as supporting vehicle and energy infrastructure. Only the funds committed by December 31, 2021, are included within this report. Any portion of the Clean Fuels Funds not spent by the end of Fiscal Year 202-22 ending June 30, 2022, 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. This supplemental revenue for pass-through contracts executed in 2020 totaling approximately $4.3 million is listed within Table 4.

For Clean Fuels executed and amended contracts, projects and studies in 2021, the average South Coast AQMD contribution was leveraged with nearly $39 of outside investment. The typical historical leverage amount is $4 for every $1 of South Coast AQMD Clean Fuels funds, but from 2016 to 2021 there were several significant contracts, significant both in funding and in the impact that they hopefully will make in strides toward developing and commercializing clean transportation technologies.

During 2021, the distribution of funds for South Coast AQMD executed contracts, purchases and contract amendments with additional funding for the Clean Fuels Program totaling approximately $10.6 million are shown in the figure below.

Additionally, the South Coast AQMD continued to seek funding opportunities and was awarded an additional $48.7 million in CY 2021 for RD[3] projects as listed in Table 5.

As of January 1, 2022, there were 109 open Clean Fuels Fund contracts. Appendix B lists these contracts by core technology.

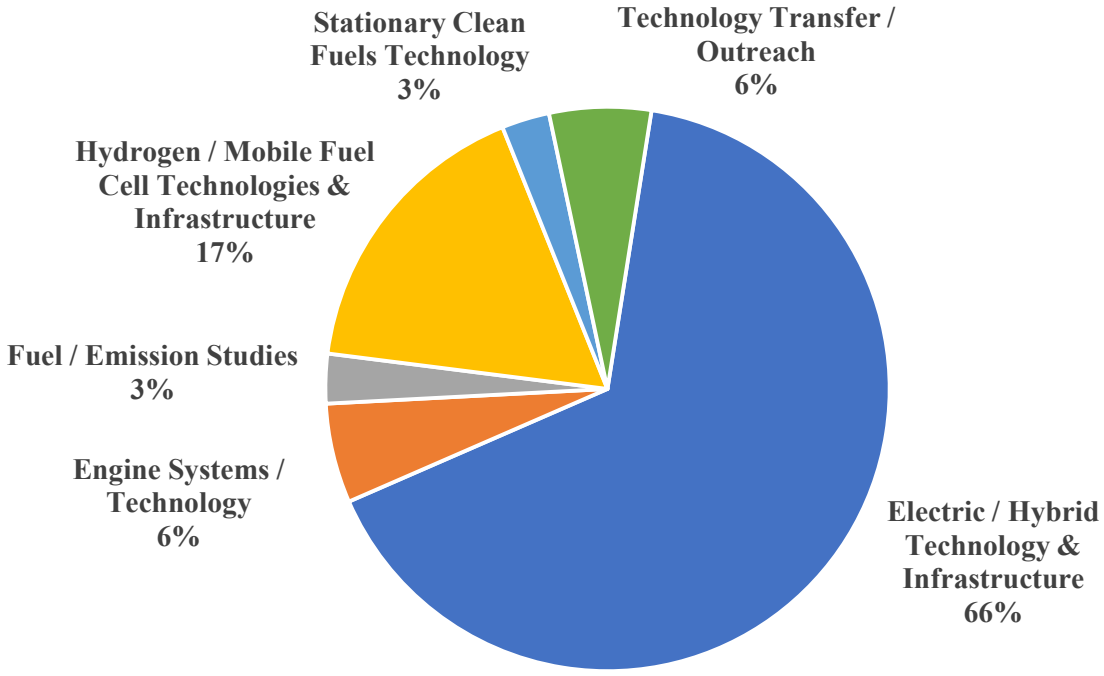

Figure 10: Distribution of Funds for Executed Clean Fuels Projects CY 2021 ($10.6M)

Review of Audit Findings

State law requires an annual financial audit after the closing of each South Coast AQMD's fiscal year. The financial audit is performed by an independent Certified Public Accountant selected through a competitive bid process. For the fiscal year ended June 30, 2021, the firm of BCA Watson Rice, LLP, conducted the financial audit. As a result of this financial audit, a Comprehensive Annual Financial Report (CAFR) was issued. There were no adverse internal control weaknesses with regard to South Coast AQMD financial statements, which include the Clean Fuels Program revenue and expenditures. BCA Watson Rice, LLP, gave the South Coast AQMD an "unmodified opinion," the highest obtainable. Notably, the South Coast AQMD has achieved this rating on all prior annual financial audits.

Project Funding Detail by Core Technologies

The 24 new and continuing contracts/agreements, projects and studies that received South Coast AQMD funding in CY 2021 are summarized in Table 3 (beginning on the next page), together with the funding authorized by the South Coast AQMD and by the collaborating project partners.

Table 3: Contracts Executed or Amended (w/$) between January 1 & December 31, 2021

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	06/30/22	0	1,098,963
20296	Daimler Trucks North America LLC	Deploy Zero Emission Electric Delivery Trucks	05/27/21	12/31/24	4,010,000	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
Engine Systems / Technologies						
20199	Agility Fuel Solutions LLC	Develop a Near-Zero Natural Gas and Propane Conversion System for On-Road Medium-Duty Vehicles	07/01/21	06/30/22	607,825	1,834,000
Fuel / Emission Studies						
21103	University of California Riverside	Perform Investigation Study of E15 Gasoline Fuel Effects	03/09/21	06/08/22	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
Hydrogen / Mobile Fuel Cell Technologies and Infrastructure						
20033	Port of Long Beach	Sustainable Terminals Accelerating Regional Transportation (START) Phase I	06/04/21	04/30/22	500,000	102,964,064
20169	Port of Los Angeles	Develop & Demonstrate Near-Zero and Zero Emissions Vehicles and Equipment at the Ports	06/28/21	11/30/22	1,000,000	83,548,872
21313	SunLine Transit Agency	Deployment of 5 Zero-Emission Fuel Cell Transit Buses	08/27/21	09/30/25	204,921	6,761,125
21336	Frontier Energy, Inc.	Participate in California Fuel Cell Partnership for Calendar Year 2021	01/01/21	12/31/21	70,000	1,300,000

Table 3: Contracts Executed or Amended (w/$) between January 1 & December 31, 2021 (cont'd)

Contract	Contractor	Project Title	Start Term	End Term	South Coast AQMD $	Project Total $
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
Stationary Clean Fuels Technologies						
21266	University of California Irvine	Develop Model for Connected Network of Microgrids	08/17/21	02/16/24	290,000	370,000
Technology Assessment and Transfer / Outreach						
12376	University of California, Riverside/CE-CERT	Technical Assistance with Alternative Fuels, Biofuels, Emissions Testing & Zero-Emission Transportation Technology	06/13/14	05/31/24	75,000	75,000
19078	Green Paradigm Consulting, Inc.	Technical Assistance with Alternative Fuels, EVs, Charging & Infrastructure and Renewable Energy	09/07/18	09/30/24	50,000	50,000
19227	Gladstein, Neandross & Associates LLC	Technical Assistance with Alternative Fuels & Fueling Infrastructure, Emissions Analysis & On-Road Sources	02/01/19	01/31/22	100,000	100,000
20085	CALSTART Inc	Technical Assistance for Development & Demonstration of Infrastructure and Mobile Source Applications	11/08/19	11/07/23	100,000	100,000
21260	Fred Minassian	Technical Assistance with Incentive and Research and Development Programs	04/13/21	10/12/21	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
Various	Various	Cosponsor 7 Conferences, Workshops & Events plus 2 Memberships	01/01/21	12/31/21	132,091	1,234,920
Direct Pay	Prizm Imaging	Procure Outreach Materials	01/01/21	12/31/21	4,577	4,577
Direct Pay	Various	Advanced Technology Program Expenses	01/01/21	12/31/21	21,331	21,331
						$252,950,852

Table 4: Supplemental Grants/Revenue Received into the Clean Fuels Fund (31) in CY 2021

Revenue Agreement #	Revenue Source	Project Title	Contractor	SCAQMD Contract #	Award Total $
20309	US EPA Airshed Grant	Delivery Truck Replacement Project	Daimler Trucks North America LLC	20296	4,010,000
20132	Southern California Gas Company	Develop a Near-Zero Natural Gas and Propane Conversion System for On-Road Medium-Duty Vehicles	Agility Fuel Solutions LLC	20199	154,325
21069	Southern California Gas Company	Evaluate Vehicle Maintenance Costs between NG and Diesel Fueled On-Road Heavy Duty Vehicles	West Virginia University Research Corp	21169	150,000
Table 4 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 (2021).					**$4,314,325**

Table 5: Summary of Federal, State and Local Funding Awarded or Recognized in CY 2021

Awarding Entity or Program	Award (*) or Board Date	Purpose	Contractors	Award Total/ Fund
California Air Resources Board	01/08/21	Develop and Demonstrate Capture and Control System for Oil Tankers	STAX Engineering, Inc.	$10,000,000 Fund 83
San Pedro Bay Ports	01/08/21	Develop and Demonstrate Capture and Control System for Oil Tankers	STAX Engineering, Inc.	$666,667 Fund 83
US EPA CATI Grant	06/04/21	Develop and Demonstrate Two Class 8 Hydrogen Fuel Cell Trucks	Hyundai Motor Company	$500,000 Fund 31
California Air Resources Board	06/04/21	Zero-Emission Drayage Truck and Infrastructure Pilot Project	Various	$16,019,316 Fund 67
California Energy Commission	06/04/21	Zero-Emission Drayage Truck and Infrastructure Pilot Project	Various	$10,964,955 Fund 67
Port of Long Beach	06/04/21	Zero-Emission Drayage Truck and Infrastructure Pilot Project	Various	$1,500,000 Fund 67
Port of Los Angeles	06/04/21	Zero-Emission Drayage Truck and Infrastructure Pilot Project	Various	$1,500,000 Fund 67
California Air Resources Board	09/03/21	Establish Wildfire Smoke Clean Air Centers Incentive Pilot Program	Various	$250,000 Fund 75
US EPA Airshed Grant	12/03/21	Zero-Emission Freight Line-Haul Locomotive Repower with Supporting Charging Infrastructure	BNSF	$4,967,000 Fund 17

Table 5: Summary of Federal, State and Local Funding Awarded or Recognized in CY 2021 (cont'd)

Awarding Entity or Program	Award (*) or Board Date	Purpose	Contractors	Award Total/ Fund
US EPA Airshed Grant	12/03/21	Long-Range Class 8 Fuel Cell Truck Demonstration	Hyundai Motor Company	$3,500,000 Fund 17
Table 5 provides a comprehensive summary of revenue awarded to South Coast AQMD during the reporting CY (2021) 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.				**$48,682,950**

Project Summaries by Core Technologies

The following summaries describe the contracts, projects and studies executed, or amended with additional dollars, in CY 2021. They are listed in the order found in Table 3 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 *(received as pass-through funds into Fund 67)*	596,963
	U.S. EPA *(received as pass-through funds into Fund 67)*	600,000
Term: 4/17/19 – 6/30/22	Total Cost:	$ 1,096,963

Volvo Group North America and South Coast AQMD secured a CARB ZANZEFF grant for the Volvo LIGHTS project to demonstrate 23 Class 8 battery electric trucks at two freight handling facilities, Dependable Highway Express (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; 56 Level 2 and DC fast chargers; and production of 1.8 million MWh annually of solar. This contract amendment is for installation of 832 kW of solar at NFI and for the deployment of two additional battery electric trucks, utilizing CARB and U.S. EPA funds respectively.

20296: Deploy Zero Emission Electric Delivery Trucks

Contractor: Daimler Trucks North America	South Coast AQMD Cost-Share	$ 0
	Cosponsors:	
	US EPA *(received as pass-through funds into Fund 31)*	4,010,000
	DTNA	3,260,000
	HVIP/SCE Charge Ready	5,040,000
Term: 5/27/21 – 12/31/24	Total Cost:	$ 12,310,000

Daimler Trucks North America (DTNA) to develop and deploy its first commercial-ready Class 8 (eCascadia) and Class 6 (eM2) battery electric vehicles with major fleet operators in the Basin beginning in 2022. Twenty eCascadia and 15 eM2 heavy-duty trucks will be distributed amongst U.S. Foods, JB Hunt, Ryder Truck, and Schneider. Fleet operators will secure DC Fast Charge infrastructure with technical support from DTNA and financial support from Southern California Edison's Charge Ready program.

21077: Develop and Demonstrate up to 8 Heavy-Duty Battery Electric Trucks and Transportable Fast-Charging

Contractor: Daimler Trucks North America	South Coast AQMD Cost-Share	$ 1,000,000
	Cosponsors:	
	DTNA	4,919,500
	BAAQMD	322,500
	SCE and PG&E	500,000
Term: 3/11/21 – 3/31/23	Total Cost:	$ 6,742,000

Daimler Trucks North America (DTNA) to develop a Commercial Experience (CX) project to demonstrate up to eight pre-commercial-ready battery electric Class 8 (eCascadia) and Class 6 (eM2) trucks with 12-18 major fleets in the South Coast Air Basin and in the Bay Area AQMD. This project will provide DTNA customers with 2 to 9 months of vehicle use and to experience EV recharging using a transportable DC Fast Charge system from Charge Point that will minimize costs and installation challenges associated with in-ground charging infrastructure. The project is expected to stimulate customer interest in and accelerate customer orders for commercial product.

21153: Switch-On: Develop and Deploy Seventy Heavy-Duty Battery Electric Vehicles

Contractor: Volvo Group North America, LLC	South Coast AQMD Cost-Share	$ 2,000,000
	Cosponsors:	
	U.S. EPA	19,460,000
	Volvo/Fleets	10,000,000
Term: 6/10/21 – 9/30/24	Total Cost:	$ 31,460,000

The Switch-On project builds on the progress achieved from the Volvo LIGHTS project by deploying 70 commercial Class 8 battery electric trucks at six fleets for drayage and freight applications. Trucks will be deployed in 2022 and 2023 and EV charging infrastructure will be installed at each fleet to support fleet operations. Data collection and analysis will be conducted by Volvo and their subcontractor Energetics through March 2024. Volvo will provide a final report to U.S. EPA detailing the experiences of fleets with commercial battery electric trucks and lessons learned.

Engine Systems / Technologies

20199: Develop a Near-Zero Natural Gas and Propane Conversion System for On-Road Medium-Duty Vehicles

Contractor: Agility Fuel Solutions LLC	South Coast AQMD Cost-Share	$ 453,500
	Cosponsors:	
	SoCalGas *(received as pass-through funds into Fund 31)*	154,325
Term: 07/01/21 – 12/31/22	Total Cost:	$ 1,834,000

In October 2019, South Coast AQMD's Governing Board (Board) approved three projects to develop the new Ford 7.3-liter near zero NOx engine natural gas and propane conversion systems, including an award to Agility Fuel Solutions (Agility). Due to the lack of Ford Qualified Vehicle Modifiers (QVM) program approvals, staff was unable to finalize the contract with Agility. The Ford QVM program assures that vehicles converted through the program are converted to Ford standards and the given QVM can carry the added alternative fuel components and emissions warranty. Agility has demonstrated their commercialization strategy as well as aftermarket service and warranty capability for their current large fleet of low-NOx natural gas and propane vehicles that include the Ford 6.8-liter natural gas trucks converted under the QVM program. Agility Fuel Solutions will develop all hardware and software necessary to operate and certify the next generation Ford 7.3L engine on both CNG and propane (liquid petroleum gas or LPG). Agility will secure MY 2021 CARB Executive Orders for the 7.3L running on CNG and LPG at the lowest OLNS (Optional Low NOx Standard) of 0.02 g/bhp-hr NOx, with a demonstration target of 0.01 g/bhp-hr over a certification test cycle.

Fuel / Emissions Studies

21103: Perform Investigation Study of E15 Gasoline Fuel Effects

Contractor: University of California, Riverside	South Coast AQMD Cost-Share	$ 200,000
	Cosponsors:	
	CARB	500,000
	RFA/Growth Energy	600,000
Term: 03/09/21 – 06/08/22	Total Cost:	$ 1,300,000

CARB's, Renewable Fuels Association (RFA), Growth Energy and UCR have partnered together and are proposing to evaluate criteria and toxic pollutant emissions from twenty gasoline vehicles of different model years, emission standards, manufacturers and engine technology on both E10 and E15 fuels for the purpose of approving the use of E15 in California. Triplicate testing will be conducted using U.S. EPA's Federal Test Procedure-75 typically used for passenger cars. Emission measurements will include regulated pollutants, fuel economy, carbonyl compounds and VOCs. UCR proposes to expand the scope and add in-depth characterization of the secondary organic aerosols (SOA) forming potential from a subset of ten vehicles that best represent vehicle populations in the Basin. Both primary and secondary aerosols will be characterized in each experiment. UCR will perform a SOA formation potential study on a subset of ten vehicles that best represent the fleet of the Basin. The data gathered

will add additional information of impact of E15 on air quality in our region. There are three novel aspects for this program: (1) characterizing SOA forming potential from current generation gasoline vehicles, including port fuel injection (PFI), gasoline direct injection (GDI), and possible hybrid technologies, (2) compare the SOA forming potential between the typical CA E10 fuel and the candidate E15 blend to potentially be introduced to the CA gasoline pool, and (3) show environmental, air quality, and health benefits from the introduction of a gasoline fuel containing higher content of biofuel.

21169 Evaluation of Vehicle Maintenance Costs Between NG and Diesel Fueled On-Road Heavy-Duty Vehicles

Contractor: West Virginia University Research Corp	South Coast AQMD Cost-Share	$ 100,000
	Cosponsors:	
	SoCalGas *(received as pass-through funds into Fund 31)*	150,000
Term: 09/29/21 – 03/08/24	Total Cost:	$ 250,000

South Coast AQMD has been supporting the rapid deployment of near-zero emission 0.02 g/bhp-hr NOx vehicles through its incentive programs since the first near-zero heavy-duty natural gas engines became commercially available in 2015. In evaluating natural gas vehicle (NGV) total cost of ownership (TCO), maintenance costs are often cited as a potential advantage that reduces NGV TCO relative to comparable diesel-powered vehicles due to lack of exhaust aftertreatment systems. There is no recent data that clearly compares the relative maintenance costs of NGVs and diesel trucks, especially for advanced natural gas and diesel technologies introduced in the last decade. The Basin includes one of the largest NGV fleets, including near-zero emission NGVs. Combined with the unique urban duty cycle Basin, a more detailed and regionally focused maintenance study is necessary to help understand the TCO and drive greater adoption of the NGVs. West Virginia University-Center for Alternative Fuels Engines (WVU) and Emissions is to perform a comparative evaluation of vehicle maintenance costs between natural gas and diesel fueled vehicles. The WVU project will enable correlation of vehicle maintenance costs to already available fleet information, real-world vehicle activity and in-use emissions data.

Hydrogen / Mobile Fuel Cell Technologies and Infrastructure

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

Contractor: Port of Long Beach	South Coast AQMD Cost-Share	$ 500,000
	Cosponsors:	
	CARB	50,000,000
	Ports/Project Parnters	52,464,064
Term: 6/4/21 – 4/30/22	Total Cost:	$ 102,964,064

CARB provided funding to POLB for their START project to demonstrate 102 zero and near-zero emission vehicles, vessels, and cargo handling equipment across an intermodal freight network at the Ports of Long Beach, Oakland and Stockton and partnership with South Coast, Bay Area, and San

Joaquin Valley air quality agencies. This project will assist in the transition to zero emission operations, reduce GHG and criteria pollutants, and provide economic, environmental and public health benefits to residents in disadvantaged communities. This demonstration includes battery electric yard tractors, top handlers, forklifts, Class 8 trucks, RTG cranes, electric drive tugboat, rail car mover, and low NOx ocean going vessels. This project was originally planned to be completed in April 2022 and is now being extended by CARB.

20169: Develop & Demonstrate Near-Zero and Zero Emissions Vehicles and Equipment at the Ports

Contractor: Port of Los Angeles	South Coast AQMD Cost-Share	$ 1,000,000
	Cosponsors:	
	CARB	41,122,260
	CEC	25,999,331
	Toyota	9,740,000
	Others: --Kenworth Truck Company --Port of Hueneme --Shell Oil Products USA --Southern Counties Express --Total Transportation Services --UPS,	4,685,433
Term: 07/21/21 – 11/30/22	Total Cost:	$ 82,547,024

The POLA's Shore to Store (S2S) Project is to develop and demonstrate ten Kenworth zero emissions Class 8 hydrogen fuel cell electric trucks, integrated with Toyota's fuel cell drive technology, along with the two hydrogen fueling stations that will be built in Ontario and Wilmington. All deployments will be based in disadvantaged communities. The hydrogen fuel cell electric trucks will be operated by UPS, Total Transportation Services, Inc., Southern Counties Express and Toyota Logistics Services (TLS) throughout the Los Angeles basin ports, inland locations such as Riverside County and the Port of Hueneme (POH). Additionally, POH will demonstrate two electric yard tractors, and TLS will demonstrate two zero emissions forklifts at their facility.

21313: Deployment of 5 Zero-Emission Fuel Cell Transit Buses

Contractor: SunLine Transit Agency	South Coast AQMD Cost-Share	$ 204,921
	Cosponsors:	
	US EPA *(received as pass-through funds into Fund 17)*	5,750,0000
	SunLine Transit Agency	806,204
Term: 08/27/21 – 09/30/25	Total Cost:	$ 6,761,125

SunLine Transit Agency provides transit services to the Coachella Valley, an ozone non-attainment area, including Eastern Coachella Valley, which is a Year 2 Community under South Coast AQMD's AB 617 Program. SunLine has recently commissioned their onsite renewable hydrogen fueling station

at a 900 kg per day capacity, which is the largest onsite hydrogen generation station at any U.S. transit agency, and their existing fleet SunLine's goal is to accelerate the transition to a fully zero emission bus fleet by 2035 to comply with CARB's Innovative Clean Transit (ICT) regulation. South Coast AQMD is partnering with SunLine Transit Agency to purchase and deliver up to five fuel cell transit buses. The newly upgraded hydrogen fueling station has a capacity for 30 buses, with a total of 21 buses now utilizing the station. Buses will operate on several routes in disadvantaged communities and replace older model year CNG transit buses. SunLine expects to operate up to five fuel cell transit buses for their 12-year equipment lifetime.

21336: Participate in California Fuel Cell Partnership for Calendar Year 2021

Contractor: Frontier Energy Inc	South Coast AQMD Cost-Share	$ 70,000
	Cosponsors:	
	7 automakers, 3 public agencies, 7 industry stakeholders, 35 Full & Associate Members	1,288,000
Term: 01/01/21 – 12/31/21	Total Cost:	$ 1,358,000

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 2021, South Coast AQMD contributed $70,000 for Executive membership.

21386: California Hydrogen Heavy-Duty Infrastructure Research Consortium H2@Scale Initiative

Contractor: National Renewable Energy Laboratory	South Coast AQMD Cost-Share	$ 25,000
	Cosponsors:	
	Fuel Cell Technologies Office, U.S. DOE	999,000
	CEC	25,000
	GO-Biz, CARB (In-kind)	65,000
Term: 06/30/20 – 04/01/22	Total Cost:	$ 1,114,000

A team of California public agencies (CARB, CEC, Governor's Office of Business and Economic Development (GO-Biz), South Coast AQMD) and national laboratories formed a research partnership in 2017 focused on near-term hydrogen infrastructure development, deployment, and operation needs in California and was awarded DOE H2@Scale CRADA funds that year. The research partnership framework was intended to continue beyond that project for a long-lasting strategic partnership with the DOE, agencies, and national laboratories. As California has begun in earnest to expand its light-duty focus to include the medium- and heavy-duty fuel cell electric vehicle market, the research partnership submitted a project proposal to DOE's H2@Scale CRADA Call AOI 1: Fueling Components for Heavy-Duty Vehicles. This project will continue to conduct hydrogen infrastructure research efforts, focused on California heavy-duty hydrogen infrastructure priorities. Tasks include

heavy-duty reference station design, fueling performance test device design, and modeling of heavy-duty station capacity.

Stationary Clean Fuels Technologies

21266: Develop Model for Connected Network of Microgrids

Contractor: University of California, Irvine	South Coast AQMD Cost-Share	$ 290,000
	Cosponsors:	
	University of California, Irvine	80,000
Term: 08/17/21 – 02/16/24	Total Cost:	$ 370,000

The proposed project will develop a model to assess air quality impacts of connected microgrids serving the SCAB by evaluating the use of various power generation technologies in microgrids and alternative transportation (battery electric and fuel cell) vehicles operating under microgrid control. In the project, university campuses, ports, shopping centers and critical facilities will be modeled to assess air quality impacts resulting from widespread deployment of microgrids. The study will include evaluating air quality impacts during both grids connected and islanded modes, including public safety power shutoff events, and estimating overall NOx benefits by emission reduction factors of microgrids such as system efficiency, energy storage, electricity delivery losses and combined heat and power system. Potential aggregated NOx emission reductions using connected and islanded operations may be up to 6 tons per day, comparable to the NOx emission reductions from the recently adopted Omnibus Regulation for heavy-duty engines. For mobile sources, electrolysis facilities could allow a more sustainable and economic hydrogen supply for fuel cell electric vehicles.

Technology Assessment and Transfer / Outreach

12376: Technical Assistance with Alternative Fuels, Biofuels, Emissions Testing & Zero-Emission Transportation Technology

Contractor: University of California, Riverside/CE-CERT	South Coast AQMD Cost-Share	$ 75,000
Term: 06/13/14 – 05/31/24	Total Cost:	$ 75,000

South Coast AQMD seeks to implement aggressive programs to develop and demonstrate pre-commercial technologies for low- and zero-emission vehicles and equipment, alternative fuels, and renewable energy sources. Due to constant and rapid changes in technologies and the sheer breadth of potential projects, South Coast AQMD supplements in-house technical resources with outside expertise and assistance to evaluate and implement these demonstration projects. The College of Engineering/Center for Environmental Research and Technology (CE-CERT) is a research center at University of California Riverside dedicated to research on air quality and energy efficiency with approximately 120 investigators including 30 Ph.D. level researchers. CE-CERT will provide technical expertise to evaluate a broad range of emerging technologies in alternative and/or renewable fuels and vehicles as well as to conduct air pollution formation and control studies.

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

Contractor: Green Paradigm Consulting, Inc.	South Coast AQMD Cost-Share	$ 50,000
Term: 09/07/18 – 09/30/24	Total Cost:	$ 857,236

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. The contract also includes assistance in implementing complementary programs including CARB's GGRF Zero Emission Drayage Truck project and ZANZEFF Volvo LIGHTS project, and U.S. EPA's Targeted Airshed Volvo Switch-On project.

19227: Technical Assistance with Alternative Fuels and Fueling Infrastructure, Emissions Analysis and On-Road Sources

Contractor: Gladstein, Neandross & Associates LLC	South Coast AQMD Cost-Share	$ 100,000
Term: 02/01/19 – 01/31/22	Total Cost:	$ 300,000

This contract leverages staff resources with specialized outside expertise. Gladstein, Neandross & Associates LLC (GNA) has previously assisted South Coast AQMD with implementing a wide-array of incentive programs to deploy lower-emitting heavy-duty vehicles 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. This contract amendment is for assistance in preparation of proposals for zero emission trucks and charging infrastructure.

20085: Technical Assistance for Development and Demonstration of Infrastructure and Mobile Source Applications

Contractor: CALSTART Inc.	South Coast AQMD Cost-Share	$ 100,000
Term: 11/08/19 – 11/07/23	Total Cost:	$ 250,000

This contract is to leverage staff resources with specialized outside expertise. CALSTART Inc.is a nonprofit that specializes in clean transportation technologies, fuels, and systems. CALSTART Inc. manages a wide range of national clean transportation and grant programs in close partnership with federal, state and regional agencies that address national and international issues related to creating the next generation of jobs and reducing emissions from transportation. CALSTART has been working as an effective catalyst for the global advanced transportation technology industry for over a decade and works closely with key public and private sector stakeholders in the industry. This contract amendment is for assistance on deployment and demonstration of infrastructure and mobile source applications.

21260: Technical Assistance with Incentive and Research and Development Programs

Contractor: Fred Minassian	South Coast AQMD Cost-Share	$ 75,000
Term: 04/13/21 – 10/12/22	Total Cost:	$ 75,000

This contract leverages staff resources with specialized outside expertise. Over the course of his 35+ year career, Mr. Minassian has been involved with many aspects of air quality management and policy-making, including implementing and managing incentive programs, overseeing research projects and serving in a variety of advisory roles. He managed numerous research and development (R&D) projects including on-road emissions, development of low-NOx heavy-duty engines, and development of electric and hybrid electric vehicles. He then served as Technology Implementation Manager where he was responsible for the successful implementation of incentive programs such as the Carl Moyer, Lower-Emission School Bus, Prop 1B, Replace Your Ride and the NOx and PM credit generation programs. After his retirement from South Coast AQMD employment as Assistant Deputy Executive Officer for Science and Technology Advancement, he served as Board Assistant for Board Member Judith Mitchell at South Coast AQMD and CARB boards for a period of fourteen months. Fred has B.S. and M.S. degrees in Chemical Engineering from the Engineering Academy of Denmark, and the California State University, Northridge, respectively. Under this contract, Mr. Minassian will provide technical expertise across a broad spectrum of incentive and R&D programs to be implemented under Technology Advancement Office (TAO) activities on an-as-needed basis. Mr. Minassian has expert, in-depth understanding of both the incentive and R&D programs.

22096: Technical Assistance with Heavy-Duty Vehicle Emissions Testing, Test Methods and Analysis of Real-World Activity Data

Contractor: AEE Solutions, LLC	SCAQMD Cost-Share	$ 100,000
Term: 11/08/21 – 11/07/23	Total Cost:	$ 100,000

This contract leverages staff resources with specialized outside expertise. Under this contract, AEE Solutions, LLC, will provide technical assistance for the in-use emissions study under this existing Board-approved technical assistance contract. Specifically, AEE Solutions will assist in the: 1) development of test vehicle selection, activity and emissions protocols, 2) recruitment of 200 heavy-duty test vehicles, 3) preparation of a technology assessment plan to identify the impact of current and near-future technology on engine performance, emissions and fuel usage, 4) identification of engine and aftertreatment issues and how to mitigate them, and 5) matching of vehicle technologies to vocations for which technology benefits can be maximized.

Various: Cosponsor 7 Conferences, Workshops and Events plus 2 Memberships

Contractor: Various	South Coast AQMD Cost-Share	$ 132,091
	Cosponsors:	
	Various	1,102,829
Term: 01/01/21 – 12/31/21	Total Cost:	$ 1,234,920

The South Coast AQMD regularly participates in and hosts or cosponsors conferences, workshops and miscellaneous events. In CY 2021, South Coast AQMD provided funding for 7 conferences, workshops and events and 2 memberships in key stakeholder organizations, as follows: Clean Fuels Advisory Group Retreat in January and September 2021; the PEMS Conference in March 2021; Special Awards

at the California State Science Fair in April; the ACT Conference and Expo in August 2021; the International Colloquium on Environmentally Preferred Advanced Generation (ICEPAG) 2021 Hydrogen: Fueling the Sustainable Future in September 2021; the Asilomar 2021 Conference on Transportation & Energy in October 2021; and the 2021 Southern California Chinese-American Environmental Protection Association 30-Year Anniversary and Annual Convention in November 2021. Additionally, for 2021, two memberships were renewed for participation in California Stationary Fuel Cell Collaborative, consists of a Core Group comprised of representatives of California agencies associated with fuel cell technology and an Industrial Advisory Panel (IAP) to explore, support, and facilitate the deployment of fuel cell technologies as a means of reducing or eliminating air pollutants and greenhouse gas emissions; increasing energy efficiency; enhancing resiliency, public health and energy independence; and assisting the state of California in realizing a sustainable energy future; and 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.

Direct Pay: Procure Outreach Materials

Contractor: Prizm Imaging	South Coast AQMD Cost-Share	$ 4,577
Term: 01/01/21 – 12/31/21	Total Cost:	$ 4,577

South Coast AQMD's Technology Advancement Office offers funding for research, development, demonstration and deployment of transformative transportation technologies, incentive funding to accelerate fleet turnover of both on- and off-road transportation, and rebates for residential electric lawn mowers and home EV charging, among other programs. Technology assessment and outreach efforts are a small but essential part of any effective program. It is important to inform potential stakeholders and educate the public about South Coast AQMD's technology advancement efforts toward reducing pollutants and ensuring public health. In 2021, high performance vinyl decals were procured to show South Coast AQMD's support and participation of the numerous truck projects being demonstrated and deployed.

Direct Pay: Advanced Technology Program Expenses

Contractor: Various	South Coast AQMD Cost-Share	$ 21,331
Term: 01/01/21 – 12/31/21	Total Cost:	$ 21,331

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 and use tax on purchase of hydrogen fueling equipment.

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CLEAN FUELS PROGRAM
Progress and Results in 2021

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 shifted to near-zero and zero emission technologies for medium- and heavy-duty trucks, especially those in the goods movement and freight handling industry.

Table 8 provides a list of 30 projects and contracts completed in 2021. Summaries of the completed technical projects are included in Appendix C. Selected projects completed in 2021 which represent a range of key technologies from near-term to long-term are highlighted below: (a) Zero Emission Cargo Transport (ZECT) Program; (b) Demonstrate Zero Emission Cargo Handling Vehicles at POLB; and (c) Develop and Demonstrate Zero-Emission Fuel Cell Electric Buses.

Zero Emission Cargo Transport (ZECT) Program

Heavy-duty diesel-powered trucks are a prime contributor to NOx and ozone emissions in the Basin and carbon dioxide from fossil-fueled internal combustion engines (ICEs) contribute to global GHG emissions. Accelerating the widespread deployment of zero and near-zero tailpipe emission vehicles, powered by low carbon intensity energy will significantly reduce NOx, ground level ozone and GHGs.

The ZECT program, developed through the US Department of Energy (USDOE), provided the South Coast AQMD with $4.17 million in 2012 to advance battery electric Class 8 tractors used in cargo transportation. The program intended to develop 13 trucks with four manufactures using battery-electric and hydrogen fuel cell technologies; two of the companies dropped out of the project in the early stages. South Coast AQMD secured two contracts each with two California-based integrators: TransPower (Escondido, CA now with Meritor) and US Hybrid (Torrance, CA now with Ideanomics) to build all battery-electric tractors (BET), and plug-in hybrid-electric tractors (PHET) with all-electric-range (AER) and clean alternative fuel. Vehicles were demonstrated in "real-world" operations with local drayage fleets operating in the San Pedro Bay Ports complex. Total project costs were $9.375 million. Project closure was March 31, 2020.

Figure 11: San Pedro Bay Ports Complex (J. Gritchen, LB Press telegram)

ZECT-1 was the first of two "ZECT" programs. ZECT-1 focused on advancing the BET technology. With less emphasis placed on electric vehicle supply equipment (EVSE) charging infrastructure, all vehicles were designed to charge with a low cost 60 kW marine-grade charging system selected and installed by TransPower. NREL provided third-party data analysis, and independent chassis dynamometer work was performed by the University of California at Riverside (UCR).

ZECT-1 has successfully demonstrated and advanced BET and PHET technologies. BET system efficiencies nearly doubled to 2.2 kWh/mi from a comparable 2011 study and freight customers began considering zero-emission goods movement. Further impact of the ZECT-1 is that it attracted major OEMs to initiate commercial-ready Class 6 and 8 battery-electric product development and demonstration efforts, with expected commercial releases in 2022 and 2023. Each platform met or exceeded the power and torque of 9-liter diesel tractors, demonstrated good gradeability and load hauling capability with range (under 100 miles) and systems troubleshooting being limiting factors. Both integrators started with Lithium Iron Phosphate (LFP) and ended with Nickel Manganese Cobalt (NMC) batteries. Poor battery quality, poor battery supplier reliability, greater range without payload loss were driving forces to change from LFP to NMC systems. Below are the BET and PHET platforms developed under ZECT-1.

Figure 12: BETs

Figure 13: PHETs

Table 6: 2012 ZECT-I Demonstration Portfolio

	Battery Electric Trucks		Plug-In Hybrid Electric Trucks	
Developer	TransPower	US Hybrid	TransPower	US Hybrid
No. of Trucks	4	2	2	3
Hybrid Architecture	N/A	N/A	Series	Parallel
Chassis Make and Model	International Prostar	International Prostar	International Prostar	Peterbilt 384
Traction Motor/kW	D-PMag*/300	D-PMag/320	D-PMag/300	D-PMag/240
Transmission	Auto-Manual	Direct Drive	Auto-Manual	Automatic
Auxiliary Power Unit	N/A	N/A	3.7 liter CNG	8.9 liter LNG
Batt. (kWh)/Fuel (DGE)	215-311	180-240	138/60 (CNG)	80/72 (LNG)
Charger/Power (kW)	On-Board ICU/70	On-Board/60	On-Board ICU/70	On-Board/20
Charge/Fuel Time	2.5–4 hrs	3-4 hrs	2 hrs /15 min	3-4 hrs /15 min
Vehicle Range / AER	75-150	70-100	200 /30-40	250+ /30

*D-PMag is Dual Permanent Magnet Motor

BETs: TransPower developed its ElecTruck™ or Electric Drayage Demonstration (EDD) trucks. These trucks employed two tandem-mounted 150 kW Permanent Magnet (PM) electric traction drive motors designed and supplied by Quantum Technologies (used in the Fisker-Karma hybrid-electric vehicle). An Eaton 10-speed manual transmission with computer-controlled actuation produced the "automated manual transmission" feature. Drive batteries started with 215 kWh LFP and later to 311 kWh NMC. EDDs used a combined Inverter/Charger Unit (ICU), company-designed battery modules and Battery Management System (BMS) and a proprietary vehicle control system to optimize vehicle efficiency, maximize battery life, and protect key components from excessive temperatures, voltage spikes, or current surges. Figure 14 shows the four EDD trucks; three additional EDDs were developed with CEC funds under separate contract. EDD trucks accumulated more than 43,000 in-use miles with various fleet operators, including TTSI, California Cartage Company, National Retail Trucking, 3 Rivers Trucking, SA Recycling, Knight Transportation Services, Pasha Stevedoring and Terminals, BAE Systems, and Terminalift. Data collected from this project showed runs averaging about 50-60 miles and an average energy efficiency of 2.3 kWh/mi with loads.

Figure 14: First Four EDD Trucks – March 2015

Another advancement that resulted from the early work on ZECT-1 was that TransPower integrated improved electric drive systems adding 308 kWh of Nissan NMC batteries into 12 Peterbilt 579 Class 8. Also, the EDD trucks served as the base system for a hydrogen fuel cell range extender project under separate funding from CARB.

Figure 15: eTruck-1 with 180 kWh LFP 11-Pack

Figure 16: eTruck-2 with 280 kWh NMC 6-Pack

US Hybrid built two BETs or eTrucks™ under ZECT-1 (Figures 15 & 16). Initially, a single, less costly 320 kW Induction drive motor was selected, but in 2014 following their study of how to meet necessary and continuous power and torque requirements, changed to a DPM. US Hybrid used a direct drive transmission to reduce drivetrain losses. US Hybrid's first eTruck, deployed into drayage demonstration in 2015, used 180 kWh of LFP batteries configured into 11 battery packs mounted along the rail. Preliminary testing showed an average energy efficiency of 3.3 kWh/mi and 50 mile range under full load. eTruck-2 used 280 kWh of NMC batteries, configured into 6 battery packs, to produce 100 mile range and an overall average efficiency of 2.2 kWh/mile.

Figure 17 TransPower's PHET-2 Rear Mounted ICE

PHETs: TransPower built two series-hybrid PHET's based on its BET platform. The series-hybrid used a Ford 3.7-liter spark-ignited, CNG-fueled, automotive ICE with a three-way catalyst as a "gen-set", to supplemental the drive batteries. The small ICE was mounted "behind-the-cab" as seen in Figure 17. US Hybrid developed a parallel-hybrid PHET using a conventional 300 h.p. Cummins ISL-G, 8.9-liter, spark-ignited LNG-powered ICE paired with a 240 kW electric motor, an automatic Allison transmission and 30-miles of AER (see Figures 18 & 19). The electronically controlled pneumatic driven clutch allowed the electric motor to be decoupled from the engine and permit electric only operation seamlessly and fully transparent to the driver. The parallel-hybrid performed like a 13-liter diesel tractor. Each PHET had a different outcome. The series-hybrid was battery dominant, the parallel-hybrid was engine dominant. The series-hybrid met "proof-of-concept" in UCR chassis dynamometer studies, extending battery life and battery electric range, but was less effective in-use, and generated higher than expected emissions because engine codes could not be obtained to fully utilize variable-valve-timing, relegating the ICE to a stationary not automotive application. The parallel-hybrid fulfilled operator's needs with more than

Figure 18: Two US Hybrid PHETs at TTSI

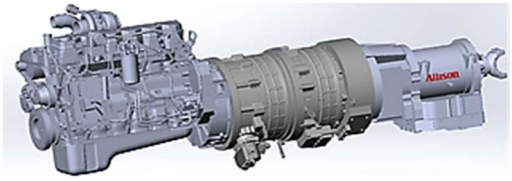


Figure 19: Parallel Hybrid Powertrain: 8.9L ISLG, Dual Electric Motors, AllisonTransmission

sufficient power and torque, and in UCR chassis dynamometer studies indicated improved efficiency and emission reductions with AER drive batteries. However, operators rarely recharged the drive batteries, relying on the ICE to maintain state-of-charge, hence minimizing the potential efficiencies and emission reductions.

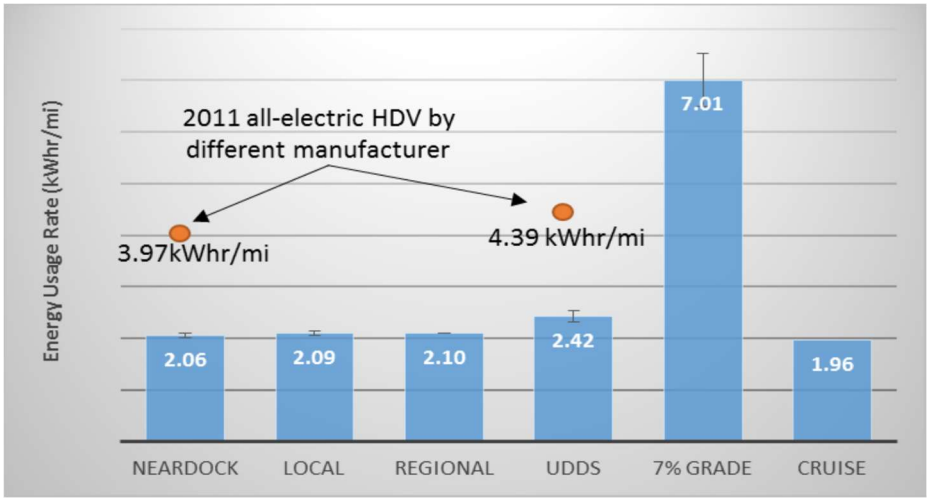


Figure 20: Energy Efficiencies ZECT-1 BETs vs 2011 BET Demonstration

Demonstrate Zero Emission Cargo Handling Vehicle at POLB

POLB completed its C-PORT (Commercialization of POLB Off-Road Technology Demonstration) project in 2021. POLB received $5.3M in a CARB ZANZEFF grant for its first demonstration of zero emission cargo handling equipment. This included the demonstration of three battery electric top handlers, one battery electric yard tractor and one fuel cell yard tractor.

Figure 21: POLB Demonstrated Battery Electric Top Handlers and Yard Tractor, and a Fuel Cell Yard Tractor

C-PORT required the collaboration of a significant number of project partners. Three Taylor battery electric top handlers developed by BYD; one Kalmar battery electric yard tractor developed by TransPower/Meritor, and one China National Heavy Duty Truck Group Co. fuel cell yard tractor developed by Loop Energy. SSA Marine demonstrated two Taylor and BYD battery electric top handlers at Pier J, and Long Beach Container Terminal (LBCT) demonstrated one Taylor and BYD battery electric top handler and one Kalmar and TransPower/Meritor battery electric yard tractor at Pier E. The project originally included the design, development and demonstration of one fuel cell yard tractor at LBCT. Prior to the demonstration phase, the fuel cell yard tractor developed by CNHTC and Loop Energy was not demonstrated due to a lack of engineering documentation to fully address POLB's safety and design concerns. The scope change in the C-PORT project reduced the CARB grant funding to $5.25M with a 50% match share requirement.

Other project partners included: disadvantaged community/equity partners California State University, Long Beach Center for International Trade and Transport, Green Education, Long Beach City College, Long Beach Unified School District Cabrillo High School Academy of Global Logistics; labor partner International Longshore & Warehouse Union; project management partner Momentum; and data collection partners Tetra Tech and University California Riverside College of Engineering Center for Environmental Research and Technology.

Figure 22: C-PORT Project Sponsors

C-PORT overall goals during its demonstration included: 1) advance economic viability of two types of pre-commercial zero emission cargo handling equipment towards commercialization, 2) demonstration zero emission cargo handling equipment under tough duty cycles in the Port setting, 3) achieve significant GHG and emission reductions, and 4) communicate benefits of zero emission cargo handling equipment at POLB to residents in disadvantaged communities (DAC).

These goals were achieved through the design, manufacture, and demonstration of three battery electric top handlers in operations at two Port terminals, 2) design, manufacture, and demonstration of one battery electric yard tractor and one hydrogen fuel cell yard tractor in a single Port terminal (the fuel cell yard tractor was ultimately removed from the demonstration due to safety concerns), 3) install EVSE to support operation of battery electric cargo handling equipment, and 4) demonstration equipment in revenue service for at least six months and collect real-world data on equipment performance.

Figure 23: LBCT (Left) and SSA (Right) Demonstrated Taylor and BYD Battery Electric Top Handlers

One battery electric top handler (Taylor and BYD) and one battery electric yard tractor (Kalmar and TransPower/Meritor) were demonstrated at LBCT, which is a mostly autonomous zero emission terminal that used the battery electric cargo handling equipment against rail-limited ad hoc operations. SSA Marine demonstrated two battery electric top handlers (Taylor and BYD) in a more typical seaport container terminal, requiring cargo handling equipment to operate two full shifts entirely.

Figure 24: Kalmar and TransPower/Meritor Battery Electric Yard Tractor (Left) and CNHTC/Sinotruck and Loop Energy Fuel Cell Tractor (Right) Demonstrated at LBCT

To support the battery electric cargo handling equipment, C-PORT required installation of four EVSE. Three 200 kW BYD DC fast chargers were installed for three top handlers and one 200 kW TransPower DC fast charger was installed for the yard tractor. One BYD and one TransPower 200 kW DC fast charger were installed at LBCT, and two 200 kW BYD DC fast chargers were installed at SSA Marine. Battery electric cargo handling equipment and EVSE deployed are shown in Table 7.

Table 7: Battery Electric Cargo Handling Equipment and EVSE by Terminal

User	OEM	Vendor	Equipment	Quantity	Infrastructure
LBCT	Taylor	BYD	Battery-Electric Top Handler	1	200 kW
	Kalmar	TransPower/ Meritor	Battery-Electric Yard Tractor	1	200 kW
	CNHTC	Loop Energy	Fuel-Cell Electric Yard Tractor	1	Mobile fueler
SSA Marine	Taylor	BYD	Battery-Electric Top Handler	2	2 x 200 kW

Port staff assisted in EVSE installation and these were the first EVSE that POLB has deployed. Due to time constraints for the CARB grant, the typical Port design, bid, and build process was not followed and a more dynamic process utilizing OEM and technology providers and performing the work in-house enabled the EVSE installation to be completed more quickly.

C-PORT included educational and workforce development. Green Education led the effort to proactively engage and educate residents of DACs by developing educational materials, conducting 10 citywide community workshops and organizing the 2018 Green Prize Festival to promote interest in zero emission Port technologies. POLB collaborated with Long Beach City College and Academy of Global Logistics (AGL) to develop and execute a capstone project to promote critical thinking around zero emission transformation at POLB. AGL introduced high school students to career opportunities in global trade and logistics through a wide range of training and educational certification programs offered by Long Beach City College and California State University Long Beach. The capstone project focused on how POLB can achieve its 2030 zero emission goal without disrupting economics and job creation at POLB.

The battery electric top handlers were not able to meet the performance requirements of two shifts at SSA Marine terminal, but the battery electric top handler was suitable for work at LBCT. SSA Marine is a busy container terminal where the top handlers have a challenging duty cycle and are required to operate two entire shifts. Operators found that the battery electric top handlers did not maintain enough battery life to be comfortably used for two full shifts. The greatest battery discharge during the demonstration was 91% for 7.61 hours and the longest day was 12.43 hours, with 29% of the days showing operations longer than 7.61 hours for diesel top handlers.

Based on POLA and POLB 2019 Emission Inventories, deploying the battery electric top handlers and yard tractor results in 237,186 MT CO2e in GHG reductions, 445.1 tons of NOx, 85.8 tons of total hydrocarbons (THC), and 7.2 tons of PM10.

Taylor reported that the next generation of their battery electric top handler will be a commercial unit featuring technology directly evolved from the C-PORT project. Kalmar reported that information from C-PORT will be used to improve the next generation of their battery electric yard tractors which will go into production in 2022.

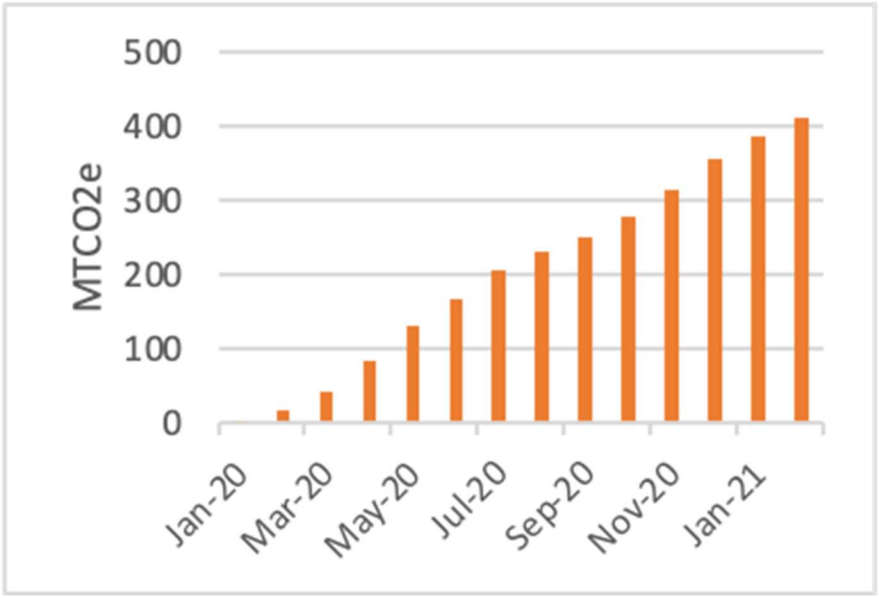
Develop and Demonstrate Zero-Emission Fuel Cell Electric Buses

As part of a larger deployment with AC Transit in the Bay Area AQMD jurisdiction, Center for Transportation and Environment (CTE) received a $22.3 million CARB GGRF grant and $1 million from South Coast AQMD's Clean Fuels Fund. South Coast AQMD funding went towards the fuel cell buses. Orange County Transportation Authority (OCTA) deployed 10 New Flyer fuel cell transit buses for $12.9 million, as well as $989,000 for facility upgrades and $5.4 million for the hydrogen station, capable of fueling up to 50 fuel cell buses. These prototype buses were placed into daily operations and provided OCTA an opportunity to learn how fuel cell buses could be successfully integrated into their operations. AC Transit also deployed 10 New Flyer fuel cell buses and had previous experience with fuel cell buses and an existing hydrogen station, which they upgraded for this project. The deployment of 20 buses allowed for some savings on the buses as well as to validate vehicle performance, reduce costs, rapid refueling, extended range, and reduced curb and axle weight to increase passenger carrying capacity. The OCTA New Flyer fuel cell bus is shown in Figure 25 below.

Figure 25: New Flyer XHE60 Xcelsior Fuel Cell Bus Deployed at OCTA

Construction of the hydrogen station and delivery of the buses allowed buses to enter into revenue service at AC Transit in January 2020 and at OCTA in February 2020. During one year of revenue service at both transit agencies, the buses accumulated 570,057 miles, 628 metric tons of GHG reductions, and 1.15 tons of weighted emission reductions. In the first year of deployment, the two fleets had an average fuel economy of 8.46 miles per kg, or roughly 9.56 miles per diesel gallon equivalent. This is about twice the average fuel economy of diesel (4.15 miles per diesel gallon) or CNG buses. Figure 26 below illustrates that the buses were able to offset a combined total of 413 metric tons of GHG reductions compared to their respective diesel fleets. The energy efficiency of the fuel cell buses was more than twice of comparable CNG buses.

Figure 26: Cumulative GHG Reductions in First Year of Deployment



The most significant metric used to rate the performance of transit buses is average vehicle availability. The average availability of the fuel cell buses was around 70%, with maximum availability of 80% for any month. Typical transit fleet operators target 85% vehicle availability to provide reliable service. As the technology matures and maintenance becomes routine, fuel cell buses are expected to meet an 85% vehicle availability target.

Another key challenge is minimizing overall environmental impacts by sourcing renewable hydrogen, which is not widely available. Emission reductions were calculated based on the realized carbon intensity of hydrogen fuel supply. Although the fuel cell buses are capable of traveling the same number of miles as diesel buses, their lower vehicle availability meant that the buses did not meet the expected target mileage. This project will provide 11.32 tons of NOx, 2.35 tons of ROG, 0.53 tons of PM 10, and 13,550 metric tons of GHG reductions during the 12-year lifetime for the 10 fuel cell buses deployed at OCTA.

Figure 27: OCTA Hydrogen Station

OCTA Hydrogen Station Statistics

- Developed by Trillium and Air Products
- Liquid hydrogen delivery
- 1600 kg/day @ 350 bar
- Capacity for up to 50 fuel cell buses
- Fueling time: 6 – 10 minutes per bus
- 280 kg peak back to back fills

The project succeeded in validating vehicle performance with increased reliability, durability, and utilization.

- Consistent in-service deployment of 47,787 service hours for the 20 buses.
- 50% reduction in cost compared to AC Transit's current generation of buses. The cost of the 20 fuel cell buses average $1,288,626 when pricing was negotiated in 2017 upon receipt of CARB grant funding. Previous generation fuel cell buses prior to 2014 were about $2.5 million per bus. The 2019 California state contract value of buses is now set at $1,014,979 per bus.
- Fill rates for fuel cell buses were about 2.98 kg per minute for OCTA and 3.16 kg per minute for AC Transit, allowing transit agencies to fill a 36 kg tank in 12 minutes. This falls within the acceptable dwell time of 10-15 minutes for conventional diesel and CNG fleets.
- Increased range, reduced curb weight allowing for higher payloads, shorter fueling times compared to battery electric buses
- Range of up to 300 miles on a single fill of hydrogen were observed in this project
- Reductions of vehicle curb and axle weights (AC Transit bus weighs 32,360 lbs. and OCTA bus weights 33,120 lbs.) enabled these buses to carry more passengers

Newer fuel cells with higher power density, more compact energy storage systems with higher capacity, and use of composite materials in future bus designs will further decrease overall vehicle weight and enable fuel cell buses to meet California's 20,000 lb axle weight limit regulation. Current axle weights are about 21,000 lbs.

In addition, several transit agencies in the Basin have expressed interest in integrating fuel cell buses into their fleets including Santa Monica Big Blue Bus, Foothill Transit, Long Beach Transit, OmniTrans, and SunLine Transit. There are two American bus OEMs, New Flyer, and ENC, that are Buy America compliant so that buses can be purchased as part of other federal funding programs. New Flyer's XHE40 and XHE60 Xcelsior fuel cell buses completed Altoona testing in 2019, making them eligible for purchase through California and federal funding programs. Costs for fuel cell buses have dropped steadily since 2004 when fuel cell bus costs exceeded $3 million. OEM estimates are now around $1 million per bus and will continue to decrease as more fuel cell buses are deployed.

Table 8: Projects Completed between January 1 & December 31, 2021

Contract	Contractor	Project Title	Date
Electric / Hybrid Electric Technologies and Infrastructure			
17065	Clean Fuel Connection, Inc.	Installation Services for Installation of EV Chargers at South Coast AQMD Headquarters	Dec 2021
17316	Center for Transportation and the Environment	Develop and Demonstrate 10 Zero-Emission Fuel Cell Electric Buses	Sept 2021
18075†	Selman Chevrolet Company	Lease Two 2017 Chevrolet Bolt All-Electric Vehicles for Three Years	Feb 2021
18151	Rail Propulsion System	Develop & Demonstrate Battery Electric Switcher Locomotive	Dec 2021
18280†	Honda of Pasadena	Three-Year Lease of One Honda 2018 Clarity Plug-In Vehicle	Jun 2021
18397	Port of Long Beach	Demonstrate Zero Emission Cargo Handling Vehicle at POLB	May 2021
20248	Los Angeles County Economic Development Corp	Economic and Workforce Impact Analysis of Electric Revolution in Southern California	Jan 2021
Engine Systems / Technologies			
20122	Landi Renzo USA Corp	Develop and Commercialize a Near-Zero Natural Gas Conversion System for On-Road Medium-Duty Vehicles	Jul 2021
Fuel / Emission Studies			
17245†	West Virginia University Research Corp	In-Use Emissions Testing and Fuel Usage Profile of On-Road Heavy-Duty Vehicles	Sept 2021
17352	California State University Maritime Academy	Develop and Demonstrate Vessel Performance Management Software and Equipment	Jun 2021
18090†	University of California Riverside	Study Secondary Organic Aerosol Formation from Heavy-Duty Diesel & Natural Gas Vehicles	Oct 2021
19208	University of California Riverside	Conduct Emission Study on Use of Alternative Diesel Blends in Off-Road Heavy-Duty Engines	Jul 2021
20058	University of California Riverside	Evaluate Meteorological Factors and Trends Contributing to Recent Poor Air Quality in Basin	Sept 2021
Hydrogen / Mobile Fuel Cell Technologies and Infrastructure			
15618	FirstElement, Inc.	Installation of Eight Hydrogen Stations in Various Cities (two renewable, 6 delivered)	Feb 2021
15635	Center for Transportation and the Environment	ZECT II - Development & Demonstration of 1 Class 8 Fuel Cell Range Extended Electric Drayage Truck	Sept 2021
16251	H2 Frontier Inc.	Develop & Demonstrate Commercial Mobile Hydrogen Fueler	May 2021
17317†	American Honda Motor Co., Inc.	Three Year Lease of One Honda 2017 Clarity Fuel Cell Vehicle	Mar 2021
17343†	American Honda Motor Co., Inc.	Three Year Lease of One Honda 2017 Clarity Fuel Cell Vehicle	Feb 2021

Table 8: Projects Completed between January 1 & December 31, 2021 (cont'd)

Contract	Contractor	Project Title	Date
Hydrogen / Mobile Fuel Cell Technologies and Infrastructure (cont'd)			
17385†	American Honda Motor Co., Inc.	Three Year Lease of One Honda 2017 Clarity Fuel Cell Vehicle	May 2021
18158	National Renewable Energy Laboratory	California Hydrogen Infrastructure Research Consortium H2 @ Scale Initiative	Mar 2021
19172†	Longo Toyota	Three Year Lease of Two 2018 Toyota Mirai Fuel Cell Vehicles	Oct 2021
20108	University of California Irvine	Develop Optimal Operation Model for Renewable Electrolytic Fuel Production	Jun 2021
21336	Frontier Energy, Inc.	Participate in California Fuel Cell Partnership (CaFCP) for Caledar Year 2021	Dec 2021
Fueling Infrastructure and Deployment (NG / RNG)			
17092†	Kore Infrastructure LLC	RNG Production & Vehicle Demonstration	Oct 2021
Technology Assessment and Transfer / Outreach			
17358†	AEE Solutions LLC	Technical Assistance with Heavy-Duty Vehicle Emissions Testing, Analyses & Engine Development	May 2021
20348†	Gladstein, Neandross & Associates LLC	Cosponsor the 2021 Renewable Gas 360 Symposium and Webinar Series	March 2021
21078†	Charging Interface Initiative e.V.	Cosponsor High Power Charging for Commercial Vehicles Event	Jan 2021
21203†	University of California Riverside	Cosponsor the 2021 Portable Emissions Measurement Systems Conference	Aug 2021
21357†	University of California Davis	Cosponsor the Asilomar 2021 Conference on Transportation & Energy	Oct 2021
22044†	Gladstein, Neandross & Associates LLC	Cosponsor the 2021 Advanced Clean Transportation (ACT) Expo	Sept 2021
22073†	University of California Irvine	Cosponsor ICEPAG 2021	Dec 2021

†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.

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CLEAN FUELS PROGRAM

2022 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 2022 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 AQMP, which will be updated in 2022, is the long-term regional "blueprint" that relies on fair-share emission reductions from all jurisdictional levels (e.g., federal, state and local). The 2016 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).

The emission reductions and control measures in the 2016 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 2016 AQMP identifies a 45 percent reduction in NOx required by 2023 and an additional 55 percent reduction by 2031 to achieve 8-hour ozone standards of 80 ppb and 75 ppb, respectively. The majority of NOx reductions must come from mobile sources, including both on- and off-road vehicle and equipment. Notably, South Coast AQMD is currently only one of two regions in the nation designated as an extreme nonattainment area (the other region is California's San Joaquin Valley). Furthermore, in April 2019, South Coast AQMD requested a voluntary re-classification from U.S. EPA of the 1997 8-hour federal ozone standard for the Coachella Valley region of the South Coast AQMD to "extreme" status. Hotter temperatures and other meteorological changes impacted by climate change in this region have presented challenges that require additional time to reach attainment.

While current state efforts in developing regulations for on- and off-road vehicles and stationary equipment are expected to reduce NOx emissions significantly, they will be insufficient to meet South Coast AQMD needs, particularly in terms of timing. The 2016 AQMP identified a means to achieving the NAAQS through regulations and incentives for near-zero and zero emission technologies that are commercial or nearing commercialization. This strategy requires a significantly lower state and national heavy-duty truck engine emissions standard with the earliest feasible implementation date, significant additional financial resources, and accelerated fleet turnover on a massive scale. To support the fleet turnover the Clean Fuels Program's emphasis continues on commercialization of larger heavy-duty (HD) low NOx engines and large

deployment projects of zero emission HD trucks like the Joint Electric Truck Scaling Initiative (JETSI) Pilot Project. [6]

While zero emission technologies, battery and fuel cell electric vehicles are making strides towards commercialization the number of battery electric HD trucks that will be deployed in time to meet the 2023 and 2031 ozone standards will fall short of what is required. The impacts and challenges of large deployments of battery electric vehicles are not yet fully understood or have been addressed. Vehicle and infrastructure costs, fleet adoption, impacts to the electrical grid, OEM supply chain and re-tooling of assembly plants and support networks for vehicle maintenance and service, development and standardization of ultra fast megawatt charging and fleet integration of limited range battery electric vehicles into their logistics and business model are some of the challenges that must be dealt with before widespread deployments of battery electric HD trucks become a reality. Efforts to address these challenges are being undertaken by projects like the JETSI 100 truck deployment and EPRI's RHETTA project for ultra fast megawatt charging development are the first trials to address the complex challenges of integrating large fleets of zero emission vehicles. In addition to these efforts once completed the findings and results will need to be studied, resolutions developed, funded and implemented.

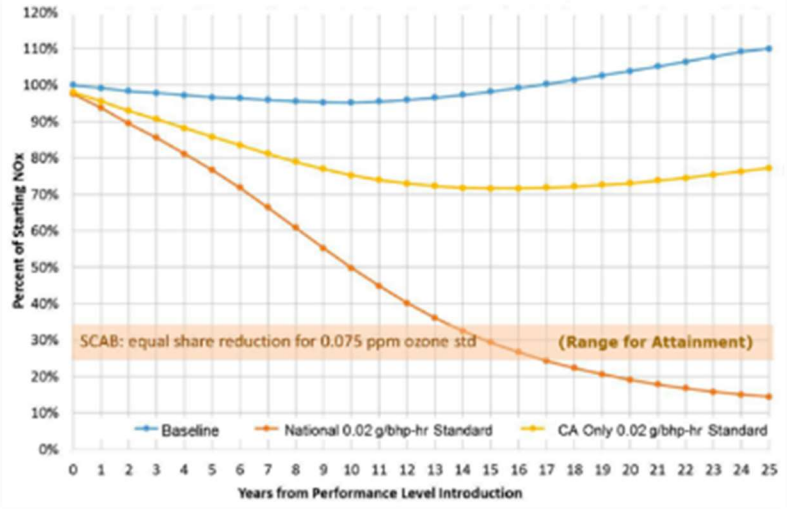
In light of the projected limited deployment of zero emission battery electric vehicles and infrastructure in the near term and the development and commercialization of fuel cell electric vehicles and infrastructure in the mid term our strategy is to continue development of near-zero low NOx engines to meet the NAAQS. On June 3, 2016, South Coast AQMD petitioned the U.S. EPA to initiate rulemaking for a lower national NOx standard for on-road heavy-duty engines to achieve additional mobile source emission reductions. A national NOx standard (as opposed to a California standard) for on-road heavy-duty 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 heavy-duty 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 heavy-duty vehicles.

U.S. EPA has since acknowledged the need for additional NOx reductions through a harmonized and comprehensive national NOx reduction program for heavy-duty 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 heavy-duty trucks. The progress was stalled in 2020 but EPA recently confirmed the deadline given by the president's Executive Order to finalize low NOx rulemaking by the end of 2022 for lower NOx standard with model year 2027. In the summer of 2020 CARB adopted its own Low NOx Omnibus rule. The new regulation imposes lower NOx standards starting in model year 2024, that will harmonize with U.S. EPA's Cleaner Truck Initiative's national NOx standard of 0.02 g/bhp-hr in 2027, 90% below today's NOx standard. Although both regulations are welcome news, their implementation and effectiveness are too late to help the South Coast AQMD meet its 2023 federal ozone attainment deadline. So, despite the milestone progress, commercialization and deployment of cost-effective near-zero engines are still needed to meet near-term goals.

Given that the Basin must attain the 75-ppb ozone NAAQS by 2031, a new on-road heavy-duty 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.

[6] The project, known as Joint Electric Truck Scaling Initiative, or JETSI, is the largest commercial deployment of battery-electric trucks in North America to date, helping to significantly increase the number of zero-emission heavy-duty 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.

Figure 28 shows the difference in NOx reductions from on-road heavy-duty trucks under three scenarios: baseline (no change in the low NOx standard) in blue, a low NOx standard adopted only in California in yellow, and lastly, a federal low NOx standard in orange.



Source: Presentation by Mr. Cory Palmer, ARB at the Symposium on California's Development of its Phase 2 Greenhouse Gas Emission Standards for On-Road Heavy-Duty Vehicles (April 22, 2015)

Figure 28: NOx Reduction Comparison: No New Regulations vs Low NOx Standard in California only vs National Standard

In mid-2017, South Coast AQMD initiated MATES V 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, finalized in June 2021, 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 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. In the meantime, 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 $231.6 million toward projects exceeding $1.14 billion. 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 technologies 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 in 1998, South Coast AQMD has implemented other incentive programs (i.e., Volkswagen Mitigation, Proposition 1B-Goods Movement, and Community Air Protection Program), with cumulative funding of

$250 million annually. Starting in 2022, there will also be AB 617 incentive funding reserved for zero emission trucks in AB 617 communities which was identified as a funding priority in their CERPs. The 2016 AQMP also included control measures to develop indirect source regulations and strengthen the 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 are still needed for the scale necessary to achieve the NAAQS for this region. Meanwhile, South Coast AQMD is seeking to commercialize alternative low-NOx technologies that do not rely on incentives by providing customer fuel savings with low payback periods. There are several emerging key technologies that are discussed in detail later that will provide the NOx and GHG co-benefit which might no longer require vehicle purchase incentives.

As technologies move towards commercialization, such as heavy-duty battery electric trucks, the Clean Fuels Program has been able to partner with large OEMs, such as Daimler and Volvo to deploy these vehicles in large numbers. These OEM partnerships allow the Program to leverage their research, design, engineering, manufacturing, sales and service, and financial resources that are needed 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 hydrogen fuel cells, manufacture in large quantities and distribution network to support sales across the state. To obtain the emission reductions needed to meet NAAQS, large numbers of advanced technology clean-fueled vehicles must be deployed across our region and state.

Figure 29 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 South Coast AQMD's 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 to achieve near-term and long-term emission reduction benefits.

Figure 29: Technology Readiness Levels

Many of the technologies that address the Basin's needed NOx reductions align with the state's GHG reduction efforts. U.S. EPA (2021)[7] noted that the transportation sector contributed 29 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.

[7] *U.S. Greenhouse Gas Emissions and Sinks 1990-2019*. 2021. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

Program and Funding Scope

This 2022 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 by including accelerated development of technologies nearing commercialization and deploying 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 2022 Plan Update needs to remain sufficiently flexible to address new technologies and control measures identified in the 2016 AQMP, dynamically evolving technologies, and new research and data. The latter includes findings from MATES V and revised emission inventories from the recently released EMFAC 2021.

Within the core technology areas defined later in this section, project objectives range from near term to long term. The South Coast AQMD 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 2021, including obtaining required certifications from CARB and U.S. 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 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 depend on efforts to increase stakeholder confidence that these technologies are viable and cost-effective in the long term.
- Technologies ready to begin field *demonstration* in 2022 are expected to result in commercially available products in the 2023-2025 timeframe, and technologies being demonstrated generally are in the process of being verified or certified by CARB and U.S. 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 the technologies. Field demonstrations provide real-world evidence of performance to allay any concerns by early adopters.
- Finally, successful technology *development* projects are expected to begin during 2022 with duration of two or more years. Additionally, field demonstrations to gain long term verification of performance may also be needed prior to commercialization. Certification and commercialization would be expected to follow. Development projects identified in this plan may result in technologies ready for commercial introduction as soon as 2022-2026. 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 2027 or later.

Core Technologies

The following technologies have been identified as having the greatest potential to enable the emission reductions needed to achieve 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 2022 due to funding limitations, and the focus will remain on control measures identified in the 2016 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 heavy-duty 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 operating on an alternative fuel as a range extender. Elements of the core hybrid electric system 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 mid-2017, will implement actions and provide 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 nine core technology areas are listed by current South Coast AQMD priorities based on the goals for 2022.

Hydrogen/Mobile Fuel Cell Technologies and Infrastructure

The South Coast AQMD supports hydrogen infrastructure and fuel cell technologies as one option in the technology portfolio; the agency is dedicated to assisting federal and state government programs to deploy light-, medium-, and heavy-duty fuel cell electric vehicles (FCEV) by supporting the required hydrogen fueling infrastructure.

Calendar Years 2015-2019 were a critical timeframe for the introduction of hydrogen fueling infrastructure. 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. 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. Changes to CARB's Low Carbon Fuel Standard (LCFS) regulation to provide credit for low carbon fuel capacity in addition to throughput is enabling station operators to remain solvent during the early years until vehicle numbers ramp up. 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 refueling reliability matching those of existing gasoline and diesel fueling stations. The current network of hydrogen fueling stations to support the current number of light-duty FCVs on the

road is insufficient, and supply of hydrogen and additional hydrogen production continue to be challenges that need to be addressed.

In 2018, Former Governor Brown issued Executive Order (EO) B-48-18. Among other provisions, the order sets an additional hydrogen station network development target of 200 stations by 2025. Meeting this new ambitious target clearly requires accelerated effort on the part of the State to ensure its achievement. The EO additionally sets a target for 5 million ZEVs by 2030; FCVs are expected to comprise a significant portion of this future ZEV fleet. In September 2019, Governor Newsom issued EO N-19-19 on Climate Change, which directs CARB to push OEMs to produce even more clean vehicles, and to find ways for more Californians, including residents in disadvantaged communities, to purchase these vehicles on the new and used markets. CARB is tasked with developing new grant criteria for clean vehicle programs to encourage OEMs to produce clean, affordable cars and propose new strategies to increase demand in the primary and secondary markets for ZEVs. Finally, CARB is taking steps to strengthen existing or adopt new regulations to achieve GHG reductions within the transportation sector.

Fuel cells can play a role in medium- and heavy-duty applications where battery recharge time, although improving, is insufficient to meet fleet operational requirements. The California Fuel Cell Partnership's (CaFCP's) *2030 Vision*[8] released in July 2018 provides a broader framework for the earlier *Medium- and Heavy-Duty 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 *Heavy-Duty Vision* released in July 2021 describes 70,000 fuel cell electric trucks supported by 200 heavy-duty hydrogen stations operating in California and beyond.

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 heavy-duty hydrogen fueling station using hydrogen produced by a new tri-generation fuel cell on POLB property leased by Toyota. 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.

Another player in the heavy-duty fuel cell truck space is Cummins who recently purchased Hydrogenics and EDI to develop fuel cell power trains. Cummins is currently working on the ZECT 2 and a CEC/South Coast AQMD supported project that will develop and demonstrate fuel cell drayage trucks with next generation fuel cell module - easy to package system design and other innovative integration strategies. Also, Volvo and Daimler this year 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 heavy-duty 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, CTE, in partnership with New Flyer, Trillium, and OCTA, deployed 10 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. This project also deployed 10 fuel cell transit buses and a hydrogen station upgrade at Alameda-Contra Costa Transit District (AC Transit). SunLine Transit Agency was the recipient

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

of a U.S. EPA Targeted Airshed grant in June 2020 to deploy five fuel cell transit buses, in addition to their existing fleet of 21 fuel cell (in process to accept 5 fuel cell buses) 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. In August 2021, the Clean Fuels Program committed $531,166 to a $2 million project to develop and demonstrate two medium-duty fuel cell buses at Sunline.

The 2022 Plan Update identifies key opportunities while clearly leading the way for pre-commercial demonstrations of OEM vehicles. 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 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 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 Basin;
- 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 investing as well as critical assessments of market risks to guide and protect this investment;
- 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; and
- repurpose of 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.

Engine Systems/Technologies

To achieve the emissions reductions required for the Basin, ICEs used in the heavy-duty sector will require emissions that are 90 percent lower than the 2010 standards as outlined in CARB's recently adopted Heavy-Duty On-Road "Omnibus" Low NOx regulation and EPA's Cleaner Trucks Initiative. In 2016, Cummins Westport, Inc. (CWI) achieved a new ultra-low NOx threshold by commercializing the first on-road heavy-duty 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; and powering these vehicles with low Carbon Intensity renewable fuels or biomethane, to help address GHG objectives, became a game changer for the heavy-duty 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, also 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. CARB and U.S. EPA certified both engines at 0.02 g/bhp-hr for NOx. New for 2020, Cummins 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. For trucks that cannot utilize the Cummins near-zero emission engines, the 2022 Plan Update includes potential projects to develop, demonstrate and certify natural gas and propane engines in the 6-8L range, several options has been made available for medium-duty truck and bus platforms. Although no near-zero emission diesel technology is commercially available today, South Coast AQMD has been working closely

with CARB, U.S. EPA and others on defining technology pathways via several projects, including the Ultra-Low Emissions Diesel Engine Program at SwRI, opposed piston engine development with Achates Power Inc., and Thermal Management using Cylinder Deactivation (CDA) with West Virginia University. The 2022 Plan Update includes on-road truck demonstrations for the SwRI as well as the Achates projects, these demonstration efforts are considered key milestones in driving up the TRL level toward full commercialization. CDA has proven to be a key engine enabling technology for controlling exhaust temperature and increasing efficiency. These demonstration projects, although not yet complete, show that near-zero emission diesel technologies using renewable fuel sources are feasible via advanced engine and aftertreatment or optimized engine design and calibration. At the same time, applications that require high power/torque levels are also the applications where zero emission technologies and supporting infrastructures will take longer to become commercially available, and development of near-zero emission technologies would be critical to support those applications. The Plan Update continues to incorporate pursuit of cleaner engines and hybrid powertrains for the heavy-duty sector. Future projects will support the development, demonstration and certification of engines and powertrains that can achieve these massive near-term emission reductions using an optimized powertrain systems approach. At the same time, the aggressive GHG emissions reduction targets set forth by both CARB and EPA have invigorated interest in revisiting low- and zero carbon alternative fuels for those high power/torque applications as well as off-road applications. While the GHG benefit is easy to assess, it is important to understand the criteria emissions impact where optimized engine systems are required from earlier learnings to ensure reduction of both criteria and GHG can be met. In December 2018, South Coast AQMD participated in the Natural Gas Engine & Vehicle R&D Source Review Panel meeting in Sacramento to review, discuss and prioritize several natural gas engine and vehicle technology projects that increase efficiencies using advanced engines or hybrid drive trains.

The 2022 Plan includes potential projects that the South Coast AQMD might participate in with federal and state agencies towards these efforts. Specifically, these projects are expected to target the following:

- development of ultra-low emissions and improved higher efficiency natural gas engines for heavy-duty vehicles and high horsepower applications projects that move these technologies to a higher technology readiness level and commercialization;
- continued development and demonstration of gaseous- and liquid-fueled, advanced fuels or alternative fuel medium-duty and heavy-duty engines and vehicles;
- development and demonstration of CNG hybrid vehicle technology;
- development and demonstration of diesel hybrid vehicle technology;
- development and demonstration of alternative fuel engines for on- and off-road applications;
- evaluation of alternative engine systems such as plug-in hybrid vehicles;
- development and demonstration of engine systems that employ advanced engine design features, CDA, improved exhaust or recirculation systems, and aftertreatment devices.
- further development of robust aftertreatment systems which can maintain certified emissions levels throughout useful life.

U.S. EPA's recent initiation to create a new national low NOx standard for on-highway heavy-duty 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 heavy-duty engines.

Electric/Hybrid Technologies and Infrastructure

To meet federal standards for PM2.5 and ozone, a primary focus must be on zero and near-zero emission technologies. A key strategy to achieve these goals is the wide-scale electrification of transportation. South Coast AQMD supports projects to address concerns regarding cost, battery life, all-electric range, charging infrastructure 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. Additionally, the challenges of installing infrastructure both in terms of costs and construction impacts needs to be better understood.

There are separate challenges associated with light-duty EVs vs. medium- and heavy-duty EVs, which are on opposite ends of the commercialization spectrum. Light-duty EVs and charging infrastructure have long been commercially available and availability of public charging and costs to deploy infrastructure are the main challenges. Medium- and heavy-duty 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 medium- and heavy-duty EVs has generally been with the Combined Charging System Combo 1 (CCS1) connector in North America. Although Volvo and ABB obtained UL certification of the Combined Charging System Combo 2 (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 medium- and heavy-duty charging infrastructure increase exponentially compared to light-duty infrastructure. Each year there are more commercially available options for medium- and heavy-duty on-road EVs and off-road equipment, charging infrastructure to support these EVs and equipment, and an ability to fund larger scale deployment projects for medium- and heavy-duty EVs, equipment, and infrastructure.

The 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/infrastructure (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% GHG and criteria pollutant reductions. The San Pedro Bay Ports *Clean Air Action Plan* (2017) calls for zero emissions cargo handling equipment by 2030 and zero emission drayage trucks by 2035, respectively.

New zero emission battery electric technology projects include: 1) 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 $16M from CARB and $11M from CEC; 2) Switch-On Project with deployment of 70 Volvo Class 8 battery electric drayage/freight trucks at up to five fleets in the Inland Empire and San Fernando Valley in Los Angeles funded by a $20 million U.S. EPA Targeted Airshed grant, 3) deployment of two additional Class 8 battery electric drayage trucks as part of the CARB funded 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 and 150 kW DC fast chargers at Producers Dairy in Fresno as part of the CARB funded GGRF Zero Emission Drayage Truck Project, 5) Daimler Commercial Experience project to demonstrate eight Class 6 and 8 battery electric trucks and fast charging infrastructure funded with $1 million by the South Coast AQMD Clean Fuels Fund.

Continued technology advancements in light-duty infrastructure have facilitated the development of corresponding codes and standards for medium- and heavy-duty infrastructure including the 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 (LADWP) include funding for medium- and heavy-duty vehicles and infrastructure.

Heavy-duty 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, will 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. CARB adopted new test procedures for medium-duty and heavy-duty hybrid powertrains to certify to engine standards in CARB's proposed Heavy-Duty On-Road "Omnibus" Low NOx regulation. The new hybrid powertrain test procedures will properly credit for the fuel and emission benefits of hybrid vehicles via vehicle simulation on vehicle-based cycles and allow the entire powertrain system to certify to potentially lower emissions standards than traditional engine only tests. 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 reducing NOx emissions in the near term. Furthermore, CARB's Advance Clean Trucks and Advance Clean Fleets regulations both allow sales of plug-in hybrid vehicle that's capable of zero-emission operation as a compliance pathway for meeting the zero emission mandate.

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., heavy-duty battery electric or plug-in electric drayage trucks with all electric range;
- large scale deployments of commercial battery electric vehicles and infrastructure (i.e. 50 or more vehicles) to prove feasibility and develop tools for fleets to assist in successful operation for drayage and short regional haul operations;
- demonstration of medium-duty battery electric and fuel cell electric vehicles in package delivery operations, e.g., battery electric walk-in vans with fuel cell or CNG 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 CNG hybrid vehicle technology;
- development and demonstration of diesel hybrid vehicle technology;
- development of hybrid vehicles and technologies for off-road equipment;
- demonstration of niche application battery and fuel cell electric medium- and heavy-duty 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 heavy-duty trucks;
- demonstration and installation of infrastructure to support battery electric and fuel cell electric vehicle light-, medium- and heavy-duty 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);
- development of higher density battery technologies for use in heavy-duty vehicles;
- repurpose 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;
- 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; and
- deployment of infrastructure corresponding to codes and standards specific to light-, medium- and heavy-duty vehicles, including standardized connectors, fuel quality, communication protocols, and open standards and demand response protocols for EV chargers to communicate across charging networks.

Fueling Infrastructure and Deployment (Natural Gas/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.

CNG and LNG refueling stations continue to be positioned to support both public and private fleet applications. Funding has been applied to provide refueling at key points for all classes of vehicles, with an emphasis on heavy-duty natural gas 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 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 partial or complete transition to renewable fuels, particularly natural gas delivered through existing natural gas pipelines. Funding has been provided to support local production and use of renewable natural gas to incentivize turnover to near-zero natural gas-powered heavy-duty 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 natural gas end uses by 2030.

Some of the 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, 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 emissions reductions from natural gas refueling equipment;
- expansion of fueling infrastructure, fueling stations, and equipment, with an emphasis on renewable energy sources; and
- 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. For example, a recent 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 particulate matter in the form of ammonium sulfates. An ongoing demonstration project funded in part by the South Coast AQMD 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 SCR NOx emissions or lower. 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. 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 potentially stranded renewable electricity to be stored as hydrogen fuel. 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 the 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.

The development, demonstration, deployment and commercialization of advanced stationary clean fuel technologies will support control measures in the 2016 AQMP in that they reduce emissions of NOx and VOCs from traditional combustion sources by replacement or retrofits with zero and near-zero emission technologies.

Health Impacts, Fuel and Emissions Studies

The monitoring of pollutants in the Basin is extremely important, especially when linked to (1) a particular sector of the emissions inventory (to identify the responsible source or technology) and/or (2) exposure to pollution (to assess potential health risks). In fact, studies indicate that ultrafine particulate matter (PM) can produce irreversible damage to children's lungs. This information highlights the need for further emission and health studies to identify emissions from high polluting sectors as well as the health effects 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 in an effort to approve these fuels in California, the results of these studies are expected in 2022. 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, 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 published in 2022. 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 the 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 heavy-duty 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; the NOx reduction from natural gas fueled vehicles, especially ones certified to near-zero emission levels, are significant compared to diesel baseline. The results of the study also contributed to the new EMFAC 2021 emissions model. In 2020, CARB adopted 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), and 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 short-falls of previous in-use testing methods and should address the issue of gap between in-use emissions and certification standard, an issue commonly seen in the Basin where many heavy-duty vehicles operate in low-speed, low load modes The current and future real-world emissions study could help stakeholders better understand the impacts of emissions in real time to a specific geographic area.

Senate Bill 210 was signed in the law in 2019 which directs CARB to develop and implement a new comprehensive heavy-duty inspection and maintenance (HD I/M) program to support higher emitter and issues with mal-maintenance to ensure trucks maintain their emissions for their intended useful life. The HD I/M program includes a measurement emission from a large population of trucks which is critical for

success of this program. Remote sensing technology, which can be setup near roadside and on freeway over passes has gained the spotlight for enabling a new suite of technology for assess emissions in-use. In August 2021, CARB staff shared findings from the pilot program. 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 as OBD testing technologies have proven to be capable of reliably collecting OBD parameters of interest and diagnosing emissions related vehicle issues. REMD testing has good inter-system correlation and repeatability for NOx, and repairs for identified emissions related issues were found to be feasible and effective at reducing emissions. Automated License Plate Recognition (ALPR) camera technologies were also able to capture 80% of license plates to assist in enforcement efforts. A statewide vehicle compliance program would likely be phased in with vehicle screening starting in January 2023, enforcement of compliance certificate requirements in July 2023, and periodic testing and certified devices for OBD submissions in 2024. CARB would take a HD I/M Proposed Regulation for a statewide vehicle compliance program to their Board for consideration in December 2021. The new HD I/M rule should address the concerns of high emitters in the legacy fleet which are expected to remain service well into 2030s, further reducing emissions in our region.

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. In mid-2017, South Coast AQMD initiated MATES V 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 finalized in August 2021 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. Highest risk locations are at LAX and the Ports along goods movement and transportation corridors. Diesel PM continues to be the major contributor to 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.

In recent years, there has also been an increased interest at the state and federal level on the use of alternative fuels to reduce petroleum oil dependency, GHG emissions and air pollution. In order 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, the 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, along with SoCalGas, UCR/CE-CERT launched a study to assess emissions of hydrogen-natural gas blends on near-zero emission natural gas engines, the study was impacted by Covid-19 shut downs but recently has resumed testing with results available in early 2022. Moreover, based on higher average summer temperatures noted over the past few years, there is interest on how the higher temperatures impact ozone formation. In line with this, a project 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, to evaluate in-use emission composition;
- in-use emission studies to determine impact of new technologies, in particular EVs on local air quality as well as 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 hydrogen-fossil fuel blends on latest technology engines; and
- evaluation of impact of higher ambient temperatures on emissions of primary and secondary air pollutants.

Emissions Control Technologies

Although engine technology and engine systems research are required to reduce the 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 natural gas RNG, biofuels, synthetic and low carbon fuels into the engine or via aftertreatment controls such as PM traps, advanced SCR and DPF catalysts coupled with electrically heated diesel exhaust fluid (DEF) dosers and electrical heaters that increase the aftertreatment temperature utilizing the 48V battery system from diesel-hybrid powertrain, as well as using low sulfur fuel. 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 and lower, the lubricant contributions to VOC and PM emissions become increasingly important. Recently, particulate matter (PM and PN) emissions from GDI fueled light-duty vehicles, natural gas fueled medium- and heavy-duty vehicle have gathered attention due to lack of a particulate filter. While relative PM level are low and below the applicable standard, concerns on ultra-fine emissions needs to be assessed. South Coast AQMD have been and will continue to fund studies to help mitigate particulate matter related concerns to gasoline and natural gas fueled engines.

Recently, onboard emissions sensors have been identified by CARB and other agencies as a new 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, to enable advanced concepts like Geofencing, Eco-routing, and more. 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 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.

Technology Assessment and Transfer/Outreach

Since the value of the Clean Fuels Program depends on the deployment and adoption of the demonstrated technologies, outreach and technology transfer efforts are essential to its success. This core area encompasses assessment of advanced technologies, including retaining outside technical assistance to expedite the 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). As part of AB 617[9], which requires reduce exposure to communities most 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 the deployment of zero emission heavy-duty trucks has been included in the CERPs and an RFP for zero emission heavy-duty truck incentive funding will be released in 2022 for these AB 617 communities.

Target Allocations to Core Technology Areas

The figure below presents the potential allocation of available funding, based on South Coast AQMD projected program costs of $21.8 million for all potential projects. The actual project expenditures for 2022 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. Specific contract awards throughout 2022 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.

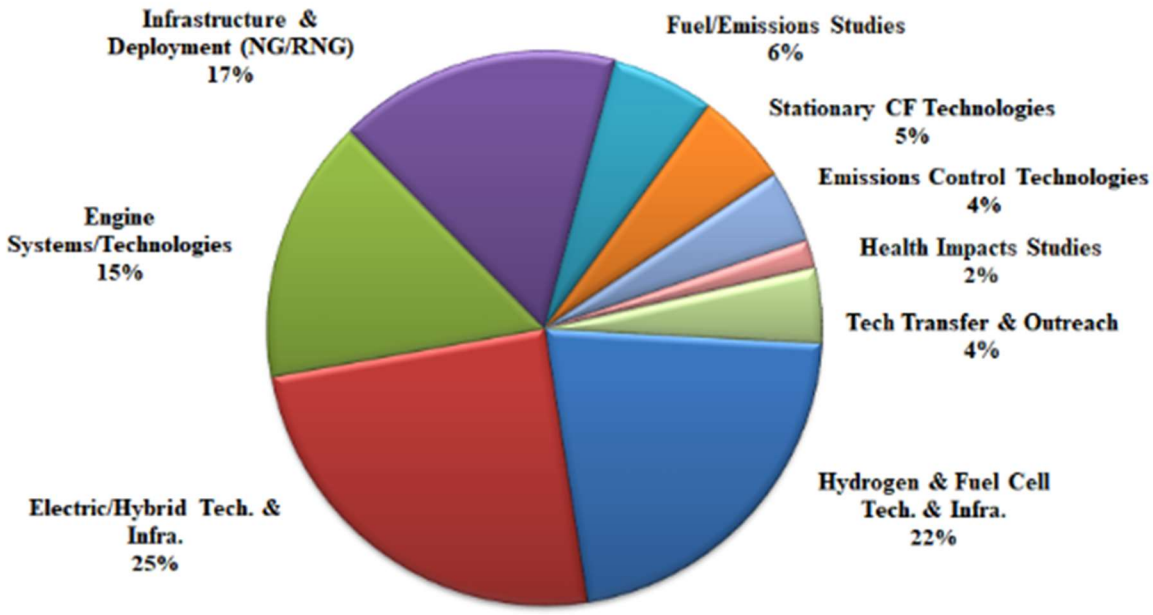


Figure 30: Projected Cost Distribution for Potential South Coast AQMD Projects in 2022 ($21.8M)

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

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CLEAN FUELS PROGRAM

Program Plan Update for 2022

This section presents the Clean Fuels Program Plan Update for 2022. 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 (CAP) funding, Volkswagen Mitigation and Carl Moyer, and VOC and NOx mitigation.

Table 9 summarizes potential projects for 2022 as well as the distribution of South Coast AQMD costs in some areas as compared to 2021. The funding allocation continues the focus on development and demonstration of zero and near-zero emission technologies including infrastructure to support these vehicles and off-road equipment. For the 2022 Draft Plan Update, the same four funding categories remain at the top but with reduced funding for electric/hybrid technologies in light of large electric/hybrid projects recently funded and with additional funding to Stationary Clean Fuel Technologies and Emissions Control Technologies for planned projects in 2022, including:

- Heavy-duty zero emission battery electric and fuel cell trucks and infrastructure;
- 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;
- Heavy-duty diesel truck replacements with near-zero emissions natural gas trucks; and
- Fuel and emissions studies, such as conducting airborne measurements and analysis of NOx emissions and assessing emissions impacts of hydrogen-natural gas fuel blends on near-zero emissions heavy-duty natural gas engines.

As in prior years, the funding allocations again align well with the South Coast AQMD's FY 2021-22 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 the projects, participating host sites and fleets, and securing sufficient cost-sharing to complete the project, and other necessary factors. Recommendations to the South Coast AQMD Governing Board will include descriptions of the technologies to be demonstrated or deployed, their applications, proposed scope of work, and capabilities of the selected contractor(s) and project team, in addition to the expected costs and benefits of the projects as required by H&SC 40448.5.1.(a)(1). Based on communications with all of the organizations specified in H&SC 40448.5.1.(a)(2) and review of their programs, the 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 9.

Proposed Project: A descriptive title and a designation for future reference.

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

Expected Total Cost: The estimated total project cost including the South Coast AQMD cost-share and the 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: A brief summary of the proposed technology to be developed and demonstrated, including the expected vehicles, equipment, fuels, or processes that could benefit.

Potential Air Quality Benefits: A brief discussion of the expected benefits of the proposed project, including the expected contribution towards meeting the goals of the 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, the true benefits will be seen over a longer term, as a successfully demonstrated technology is eventually commercialized and implemented on a wide scale.

Table 9: Summary of Potential Projects for 2022

Proposed Project	Expected SCAQMD Cost $	Expected Total Cost $
Hydrogen/Mobile Fuel Cell Technologies and Infrastructure		
Develop and Demonstrate Hydrogen Research to Support Innovative Technology Solutions for Fueling Fuel Cell Vehicles	50,000	800,000
Develop and Demonstrate Hydrogen Production and Fueling Stations	2,000,000	6,500,000
Develop and Demonstrate Medium- and Heavy-Duty Fuel Cell Vehicles	2,644,500	12,000,000
Demonstrate Light-Duty Fuel Cell Vehicles	30,000	75,000
Subtotal	$4,724,500	$19,375,000
Engine Systems/Technologies		
Develop and Demonstrate Advanced Gaseous- and Liquid-Fueled Medium- and Heavy-Duty Engines & Vehicle Technologies to Achieve Ultra-Low Emissions	3,000,000	21,000,000
Develop and Demonstrate Alternative Fuel and Clean Conventional Fueled Light-Duty Vehicles	176,300	1,000,000
Develop and Demonstrate Low Emissions Locomotive Technologies and After Treatment Systems	176,300	1,000,000
Subtotal	$3,352,600	$23,000,000
Electric/Hybrid Technologies and Infrastructure		
Develop and Demonstrate Medium- and Heavy-Duty On-Road and Off-Road Battery Electric and Hybrid Vehicles and Equipment	2,400,000	22,800,000
Develop and Demonstrate Electric Charging Infrastructure	2,600,000	52,090,000
Demonstrate Alternative Energy Storage	300,000	2,000,000
Demonstrate Light-Duty Battery Electric Vehicles and Plug-In Hybrid Vehicles	75,000	200,000
Subtotal	$5,375,000	$77,090,000
Fueling Infrastructure and Deployment (Natural Gas/Renewable Fuels)		
Demonstrate Near-Zero Emission Natural Gas Vehicles in Various Applications	1,400,000	19,000,000
Develop, Maintain and Expand Renewable Fuel Infrastructure	200,000	2,100,000
Demonstrate Renewable Transportation Fuel Manufacturing and Distribution Technologies	2,000,000	10,000,000
Subtotal	$3,600,000	$31,100,000
Stationary Clean Fuel Technologies		
Develop and Demonstrate Microgrids with Photovoltaic/Fuel Cell/Battery Storage/EV Chargers and Energy Management	1,000,000	4,500,000
Develop and Demonstrate Zero or Near-Zero Emission Energy Generation Alternatives	200,000	500,000
Subtotal	$1,200,000	$5,000,000

Table 9: Summary of Potential Projects for 2022 (cont'd)

Proposed Project	Expected SCAQMD Cost $	Expected Total Cost $
Fuel/Emissions Studies		
Conduct In-Use Emissions Studies for Advanced Technology Vehicle Demonstrations	500,000	2,000,000
Conduct Emissions Studies on Biofuels, Alternative Fuels and Other Related Environmental Impacts	400,000	1,500,000
Identify and Demonstrate In-Use Fleet Emissions Reduction Technologies and Opportunities	400,000	1,500,000
Subtotal	$1,300,000	$5,000,000
Emissions Control Technologies		
Develop and Demonstrate Advanced Aftertreatment Technologies On Highways	500,000	2,000,000
Develop Methodology and Evaluate and Demonstrate Onboard Sensors for On-Road Heavy-Duty Vehicles	250,000	1,000,000
Demonstrate On-Road Technologies in Off-Road and Retrofit Applications	176,300	800,000
Subtotal	$926,300	$3,800,000
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 Assessment/Transfer and Outreach		
Assess and Support Advanced Technologies and Disseminate Information	600,000	1,000,000
Support Implementation of Various Clean Fuels Vehicle Incentive Programs	350,000	400,000
Subtotal	950,000	$1,400,000
TOTALS FOR POTENTIAL PROJECTS	$21,781,000	$167,565,000

Technical Summaries of Potential Projects

Hydrogen/Mobile Fuel Cell Technologies and Infrastructure

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 light-duty 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.

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 medium- and heavy-duty applications and ensuring hydrogen quality is maintained. DOE awarded new H2@Scale funding in 2021 to focus on heavy-duty tasks to develop heavy-duty reference station design, model heavy-duty 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 light-duty (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.

These efforts are complemented by projects undertaken and supported by the CaFCP 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 refueling 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 cofunding support for additional or follow on mutually agreed technical tasks with the California Hydrogen Infrastructure Research Consortium members, the CaFCP as well as other collaborative efforts that may be undertaken to advance hydrogen infrastructure technologies.

Potential Air Quality Benefits:

The 2016 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. This South Coast AQMD project, with significant additional funding from other governmental and private entities, will work towards providing the necessary hydrogen fueling infrastructure network.

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 refueling 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 refueling and production sites. This project would support the development and demonstration of hydrogen refueling technologies. Proposed projects would address:

Fleet and Commercial Refueling Stations: Further expansion of the hydrogen fueling network based on retail models, providing renewable generation, adoption of standardized measurements for hydrogen refueling, other strategic refueling 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 Refueling Appliances: Home or small scale refueling/recharging 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[10] and the majority of these do not include medium- and heavy-duty vehicles deployed in the Basin. To meet demand, number of hydrogen fueling infrastructures need 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 be realized by the Governor's 2018 Executive Order to establish 200 light-duty stations by 2025, increase investment in heavy-duty hydrogen stations to support CARB's Advanced Clean Truck Regulation, and anticipated adoption of the Advanced Clean Fleets Regulation in 2022.

Potential Air Quality Benefits:

The 2016 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 certain private fleets to purchase clean-burning alternative-fueled vehicles when adding or replacing vehicles to their vehicle fleets. 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 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

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

reductions in NOx, VOC, CO, PM and toxic compound emissions from vehicles.

Proposed Project: Develop and Demonstrate Medium- and Heavy-Duty Fuel Cell Vehicles

Expected South Coast AQMD Cost: $2,644,500

Expected Total Cost: $12,000,000

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 medium- and heavy-duty ZEVs. CARB's Advanced Clean Truck and Fleet and Innovative Clean Transit Bus Regulations will also increase deployment of medium- and heavy-duty FCVs. Fleets are useful demonstration sites because economies of scale exist in central refueling, training skilled personnel to operate and maintain FCVs, monitoring and collecting data on vehicle performance, and OEM technical and customer support. In some cases, medium- and heavy-duty FCVs could leverage the growing network of hydrogen stations and provide an early base load of fuel consumption until the number of passenger 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 heavy-duty 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, US 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 • Medium- & Heavy-Duty Trucks	• Vehicle Auxiliary Power Units • Construction Equipment • Lawn and Garden Equipment • Cargo Handling Equipment

Potential Air Quality Benefits:

The 2016 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.

Proposed Project: Demonstrate Light-Duty Fuel Cell Vehicles

Expected South Coast AQMD Cost: $30,000

Expected Total Cost: $75,000

Description of Technology and Application:

This proposed project would support the demonstration of limited production and early commercial light-duty FCVs using gaseous hydrogen with PEM fuel cell technology, mainly through showcasing this technology. Recent designs of light-duty FCVs include hybrid batteries to recapture regenerative braking and improve overall system efficiency.

Fleets are useful demonstration sites because economies of scale exist in central refueling, training skilled personnel to operate and maintain FCVs, monitoring and collecting data on vehicle performance, and OEM technical and customer support. South Coast AQMD has included FCVs as part of its demonstration fleet since it started the Five Cities Program in 2005 with the Cities of Burbank, Ontario, Riverside, Santa Ana, and Santa Monica to deploy 30 hydrogen ICE vehicles and five hydrogen stations. As part of this effort, South Coast AQMD has provided support, education, and outreach regarding FCV technology on an ongoing basis. In addition, demonstration vehicles could include hybrid-electric vehicles powered by fuel cells and equipped with larger batteries capable of being charged from the grid and even supplying power to the grid.

Hyundai, Toyota and Honda have commercial FCVs in California, and Toyota redesigned the 2020 Mirai as a five-passenger sedan. The first commercial FCV leases are ending, and solo carpool lane access extends only for vehicles with MY 2019 and later, with all Clean Air Vehicle decals expiring between 2023 – 2025, unless legislation is adopted to continue. Innovative strategies and demonstration of dual fuel, ZEVs could expand the acceptance of BEVs and accelerate the introduction of fuel cells in vehicle propulsion. As hydrogen production dedicated to transportation increases from multiple providers in the next few years, and station throughput increases, dispensed hydrogen cost should start to decrease, which would encourage more model development and enable more demonstration and deployment.

Potential Air Quality Benefits:

The 2016 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, with acquisition requirements proposed to start in 2024. 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 deployment of zero emission vehicles 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 AQMP.

Engine Systems/Technologies

Proposed Project: Develop and Demonstrate Advanced Gaseous- and Liquid-Fueled Medium- and Heavy-Duty Engines and Vehicles Technologies to Achieve Ultra-Low Emissions

Expected South Coast AQMD Cost: $3.000.000

Expected Total Cost: $21,000,000

Description of Technology and Application:

The objective of this proposed project would be to support development and certification of near-commercial prototype low emission medium- and heavy-duty 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. Recent development of low-NOx diesel or natural gas engine hybrid powertrain also shown 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 medium- and heavy-duty 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.

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 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 heavy-duty 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 depoly 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 lower 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 reaches 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 mild hybrid powertrain technologies to achieve targeted lower-NOx emission standard and 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 internal combustion engines and electric components that assists engine operation and maintain aftertreatment temperature and efficiency. Simulation results shown that these newly integrated hybrid powertrains could achieve the CARB 2024-2026 NOx standard of 0.05 g/bhp-hr while maintain reasonable cost and a feasible pathway to 0.02 g/bhp-hr. Even though lower NOx engines are due to arrive in 2024 and 2027, due to the slow turn over, the legacy 2010+ diesel fleet will remain in service well into the 2030s. Thus, continued development of cost-effective low emission engine technologies are 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 medium- and heavy-duty engine technology both in the Basin and in intrastate operation. The emissions reduction benefits of replacing one 4.0 g/bhp-hr heavy-duty engine with a 0.2 g/bhp-hr engine in a vehicle that consumes 10,000 gallons of fuel per year is about 1,400 lb/yr of NOx. A heavy-duty 8.9L and 11.9L engines using natural gas 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 undergoing development. Further, renewable or blended alternative fuels can also reduce heavy-duty engine particulate emissions by over 90 percent compared to current diesel technology. The key to future engine system project success is cost-effectiveness and availability of future incentives. This project is expected to lead to increased availability of low emission alternative fuel heavy-duty 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 2016 AQMP control measures as well as future CARB and EPA low NOx regulations.

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

Expected South Coast AQMD Cost: $176,300

Expected Total Cost: **$**1,000,000

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 2016 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 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 Emissions 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 be needed to provide a sufficient amount of 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 in early-stage of commercialization, especially in the marine sector. The development of engines and systems to fill this need is currently on-going in the locomotive sector. Engines emissions are expected to be below the current 0.2g/bhp-hr NOx standard. The adaptation of alternative fueled locomotives in coordination with required infrastructure improvement 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:

This project is expected to reduce emissions of around 97 tons per year of NOx for each locomotive. The reduction of PM and GHG emissions also shows great potential mitigation in environmental justice communities.

Electric/Hybrid Technologies and Infrastructure

Proposed Project: Develop and Demonstrate Medium- and Heavy-Duty On-Road and Off-Road Electric and Hybrid Vehicles and Equipment

Expected South Coast AQMD Cost: $2,400,000

Expected Total Cost: $22,800,000

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 (2021)[11] estimated that transportation was responsible for 29 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 light-duty vehicle propulsion technologies (and fuels). However, given the commercial availability of light-duty EVs, priorities have shifted. South Coast AQMD will continue to evaluate market offerings and proposed technologies in light-duty vehicles to determine if any future support is required.

Meanwhile, medium- and heavy-duty vehicles make up 5[12] percent of vehicles in the U.S. and drive 9[13] percent of all vehicle miles traveled each year yet are responsible for more than 25[14] percent of all the fuel burned annually. Moreover, the 2016 AQMP identified medium- and heavy-duty vehicles as the largest source of NOx emissions in the Basin. Electric and hybrid technologies have gained momentum in the light-duty sector with commercial offerings by most of the automobile manufacturers. Unfortunately, there are significant emission reductions needed for medium- and heavy-duty 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. 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. Hybrid powertrain based projects are further described under the Engine Systems section.

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 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 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,

[11] *U.S. Greenhouse Gas Emissions and Sinks 1990-2019*. 2021. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

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

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

[14] https://www.bts.gov/content/fuel-consumption-mode-transportation-physical-units

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 include cargo handling and construction equipment. The Volvo LIGHTS project included the demonstration of a zero emission freight handling system including 29 battery electric yard tractors and forklifts at fleets DHE and NFI. Volvo Construction Equipment just recently finished demonstrating small battery electric compact excavator and wheel loader in California which are now ready for commercial release in 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 funding plan suggested CORE will be including off-road construction equipment in the future. Since the applications are more diverse in this sector, continued development and incentives are needed to accelerate progress in this sector.

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 medium- and heavy-duty 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 such as excavators and wheel loaders);
- development and demonstration of CNG hybrid vehicle technology; and
- development and demonstration of diesel hybrid vehicle technology.

Potential Air Quality Benefits:

The 2016 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 2016 AQMP.

Proposed Project: Develop and Demonstrate Electric Charging Infrastructure

Expected South Coast AQMD Cost: $2,600,000

Expected Total Cost: $52,090,000

Description of Technology and Application:

There is a critical need to address gaps in EV charging infrastructure availability. Almost half (44 percent) of the 2,084,118[15] EVs sold in the U.S. since 2010 were in California, and of those sales in California, almost half (44 percent) of CVRP[16] 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 light-duty EVs vs. medium- and heavy-duty EVs, which are on opposite ends of the commercialization spectrum. Light-duty 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 light-duty EVs.

Medium- and heavy-duty 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 medium- and heavy-duty 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 medium- and heavy-duty charging infrastructure are exponentially increased compared to light-duty infrastructure. Each year there are more commercially available options for medium- and heavy-duty on-road EVs and off-road equipment, charging infrastructure to support these EVs and equipment, and an ability to fund larger scale deployment projects for medium- and heavy-duty EVs, equipment, and infrastructure. As the deployment of medium- and heavy-duty 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.

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 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

[15] California Energy Commission *Zero Emission Vehicle and Charger Statistics. Q2 2021 Data Update* (posted August 5, 2021). http://www.energy.ca.gov/zevstats

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

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[17] 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 (up to 350 kW) 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 to support medium- and heavy-duty vehicle and off-road equipment demonstration and deployment projects;
- 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 heavy-duty trucks in goods movement.

Potential Air Quality Benefits:

The 2016 AQMP identifies zero emission vehicles as a key attainment strategy. 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 2016 AQMP.

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

Proposed Project: Demonstrate Alternative Energy Storage

Expected South Coast AQMD Cost: $300,000

Expected Total Cost: $2,000,000

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 2016 AQMP. This project is expected to further efforts to develop alternative energy storage technologies that could be implemented in medium- and heavy-duty 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 and Plug-In Hybrid Vehicles

Expected South Coast AQMD Cost: $75,000

Expected Total Cost: $200,000

Description of Technology and Application:

This proposed project would support the demonstration of limited production and early commercial light-duty BEVs and PHEVs using advanced technology, mainly through showcasing this technology. Recent designs of light-duty 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 also 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 supporting education and outreach regarding BEV and PHEV technology. Thirty networked Level 2 chargers were added through the Southern California Edison Charge Ready Fleet program in 2020, which will help South Coast AQMD acquire 8500 GVW and over ZEVs like light-duty trucks and vans to comply with the proposed CARB Advanced Clean Fleet regulation.

Light-duty 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 2016 AQMP identifies the need to implement light-duty 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 2016 AQMP.

Fueling Infrastructure and Deployment (Natural Gas/Renewable Fuels)

Proposed Project: Demonstrate Near-Zero emission Natural Gas Vehicles in Various Applications

Expected South Coast AQMD Cost: $1,400,000

Expected Total Cost: $19,000,000

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 heavy-duty vehicles utilizing this clean fuel. Currently, increasing number of on-road heavy-duty 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 heavy-duty 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 emissions and useable in a wide variety of medium- and heavy-duty applications, such as Class 6 vehicles used in 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, and 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 heavy-duty vehicle consumers to NGVs. Under Engine Systems, South Coast AQMD is support efforts for development high-powered natural gas vehicles 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 engine has been the only option.

Potential Air Quality Benefits:

Natural gas-powered vehicles have inherently lower engine criteria pollutant emissions relative to conventionally fueled vehicles, especially older diesel-powered vehicles. Recently, on-road heavy-duty 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, transit buses will help reduce local emissions and emissions exposure to nearby residents. Natural gas vehicles can also have lower greenhouse gas emissions and can increase energy diversity, help address national energy security objectives, and can reduce biomass waste when produced from such feedstocks. Deployment of additional NGVs is consistent with South Coast AQMD's AQMP to reduce criteria pollutants, and when fueled by RNG supports California's objectives of reducing GHGs and the 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 stations in strategic locations throughout the Basin, including the Ports, and advancing technologies and station design to improve fueling and refueling efficiencies of heavy-duty NGVs. This category supports the broader deployment of near-zero emission heavy-duty vehicles and the implementation of South Coast AQMD's fleet rules. In addition, as natural gas fueling equipment begins to age or has been placed in demanding usage, components will deteriorate. This project offers facilities to replace worn-out equipment or to upgrade existing fueling and/or garage and maintenance equipment to offer increased fueling capacity to public agencies, private fleets and school districts.

Potential Air Quality Benefits:

The AQMP identifies the use of alternative clean fuels in mobile sources as a key attainment strategy. Heavy-duty NGVs have significantly lower emissions than their diesel counterparts and represent the cleanest internal combustion engine-powered vehicles available today. The project has the potential to significantly reduce the installation and operating costs of NGV refueling stations, and improving vehicle refueling times through improved refueling systems designs and high-flow nozzles. While new or improved NGV stations have an indirect emissions reduction benefit, they help facilitate the introduction of near-zero emission NGVs in private and public fleets in the area, which have a direct emissions reduction benefit. It is expected that natural gas' lower fuel cost relative to diesel and the added financial incentives of renewable natural gas (RNG) under the state's Low Carbon Fuel Standard program and the federal Renewable Fuel Standard program will significantly reduce operating costs of high fuel volume heavy-duty NGVs and attract consumers to this technology. The increased exposure and fleet and consumer acceptance of NGVs would lead to significant and direct reductions in NOx, VOC, CO, PM and toxic compound emissions from mobile sources. Such increased penetration of NGVs will provide direct emissions 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: $2,000,000

Expected Total Cost: $10,000,000

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 federal clean air standards. Alternative fuels produced from renewable sources such as waste biomass help further efforts associated with landfill and waste diversion, greenhouse gas reduction, energy diversity and petroleum dependency. Locally produced renewable fuels further reduce concerns associated with out-of-state production and transmission of fuel as well as helps support the local economy. Renewable fuels recognized as a transportation fuel under the state's Low Carbon Fuel Standard program and the federal government's Renewable Fuel Standard program can provide financial incentives, including the reduced fuel price and operational costs, the incentives to purchase and deploy alternative or renewable energy powered vehicles.

The project category will consider the development and demonstration of technologies for the production and use of renewable transportation fuels such as renewable natural gas (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 waste water 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 South Coast AQMD relies on a significant increase in the penetration of zero and near-zero emission vehicles in the Basin to attain federal clean air standards by 2023 and 2032. This project would help develop a number of renewable transportation fuel production and distribution facilities to improve local production and use of renewable fuels to help reduce transportation costs and losses that can 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 greenhouse gases 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: $4,500,000

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 medium-and heavy-duty 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 heavy-duty trucks is currently under way with two of the largest manufacturers announcing plans for commercial products in Southern 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 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+ kW hours 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 platforms. Many fleet operators do not own but lease their facilities making the capital expenditure of EV or hydrogen infrastructure impossible to recoup in a short period of time. Like the diesel vehicles they presently operate, fleets purchase fuel for their trucks, not the fueling station. 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 refueling. Additionally, if the microgrid equipment is owned by a third party and the energy is sold to the fleet through a power purchase agreement, the financial challenge of large capital investment can be avoided by the fleet operator.

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 refueling 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 all the technologies that make up microgrids already exist including 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 it and continue to operate as an energy island independent from the grid. Having assurance of an uninterrupted fueling source is an important consideration for a fleet operator. Also, if the microgrid is connected to the fleet operator's logistics system, 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 going to travel, it can charge the vehicle with enough energy for the trip so the truck will operate within 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 the charging schedules with 150 kW or less powerful chargers which again will have less impact on battery life than the planned higher powered 300+ kW chargers and lower the costs for the charging infrastructure.

The energy demand of electric and fuel cell heavy-duty trucks is substantial; for a 100-vehicle fleet of BETs with 300 kWh the batteries would require 30 MW hours/day of energy. For a 100-vehicle fleet of FCTs the hydrogen requirement is 2,000 kg/day. Microgrids can provide energy for hydrogen and EV infrastructure and can serve to enable large zero emission vehicle deployments and make refueling economical and reliable. Staff has demonstrated several microgrid projects with the 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 fleet operators 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. Also, 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 that are 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 here in the Basin.

Potential Air Quality Benefits:

Microgrids can provide grid resilience and potentially support large deployments of zero emission medium- and heavy-duty trucks that are necessary to meet the AQMP target of a 45 percent reduction in NOx required by 2023 and an additional 55 percent reduction by 2031. 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 that are in excess of the assumptions in the 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: $500,000

Description of Technology and Application:

The objective of this proposed project is to support the 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, a clean fuel. Hydrogen, when used in internal combustion engines, can potentially reduce tail-pipe emissions of NOx, while in fuel cells the emissions are reduced to zero.

The 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 the implementation of successful technologies.

Potential Air Quality Benefits:

The 2016 AQMP identifies the development and ultimately the implementation of non-polluting power generation could gain the maximum air quality benefit. 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, especially as the transportation sector becomes more reliant on the electrical grid.

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

Fuel/Emissions Studies

Proposed Project: Conduct In-Use Emissions 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 role in the future of transportation. Each of these transportation technologies has attributes that could provide unique benefits to different transportation sectors. Identifying the optimal placement of each transportation technology will provide the co-benefits of maximizing the environmental benefit and return on investment for the operator.

In addition, South Coast AQMD has been supporting rapid deployment of near-zero emission natural gas technologies ever since the first heavy-duty engine is commercially available in 2015. As more near-zero emission natural gas (and propane) technology penetrates the different segments, in-use assessment of real-world benefit is needed especially now CARB has introduced a new in-use testing metric.

The CARB EMFAC model that the 2016 AQMP is based on uses emissions data from in-use emissions studies for calculating emission factors for heavy-duty trucks rather than the certification data but it's limited and outdated. For the upcoming EMFAC 2021, more complete natural gas engine modules have been included for the first time with emissions data gathered from the current South Coast AQMD funded in-use emissions characterization effort. CARB and EPA low-NOx regulations focused 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 are still significant population of the MY 2010+ legacy fleet is expected to remain in service well over 2030s. There is always a need to better assess real world truck emissions, fuel economy, and their activity from both engines, hybrid powertrain and zero emission technologies for continued technology improvements.

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

The proposed project would review and potentially coordinate application specific drive cycles for specific applications. The potential emissions 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 are used for planning purposes for building medium- and heavy-duty public refueling stations. Furthermore, some of the standardized test cycle, like the chassis dyno based cycle, can be used to evaluate the efficiency of the zero-emissions vehicles and compare directly with the diesel and natural gas vehicle.

Another proposed project would be the 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 of and contribute to the formation of urban ozone and SOA, which is an important component of PM2.5. Natural-gas vehicles are also a concern due to lack of particulate filter, however, the actual impact based on current and projected population are to be further studied.

Finally, while early developments in autonomous and vehicle-to-vehicle controls are focused on light-duty passenger vehicles, the early application of this technology to heavy-duty, drayage and container transport technologies is more likely. The impact 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:

The development of an emissions reduction database, for various application specific transportation technologies, would assist in the 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 a significant environmental benefit. The demonstration of a quantifiable reduction in operating cost through the intelligent deployment of vehicles will also accelerate the commercial adoption of the various technologies. The accelerated adoption of lower emitting vehicles will further assist in attaining South Coast AQMD's air quality goals.

Proposed Project: Conduct Emissions 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 goal. 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 biofuel use, it is the objective of this project to further analyze these fuels to better understand their benefits and impacts not only on greenhouse gases but also air pollution and associated health effects.

In various diesel engine studies, replacement of petroleum diesel fuel with biodiesel fuel has demonstrated reduced PM, CO and air toxics emissions. Biodiesel also has the potential to reduce greenhouse gas emissions because it can be made from renewable feedstocks, such as soy and canola. However, certain blends of biodiesel have a tendency to increase NOx emissions for certain engines and duty cycles, which exacerbates the 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 to further increase the ethanol content to 10% as a means to increase the amount of renewable fuels in the state. It is projected that the state's ethanol use will increase from 900 million gallons in 2007 to 1.5 billion gallons by 2012 as a result. 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, the U.S. EPA approved 15% ethanol (E15) blends for year-round use and CARB, along with South Coast AQMD and other launched an emissions study of E15 to assess the emissions impact of the current fleet of California light duty vehicles, the data is due to be released soon to support the approval of E15. South Coast AQMD also has been monitoring efforts in using ethanol as a primary fuel for medium- and heavy-duty application in optimized engine systems that allows both criteria and GHG reduction which could be another pathway for reducing emissions due to abundance of ethanol from the light duty sector.

CARB recently proposed a regulation on the commercialization of alternative diesel fuels, including biodiesel and renewable diesel, while noting that biodiesel in older heavy-duty vehicles can increase NOx and the need for emerging alternative diesel fuels to have clear ground rules for commercialization. The impact of natural gas fuel composition on emissions from heavy-duty trucks and transit buses is also being studied. Researchers have proposed to evaluate the emissions impact of renewable natural gas and other natural gas blends such as renewable hydrogen.

In order to address these concerns on potential health effects associated with biofuels, namely biodiesel and ethanol blends, this project will investigate the physical and chemical composition and associated health effects of tailpipe PM emissions from light- to heavy-duty vehicles burning biofuels in order 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 for biofuels. Additionally, a study of emissions from well-to-wheel for the extraction and use of shale gas might be considered.

More recently, the Power-to-Gas concept has renewed interest in hydrogen-fossil fuel blends which its emissions impact on the latest ICE technologies needs to be reassessed. Hydrogen fueled ICE was studied heavily in the early 2000's and results have shown significant criteria emissions reduction possible with optimized engine calibration. Since then, ICE technologies have been fitted with advanced aftertreatment

to allow the engines to be certified to today's low NOx standards. Therefore, emissions impact assessment is needed on the latest ICE technologies.

Lastly, in an effort to evaluate the contribution of meteorological factors to high ozone and PM2.5 episodes occurring in the Basin, mainly as a result of higher summer time temperatures and increased air stagnation following the drought years, a comprehensive study is necessary to evaluate the trends of meteorological factors that may adversely impact air quality in the Basin. The study will assist staff to better understand the potential impact of recent weather trends on criteria pollutant emissions and potentially develop 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 any NOx impact, this technology will become a viable strategy to assist 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 the emission benefits and any tradeoffs (NOx impact) that may result from using this alternative fuel. With reliable information on the emissions from using biodiesel and biodiesel blends, the South Coast AQMD can take actions to ensure the use of biodiesel will obtain air pollutant reductions without creating additional NOx emissions that may exacerbate the Basin's ozone problem. Additionally, understanding meteorological factors on criteria pollutant emissions may help identify ways to mitigate them, possibly through targeted advanced transportation deployment.

Proposed Project: Identify and Demonstrate In-Use Fleet Emissions 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 heavy-duty 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 the 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, the in-use fleet lacks telematic systems--particularly heavy-duty engines in trucks, buses, construction equipment, locomotives, commercial harbor craft and cargo handling equipment--have fairly long working lifetimes (up to 20 years due to remanufacturing in some cases). Even light-duty vehicles routinely have lifetimes exceeding 200,000 miles and 10 years. And it is the in-use fleet, especially the oldest vehicles, which are responsible for the majority of emissions. In the last a few years, real-time emissions and fuel economy data reporting along with telematics has been demonstrated with large fleets to as fleet management tools to identify high emitters and increase operational efficiency. Similar efforts have already been proposed by CARB as part of HD I/M regulation. Moreover, the same telematic systems are being installed on zero-emission trucks where fleet and charging management are more important than ever, cloud based fleet management concept are being proposed by researchers to maximize the range and air quality benefits of zero-emission trucks.

This project category is to investigate near-term emissions 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 heavy-duty vehicles;
- annual testing for high mileage vehicles (>100,000 miles);
- replace or upgrade emissions 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; and
- fleet and charger management concepts low NOx sensor development.

Potential Air Quality Benefits:

Many of the technologies identified can be applied to light- and heavy-duty 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. The identification and replacement of high-emitting vehicles has been identified in the Community Emission Reduction Plans (CERPs) from the Year 1 AB 617 communities as a high priority for residents living in these communities, particularly as heavy-duty trucks frequently travel on residential streets to bypass traffic on freeways surrounding these disadvantaged communities.

Emissions Control Technologies

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

Expected South Coast AQMD Cost: $500,000

Expected Total Cost: $2,000,000

Description of Technology and Application:

There are a number of aftertreatment technologies which have shown substantial emissions 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 the availability of 48 volt battery system can be used to keep desired catalyst temperatures such as heated dosing and heated catalysts are also part of the complete aftertreatment system design towards near-zero emission NOx. 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 particles, nanoparticles, NOx, CO, carbonyl and hydrocarbon emissions in retrofit and new applications. With the increasing focus on zero and near-zero emissions 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 the EPA as well as the adopted CARB Omnibus Regulation will require aftertreatment systems to maintain certification to a much longer useful life via new in-use testing metrics. Technology durability and in-use performance will need to be studied.

Possible projects include advancing the technologies for on-road truck demonstrations beyond the lab based testing, retrofit applications, such as heavy-duty line-haul and other large displacement diesel engines, street sweepers, and waste haulers. Applications for non-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 the performance, economic feasibility, viability (reliability, maintainability and durability) and ease-of-use to ensure a pathway to commercialization.

Potential Air Quality Benefits:

The 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 emissions reductions. Further development and demonstration of other technologies, such 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 Heavy-Duty Vehicles

Expected South Coast AQMD Cost: $250,000

Expected Total Cost: $1,000,000

Description of Technology and Application:

New heavy-duty on-road vehicles represent one of the largest categories in the NOx emissions inventory in the Basin. To meet the 2023 and 2031 ozone standards, NOx emissions need to be reduced by 45% and an additional 55% from 2012 levels, respectively, mainly from mobile sources. Previous in-use emission studies, including studies funded by the South Coast AQMD, have shown significantly higher NOx emissions from on-road heavy-duty vehicles than the certification limit under certain in-use operations, such as low power duty cycles. In CARB's adopted Heavy-Duty On-Road "Omnibus" Low NOx regulation, in addition to the lower certification values, a low load test cycle and revisions to the not-to-exceed compliance tests. A NOx sensor data reporting is also introduced where the vehicle computer are 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 the sensors to better monitor emissions compliance and leverage the real-time data from sensors to enable advances concepts such as geofencing. CARB's newly proposed HD I/M rule will be looking at address in-use emissions from the older legacy fleets, one of the pathways is also using onboard sensors.

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 of existing 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 light-duty, 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. 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 heavy-duty engines have demonstrated progress in meeting increasingly stringent federal and state requirements. New heavy-duty 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 the engine size. For example, Tier 3 standards for heavy-duty 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 the cleaner emission standards as the engine being 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 the 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 heavy-duty line-haul trucks at weigh stations.

Potential Air Quality Benefits:

The transfer of mature emission control technologies, such as certified engines and SCR, to the off-road and retrofit sectors offers high potential for immediate emissions reductions. Further development and demonstration of these technologies will assist in the 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 of the toxic air contaminants emitted from diesel exhaust. Additionally, health studies indicate that the ultrafine particulate matter (UPM) may be more toxic on a per-mass basis than other fractions. Several technologies have been introduced and others are under development to reduce diesel emissions. These include among others low-sulfur diesel fuel, particulate matter traps and heavy-duty engines operating on alternative fuel such as CNG and LNG. 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 the number of 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 the 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 to characterize their toxicity. The composition of PM can further be used to determine the contribution from specific combustion sources. Additionally, engine or chassis dynamometer testing may be conducted on heavy-duty vehicles to measure, evaluate and compare UPM, PAH and other relevant toxic emissions from different types of fuels such as CNG, low-sulfur diesel, biofuels and others. This project needs to be closely coordinated with the development of technologies for alternative fuels, aftertreatment technologies, and new engine development in order to determine the 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 the SOA potential from these vehicles as it could lead to further impact on the ambient PM concentration in our region. Consequently, in 2015 a project was initiated with UCR/CE-CERT to investigate the physical and chemical composition of aerosols from GDI vehicles using a mobile environmental chamber that has been 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 medium- and heavy-duty vehicles to understand potential emissions impact.

Potential Air Quality Benefits:

The AQMP for the Basin relies on significant penetration of low emission vehicles to attain federal clean air standards. Reduction of PM emissions from the 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 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.

MATES V was launched in 2017 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 finalized in June 2021 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. Highest risk locations are at LAX and the Ports along goods movement and transportation corridors. Diesel PM continues to be the major contributor to 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 (heavy-duty, light-duty 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 Assessment/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 the assessment of clean fuels and advanced technologies, their progress towards commercialization and the dissemination of information on demonstrated technologies. The objective of this project is to expedite the transfer of technology developed as a result of Technology Advancement Office projects to the public domain, industry, regulatory agencies and the scientific community. This project is a fundamental element in the South Coast AQMD's outreach efforts by coordinating activities with other organizations to expedite the 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 fuel refueling and 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 demonstrations;
- participation in and coordination of workshops and various meetings;
- support for training programs related to fleet operation, maintenance and refueling 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:

South Coast AQMD adopted fleet regulations requiring public and private fleets within the Basin to acquire alternatively fueled vehicles when making new purchases. The benefits of highlighting success stories in the use of advanced alternatively fueled vehicles could expedite the acceptance and commercialization of advanced technologies. Especially, by the operators seeking to comply with the provisions of the South Coast AQMD fleet rules. The emission reduction benefits will contribute to the goals of the AQMP.

Proposed Project: Support Implementation of Various Clean Fuels Vehicle Incentive Programs

Expected South Coast AQMD Cost: $350,000

Expected Total Cost: $400,000

Description of Project:

This project supports the implementation of incentive programs, including the state and federal grant programs, the Carl Moyer, lower emission school bus, Replace Your Ride Programs and the South Coast AQMD residential EV charger rebate program. Implementation support includes application review, funds allocation, equipment owner reports collection, documentation to the 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 dealers, individuals and fleets. To date, the South Coast AQMD residential EV charger rebate program has provided over 1,900 rebates, totaling $553,596. The total available funds of $1 million is consisted with $500,000 from South Coast AQMD Clean Fuels Fund and $500,000 from the Mobile Source Air Pollution Reduction Review Committee (MSRC).

Potential Air Quality Benefits:

As described earlier, the South Coast AQMD will provide matching funds to implement several key incentives programs to reduce emissions in the Basin. Furthermore, the South Coast AQMD adopted fleet regulations requiring public and private fleets within the Basin to acquire alternatively fueled vehicles when making new purchases. The benefits of highlighting zero emission vehicle incentives could potentially expedite the acceptance and commercialization of advanced technologies by operators seeking to comply with the South Coast AQMD fleet rules provisions. The result of future emission reduction benefits will contribute to the goals of the AQMP. The lower emission school bus, AB 617 Community Air Protection, Volkswagen Environmental Mitigation Trust and Carl Moyer incentives programs could reduce large amounts of NOx and PM emissions, and toxic air contaminants in the Basin.

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Appendix A

South Coast AQMD Advisory Groups

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Technology Advancement Advisory Group[1]

Dr. Matt Miyasato, 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.
Tim Olson	California Energy Commission
David Pettit	Natural Resources Defense Council
Dr. Sunita Satyapal	Department of Energy
Heather Tomley	Port of Long Beach
Laura Renger	Southern California Edison

*Newly appointed member

[1] Members as of February 18, 2022

SB 98 Clean Fuels Advisory Group[2]

Dr. Matt Miyasato, 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
Dr. Mark Duvall	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
Dr. Robert Sawyer	Sawyer Associates
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 4, 2022

Appendix B

Open Clean Fuels Contracts as of January 1, 2022

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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
16081	Broadband Telcom Power Inc	Provide EV Hardware and Control System at SCAQMD Headquarters Including Installation Support, Warranty and Networking	04/27/16	04/26/22	367,425	689,850
17105	BYD Motors Inc	Development and Demonstration of up to 25 Class 8 Battery Electric Drayage Trucks	04/14/17	10/13/23	2,294,436	8,942,400
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
17225	Volvo Technology of America LLC	Development and Demonstration of up to 2 Class 8 Battery Electric Drayage Trucks	06/09/17	03/31/22	1,741,184	11,065,938
17244	Kenworth Truck Company	Development & Demonstration of four Class 8 CNG Hybrid Electric Drayage Trucks	09/08/17	06/30/22	2,239,106	6,492,238
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
18277	Velocity Vehicle Group DBA Los Angeles Truck Centers LLC	Southern California Advanced Sustainable Freight Demonstration	09/07/18	03/06/22	582,305	4,198,000
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	01/30/22	0	7,311,456
19182	Los Angeles County	Disburse donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	01/03/19	01/03/22	0	0
19183	Southern California Public Power Authority (SCPPA)	Disburse Donated Mercedes-Benz USA, LLC Electric Vehicle Chargers	01/10/19	01/10/22	0	0
19190	Daimler Trucks North America LLC	Zero Emission Trucks and EV Infrastructure Project	12/18/18	06/17/22	8,230,072	31,340,144
19202	City of Compton	Disburse donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	04/11/19	04/10/22	0	0
19250	Baldemar Caraveo	Disburse donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	03/06/19	03/06/22	0	0
19251	Gary Brotz	Disburse donated Mercedes-Benz USA, LLC Electric Vehicle Chargers	03/27/19	03/26/22	0	0
19252	Hui Min Li Chang	Disburse donated Mercedes-Benz USA, LLC Electric Vehicle Chargers	03/29/19	03/28/22	0	0

Contract	Contractor	Project Title	Start Term	End Term	South Coast AQMD $	Project Total $
Electric / Hybrid Electric Technologies and Infrastructure (cont'd)						
19253	Jennifer Chin	Disburse donated Mercedes-Benz USA, LLC Electric Vehicle Chargers	04/19/19	04/18/22	0	0
19254	Liping Huang	Disburse donated Mercedes-Benz USA, LLC Electric Vehicle Chargers	04/11/19	04/18/22	0	0
19255	Ramona Manning	Disburse donated Mercedes-Benz USA, LLC Electric Vehicle Chargers	04/05/19	04/04/22	0	0
19256	Tony Chu	Disburse donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	04/04/19	04/03/22		0
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	04/17/19	06/30/22	4,000,000	92,345,863
19279	Douglas Harold Boehm	Disburse donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	03/29/19	03/28/22	0	0
19280	Emile I. Guirguis	Disburse donated Mercedes-Benz USA, LLC Electric Vehicle Chargers	04/19/19	04/18/22	0	0
19281	Helen Chi	Disburse donated Mercedes-Benz USA, LLC Electric Vehicle Chargers	03/27/19	03/26/22	0	0
19282	Hosneara Ahmed	Disburse donated Mercedes-Benz USA, LLC Electric Vehicle Chargers	04/05/19	04/04/22	0	0
19283	Hsuan Hu	Disburse donated Mercedes-Benz USA, LLC Electric Vehicle Chargers	03/27/19	03/26/22	0	0
19284	Jyi Sy Chiu	Disburse donated Mercedes-Benz USA, LLC Electric Vehicle Chargers	04/05/19	04/04/22	0	0
19285	Mercedes Manning	Disburse donated Mercedes-Benz USA, LLC Electric Vehicle Chargers	04/19/19	04/18/22	0	0
19286	Monica Sii	Disburse donated Mercedes-Bens USA, LLC Electric Vehicle Chargers	04/19/19	04/19/22	0	0
19287	Quei-Wen P Yen	Disburse donated Mercedes-Benz USA, LLC Electric Vehicle Chargers	03/29/19	03/28/22	0	0
19288	Rae Marie Johnson	Disburse donated Mercedes-Benz USA, LLC Electric Vehicle Chargers	04/05/19	04/04/22	0	0
19289	Yilong Yang	Disburse donated Mercedes-Benz USA, LLC Electric Vehicle Chargers	04/09/19	04/08/22	0	0
19295	Ivan Garcia	Disburse donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	04/11/19	04/10/22	0	0

Contract	Contractor	Project Title	Start Term	End Term	South Coast AQMD $	Project Total $
Electric / Hybrid Electric Technologies and Infrastructure (cont'd)						
19296	Jamei Kun	Disburse donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	04/19/19	01/18/22	0	0
19297	Laizheng Wei	Disburse donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	04/19/19	04/18/22	0	0
19438	Puente Hills Hyundai LLC	Lease Two 2019 Hyudai Kona EVs for Three Years	06/06/19	06/05/22	61,156	61,156
20054	Puente Hills Hyundai LLC	Lease One 2019 Hyundai Kona EV for Three Years	08/23/19	08/22/22	29,640	29,640
20097	Zeco Systems, Inc. DBA Greenlots	Operate, Maintain and Network the EV Chargers	02/14/20	02/13/23	155,664	155,664
20124	Volvo Technology of America LLC	Develop & Demonstrate Battery-Electric Excavator & Wheel Loader	09/01/19	09/30/22	0	2,000,000
20125	Roush Cleantech, LLC	Develop and Demonstrate Battery Electric Medium-Duty Truck	03/19/20	03/18/22	937,500	3,200,000
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
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	02/28/22	900,000	6,955,281
18194	CALSTART	Develop and Demonstrate Near-Zero Emission Opposed Piston Engine	05/30/18	06/30/22	1,000,000	15,550,000
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
20158	University of California Riverside	OnBoard Nox and PM Measurement Method	05/19/20	05/18/22	201,087	688,587
20199	Agility Fuel Solutions LLC	Develop a Near-Zero Natural Gas and Propane Conversion System for On-Road Medium-Duty Vehicles	07/01/21	06/30/22	453,500	1,834,000

Contract	Contractor	Project Title	Start Term	End Term	South Coast AQMD $	Project Total $
Engine Systems and Technologies (cont'd)						
20316	US Hybrid	Natural Gas Engine & Vehicles Research & Development - Plug-In Hybrid CNG Drayage Truck (PHET)	06/02/20	12/01/23	500,000	2,853,006
Fuel / Emission Studies						
17276	University of California Riverside, Ce-Cert	Development of ECO-ITS Strategies for Cargo Containers	08/03/17	01/31/22	543,000	2,190,233
17286	University of California Riverside	In-Use Emissions Testing and Fuel Usage Profile of On-Road Heavy-Duty Vehicles	06/09/17	03/31/22	300,000	1,625,000
21103	University of California Riverside	Perform Investigation Study of E15 Gasoline Fuel Effects	03/09/21	06/08/22	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
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
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

Contract	Contractor	Project Title	Start Term	End Term	South Coast AQMD $	Project Total $
Fueling Infrastructure and Deployment (NG / RNG) (cont'd)						
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	513,600	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
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
21099	CR & R, Inc.	Renewable Natural Gas Production and Vehicle Demonstration Project	03/03/20	09/30/22	166,250	166,250
21140	Inland Kenworth (US) Inc	SCAQMD Approved Participating Dealership in TRUCK TRADE DOWN PROGRAM	01/07/21	12/31/23	0	0
21141	Velocity Truck Centers	SCAQMD Approved Participating Dealership in TRUCK TRADE DOWN PROGRAM	03/04/21	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	04/09/22	1,000,000	17,335,439
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
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
17059	CALSTART Inc	Develop and Demonstrate Fuel Cell Extended Range Powertrain for Parcel Delivery Trucks	10/27/16	02/28/22	589,750	1,574,250
17312	Cummins EP NA Inc	ZECT II - Develop Fuel Cell Range-Extended Drayage Truck	11/20/17	05/30/24	125,995	2,093,146
18150	California Department of Food and Agriculture	Conduct Hydrogen Station Site Evaluations for Hydrogen Station Equipment Performance	06/28/18	02/27/22	100,000	805,000

Contract	Contractor	Project Title	Start Term	End Term	South Coast AQMD $	Project Total $
Hydrogen and Mobile Fuel Cell Technologies and Infrastructure (cont'd)						
19248	Tustin Hyundai	Three Year Lease of 2019 Fuel Cell Hyundai Nexo	03/07/19	03/06/22	25,193	25,193
19313	Equilon Enterprises LLC DBA Shell Oil Products	Construct & Operate Renewable Hydrogen Refueling Station	06/30/20	04/01/22	1,200,000	12,000,000
20033	Port of Long Beach	Sustainable Terminals Accelerating Regional Transportation (START) Phase I	06/04/21	04/30/22	500,000	102,964,064
20038	University of California Irvine	Expansion of the UCI Hydrogen Refueling Station	10/18/19	02/17/27	400,000	1,800,000
20169	Port of Los Angeles	Develop & Demonstrate Near-Zero and Zero Emissions Vehicles and Equipment at the Ports	06/28/21	11/30/22	1,000,000	83,548,872
20244	Cummins Electrified Power NA Inc	Demonstrate Fuel Cell Range-Extended Drayage Trucks	12/16/19	06/30/22	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
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
Technology Assessments and Transfer / Outreach						
08210	Sawyer Associates	Technical Assistance on Mobile Source Control Measures and Future Consultation on TAO Activities	02/22/08	02/28/22	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	06/30/22	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	12/11/22	30,000	30,000
16262	University of California Davis	Support Sustainable Transportation Energy Pathways (STEPs) 2015-2018 Program	01/05/18	01/04/22	240,000	5,520,000
17097	Gladstein, Neandross & Associates LLC	Technical Assistance with Alt Fuels and Fueling Infrastructure, Emissions Analysis and On-Road Sources	11/04/16	06/30/22	200,000	200,000

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	857,236
19227	Gladstein, Neandross & Associates LLC	Technical Assistance with Alternative Fuels & Fueling Infrastructure, Emissions Analysis & On-Road Sources	02/01/19	01/31/22	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
20163	Gladstein, Neandross & Associates LLC	Technical Assistance with Implementation & Outreach Support for California VW Mitigation Trust Fund	01/21/20	01/21/22	26,000	26,000
20265	Eastern Research Group	Technical Assistance with Heavy-Duty Vehicle Emissions Testing, Analyses & Engine Development & Applications	06/17/20	06/16/22	50,000	50,000
21260	Fred Minassian	Technical Assistance with Incentive and Research and Development Programs	04/13/21	10/12/22	75,000	75,000
22032	Southern California Chinese American Environmental Protection Association	Cosponsor the 2021 Southern California Chinese-American Environmental Protection Association 30-Year Anniversary and Annual Convention	08/20/21	05/31/22	1,500	20,000
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

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Appendix C

Final Reports for 2021

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South Coast AQMD Contract #17065 **December 2021**

Installation Services for Installation of EV Chargers at South Coast AQMD Headquarters

Contractor
Clean Fuel Connection, Inc. (CFCI)

Cosponsors
South Coast AQMD

Project Officer
Patricia Kwon

Background

Clean Fuel Connection, Inc. (CFCI) was chosen by a competitive RFP process for installation of ninety-two (92) Level 2 electric vehicle supply equipment (EVSE) at South Coast AQMD headquarters. Goss Engineering, Inc. was also hired through a competitive RFP process to provide required engineering services prior to the release of an RFP for installation of EV chargers, preparation of construction plans to obtain a permit from the City of Diamond Bar, and engineering services as required during the installation of EV chargers from October 2016 through December 2017.

Project Objective

CFCI performed the installation services as outlined in the City of Diamond Bar's approved construction plans and line drawings. These installation services included six ADA accessible chargers for both the front lobby entrance and the side entrance closest to conference room GB which is commonly used for public meetings and workshops. These services included working with the hardware provider Broadband Telecom Power, Inc. (BTC), Goss Engineering, and the City of Diamond Bar for permitting approvals.

Additional services included obtaining electrical and trenching permits from the City of Diamond Bar, providing a phased construction plan for work to be performed in different areas of the parking lot to minimize disruption, and performing the final job walk with South Coast AQMD staff and CFCI based on completing items on the final punch list. This also included ensuring compliance with the State of California Governor's Office of Planning and Research and Division of the State Architect EVSE universal charging access guidelines, as well as the American with Disabilities Act accessibility requirements, SB 854 requirements for Public Works projects, and all applicable building, electrical and safety codes.

Technology Description

Due to the wide range of cutting-edge alternative fuel technologies that are demonstrated at the South Coast AQMD headquarters facility, even a moderately large scale construction project impacting six areas of the parking lot including upgrade and replacement of three transformers and seven electrical panels, presents technical challenges. In addition, there was an inability to shut down power at the facility for even a short thirty-minute interval due to the need to have continuous power at the facility for Air Quality Management Plan modeling runs and laboratory analyses for resolving toxics issues at metal processing plants in Paramount. Due to the need to comply with South Coast AQMD's Rule 1470 (prohibiting use of a backup natural gas generator to provide power during routine maintenance), replacement of the transformer in the main electrical room took place with the power still on through a "hot connect" procedure.

Status

CFCI played a critical role in the installation of 92 Level 2 EV charging ports at South Coast AQMD headquarters. Electrical upgrades and hardware installation occurred between October 2016 and April 2017, with minor construction tasks completed in December 2017. CFCI remained under a warranty and maintenance agreement until December 2021.

Locations of EV charging stations installed at South Coast AQMD headquarters

Results

Coordination between Goss Engineering who developed the approved plans, hardware provider BTC, and the City of Diamond Bar Plan Check department enabled the construction project to be carried out successfully and with a minimum of delays despite technical challenges, delays in receiving equipment, and unprecedented heavy rainfall.

EV charging stations under the solar carport

EV charging transactions in December 2017 showed there were over 1,329 charging sessions dispensing 15,309 kWh of electricity for EV chargers serving South Coast AQMD staff, visitors, and the general public. These EV chargers continue to be utilized but to a lesser extent since the COVID pandemic closed South Coast AQMD facilities to the public in March 2020 and have not yet re-opened to the public.

Benefits

This project showcases the benefits of providing Level 2 EV charging for staff, visitors, and the general public at a large workplace location. On average, South Coast AQMD staff have a twenty-mile one-way commute to work, with some staff having as much as a 45-mile one-way commute. Without workplace charging, staff would be unable to drive their EVs to work and make it home. This results in increased zero emission vehicle miles traveled, particularly during critical morning and evening commuting hours when congestion impacts are at their greatest.

Project Costs

Installation services for this project totaled $805,219 and were within the budget for this project. Hardware and Greenlots EVSE networking software were provided under a separate BTC contract for $367,425. Engineering services to obtain City permits were provided under a separate contract with Goss Engineering for $50,000. Total costs for the EVSE installation were $1.2M.

Commercialization and Applications

The utilization of engineering services to define the installation phase of the project and assist in providing calculations and revised plans to the City of Diamond Bar assisted greatly in allowing the installation to stay within budget and to be completed within the desired time frame. It is recommended that for the installation of workplace charging at large facilities such as South Coast AQMD headquarters that an engineering firm be available to provide the necessary technical assistance at key points during the project. In particular, the engineering services were critical to define the load of existing panels and ensure proper specifications and upsizing of transformers, panels, conduit, and wiring. This upsizing incorporated not only the planned installation of 92 EVSE but also anticipated future deployments of EV chargers that were likely to occur within the next 5-10 years to future proof the facility. This future proofing enabled staff to later serve as a site host for a new 50 kW DC fast charger with CHAdeMO and CCS1 connectors at the front lobby parking area to better serve EVs capable of fast charging. Another critical service was having an installation warranty with CFCI and a maintenance contract with hardware provider BTC and networking software provider Greenlots to address post installation EVSE issues.

South Coast AQMD Contract #17316 **September 2021**

Develop and Demonstrate 10 Zero-Emission Fuel Cell Electric Buses

Contractor

Center for Transportation and the Environment (CTE)
Orange County Transportation Authority (OCTA)
New Flyer
Air Products
Trillium

Cosponsors

California Air Resources Board (CARB)
South Coast AQMD

Project Officer

Patricia Kwon

Background

As part of the CARB-funded Fuel Cell Electric Bus Commercialization Consortium Project (FCEBCC), this project furthers the development of fuel cell technology for transit agencies nationwide. CTE partnered with Orange County Transportation Authority (OCTA) to incorporate ten (10) prototype fuel cell electric transit buses into daily operation, which reduces carbon emissions and air pollutants in the South Coast Air Quality Management District (South Coast AQMD).

Project Objective

The purpose of the FCEBCC project was to help accelerate the commercialization of zero-emission buses. Besides working to reduce greenhouse gas emissions, strengthen the economy, and improve public health and the environment, this project was also intended to create a financial incentive for industries to invest in clean technologies and develop innovative ways to reduce pollution throught the cap-and-trade program.

Technology Description

While battery-electric vehicle adoption has steadily increased, hydrogen fuel cell electric buses (FCEB) are also a necessary technology for the mass adoption of zero-emission technologies. FCEBs have an electric drive system that feature a traction motor powered by a battery. The energy supply for an FCEB is on board the bus, where hydrogen, stored in tanks, is converted to electricity using a fuel cell. The electricity from the fuel cell is used to recharge the batteries.

Status

This project is complete and the final report is on file with the technical details of the project. The project did not encounter any fatal issues, although the project timeline was extended due to infrastructure deployment and bus delivery delays. The first bus was delivered to OCTA in September of 2018, the station was commissioned in January of 2020 and buses completed 40-hour testing in December of 2020.

New Flyer Xcelsior XHE40 fuel cell bus at OCTA

Results

In the first year of deployment, the two fleets had an average fuel economy of 8.46 miles per kg, or roughly 9.56 miles per diesel gallon equivalent. This is about twice that of typical diesel and compressed natural gas (CNG) buses. **Figure 1** illustrates that the buses were able to offset a combined total of 413 Metric Tons CO2e compared to their respective baseline fleets (CNG for OCTA, diesel for AC Transit). The energy efficiency of the fuel cell buses was greater than 2x that of comparable CNG buses. However, perhaps the biggest obstacle to adoption of FCEBs seen as a result of this project is vehicle availability.

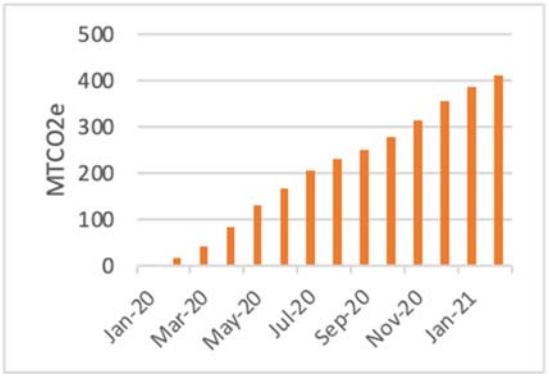

Figure 1. Cumulative GHG Emission Reductions of FCEBs over first year of deployment, from February 09, 2020 through February 28, 2021.

The average fleet availability through the first year of deployment was around 70%, with a maximum availability by month between the two fleets of 80%. Typical transit fleet operators target 85% vehicle availability in order to provide reliable service. As the technology matures and maintenance becomes more routine, FCEBs are expected to meet these targets.

Benefits

A key challenge with the overall environmental impacts of fuel cell vehicles is the difficulty of sourcing hydrogen produced renewably. Despite this issue, the FCEBs were still able to provide environmental benefits by eliminating the release of key criteria pollutants such as nitrogen oxides (NOx), reactive organic gases (ROG), and particulate matter (PM10) compared to the agencies' baseline conventional diesel and CNG fleets. The expected annual emission reductions from the project application, and the actual realized reductions from the first year of deployment, are presented in the following table.

	GHG (MTCO2e)	NOx (tons)	ROG (tons)	PM10 (tons)
Expected	*348*	*0.47*	*0.15*	*0.023*
Actual	413	0.29	0.09	0.014

The expected emission reduction calculations assumed a general carbon intensity of the hydrogen fuel supply for California, while the actual calculations are based on the realized carbon intensity of fuel supply, which was significantly lower. The expected emission reduction calculations also assumed the FCEBs would travel the same number of miles as their baseline fleets. However, due to early maintenance issues, the buses did not meet the target mileage. The agencies expect the buses to meet their respective mileage targets as the maintenance becomes more routine.

Several other transit agencies in the South Coast Air Basin have also expressed interest in integrating fuel cell buses into their fleets including: Big Blue Bus, Foothill Transit, Long Beach Transit, OmniTrans, and SunLine Transit. Assuming these agencies are able to deploy 100 buses in total, replacing conventional diesel vehicles, this technology has the potential to reduce up to 73,450 MTCO2e in the South Coast Air Basin over the lifetime of the vehicles.

Project Costs

The following table summarizes the project budget and actual expenditure.

		SCAQMD Share	Total
Budget	Buses	*$1,000,000*	*$13,338,000*
	Facility Upgrades	-	*$414,819*
	Station	-	*$5,486,895*
Actual	Buses	$1,000,000	$12,978,382
	Facility Upgrades	-	$989,377
	Station	-	$5,403,097

Commercialization and Applications

This project has already had an impact on the commercialization of FCEBs. There are two American original equipment manufacturers, New Flyer and ENC, that are Buy America compliant and these buses can therefore be purchased as part of other federal funding programs. New Flyer's XHE40 and XHE60 Xcelsior FCEBs also completed Altoona testing in early 2019, in parallel to this project, which made these buses eligible for purchase through federal, as well as California funding programs, which will only further their adoption. FCEB costs have also dropped steadily since 2004, when FCEB demo bus costs exceeded $3 million. OEM estimates for a 40-bus order are now around $1 million.

South Coast AQMD Contract #18151 **December 2021**

Develop & Demonstrate Battery Electric Switcher Locomotive

Contractor

Rail Propulsion Systems

Cosponsors

Coast Rail Services
South Coast AQMD
US Environmental Protection Agency (EPA)

Project Officer

David Cook

Background

Prior to the start of this project in 2018, there had been several attempts to develop and market battery-based hybrid or pure electric locomotives. Due primarily to the low energy density of the batteries used, new product reliability issues and poor cost benefit relative to the abundance of diesel locomotives available on the used market, these projects were unsuccessful in bringing a battery locomotive to market.

In 2017, following the implementation and subsequent EPA certification of the Blended Aftertreatment System (BATS) emissions reduction upgrade for existing passenger locomotives, Rail Propulsion Systems (RPS) proposed to South Coast AQMD a project for the design, development, and demonstration of a battery locomotive energy system. In 2018 South Coast AQMD notified RPS of available funding ($210,000) and RPS offered to provide the additional funds, access to the facilities, locomotive platform, and batteries required to support the project.

Project Objective

The goal of this project was to utilize available funds from South Coast AQMD along with contributions from RPS to demonstrate and assess the viability of a battery locomotive conversion. Further, this project utilized existing "2nd life" batteries both for economic reasons and to assess viability for use of 2nd life batteries in certain applications as a deferment of, or an alternative to, costly and inefficient recycling of the batteries after being removed from first life services such as electric passenger vehicles. The project required RPS to design, develop and implement a large (300 kW-hr) battery system, power electronics, and related subsystems necessary to convert a diesel locomotive platform to a zero-emissions battery locomotive on a limited budget. Following the conversion, RPS was to assess and report on the performance of the battery locomotive followed by an option for additional in-service operation.

Figure 1. The Simple Battery Switcher Locomotive

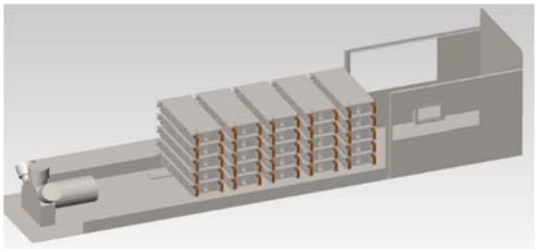

Figure 2. Battery module cans in locomotive chassis

Technology Description

The RPS conversion package for the Simple Switcher project consists of an air cooled, modular, rack-based battery system, battery management, power electronics, motor driven cooling blowers and air compressor, and a lab view based locomotive control system. The

battery system contains approximately 300kW-hrs of second life Lithium-Ion batteries packaged into fifteen modules that could be individually removed and serviced or replaced. The battery management system consists of local monitoring units that measure the current, voltage and temperature of the batteries in a given module. This data is communicated to and monitored by a central controller unit that conveys data to the power electronics and locomotive control system to process fault indications and command power contactors to isolate specific modules if necessary. The power electronics receive inputs from the locomotive control system and battery management controller which are then processed to manage the flow of current from and too the battery system. The LabVIEW based locomotive controller receives command inputs from the operator control stand for throttle and direction and processes them into outputs to command the traction motor power contactors and the current input from the power electronics.

Status

The Simple Switcher completed the performance test requirements of the project, successfully pulling trains of up to five loaded hopper cars in the railyard. Though the testing was successful, the operators on site assessed that, in its current configuration, the 1201 was not sufficient for daily in-service use. The compressed air system on the locomotive did not have sufficient capacity to support the flow and pressure requirements necessary to affectively charge and control the trainline braking system on consists of greater than five cars. Furthermore, the locomotive control system specified in this project was determined to be too simplistic and lacked the ruggedness and features necessary for daily switching use. These two items would need to be addressed through redesign or upgrades requiring additional funds beyond the scope of work of this contract.

Results and Benefits

RPS successfully designed, manufactured and demonstrated that its battery locomotive conversion package is capable of powering a locomotive in place of a conventional internal combustion engine and generator package. The systems and related subsystems created in this project will be further improved and utilized on future RPS battery locomotives. An on-site charging station and related training for the operators were both successfully completed as well. Conversely, the budget constraints for this project did not allow for sufficient upgrade of other systems on the test locomotive resulting in a reduction in the amount of in-service testing that was ultimately conducted as part of the project. Primarily, a more robust compressed air system and a more capable locomotive control system are both required. As for the assessment of 2nd life batteries, the results of the testing found the project batteries to be sufficient in energy density and remaining cycle life to support the project locomotive. Ultimately, the labor involved with harvesting and repurposing the second life batteries may outway the perceived cost benefit when compared to sourcing new batteries of alternate compositions that have lower energy density but much higher cycle life performance. Ultimately, replacing diesel switcher locomotives with zero emissions alternatives has the potential to significantly reduce emissions and improve air quality in metropolitan areas particularly in EJ communities where most rail yards are located.

Project Costs

Participant	Funding
South Coast AQMD *(pass-thru from US EPA)*	$210,000
Rail Propulsion Systems	$2,059,603
Total	**$2,269,603**

Commercialization and Applications

The Simple Battery Switcher project provided a basis for requirements necessary to develop and market battery electric locomotives that would be acceptable to switching railyard operations and commuter rail service. Based on current battery and system development and manufacturing costs, it is estimated that battery switchers can be made available to the market for a retail cost of $4-6M and passenger locomotives for a cost of $12-15M for commuter applications. RPS is prepared to deliver battery switcher locomotives by early 2023 or sooner and battery commuter locomotives by 2025

South Coast AQMD Contract #18397 **May 2021**

Demonstrate Zero-Emission Cargo Handling Vehicle at Port of Long Beach

Contractor
City of Long Beach Harbor Department
Port of Long Beach (POLB)

Cosponsors
California Air Resources Board (CARB)
South Coast AQMD

Project Officer
Patricia Kwon

Background

C-PORT: The Commercialization of POLB Off-Road Technology (C-PORT) Demonstration demonstrated the first zero-emission human-operated cargo-handling equipment (CHE) at the Port of Long Beach (POLB). C-PORT is focused on demonstrating zero emission battery electric yard tractors and top handlers since these represent 60% of the CHE utilized at the POLB. Utilizing battery electric yard tractors and top handlers would be a critical way to achieve the POLB's emission reduction goals as well as meeting the goals in the POLB's Clean Air Action Plan Update. The Clean Air Action Plan set a goal for zero emission CHE by 2030.

Project Objective

C-PORT's objectives were to design, manufacture, and deploy three battery electric top handlers, one battery electric yard tractor, and one hydrogen fuel cell yard tractor across two port terminals with differing duty cycles; install sufficient infrastructure to support charging and operation of zero emission equipment in revenue service; and demonstrate the proposed equipment in revenue service for at least six months, collecting real-world data on equipment performance. The project also included important stakeholder and community engagement, workforce development and educational components.

Technology Description

Three battery electric top handlers were manufactured as a collaboration between original equipment manufacturer (OEM) Taylor Machine Works, Inc., and the technology developer, BYD Motors, Inc. The battery-electric yard tractor was manufactured as a collaboration between Kalmar USA (OEM) and TransPower/Meritor, Inc. (technology developer). Each OEM provided its own 200kW proprietary charger at a one-to-one vehicle to charger ratio. The fuel cell yard tractor was manufactured as a collaboration between China National Heavy Duty Truck Group Co., Ltd. (OEM) and Loop Energy, Inc. (technology developer). Each of these vehicles represent the first zero emission technologies deployed from these OEMs. The fuel cell yard tractor was not demonstrated due to the lack of engineering documentation to fully address the POLB's safety and design concerns.

Figure 1. Battery-Electric Kalmar Yard Tractor

Figure 2. Battery-Electric Taylor Top Handler

Status

C-PORT was a 38-month long project, commencing in June of 2018 and completed in August of 2021. A final report is on file with complete technical details.

Results

The demonstration of battery electric top handlers and yard tractors was successfully completed. The battery electric yard tractor was able to meet the performance requirements at the Long Beach Container Terminal (LBCT). The battery electric top handlers were not able to meet the performance requirements for the long shifts at the SSA Marine Terminal at the POLB. However, the battery electric top handler deployed at the LBCT was suitable for the required work.

SSA Marine is a busy container terminal where the top handlers have a challenging duty-cycle and are required to operate two entire shifts. As such, operators found that due to the nature of the work and limitations around opportunity charging, the units did not maintain enough battery life to be comfortably used for the full two shifts. The greatest measured battery discharge (usage) during the demonstration was 91% during operations for 7.61 hours. The longest day for the tested SSA Marine diesel top handler was 12.43 hours. A full 29% of the days in which data was collected showed operations longer than 7.61 hours.

Table 1. Daily averages for battery electric and diesel top handlers (top two) and yard tractor (bottom)

Daily Averages	Electric SSA Marine Top Handler #1	Electric SSA Marine Top Handler #2	LBCT Top Handler
Energy Use (kWh)	382	301	63
SOC Use (%)	38	43	7
Hourly Electricity Use Rate (kWh/hr)	67	57	28
Time Operational (Hours)	5.2	4.7	2.6
Speed (mph)	3	2.5	0.5
Distance (miles/day)	18	13	1

Daily Averages	SSA Marine Diesel Top Handler (a)	SSA Marine Diesel Top Handler (b)
Engine Load (%)	41	22
Engine Torque (%)	27	41.3
Time Operational (hours)	5	4.8
Speed (mph)	1.6	1.4
Distance (miles/day)	7.4	8.5
Fuel Consumption (gal/day)	29	21.7

	Electric Yard Tractor	Diesel Yard Tractor
Daily Averages	95 kWh	28% engine load
	56% of SOC use	57% engine torque
	15 kWh/hr	6.6 liters per hour of fuel per day
	6 hours	7 hours
	8 mph	5.5 mph
	42 miles per day	44 miles per day

Table 2. Greenhouse gas (GHG) and criteria pollutant emission reductions from the demonstration

	Net GHG Reductions based on the Demonstration Period	Estimated Avoided NOx Emissions	Estimated Avoided THC Emissions	Estimated Avoided PM Emissions
Units	MTCO2e	ton	ton	ton
SSA Top Handler 80367	49.0	0.32	0.00048	0.010
SSA Top Handler 80368	44.3	0.28	0.00041	0.009
LBCT Top Handler BYD	17.4	0.09	0.00013	0.003
LBCT Yard Tractor Kalmar	11.1	0.03	0.00000	0.00000007
Total	**121.7**	**0.72**	**0.00103**	**0.022**

Benefits

The project demonstrated that the vehicles were able to provide the expected operational benefits (GHG savings/operating hour). Based on the POLA & POLB 2019 Emission Inventories, deploying battery electric technologies across the entire fleet of yard tractors and top handlers would be equivalent to reducing annual emissions by 237,186 metric tons of $CO2_e$, 445.1 tons of NO_x, 85.8 tons of THC, and 7.2 tons of PM10.

Project Costs

The total project cost was $7,784,086. The California Air Resources Board (CARB) awarded $5,339,820 through its Off-Road Advanced Technology Demonstration Project grant program. Of the required match funding, South Coast AQMD provided $350,000 and the balance of $2,184,266.74 was funded by the POLB.

Commercialization and Applications

The project provided an important first step in full commercialization of these, and other battery electric CHE. Battery electric off-road vehicles, mobile equipment, and CHE are rapidly developing markets, and the knowledge gleaned from C-PORT will be applied to future products developed by Taylor and Kalmar.

Taylor has reported that the next generation of battery electric ZLC-996 series top handler will be a commercialized unit which will feature technology directly evolved from the precommercial C-PORT unit. Kalmar has reported that the information gleaned from C-PORT will be used to improve the next generation of battery electric yard tractors going into production in late 2022.

South Coast AQMD Contract # 20248 **January 2021**

Economic and Workforce Impact Analysis of Electric Revolution in Southern California

Contractor

The Los Angeles County Economic Development Corporation

Cosponsors

Southern California Edison
Southern California Association of Governments (SCAG)
Los Angeles County Metropolitan Transportation Authority (LA Metro)
Los Angeles Department of Water and Power
South Coast AQMD

Project Officer

Seungbum Ha

Background

The Energizing an Ecosystem: The Electric Mobility Revolution in Southern California (hereafter the LAEDC Electric Vehicle or EV report) was a collaboration between the LAEDC and five regional partners to analyze the electric vehicle ecosystem in the state of California as a whole and the five-county (Los Angeles, Orange, Ventura, San Bernardino and Riverside counties) Southern California region specifically. The purpose of this report was to build on existing LAEDC industry cluster development around electric mobility in addition to LAEDC research expertise in industry cluster and workforce analysis. This report was commissioned as of September 2019.

Project Objective

The objective of this project was to define and assess the size and scope of the electric vehicle cluster in California from the perspective of firms and employment. The report was also to provide analysis of the scope of electric vehicle (EV) adoption thus far in the state; state and local goals and resources for adoption; the environmental concerns motivating adoption; and policies and programs that could be enacted to further the industrial and workforce development of the EV cluster in California.

Technology Description

The final LAEDC Electric Vehicle report is divided into five sections followed by a conclusion.

The introductory stage qualitative sets the framework for a return of the automotive industry in California in the form of electric and alternative energy mobility. This section also includes a summary of the major finders of the report.

Section two of the report provides an asset mapping of all major firms in the state of California operating in the EV cluster. These firms were broken into three broad categories: passenger (light duty) vehicle companies; bus, truck, and tram companies; and charging and alternative fuel companies. Each category also included a summary of pertinent public and private initiatives and resources.

The third section focuses on the scope of EV deployment in the 5-county Southern California region, with an emphasis on City of Los Angeles and County of Los Angeles strategic plans for EV adoption and the environmental concerns the single out Southern California as a region for concentrated EV adoption and industry cluster development.

Section four provides a definition of the electric vehicle ecosystem across 17 industries as defined by the North American Industry Classification System (NAICS). Estimates and forecasts are given

for the electric vehicle cluster and for specific occupations in the cluster. Finally, consideration is given to jobs that might be lost as result of the EV cluster's growth.

The final section of the report recommends certain policies, such as new commissions, incentives, and data tools, to motivate the continued growth and success of the EV cluster in California.

Status

This report was released publicly on March 4th, 2020, at the 2020 Veloz Forum in Sacramento, California.

Results

Major Findings

New EVs to Reach 7 million by 2030		
Annual New Registrations	565,300	
Annual % Change	25%	
EV Companies in California		
Passenger Vehicle Companies		
Headquarters	*13*	
Design & Tech Studios	*19*	
Manufacturing	*4*	
R&D	*6*	
Bus, Truck & Tram Companies		
Headquarters	16	
Other Offices	17	
EV Charging and Alternative Energy Companies		
Headquarters	31	
Other Offices	6	
EV Employment	2018	2023f
California	275,600	312,000
SoCal	119,200	152,200
EV Wages	EV Jobs	Average
California	$91,300	$68,500
SoCal	$80,900	$54,900

Estimates by LAEDC

Benefits

This report is intended to enhance the understanding of the EV cluster in California by estimating the scope of business development in the cluster; the extent to which the cluster does and can provide for meaningful job creation; and advocating for policies and programs to enhance EV adoption and EV-related economic development. This report should aid both public and private sector actors as a data tool demonstrating the significance of the EV ecosystem as a catalyst for long-term economic growth. These anticipated benefits have not changed from the original inception and commencement of this project.

Project Costs

Project Costs by Funder

Contributor	*Amount*
SoCal Edison	*$35,000*
LA Metro	*$25,000*
SCAQMD	*$10,000*
LA DWP	*$25,000*
SCAG	*$25,000*
Total	*$120,000*

Project Costs by Item

Item	Task Description	Cost
Module 1	EV industry landscape analysis	$16,500
Module 2	Regional EV supply, demand and externality assessment	$22,040
Module 3	Regional workforce impact analysis	$34,460
Module 4	EV Policy Analysis	$22,000
Infographic printing (estimate)		$500
Copy editor		$2,000
Rpt design-(estimate)		$7,500
LAEDC Strategic Initiatives		$15,000
Total		$120,000

Commercialization and Applications

This report is the first of its kind in the state of California in that it takes a comprehensive look at the electric vehicle ecosystem from an industry and workforce standpoint. Most other reports analyze the scope of vehicle adoption and related incentives from a consumption standpoint. This report was created to be a public resource to all parties interested in electric vehicles as a unique industry cluster and who are invested in seeing this cluster grow not just to accomplish environmental policy aims but for economic development and job creation goals.

South Coast AQMD Contract # 20122 **July 2021**

Develop and Commercialize a Near-Zero Natural Gas Conversion System for On-Road Medium-Duty Vehicles

Contractor
Landi Renzo USA Corporation (LRUSA)

Cosponsors
South Coast AQMD
US Environmental Protection Agency (EPA)
California Air Resources Board (CARB)

Project Officer
Joseph Lopat

Background
Landi Renzo approached South Coast AQMD in August 2018 to discuss a potential partnership regarding the development of a near-zero emissions 7.3L compressed natural gas (CNG) engine for the automotive industry. Landi Renzo has significant experience in the field of emissions having been a manufacturer of ecological fuel systems and engines for nearly 70 years. Given the strong and growing interest in near-zero nitrogen oxide (NOx) emission engines for commercial use, there is a robust market potential for CNG engines for medium-duty vehicles. CNG is plentiful and can be sourced domestically as renewable natural gas (RNG) is a strong contributor in combating climate change. Based on previous studies it has been shown that fleets using CNG engines can meet air quality regulations more cost effectively.

Project Objective
The objective of this project was to advance existing CNG engine and aftertreatment technologies to achieve engine NOx emission levels that are at least 90% lower than 2010 heavy-duty NOx emission standards. With this goal in mind, the objective was to modify a recently introduced 7.3-liter gasoline engine and demonstrate a 0.02 g/bhp-hr NOx CARB and EPA certified CNG engine for medium-duty vehicle applications. The initial plans involved changing controller software and utilizing the latest catalyst technology.

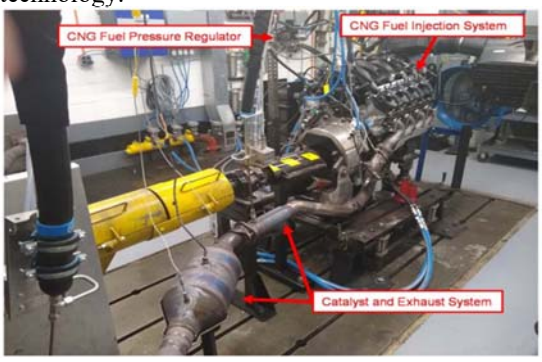

Figure 1: LRUSA / Ford 7.3L CNG Engine on Dynamometer

Technology Description
The LRUSA CNG system consisted of a CNG fuel system containing a pressure regulator, engine feed lines, high pressure filter and supply, and fuel rail and injectors. All of these were installed on a Ford 7.3-liter engine within a Ford F-450 vehicle and a Ford E-450 vehicle. An original equipment manufacturer (OEM) specified catalyst and exhaust system was used. It was acknowledged that there were other potential projects of this nature that could involve modifications to the exhaust aftertreatment system.

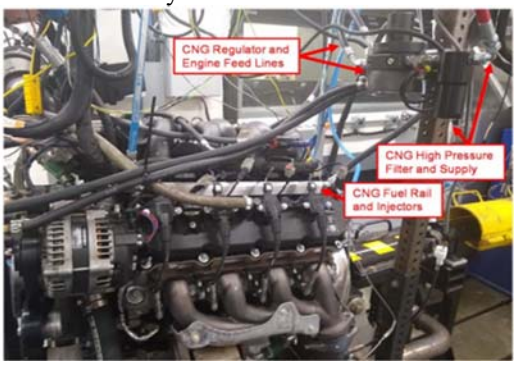

Figure 2: Close up of LRUSA CNG Fuel System Components

Status

The LRUSA 7.3-liter CNG engine project completed all eight (8) tasks associated with a successful project per the South Coast AQMD contract. It should be noted that the ultra-low NOx goal of 0.02 g/bhp-hr was not achieved with the 7.3L engine's stock exhaust aftertreatment system. The certification results of 0.038 g/bhp-hr still resulted in achieving a lower NOx standard.

Results and Benefits

In January 2020, Landi Renzo USA completed engine durability and OEM compliance testing of the Ford 7.3-liter CNG engine. The test satisfied the requirements specified by Ford in their Qualified Vehicle Modifier Bulletin Q185-R1 (Found at https://fordbbas.com/bulletins). Engine emissions development, emissions testing, and on-board diagnostics testing was completed per the test plan arranged with EPA in early February 2020. On March 25, 2020, the EPA issued LRUSA a Certificate of Conformity with the Clean Air Act for the Ford 7.3-liter CNG engine. In April 2020, the demonstration vehicle was completed and shipped to the Ford wind tunnel in Allen Park, MI to undergo chassis-level durability and OEM compliance testing. The vehicle was also reviewed and scored by Ford QVM staff to ensure that the design, build, and components meet or exceed the performance and quality standards set forth by the QVM program. After the OEM chassis-level testing was completed, the vehicle returned to California to continue on-road testing and development. Official CARB testing in our CFR 1065 compliant lab with CARB certification fuel was completed June 2020, and achieved NOx emissions of 0.038 g/bhp-hr. Despite all the delays caused by the Covid-19 pandemic, LRUSA received a conditional CARB EO November 17, 2020.

Project Costs

Participant	Funding
South Coast AQMD	$600,000
Landi Renzo USA	$900,000
Total	**$1,500,000**

Commercialization and Applications

Landi Renzo and Ford initially identified two possible development paths to meet the near-zero NOx target using either 7.3-liter chassis cert catalyst systems (used on lower gross vehicle weight rating chassis such as the MY2021 E-350) or pulling forward the production of Ford's catalyst system for an ultra-low NOx 7.3-liter gasoline engine for use in a Landi near-zero NOx system. Because of the time and resource constraints and the realities of working around the Covid-19 crisis, LRUSA was limited to utilizing the stock exhaust aftertreatment components for testing. LRUSA believes that with an improved aftertreatment system and further calibration development, a CNG system based on the 7.3-liter engine could achieve the goal of a near-zero NOx system. The Landi Renzo USA 7.3L CNG/RNG engine is currently the cleanest engine available for medium duty vehicles and allowed several fleets to meet their sustainability goals. These fleets include shuttle bus vehicles, food and beverage delivery trucks, general delivery vehicles etc. The Landi Renzo USA 7.3L engine covers a wide array of vocational vehicles that operate in high non-attainment areas, such as airports (e.g,. shuttle buses). This is particularly key as Landi Renzo exclusively supplies to the #1 bus dealer in the United States.

SCAQMD Contract # 17352 **June 2021**

Develop and Demonstrate Vessel Performance Management Software and Equipment

Contractor

California State University Maritime Academy
SkySail GmBH
Krohne Messtechnik GmBH
Alliance Marine Inc.

Cosponsors

Bay Area Air Quality Management District
South Coast AQMD
Cal State University Maritime Academy Maritime Administration

Project Officer

Naveen Berry

Background

This project, funded by the Bay Area Air Quality Management District (BAAQMD) and South Coast AQMD along with others, constituted much of the first phase of a proposed multi-year project to incorporate and evaluate emissions reduction strategies. The SkySail V-PER project was associated with the California State University Maritime Academy's (Cal Maritime) Golden Bear Research Center (GBRC) and centered on the 500-foot long United States Training Ship (USTS) Golden Bear.

Project Objective

The V-PER performance management package, a novel marine monitoring system, focused on a decrease in exhaust emissions associated with decreased fuel consumption. The package was to be installed and qualitatively evaluated on the USTS Golden Bear by Cal State Maritime staff. This required associated upgrades be made to fuel sensors essential to the operation and evaluation of that equipment. Along with these upgrades, a baseline emissions qualitative profile for the vessel was developed and shared with sponsors. Though it is understood that the deliverable for this phase will be a qualitative evaluation, it is hoped that the work will lead to additional phases and a more lengthy quantitative assessment phase.

Technology Description

The V-PER Performance Monitoring System receives input from various peripheral instruments and measurements i.e. fuel meters, anemometers, shaft torque, gyro compass, and engine/ship speed. The integration of the existing navigation, weather, and engineering data, combined with data from the new V-PER inertial measuring unit (IMU) are used to reflect real-time conditions experienced by the vessel such that the Master can make more informed decisions on economically and environmentally sound operations via course and speed selection or vessel trim.

Status

The installation of commercially available marine monitoring equipment combined with standardized emissions testing practices resulted in a highly complex logistical process impacting the original performance period objective. The conceptual phase of securing extramural funding support occupied most of 2017. Additionally, challenges presented themselves in acquisitions, software installation and vessel logistics which consumed all of 2018 and much of 2019. Control system electronic communication issues were difficult to identify and address which caused a delay in the finalization of this project. Though functional, we anticipate full capability to be realized in the spring of 2020 with significant sea time usage by the summer of 2020 on our blue water cruise on the Training Ship Golden Bear.

Picture of technology that has been supported with SCAQMD/Technology Advancement cosponsorship, if applicable. The picture, preferably a photograph, should clearly illustrate the technology. The size of the image should be about 3x3 to fit this two column format. The picture of the technology should be positioned on the front page

Results

Though the time frame for the project extended beyond what was originally anticipated, it is now

moving toward a successful conclusion. The project will continue with a longitudinal evaluation of SkySail V-PER along with additional assessments being made.

Location of the primary Human Machine Interface (HMI) for the SkySail V-PER in a central location adjacent to engine and navigational controls will provide the Master and Bridge personnel with convenient real-time feedback on propulsion responses to course and speed changes as well as adjustments to vessel loading (Figure 1).

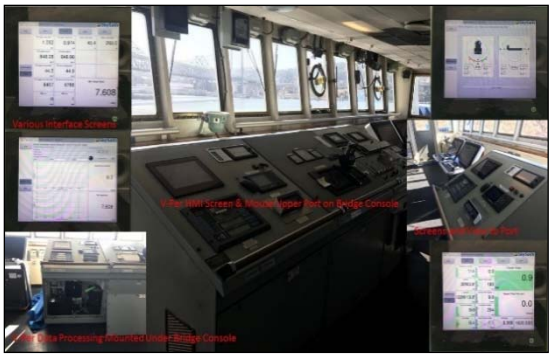

Figure 1: V-PER Installed on Training Ship Golden Bear Bridge

The HMI display is a clean and clear screen providing the viewer dimmable access to well laid out and intuitive pages. If there is any initial criticism of the provided display, it is that it is not a touch screen and requires a separate mouse or track-ball plus keyboard for input. Given current hardware technology and availability, this lack of a more cleanly integrated HMI component is somewhat surprising. Several of the intended users have expressed disappointment that a mouse and keyboard connection had to be provided on the console. Final assessment of this interface will be made after several more months of use through mid-2020.

Though the HMI provided an attractive, single-screen interface for the speed, wind direction, vessel trim and course, there was no added value given that all this data was available at nearly the same location on the bridge. As a monitoring tool, it is understood that further efforts would be required to gain engine and fuel data to fully realize the system potential.

All involved parties eagerly anticipate availability for the upcoming 2020 summer cruise in order to enhance vessel management in what is primarily an optimization effort. The Master and Chief Engineer, along with their crew must take port schedules, weather, fuel consumption and regulatory requirements into account in finding the best and safest path for delivering their cargos or completing a mission. These new tools and immediate feedback promise to greatly enhance that optimization capability.

Benefits

The primary benefit of the V-PER will be the ability to accurately monitor and assess vessel conditions affecting fuel consumption and associated exhaust emissions. Location of the primary HMI for the SkySail V-PER in a central location adjacent to engine and navigational controls will provide the Master and Bridge personnel with convenient real-time feedback on propulsion responses to course and speed changes as well as adjustments to vessel loading. This real-time data, provided in a clear and easy-to-read format, will likely be an appreciated tool in the day-to-day voyage planning.

Project Costs

The project costs totaled $135,230.14. Of this amount, South Coast AQMD and BAAQMD each paid $50,086. CSU Maritime Academy had a cost share of $35,058.14. The project came in at $2,194.14 over budget. This additional amount was cost shared by CSU Maritime Academy. The cost overage is a result of unexpected customs duties of $1,491.08, along with supplies and materials, and the associated overhead costs.

Commercialization and Applications

The SkySail V-PER performance management software system and associated wind energy propulsion equipment are commercially available, but in limited use. The intent of this project was to demonstrate and evaluate the commercial advantages that might be achieved by shipowners and operators employing these and similar technologies. Our detailed benchmarking of significant installation challenges provided to our sponsors should be of significant value to entities interested in acquiring and utilizing performance management systems and will help inform commercial or market viability of the products. Further detailed quantitative assessments and results identifying reduced consumption and emissions results will ultimately determine the market competitiveness of this system.

South Coast AQMD Contract #19208 **July 2021**

Conduct Emission Study on Use of Alternative Diesel Blends in Off-Road Heavy-Duty Engines

Contractor
University of California Riverside, Center for Environmental Research and Technology.

Cosponsors
California Air Resources Board (CARB)
South Coast AQMD

Project Officer
Joseph Lopat

Background
On-road and off-road diesel engines have long been recognized as major sources of oxides of nitrogen (NOx), particulate matter (PM) and other toxic pollutants. The use of alternative diesel fuel formulations, such as renewable diesel will address California's efforts in reducing NOx and PM emissions from diesel engines and improve local and regional air quality. Although there are many studies characterizing combustion performance and emissions of renewable diesel and biodiesel, there is a lack of literature on the emissions characterization of renewable diesel-biodiesel blends. This is particularly true for blends in higher cetane diesel fuels, such as the California Air Resources Board (CARB) Ultra Low Sulfur Diesel (ULSD), which is the focus of CARB's Low Emission Diesel (LED) regulatory effort. There is also limited information available on the impacts of renewable diesel and renewable diesel blends in new technology diesel engines that are equipped with diesel particulate filters (DPFs) and selective catalytic reductors (SCR) or in off-road engines, where the benefits of renewable diesel fuel might be more long lasting due to their less stringent emissions standards over time. The characterization of toxic pollutants from these fuel blends is also limited and needs to be expanded.

Project Objective
The goals of this study were to confirm and quantify the NOx, PM, ultrafine particles, and polycyclic aromatic hydrocarbons (PAHs) and their nitrated derivatives (nitro-PAHs) from the renewable diesel use in legacy off-road engines, as well as the potential benefits of renewable diesel in modern on-road engines with robust aftertreatment controls.

Technology Description
For this program, 2 heavy-duty diesel engines were used, including a legacy off-road John Deere engine without aftertreatment controls and a modern on-road Cummins engine equipped with diesel oxidation catalyst (DOC), DPF, and SCR systems. The off-road engine is typically used for construction applications. The on-road Cummins engine was selected because Cummins represents a good share of the California diesel engine market in Class 7 or Class 8 trucks. The test fuels included a reference CARB ULSD, used as a baseline fuel, a neat 100 percent or 99 percent renewable diesel fuel (R100/R99), a blend of 65 percent renewable diesel and 35 percent biodiesel (R65/B35), and a blend of 50 percent renewable diesel and 50 percent biodiesel (R50/B50). Testing was performed using federal testing procedures (FTP), the non-road-tested cycle (NRTC), and steady state ramped modal cycles. For the John Deere engine, a 5-mode D2 ISO 8718 cycle was used.

Status
This project was successfully completed in March 2021. Comprehensive data analysis for the toxic pollutants was completed in May 2021.

Figure 1: John Deere off-road engine in testing lab

Results
Results showed important NOx reductions with renewable diesel for the off-road engine compared to CARB ULSD. The R65/B35 showed no statistically significant differences compared to the CARB ULSD for the D2 and for the NRTC. The R50/B50 showed statistically significant increases in NOx emissions for the D2 and NRTC compared to the CARB ULSD. For the on-road

Cummins engine, no statistically significant differences were seen between the CARB ULSD and R100 over either the FTP or ramped modal cycles (RMCs). R65/B35 and R50/B50 showed statistically significant increases in NOx compared to CARB ULSD. The use of renewable diesel will likely provide NOx emission benefits from older construction engines with no aftertreatment and will not adversely affect air quality and ozone formation from newer on-road engines.

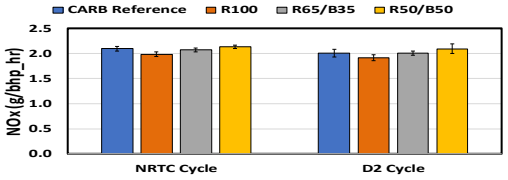

Table 1:NOx emissions for the John Deere engine

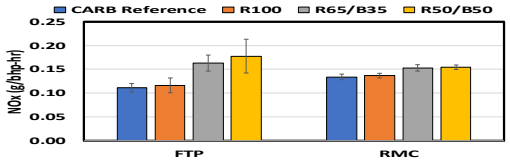

Table 2: NOx emissions for the Cummins engine

For the John Deere engine, PM emissions showed large reductions with R100 and the biodiesel blends. For the Cummins engine, PM mass emissions were found in very low levels due to the presence of DPF. Total and solid particle number emissions were generally lower for the biofuels compared to CARB ULSD. The biodiesel blends resulted in larger reductions of total and solid particle number emissions due to the oxygen content in the biodiesel molecule.

Formaldehyde and acetaldehyde were the predominant aldehydes in the tailpipe for both engines. Trends for lower carbonyl emissions were observed for the biofuels. Total gas- and particle-phase PAH emissions were significantly lower for the John Deere engine compared to the DOC/DPF-equipped engine. This finding suggests that modern heavy-duty diesel (HDD) engines equipped with robust aftertreatment controls will reduce the emissions exposures from toxic, mutagenic, and carcinogenic compounds that contribute to adverse health effects. For both engines, the use of biofuels showed reductions in particle- and gas-phase PAH emissions compared to CARB ULSD. These reductions were more pronounced with the higher biodiesel blends. Nitrated PAH emissions were seen in significantly lower levels than their parent PAHs. Nitrated PAH emissions showed mixed results with the biofuels with no consistent fuel trends. However, nitro-PAH concentrations for the DPF-equipped Cummins engine were relatively higher than those of the John Deere engine without aftertreatment controls. This phenomenon was due to the de-novo formation of nitro-PAHs inside the DPF system via nitration reactions of the parent PAHs, suggesting that DPF-equipped engines may form elevated emissions of the highly toxic and carcinogenic nitro-PAHs.

Overall, renewable diesel and its blends with biodiesel showed lower carcinogenic potential, as well as reduced ozone forming potential compared to CARB ULSD. Our findings suggest that these fuels can provide a strong pathway for emissions and emissions toxicity reductions from heavy-duty diesel applications in the South Coast Air Basin.

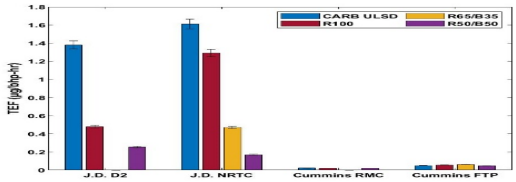

Table 3: Total grams produced per brake HP per hour

Benefits

It is important to understand the emissions from current and older HDD engines with renewable diesel. Our findings suggest that these fuels can provide a strong pathway for emissions and emissions toxicity reductions from heavy-duty diesel applications in the South Coast Air Basin. This study provides a roadmap for the widespread use of these fuel formulations not only for on-road diesel engines, but also for off-road applications including construction, agricultural, marine, and locomotives. These fuels can also help achieve CARB LED standard and contribute to the Governor's diesel emissions reduction target for California.

Project Costs

	SCAQMD
Testing & Reporting	$261,000

Commercialization and Applications

It is expected that liquid renewable diesel fuels will play a major role in heavy-duty transportation for in off-road diesel applications. Their use will likely provide emissions and air quality benefits and will likely reduce emissions toxicity and adverse health effect.

South Coast AQMD Contract # 20058 **September 2021**

Evaluate Meteorological Factors and Trends Contributing to Recent Poor Air Quality in the Basin

Contractor

University of California, Riverside

Cosponsors

South Coast AQMD

Project Officer

Sang-Mi Lee

Background

The South Coast Air Basin (SCAB) of California has achieved tremendous reductions in ozone and particulate matter (PM, particularly fine PM, or PM2.5) levels over the last decades but has recently experienced a leveling off of the reductions and even an uptick in ozone in 2016 and 2017. The immediate question is why? Also, how much of this uptick is related to meteorological factors versus a response to emissions changes from mobile and stationary sources?

Project Objective

The main objective of this project was to find why the ambient ozone and PM2.5 levels in the South Coast Air Basin have plateaued in the past few years and to provide a robust understanding of the likely causes that led to the worsening of ozone and PM air quality in recent years. The results from the study will assist staff in better understanding the complex dynamics of air pollution and weather impacts and also help to develop more effective control strategies to improve air quality under changing climate conditions.

Technology Description

The study employed long-term records of air quality data, emissions inventories and detailed meteorological information (from observations and models) to separate the contribution of meteorology and climate impacts from the effects of emission changes due to cleaner technologies and air quality agencies' regulations. The study also used satellite-derived data on trace species loadings (e.g., nitrogen dioxide (NO2), formaldehyde (HCHO) and ozone (O3)) in conjunction with modeling techniques, which include more traditional chemical transport modeling and meteorological detrending approaches, as well as "big-data" (e.g., machine learning) approaches.

Status

The study was expected to be complete by September of 2021. A no-cost extension was granted to accommodate the setbacks in research progress due to the COVID pandemic. Progress reports have been periodically provided to South Coast AQMD, and most tasks have been completed. The final report is being finalized and will be provided to South Coast AQMD staff for final review.

Results

Preliminary results show that temperature is the dominant parameter that drives ozone high concentrations. Four different approaches were used in this study. The linear regression models, chemical transport models, and machine learning techniques indicate that higher temperatures lead to higher ozone concentrations, and as a result, general global warming is increasing the potential for high ozone events. High temperatures are also generally accompanied with stagnation that promotes pollutant concentration buildup. Meteorological conditions during La Nina phenomenon also contribute to a higher concentration of ozone. The effect of meteorological conditions on PM2.5 concentration is more widely variable, as higher temperatures may lead to lowering ammonium nitrate concentrations while increasing other particulate matter components.

Using the four different approaches to accomplish the main objective provides a higher level of confidence in the findings of the study. Results are

consistent and complementary among the four approaches.

Benefits

The project results provide a comprehensive analysis on the factors that lead to increasing ozone concentrations despite the decrease in ozone precursor emissions. While there are uncertainties associated with the use of any one of the analysis techniques employed in the study (regression modeling, chemical transport modeling, satellite observations, machine learning), results improve our understanding of why ozone may have increased in the past few years.

Project Costs

The total cost of the study was $188,798. The first three quarterly reports were provided earlier in 2020, and payment for $113,277 was processed. The remaining $75,521 will be paid once the final report is submitted and approved.

Commercialization and Applications

This report will be posted on South Coast AQMD's website and made available to the general public. Several organizations have already expressed high interest in learning the results and conclusions of the report. This report will help South Coast AQMD and the people living in the South Coast Air Basin to better understand ozone dynamics and the meteorological parameters that affects smog formation.

South Coast AQMD Contract # 15635 **September 2021**

ZECT II-Development and Demonstration of 1 Class 8 Fuel Cell Range Extended Electric Drayage Truck

Contractor
Center for Transportation and the Environment (CTE)

Cosponsors
US Department of Energy (DOE)
California Energy Commission (CEC)
Ports Technology Advancement Program (TAP)
South Coast AQMD

Project Officer
Seungbum Ha

Background
The Fuel Cell Technologies Office (FCTO) is a key component of the Department of Energy's (DOE) Energy Efficiency and Renewable Energy (EERE) portfolio. The FCTO aims to provide clean, safe, secure, affordable, and reliable energy from diverse domestic resources, providing the benefits of increased energy security and reduced criteria pollutants and greenhouse gas (GHG) emissions.

In April 2014, DOE released DE-FOA-0001106: Zero Emission Cargo Transport II (ZECT II) Demonstration. This funding opportunity sought "to focus on accelerating the introduction and penetration of Zero Emission Carbon Transportation II (ZECT II) technologies." The FOA defined ZECT technologies as, "those that produce zero emissions from the transport vehicle (or other equipment) which propels cargo for all or large portions of their duty cycle.".

South Coast AQMD wrote a proposal combining the DOE funding with funding from the California Energy Commission (CEC) and the Ports Technology Advancement Program (TAP). South Coast AQMD proposed to build and demonstrate trucks from three different teams as well as provide a single fueling infrastructure for all three teams. The Center for Transportation and the Environment (CTE) partnered with BAE Systems; Kenworth, a division of PACCAR; Total Transportation Services (TTSI); Ballard Power Systems; and World CNG to form one team for this project. The other two teams were led by Transpower and US Hybrid.

In February 2016, South Coast AQMD executed a contract with CTE to lead the team developing the Kenworth/BAE truck as well as the fueling infrastructure for all three teams.

Figure 1: Zero Emission Electric Drayage Truck with Fuel Cell Range Extender

Project Objective
The goal of this project was to build a robust zero-emission, heavy-duty Class 8 drayage fuel cell truck that can effectively demonstrate reliable service transporting up to 80,000 lbs. on multiple service routes with differing duty cycles. The intent was to leverage the success of tier one technology companies experienced at building fuel cell, hybrid-electric propulsion systems for heavy-duty transit buses. Working in partnership with Kenworth, a leading heavy-duty truck original equipment manufacturer (OEM), the project engineered and built a prototype vehicle that was then demonstrated and evaluated over a 24-month deployment on regularly scheduled routes serving outlying communities off the I-710 freeway in Los Angeles. Performance and operations data collected during the demonstration phase will help identify the pathways and barriers to commercialization.

Technology Description
The purpose of this project is to accelerate deployment of zero-emission cargo transport technologies that reduce harmful diesel emissions, petroleum consumption, and GHGs in surrounding communities along goods movement corridors. To achieve this purpose, the project team developed a zero-emission battery electric Class 8 drayage truck

with a hydrogen fuel cell range extender. This prototype truck then demonstrated its use in goods movement operations between the Ports of Los Angeles and Long Beach and the near-dock rail yards and warehouses.

To develop the initial truck prototype, the project team adapted a hybrid electric fuel cell propulsion system that is currently used for transit buses so that it was suitable for a Class 8 truck used in a drayage application. The power output of the electric drive train was two electric motors with 270 kW combined power output, comparable to a current Class 8 truck engine's power output. One absorption chiller (AC) traction motor was mounted on each rear drive axle, and the electric drive train was designed to be fully redundant. The vehicle operates using 100 kWh Li-ion batteries, engaging the 85 kW (net) fuel cell system only when the batteries reach a specified state-of-charge (SOC). The hydrogen storage capacity is 30 kg (25 kg usable), which will provide approximately 112 miles of range between refueling.

Status

The team achieved the primary goal of the project, which was to make significant strides developing zero-emission technologies for heavy-duty Class 8 trucks that would accelerate the improvement of air quality in southern California transportation corridors.

Results

Kenworth and BAE Systems collaborated to develop the preliminary vehicle design including mechanical layout and installation drawings. The preliminary design was based on the defined operational requirements as well as duty cycle information from a diesel-equivalent vehicle. To finalize the vehicle design, a combined critical design review and pre-production meeting was held at Kenworth Research and Development Center in Renton, WA.

Figure 2: Overview of truck layout

Air Products' mobile refueler performed consistently throughout the demonstration, but mobile fueling infrastructure adds cost, time, and risk that can only be justified for a small, temporary demonstration. An advantage for larger future deployments and for the heavy-duty vehicle market in general is investing in permanent on-site infrastructure. This will contribute to the cost-reduction goals achieved by mass deployment and shared resources. Expanding fueling infrastructure also guarantees the demand that hydrogen suppliers require to lower costs.

Benefits

The specific design and development assessments and observations included the determination that the supply base is not yet ready for this technology. It was observed that the routing design is integral to the chassis layout, that there are currently too many connections (high voltage, low voltage, CAN, cooling, etc.), and that the high voltage interlocks are vital for functional safety. It was noted that minimizing to two voltages was difficult, cooling was a big challenge, and the battery management systems need self-diagnostics and auto-recovery. It was also determined that the power electronics firmware must become more automated, that human-machine-interface (HMI) is critical and that the procedures and infrastructure for vehicle testing are complex.

Project Costs

The total project cost was $7,109,384. South Coast AQMD provided $821,198. An additional $3,554,691 was provided by the DOE. The CEC provided $2,400,000 and $283,495 was provided by the Port's TAP program. The contractor provided the remaining $50,000 as their cost share.

Commercialization and Applications

Overall, the ZECT demonstration has laid the foundations for the commercialization of fuel cell electric heavy-duty trucks by successfully deploying the vehicle into TTSI's daily drayage operations. The lessons learned from demonstrating this prototype vehicle have informed improvements to both vehicle system design and manufacturing processes. By utilizing permanent on-site fueling infrastructure or existing public fueling infrastructure, increasing availability of off-the-shelf components, and achieving gains in efficiency of next generation technology, fuel cell electric trucks can enter the market at costs competitive with gasoline and diesel equivalents. The penetration of these zero-emission technologies into the heavy-duty market will maximize the impact to emissions reductions and help achieve local air quality targets on time.

South Coast AQMD Contract #21336 **December 2021**

Participate in California Fuel Cell Partnership for CY 2021

Contractor
Frontier Energy Inc.

Cosponsors
South Coast AQMD
Automakers, energy companies, local, state federal public agencies, technology companies, universities, transit agencies and others.

Project Officer
Lisa Mirisola

Background
Originally 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 17 Champion members (executive board level), 9 Champion members (steering team level), and 44 associate members. The focus is on furthering commercialization of fuel cell vehicles, fueling infrastructure technologies and renewable and decarbonized hydrogen production.

Project Objectives
The goals for 2021 included 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 hydrogen stations expanding to a state-wide sustainable infrastructure network in California
- Identify new concepts and approaches to initiate exponential station network growth for light- and heavy-duty applications
- Communicate progress of fuel cell electric vehicles (FCEVs) 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 intend to continue their cooperative efforts within California and have plans to expand activities in 2022 to advance the zero-emission vehicle (ZEV) technology benefits in-state and nationally. The final report covers the South Coast AQMD for 2021 membership. This contract was completed on schedule.

Graphic 1 - CaFCP published its truck vision in August, calling for 200 stations serving 70,000 heavy-duty fuel cell electric trucks by 2035.

Technology Description
Many CaFCP 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 and UC Irvine Student Transportation for a combined 46 buses, with 96 in the coming year or two, including Foothill Transit, Long Beach Transit, Golden Empire Transit, and others. More transit agencies are expected to adopt fuel cell buses over the next 5 to 10 years as they implement the Innovative Clean Transit regulation. Class 8 fuel cell drayage trucks include a Ballard powered BAE/Kenworth truck, the Hydrogenics fuel cell powered TransPower truck, Hyundai Xcient trucks and Toyota's Portal trucks.

Results
Specific accomplishments include:
- Since 2015, more than 12,000 consumers and fleets have purchased or leased passenger FCEVs
- Transit agencies have 48 fuel cell electric buses in operation and more than 96 funded

- 48 plus light-duty retail hydrogen stations in operation in California and 124 in development; 4 bus stations in operation and 3 in early development, and 2 truck stations in operation, 2 in development and another 5 funded
- CaFCP staff and members continue to conduct targeted outreach and education throughout California and provide information to non-California requestors
- CaFCP operates and maintains the Station Operational Status System (SOSS) that the 40-plus open retail hydrogen stations use to report status. This data, in turn, feeds real-time information (address, availability, etc.) to fuel cell electric vehicle (FCEV) drivers through a CaFCP mobile website and other apps and systems. SOSS data also supports the new ZEV infrastructure credit in the Low Carbon Fuel Standard program
- CaFCP 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
- Published a truck vision document in 2021 which calls for 200 stations serving 70,000 trucks by 2035. Early discussions are under way for an implementation road map for California and western states.

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 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 provides a unique forum where infrastructure, technical and interface challenges can be identified early, discussed, and potentially resolved through cooperative efforts.

Project Costs

Auto members provide vehicles along with the staff and facilities to support them. Energy members engage in fueling infrastructure activities, including hydrogen production. CaFCP'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

Research and scaling of technology by multiple entities will be needed to reduce the cost of fuel cells and improve fuel storage and infrastructure. CaFCP has played a vital role in demonstrating fuel cell vehicle reliability and durability, fueling infrastructure and storage options, and increasing public knowledge and acceptance of the vehicles and fueling.

CaFCP's goals relate to preparing for and supporting market launch through coordinated individual and collective effort. CaFCP 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

In 2022, the primary goals are the same as the 2021 goals listed above but have been shifting to be more inclusive of heavy-duty vehicle applications due to the adoption of regulations for transit bus fleets and heavy-duty trucks as well as the technology’s potential to significantly improve emissions in these applications.

South Coast AQMD Contract #15618 **February 2021**

Installation of Eight Hydrogen Stations in Various Cities

Contractor
FirstElement Fuel, Inc.

Cosponsors
California Energy Commission
South Coast AQMD

Project Officer
Patricia Kwon

Background
The California Energy Commission (CEC) issued solicitation PON-13-607 to provide funding opportunities under the ARFVT Program for projects which expand the network of publicly accessible hydrogen fueling stations to serve the current population of fuel cell vehicles (FCVs) and to also accommodate the planned large-scale roll-out of FCVs commencing between 2015 and 2016.

South Coast AQMD is a co-sponsor for this project.

Project Objective
The objective of this project is to build and install eight public access hydrogen fueling stations in the cities of South Pasadena, Los Angeles (2 stations), Long Beach, Costa Mesa, La Canada Flintridge, Laguna Niguel and Lake Forest.

Six of the stations will have delivered hydrogen with 33% renewable content, and the remaining two stations will have 100% renewable hydrogen delivered. The fueling stations will be capable of delivering up to 100 kg of hydrogen per day nominal capacity, with a 35 kg per hour peak Type A fill. They will be designed to be easily expandable in the future. The stations will be able to fuel multiple vehicles back-to-back without delay to avoid congestion.

Technology Description
Hydrogen fuel cell electric drive technology offers tremendous potential for the light-duty passenger vehicle market and medium- and heavy-duty truck and bus markets. These vehicles have zero tailpipe emissions, and the carbon footprint is nearly the same as plug-in electric vehicles.

The hydrogen stations installed under this contract must use a minimum average of 33% renewable hydrogen on a per kg basis through direct physical pathways (on-site or offsite production).

Status
Seven out of eight public access hydrogen fueling stations have been installed and are currently in operation. The following table summarizes the completion dates along with key milestone dates of our project. Note that final reports are on file with complete technical details of the project.

Station	Develop	Delivery	Testing	Completion
South Pasadena	8/26/2016	1/17/2017	2/22/2017	4/10/2017
Los Angeles (Hollywood)	11/16/2015	3/28/2016	4/30/2016	11/10/2016
Los Angeles (PDR)	11/16/2015	4/12/2016	5/29/2016	8/18/2016
Long Beach	6/22/2015	9/9/2015	10/30/2015	2/22/2016
Costa Mesa	8/3/2015	10/13/2015	12/2/2015	1/21/2016
La Canada Flintridge	8/20/2015	10/14/2015	12/9/2015	1/25/2016
Laguna Niguel				
Lake Forest	8/6/2015	10/14/2015	2/27/2016	3/18/2016

The location of the remaining one station (Laguna Niguel) was relocated and the CEC approved location for this station was not located within South Coast AQMD jurisdiction.

Photo of installed Hydrogen Station at La Canada Flintridge. Source: FirstElement Fuel, Inc.

Results
Per California Senate Bill 1505, Environmental Standards for Hydrogen Production, at least one

third of the hydrogen sold by FirstElement's state funded hydrogen refueling stations will be produced from renewable sources. Hydrogen is supplied to the hydrogen fueling stations from Air Products' hydrogen production facilities in Wilmington/Carson, CA. Renewable biogas will be procured as feedstock for the facilities, resulting in delivered hydrogen product that meets the requirements of this PON and the 33.3% renewable hydrogen requirements of California SB 1505. Renewable hydrogen at 100% is achievable through the same supply pathway, however at a higher cost.

Air Products currently has a contract for sourcing of the renewable biogas that meets Public Resources Code Section 2574(b)(1). Air Products' biogas supply for this project is being sourced outside of California and transported to California with connection to a natural gas pipeline in the Western Electricity Coordinating Council (WECC) region that delivers gas into California.

As of July 1, 2019, FirstElement began purchasing and retiring attributes directly through a third party to better increase our renewable supply.

Benefits

The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET) produced by Argonne National Laboratory was used to determine the energy sources and greenhouse gas emissions data presented in the table below. As shown, over two-thirds of the energy feedstock is renewable, very little petroleum is used, and the only tailpipe emissions are water compared to the myriad of pollutants emitted by the combustion of gasoline. The entire well-to-wheels process results in zero greenhouse gas emissions due to our procurement of very low carbon intensity biogas feedstock.

Energy Sources	Zero Station (Gaseous Hydrogen)	Multi-Hose True Zero Station (Liquid Hydrogen)	Gasoline Vehicle
Petroleum	*5.20%*	*1.40%*	*75.50%*
Natural Gas	*16.70%*	*31.60%*	*18.90%*
Coal	*0.40%*	*0.50%*	*0.20%*
Renewable	*77.70%*	*66.80%*	*7.10%*
Total GHGs	*0 grams/mile*	*0 grams/mile*	*428 grams/mile*
Tailpipe Emissions	*Pure Water*	*Pure Water*	*VOC, CO, NO_x, PM_{10}, $PM_{2.5}$, SO_x, CH_4, N_2O*

Project Costs

The table below provides the summary of project costs for the program.

Station	CEC	SCAQMD	Match
South Pasadena	1,451,000	100,000	925,822
Los Angeles (Hollywood)	1,451,000	200,000	591,408
Los Angeles (PDR)	1,451,000	200,000	600,161
Long Beach	1,451,000	100,000	765,719
Costa Mesa	1,451,000	100,000	589,103
La Canada Flintridge	1,451,000	100,000	712,515
Laguna Niguel	-	-	-
Lake Forest	1,451,000	100,000	742,899
Total	**$ 10,157,000**	**$ 900,000**	**$ 4,927,628**

Commercialization and Applications

By adding eight additional stations to the California Hydrogen Fueling Station Network, FirstElement has helped establish the infrastructure needed for the large scale roll out of Fuel Cell Vehicles. As of January 12, 2021, our stations, as part of the network of publicly accessible hydrogen fueling stations, served approximately 8,931 light-duty passenger fuel cell cars.

As this network expands, we see the continued roll out of this technology encouraging growth in the light-duty passenger markets as well as establishing the foundation for growth in the medium- and heavy-duty truck and bus markets.

South Coast AQMD Contract #16251 **May 2021**

Develop and Demonstrate Commercial Mobile Hydrogen Fueler

Contractor
H2 Frontier Inc

Cosponsors
California Energy Commission (CEC)
South Coast AQMD
US Hybrid
H2Frontier
Gas Technology Institute (GTI)

Project Officer
Lisa Mirisola/Patricia Kwon

Background
Automakers targeted a 2015 roll-out of hydrogen fuel cell vehicles (FCEV), making the availability of hydrogen fueling stations critically important. FCEVs play an important role in promoting the transition of the mobile transportation sector towards zero emission technologies. These new technologies are necessary to attain the federal criteria pollutant standards as well as the state greenhouse gas targets. California has the most extensive fleet of fuel cell vehicles in the nation, supported by the nation's largest network of hydrogen fueling stations. Even though additional stations are expected to become available over the next few years there is little or no redundancy in the network. Consequently, the impact of a station going out of service due to planned (or unplanned) maintenance can leave fuel cell vehicle owners without a convenient reliable source of fuel until the station comes back on-line.

Project Objective
H2 Frontier Inc. proposed to design, fabricate, test, and deploy a fully operational, commercial mobile hydrogen fueler in response to the California Energy Commission's (CEC) recent Program Opportunity Notice 13-607 (Alternative and Renewable Fuel and Vehicle Technology Program, Subject Area-Hydrogen Refueling Infrastructure). The mobile fueler would be designed to provide back-up to stations during extended maintenance or upgrade and support fuel cell vehicle ride-and-drive events, while providing a fueling experience that would be similar to a full-scale station.

Technology Description
The mobile fueler was not only intended to be a stand-alone station for remote filling but designed to provide the flexibility to integrate itself into stations that may have temporary dispensing issues. The design connects to the onsite hydrogen storage supply and can connect to existing hydrogen dispensers to fill onboard storage. Another design option to be explored on a case-by-case basis was the ability of the fueler to tow and connect to a secondary tube trailer to expand its capacity for any high demand locations thus helping to limit the need to remove it from the designated site to replenish on-board storage. The mobile hydrogen fueler would use renewable fuel when possible and would be deployed at hydrogen stations as needed.

Configured on board a medium-duty, Ford F550 truck platform, with hydrogen storage, compression, and dispensing capabilities, the mobile fueler was designed to be completely self-contained, with no need for external power, pre-cooling, or delivered hydrogen supplies. Additionally, the mobile fueler would have the capability to fill either 350 bar or 700 bar vehicle tanks while meeting U.S. DOT on-road vehicle requirements, along with the intent of SAE J2601 and SAE 2719 hydrogen fueling interface and hydrogen quality requirements and guidelines. The expected life of the equipment design was ten years, assuming 80% availability.

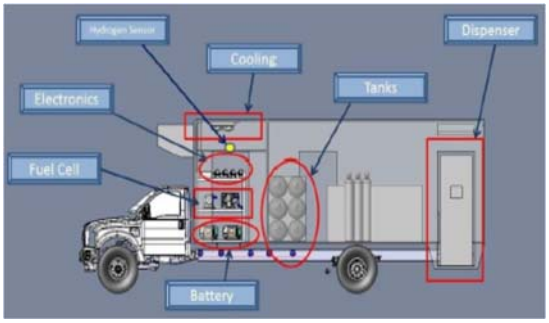

Figure 1: Mobile Refueler Design Layout

Status

The first task was to design the system, prepare the platform and specify the specific equipment. This task was completed. However, the design did not conform to revised SAE J2601 and automakers would not approve their new fuel cell vehicles to fuel with the obsolete design.

H2Frontier exited the project, but the team with CEC Grant Agreement ARV-14-003 determined that it would be necessary for the refueler to comply with the SAE International J2601:2014 fueling protocol for it to serve the industry appropriately. SAE International J2601:2014 is a fueling standard that defines conditions, such as the required hydrogen pressure and temperature, for filling light-duty FCEVs. At that time, the team focused on securing the additional funding necessary to expand the project scope to comply with the advanced fueling protocol.

The project team investigated several opportunities to secure additional funding for the project. They held discussions with private companies with needs for mobile refueling solutions, and with state agencies that have mandates for acquiring and operating fuel cell electric vehicles. The project team also contacted private station operators and constructed several design iterations and plans to develop a path forward that would satisfy all entities associated with the project and related end use. Unfortunately, the project team was not able to acquire the additional funds during the project period and, without the necessary funding to provide a viable system to the industry, the project concluded when it reached the term end date without constructing and deploying a mobile hydrogen refueler.

GTI submitted the Final Report CEC-600-2021-006 to CEC April 2021.

Figure 2: Base Truck Ford F650 with Custom Body

Benefits

In addition to criteria emission reductions, this project represented an investment in clean economical FCEV transportation to help meet California's climate goals.

Project Costs

This project was not completed. The proposed total project costs to develop and deploy the commercial mobile hydrogen fueler were estimated at $1,665,654. The proposed project costs were broken down as follows:

	CEC Funding	Partner Cost-Share
Gas Technology Institute	$224,677	$15,064
U.S. Hybrid	$400,000	$375,913
H2 Frontier, Inc.	$375,000	75,000
South Coast AQMD		200,000
Totals	**$999,677**	**$665,977**

The first task was completed for $45,000. The remaining $155,000 of Clean Fuels funds from South Coast AQMD were de-obligated.

Commercialization and Applications

New designs are being developed to address current fueling, safety and other standards.

South Coast AQMD Contract #18158 **March 2021**

California Hydrogen Infrastructure Research Consortium H2 @ Scale Initiative

Contractor

Alliance for Sustainable Energy, LLC,
National Renewable Energy Laboratory (NREL)

Cosponsors

US Department of Energy (DOE)
South Coast AQMD
California Air Resources Board (CARB)
California Energy Commission (CEC)
CA Go-Biz

Project Officer

Lisa Mirisola

Background

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 fuel cell electric vehicle deployment. This leadership has advanced a hydrogen network that is not duplicated anywhere in the United States and is unique in the world for its focus on providing a retail fueling experience. 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 United States.

Project Objective

California agencies identified tasks based on top research needs and priorities for the benefit of state and national efforts to deploy a hydrogen fueling infrastructure and has identified a need to leverage national laboratory research capabilities and staff to support these efforts. The consortium used these tasks as the first step in a strategic partnership, balancing near-term research needs with accelerating earlier-stage research into the market. Specific focus was placed on sharing and translating lessons learned to other jurisdictions, which is a priority in a partnership between state and federal agencies and laboratories.

Technology Description

California agencies prioritized a certain set of tasks for the benefit of state and national efforts to deploy a hydrogen fueling infrastructure. The set of tasks focused on the near-term challenges for California hydrogen infrastructure development, deployment, and operation.

The set of tasks included hydrogen station data analysis, insights into medium and heavy-duty vehicles running on hydrogen, hydrogen contaminant detectors for use at hydrogen fueling stations, hydrogen nozzle freeze lock evaluation (component failure scenarios), hydrogen topics for integration into California energy management strategy, and a technical assistance project that analyzed liquid hydrogen modeling for a hydrogen station capacity tool.

Status

The project was completed in April 2021. The final report is on file with complete technical details of all the project tasks.

For example, it was determined that understanding the conditions where nozzle freeze-lock occurs will help mitigate the issue in commercial hydrogen fueling stations. The observed trends can help station providers predict days when nozzle freeze-lock might occur and implement proactive countermeasures.

Figure 1. Nozzle Freeze-lock Chamber and Atmosphere Generating Cart at NREL

The medium/heavy-duty task was originally intended to analyze and report on retail and

experimental fueling of medium-/heavy-duty trucks, which were not operational in time for this project. The task was redirected towards a topical overview of medium/heavy duty truck fueling which resulted in a report and a presentation suitable for a webinar on April 7, 2021 that was shared with the California partners for their use as needed.

Results

Results have been presented as part of DOE's Annual Merit Review 2018-2021, DOE H2@Scale Working Group, and at the 2019 Fuel Cell Seminar and Energy Exposition.

The markets for trucks and light duty vehicles complement each other with the larger number of light duty vehicles providing the possibility for many parts being produced thus bringing down the prices for components used in trucking, while the trucks use a lot of hydrogen fuel encouraging increased hydrogen production and bringing down the price of hydrogen for light duty vehicles.

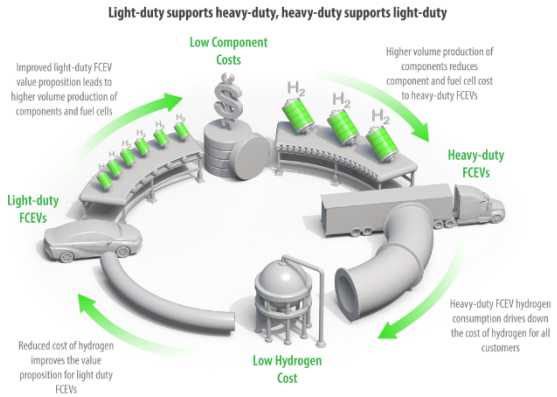

Figure 2. Light-duty fuel cell vehicles support heavy-duty cell vehicles simultaneously reducing component costs and hydrogen fuel costs as fuel cell manufacturing and hydrogen production scale increases

Benefits

This consortium coordinates research efforts that support the DOE's and California's hydrogen goals and requirements, shares lessons learned with other states and stakeholders to inform implementation efforts outside of California, supports shifting the hydrogen infrastructure progress from a government push into a market pull, advances the station technology and operation to meet the next waves of vehicle demand, and leverages existing core capabilities and researchers at national labs.

Project Costs

Project Partner	Co-Funding
Fuel Cell Technologies Office	$700,000**
California Air Resources	$100,000
California Energy Commission	$100,00
South Coast AQMD	$100,000
California Go-Biz	In kind
Total	$1,000,000

**subject to partial award, funding may be scale

The California Air Resources Board was unable to enter into a joint Cooperative Research and Development Agreement (CRADA), so CARB executed an individual CRADA with NREL for their portion.

Commercialization and Applications

To provide a more comprehensive picture of when nozzle freeze-lock occurs, NREL recommends both repeated testing and evaluating multiple nozzle manufacturers. Statistical significance and trends could be further expanded upon. New heavy-duty high flow rate nozzles will also need testing. Testing with freeze mitigation technology, such as nitrogen purging, could help determine if mitigation strategies are effective.

Hydrogen contaminant detectors are not expected to meet all requirements of SAE J2719.

Follow-on tasks focusing on heavy-duty applications proposed to DOE for H2@Scale 2020 funding were approved and a new contract is under final review. Three new tasks have been set. The first new task is an HD Reference Station Design led by Sandia National Lab. The second task is an HD Station Test Device Design to analyze hydrogen fueling performance and the third task is the development of a HD Station Capacity Tool. A fourth task under a separate agreement, is an H2 Contaminant Detector Design focused on water vapor contaminant sensing at stations. This task was determined as necessary as more electrolysis stations are expected and there will be a need to ensure compatibility of hydrogen contaminant detector (HCD) pneumatic systems with regulated contaminants with validating HCDs in the field at a California station.

South Coast AQMD Contract # 20108 **June 2021**

Develop Optimal Operation Model for Renewable Electrolytic Fuel Production

Contractor
University of California, Irvine

Cosponsors
South Coast AQMD
California Energy Commission (CEC)
US Department of Energy (DOE)

Project Officer
Seungbum Ha

Background

There is a growing interest in the use of renewable electrolytic hydrogen (green hydrogen) and methane as substitutes for natural gas. In the case of pure hydrogen, the fuel would be used as a blend stock at fractions that may be as high as 20%. The allowable blend fraction for renewable synthetic methane (also referred to as synthetic natural gas or SNG) could be as high as 100%. Both fuels have the potential to change the pollutant emissions of combustion systems with NOx being the constituent of concern.

Project Objective

The objective of the project was to assess the potential local and regional NOx emissions and air quality impacts of electrolytic fuel production systems injecting hydrogen or synthetic methane onto the natural gas grid.

Technology Description

Electrolyzers use electric power to split water into hydrogen and oxygen through a catalytic electrochemical process. When the input electricity is renewable, the product hydrogen is a renewable fuel, also called green hydrogen. Green hydrogen (GH2) can be combined with biogenic CO2 to create methane in a process called methanation. The result is a renewable substitute for natural gas also referred to as synthetic natural gas (SNG). Both GH2 (up to a blend limit that may reach 20%) and SNG (potentially up to a blend limit of 100%) can be injected onto the natural gas grid to reduce the carbon intensity of system gas.

Status

Three hypothetical electrolyzer projects were defined (size, location, electric supply sources). The (RoDEO) model developed and run by the National Renewable Energy Laboratory (NREL) was used to optimize the operating schedules of the electrolyzers to minimize hydrogen production cost based on the cost of input electricity. The result of this analysis confirmed the general feasibility of producing natural gas substitutes within the target price range and provided estimates of the quantities of produced fuel to be injected onto the natural gas grid.

Results

Air quality analysis was conducted at the local and regional levels assuming hydrogen reaches the maximum allowed blend limit of 20% by volume to bound the impacts. Impacts were assessed based on NOx emissions impacts of hydrogen methane blends and methane-CO2 (SNG proxy) blends measured in parallel projects. SNG shows reduction in NOx formation for all burner types and so does not present an air quality concern. In contrast, some common burner types show reduced NOx formation with hydrogen blends and other burner types show increases. An inventory of burner types and replacement trends is needed to ensure that deployment of hydrogen blends for greenhouse gas (GHG) mitigation does not lead to upward pressure on secondary 8-hour ozone and PM2.5 levels in the South Coast Air Basin. The best and worst case 8-hour ozone results are shown below.

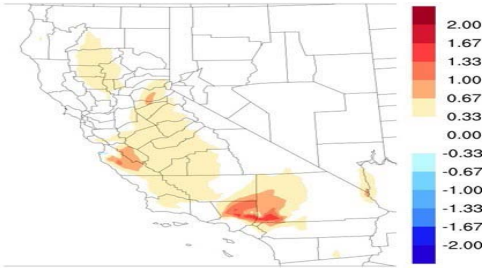

Figure 1: Worst-case increase in summer average MD8H ozone (ppb) for 20% hydrogen blend on the gas grid

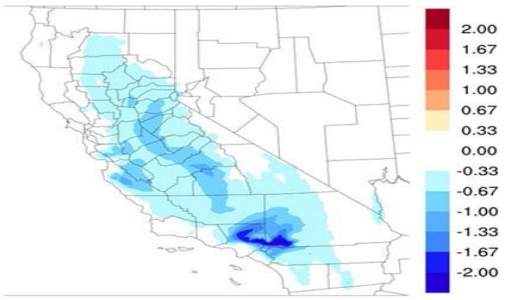

Figure 2: Best-case decrease in summer average MD8H ozone (ppb) for 20% hydrogen blend on the gas grid

Benefits

The work shed light on the potential for upward pressure on NOx and secondary ozone and PM2.5 concentrations that could result from injecting hydrogen into the natural gas grid while also showing the reduced NOx is possible from hydrogen blends. Given the potential GHG benefits of green hydrogen, future technical and policy analysis should focus on ensuring that hydrogen deployment results in net negative emissions. This can be accomplished by design specifications for hydrogen-ready burners and combustors, aftertreatment requirements and deployment of non- combustion conversion devices such as fuel cells.

Project Costs

The total planned project cost was $500,000 with $100,000 to be provided by South Coast AQMD and $400,000 from other related efforts funded by the California Energy Commission and the U.S. Department of Energy. The project was completed within the agreed budget.

Commercialization and Applications

Introduction of zero and low-carbon fuels to decarbonize the fuel provided over the natural gas grid is a key strategy for achieving deep decarbonization. A growing number of national strategies including those of Canada, the United Kingdom and the European Union are embracing these solutions. The current U.S. Department of Energy Hydrogen Shot and the local green hydrogen initiative, HyDeal LA, demonstrate growing momentum for the deployment of these solutions driven in large part by rapidly declining costs of decarbonized gaseous fuel.

Proceedings are ongoing at the California Public Utilities Commission to establish regulatory frameworks for the introduction of hydrogen and synthetic methane on the gas grid as they have done for biomethane. Ensuring that the policies and regulations for deployment of these important resources fully considers air quality impact along with safety, reliability and GHG reductions is key to achieving an equitable energy transition. This project is important to establishing the foundations for the development of air quality policies to support a truly sustainable deployment of renewable hydrogen and methane.

Appendix D

Technology Status

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Technology Status

For each of the core technologies discussed earlier in this report, staff considers numerous factors that influence the proposed allocation of funds, ranging from overall Environment & Health Benefits, Technology Maturity and Compatibility, and Cost, summarized in this technology status evaluation system.

Within the broad factors included above, staff has included sub-factors for each specific type of project that 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 2016 AQMP. Technologies that provide co-benefits of Greenhouse Gas 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 have been used to evaluate technology maturity and risk that include an evaluation of potential uncertainty in real world operations. This approach can include numerous weighting factors based on the assessed importance of a particular technology. Some key metrics that are 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. In an effort 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 and Infrastructure as Excellent or Good for Criteria Pollutant and GHG/Petroleum Reduction, but Satisfactory to Excellent for Technology Maturity, Poor to Excellent for Compatibility, and Satisfactory to Unacceptable 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 & Infrastructure									
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	◓	○	◓	●	●	●	●	◒	●
Infrastructure	-	-	-	◓	◓	◓	◓	◒	●
Hydrogen & Fuel Cell Technologies & Infrastructure									
Heavy-Duty Trucks	●	◓	◓	○	◓	○	◒	●	●
Heavy-Duty Buses	●	◓	◓		◓	◓	◓	●	●
Off-road – Locomotive/Marine	●	◓	◓	○	○	◒	◒	●	●
Light-Duty Vehicles	●	◓	◓		◓	○	○	◒	◒
Infrastructure – Production, Dispensing, Certification	-	-	-	○	○	◒		●	◒
Engine Systems									
Ultra-Low Emission Medium- and Heavy-Duty Renewable Diesel Vehicles	◓	◓	◓	●	○	●	●	◓	◒
Renewable Gaseous and Alternative Fuel Ultra-Low Emission Medium- and Heavy-Duty Vehicles	◓	◓	◓	●	●	●	●	◓	◒
Ultra-Low Emission Off-Road Applications	◓	◓	◓	◓	○	◓	●	◓	◒
Fueling Infrastructure & Deployment									
Production of Renewable Natural Gas – Biowaste/Feedstock	◓	●	◓	●	◓	◓	◓	◒	◒
Synthesis Gas to Renewable Natural Gas	◓	●	◓	●	◓	◓	◓	○	○
Expansion of Infrastructure/Stations/Equipment/RNG Transition	◓	◓	◓	●	◓	◓	◓	◓	○
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	◓	○	◓	○	○	◓	●	◓	○
Lower-Emitting Lubricant Technologies	○	○	●	-	◓	◓	◓	●	○

● Excellent ◓ Good ○ Satisfactory ◒ Poor ● Unacceptable

Appendix E

List of Acronyms

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LIST OF ACRONYMS

3B-MAW—3-bin moving average windows
AB—Assembly Bill
AC—absorption chiller
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
ARRA—American Recovery & Reinvestment Act
AWMA—Air & Waste Management Association
BACT—best available control technology
BATS – blended aftertreatment system
BEB—battery electric bus
BET – battery electric tractor
BET—battery electric truck
BEV—battery electric vehicle
BSNOx—brake specific NOx
BMEP – brake mean effective pressure
BMS—battery management system
CAP – Clean Air Protection
CAAP—Clean Air Action Plan
CAFR—Comprehensive Annual Financial Report
CaFCP—California Fuel Cell Partnership
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
CCV—closed crankcase ventilation
CDA—cylinder deactivation
CDFA/DMS—California Department of Food &Agriculture/Division of Measurement Standards
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
CFCI—Clean Fuel Connection, Inc.
CFD—computational fluid dynamic
CHBC—California Hydrogen Business Council
CHE—cargo handling equipment
CMAQ—community multi-scale air quality
CNG—compressed natural gas
CNGVP—California Natural Gas Vehicle Partnership
CO_2—carbon dioxide
CO—carbon monoxide
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—continuously regenerating technology
CSC—city suburban cycle
CTE – Center for Transportation and the Environment
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
DERA – Diesel Emissions Reduction Act
DGE—diesel gallon equivalents
DF—deterioration factor
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
DPT3—Local Drayage Port Truck (cycle) - where 3=local (whereas 2=near-dock, etc.)
DRC—Desert Resource Center
DRI—Desert Research Institute
ECM—emission control monitoring
EDD—electric drayage demonstration
EDTA—Electric Drive Transportation Association
EERE – Energy Efficiency and Renewable Energy
EGR—exhaust gas recirculation
EIA—Energy Information Administration

LIST OF ACRONYMS (cont'd)

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
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
GNA—Gladstein, Neandross & Associates, LLC
Go-Biz – Governor's Office of Business and Economic Development
GPCI – Green Paradigm Consulting, Inc.
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
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
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
H2NIP—Hydrogen Network Investment Plan
HTPH—high throughput pretreatment and enzymatic hydrolysis
HyPPO—Hydrogen Progress, Priorities and Opportunities report
Hz—Hertz
ICE—internal combustion engine
ICEV—internal combustion engine vehicle
ICT – Innovative Clean Transit Regulation
ICU—inverter-charger unit
ICTC—Interstate Clean Transportation Corridor
ITS – intelligent transportation system
IVOC—intermediate volatility organic compound
JETSI - Joint Electric Truck Scaling Initiative
kg—kilogram
kWh – kilowatt-hour
LADOT—City of Los Angeles Dept. of Transportation
LADWP—Los Angeles Department of Water and Power
LAEDC – Los Angeles Economic Development Corporation
LA Metro – Los Angeles County Metropolitan Transportation Authority
LBCT – Long Beach Container Terminal
LCA—life cycle assessment
LCFS—Low Carbon Fuel Standard
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
MATES—Multiple Air Toxics Exposure Study
MCE—multi cylinder engine

LIST OF ACRONYMS (cont'd)

MCFC—molten carbonate fuel cells
MD—medium 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
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
PAH—polycyclic aromatic hydrocarbons
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
ppb—parts per billion
PSI—Power Solutions International
PTR-MS—proton transfer reaction-mass spectrometry
QVM – qualified vehicle modifiers
R&D – research and development
RD&D—research, development and demonstration
RDD&D (or RD3)—research, development, demonstration and deployment
REMD – roadside emissions monitoring device
RFA – Renewable Fuels Association
RFI – Request for Information
RFP—Request for Proposal
RFS—renewable fuel standards
RI—reactive intermediates
RMC – ramped modal cycle
RMC-SET— ramped modal cycle supplemental emissions test
RNG—renewable natural gas
ROG – reactive organic gases
RPS – Rail Propulsion Systems
RTP/SCS—Regional Transportation Plan/Sustainable Communities Strategy

LIST OF ACRONYMS (cont'd)

S2S – Shore to Store
SAE—Society of Automotive Engineers
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
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
START – Sustainable Terminals Accelerating Regional Transportation
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
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.
TTSI—Total Transportation Services, Inc.
TWC—three-way catalyst
UCI – University of California, Irvine
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
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
ZEV—zero emissions vehicle