South Coast
Air Quality
Management District

Clean Fuels Program

2020 Annual Report & 2021 Plan Update

Technology Advancement Office

Leading the way to cleaner air

Cover Photo Credits

Left to right; top to bottom

- Starcraft E-Quest XL Type C battery electric school bus at Colton USD (top left)
- Cummins-Westport 8.9L ISL G heavy-duty natural gas engine certified to 0.02 g/bhp-hr Optional Near Zero NOx Emissions standard (top middle)
- Kenworth-Toyota Class 8 fuel cell electric truck for Zero Emission Shore to Store Project (top right)
- Vehicle charging at Level 2 with SAE J1772 connector (center left)
- Volvo Class 8 battery electric VNR Electric truck at NFI for Volvo LIGHTS (center)
- EVgo 50 kW public DC fast charging station at La Kretz Innovation Campus in Los Angeles (center right)
- New Flyer Xcelsior XHE40 40’ hydrogen fuel cell transit bus at Sunline Transit (lower left)
- Hydrogen storage for fuel cell bus fueling at OCTA (lower right)

South Coast Air Quality Management District

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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 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) ppb 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 and 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 $340 million into over $1.5 billion in projects.

As technologies move towards commercialization, such as battery electric trucks, the Clean Fuels Program has been able to partner with large original equipment manufacturers (OEMs), such as Daimler, Volvo and Peterbilt in order to deploy these vehicles in larger numbers. These OEM partnerships allow the Program to leverage their research, product creation, 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 in order to achieve the emission reductions needed to meet federal and state ambient air quality.

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. As a result, the TAO Clean Fuels Program has traditionally supported a portfolio of technologies, at different technology readiness levels, to provide a continuum of emission reductions and health benefits over time. This approach provides the greatest flexibility and enhances the region's chances toward achieving the National Ambient Air Quality Standards (NAAQS).

California Health and Safety Code (H&SC) 40448.5(e) calls for the Clean Fuels Program to consider, among other factors, the 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.

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 what the Program accomplished 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 based, in large part, 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 is updated approximately every four years, 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) draft Mobile Source Strategy.

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 ($\mu g/m^3$)], including secondary organic aerosols.

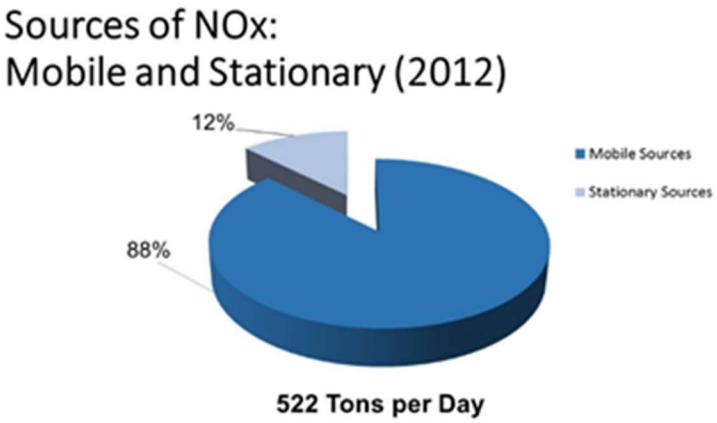
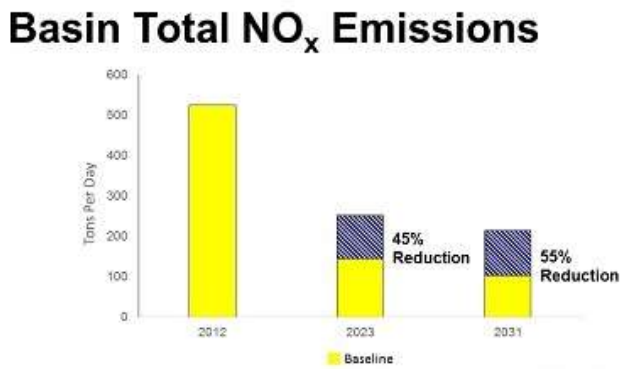


Figure 1: Sources of NOx 2012 Base Year

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 required by 2023 and an additional 55 percent reduction by 2031 to achieve ozone standards of 80 parts per billion (ppb) and 75 ppb, respectively. Figure 2 illustrates these needed NOx reductions in the Basin. The majority of these 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 San Joaquin 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 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 efforts in developing regulations for on- and off-road vehicles and equipment are expected to significantly reduce NOx emissions, but are insufficient to meet South Coast AQMD needs, particularly in terms of timing.

Clean Fuels Program

The Clean Fuels Program is a very important mechanism to encourage and accelerate the advancement and commercialization of clean fuel 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 2020 Clean Fuels Annual Report and Draft 2021 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.

2020 Annual Report

In CY 2020, the South Coast AQMD Clean Fuels Program executed 24 new contracts, projects or studies and modified 11 continuing project adding dollars toward research, development, demonstration and deployment projects as well as technology assessment and transfer of alternative fuel and clean fuel technologies. Table 1 shows our major funding partners in CY 2020. Table 2 lists the 35 projects or studies, which are further described in this report. The South Coast AQMD Clean Fuels Program contributed nearly $4.1 million in partnership with other governmental organizations, private industry, academia and research institutes, and interested parties, with total project costs of approximately $28.9 million. The $4.1 million includes nearly $500,000 recognized into the Clean Fuels Fund as pass-through funds from project partners to facilitate project administration by the Clean Fuels Program. Table 3 provides information on this outside funding received into the Clean Fuels Fund. Additionally, in CY 2020, the Clean Fuels Program continued to leverage other outside funding opportunities, securing new awards totaling $45.8 million from federal, state and local funding opportunities. Table 4 provides a comprehensive summary of these federal, state and local revenues awarded to the South Coast AQMD during CY 2020. Like the last couple of years, the significant project scope of a few key contracts executed in 2020 resulted in higher than average leveraging of Clean Fuels dollars. Typical historical leveraging is $4 for every $1 in Clean Fuels funding. In 2020, South Coast AQMD continued this upward trend with nearly $7 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 federal ozone air quality standards.

The projects or studies executed in 2020 included a diverse mix of advanced technologies. The following core areas of technology advancement for 2020 executed contracts (in order of funding percentage) include:

1. Engine Systems/Technologies (emphasizing alternative and renewable fuels for truck and rail applications);
2. Hydrogen and Mobile Fuel Cell Technologies and Infrastructure;
3. Technology Assessment and Transfer/Outreach;
4. Electric and Hybrid Vehicle Technologies and Related Infrastructure (emphasizing electric and hybrid electric trucks developed by OEMs and container transport technologies with zero emission operations); and
5. Fueling Infrastructure and Deployment (natural gas (NG)/ renewable natural gas (RNG))

The chart on page 27 shows the distribution by percentage of executed agreements in 2020 across these core technologies.

During CY 2020, 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 electric and hybrid electric technologies and infrastructure to develop and demonstrate medium- and heavy-duty vehicles in support of transitioning to a near-zero and zero emissions goods movement industry; 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 35 executed contracts and projects, 22 research, development, demonstration and deployment projects or studies and 8 technology assessment and transfer contracts were completed in 2020, as listed in Table 6. Appendix C includes two-page summaries of the technical projects completed in 2020. As of January 1, 2021, there were 106 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, 2021, after approval by the South Coast AQMD Board.

2021 Plan Update

Staff's re-evaluation of the Clean Fuels Program to develop the annual Plan Update is 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 cofunding 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 2021 Plan Update. Due to Assembly Bill (AB) 617[1], which 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 cleaner technologies. Cleaner technologies such as zero emission heavy-duty trucks are now included in the Community Emission Reduction Plans (CERPs) for these AB 617 communities. CARB adopted two critical milestone regulations for reducing emissions from heavy-duty mobile sources in 2020, the Advanced Clean Truck (ACT) regulation which mandates percent zero emission truck (ZET) sales starting in 2024 and the Omnibus Low NOx regulation which requires lower NOx standard heavy-duty engines starting in 2022. Despite these two major efforts, the expected NOx reduction will still fall short of the 2023 and 2031 attainment target.

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 emission reductions identified in the 2016 AQMP. Given the need for significant reductions over the next five to ten years, near-zero and zero emission technologies are emphasized. Areas of focus include:

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

- reducing emissions from port-related activities, such as cargo handling and container movement, and other technologies, including demonstration and deployment of zero emission drayage trucks;
- developing and demonstrating ultra-low NOx, gaseous and liquid renewable fueled, large displacement/high efficiency engines and zero emission heavy-duty vehicles;
- developing, demonstrating and deploying advanced natural gas and propone engines as well as near-zero and zero emission technologies for high horsepower applications;
- mitigating criteria pollutant emissions from 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 EV charging infrastructure to support light-, medium- and heavy-duty zero emission vehicles; and
- developing and demonstrating advanced zero emission microgrids for energy storage and demand to support transportation electrification, goods movement, and freight handling activities.

Table 6 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);
2. Electric/Hybrid Vehicle Technologies and Infrastructure (emphasizing 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 electric vehicle (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 2021 total $17.9 million, with anticipated leveraging of more than $4 for every $1 of Clean Fuels funding for total project costs of $120 million. Some of the proposed projects 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.

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 impacts. 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 this year staff is recommending 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.

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 (as of 2/19/21) 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.

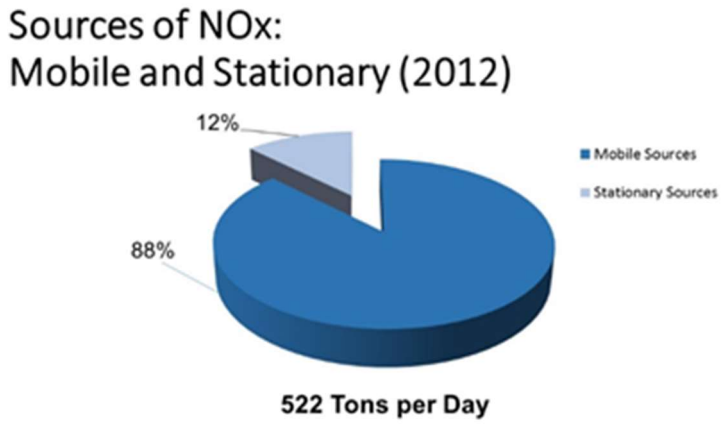
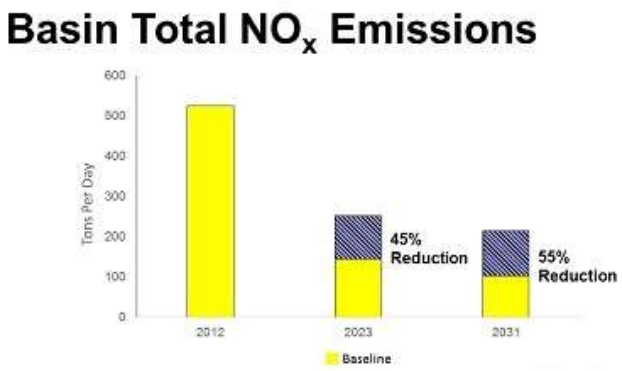


Figure 1: Sources of NOx 2012 Base Year

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 Technology Advancement Office (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.

The following sections describe program funding, provide a 2020 overview and describe core technologies of 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 2020, the funds available through each of these mechanisms were as follows:

- Mobile sources (DMV revenues) $13,258,888
- Stationary sources (emission fee surcharge) $356,174

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 California Energy Commission (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 3 lists the supplemental grants and revenues totaling almost $500,000 for contracts executed in CY 2020.

Table 4 lists the federal, state and other revenue totaling $45.8 million awarded to the South Coast AQMD in 2020 for projects that are part of the overall Clean Fuels Program's RD[3] efforts, even if for

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

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 $343 million into more than $1.55 billion in projects. For 2020, the Clean Fuels Program leveraged each $1 to nearly $7 of outside funding. Similar to last year, this atypical leverage was the result of a few key significant project awards in 2020, such as the $31.5 million project with Volvo, which includes a nearly $20 million award to the South Coast AQMD from US EPA TAG grant. 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 2020 are listed in Table 1.

2020 Overview

This report summarizes the progress of the South Coast AQMD Clean Fuels Program for CY 2020. 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 2020. During the period between January 1 and December 31, 2020, the South Coast AQMD executed 24 new contracts/agreements, projects or studies and modified 11 continuing project adding dollars during CY 2020 that support clean fuels and advanced zero, near-zero and low emission technologies (see Table 2). The South Coast AQMD Clean Fuels Program contribution for these projects was $4.1 million, inclusive of approximately $500,000 received into the Clean Fuels Fund as cost-share for contracts executed in this reporting period. Total project costs are $28.9 million. The Clean Fuels contribution, total project costs and number of contracts executed in 2020 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 2021 for a resurgence in business activity, more completed projects and newly executed projects.

The projects executed in 2020 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 3), 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 $45.8 million in 2020, see Table 4). For example, in 2020, the South Coast AQMD was awarded nearly $37 million by USEPA as project partners with Volvo on their electric drayage truck Switch-On Project ($20M), Sunline Transit for fuel cell electric buses ($6M) and MAN Energy Solutions for an SCR retrofit of an ocean going vessel ($11M) with total project costs of over $50million. These projects will advance the commercialization of electric trucks, fuel cell buses and 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 2021 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 2020 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 2020.

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 Program Opportunity Notices (PONs) to solicit project ideas and concepts as well as the issuance of Requests for Information 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. As automakers continue to collaborate on development efforts (e.g., Honda and GM) and commercialize fuel cell vehicles, in the interim plug-in hybrid technology could help enable fuel cells by using larger capacity batteries until fuel cell components mature. For example, Mercedes-Benz announced limited production of a plug-in fuel cell model GLC for 2018 in Germany, with U.S. availability to follow. However, 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 65 stations funded by CEC and CARB by the end of 2019, partially funded by South Coast AQMD for those in our region, there is one legacy and 39 retail operational in California, but most if not all 65 are expected to be operational by the end of 2020 with capacity for more than 10,000 fuel cell vehicles. 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: 2019 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California*[3] released in December 2019 covering 2019 findings states that there were 6,826 fuel cell vehicles registered in California by October 2019. However, CARB's 2017 Annual Evaluation projects 13,400 fuel cell electric vehicles (FCEVs) in California by 2020 and 37,400 by the end of 2023. 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 to expand the market with heavy-duty technologies and their infrastructure.

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 $500,000 has been 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 will be executed in 2020. 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 Zero Emission Cargo Transport (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. The battery and fuel cell dominant fuel cell trucks have a range of 150-200 miles.

[3] https://ww2.energy.ca.gov/2019publications/...2019.../CEC-600-2019-039. pdf

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 greenhouse gases (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 Greenhouse Gas Reduction Fund (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 Port of Long Beach 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[4], 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 2030 California Transportation Future Summit, the Hydrogen and Fuel Cells for Freight Workshop, the ACT Virtual Event Series from August through November 2020 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 42 for a description of the technology assessment and transfer contracts executed in CY 2020 as well as a listing of the 8 conferences, workshops and events funded in CY 2020. 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.

[4] 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 3 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 3: Stages of Clean Fuels Program Projects

Due to the nature of these advanced technology research, development, demonstration and deployment (RD^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 for Heavy-Duty Vehicles
  - Cummins Westport: 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; and
  - Kenworth CNG Hybrid Electric Drayage Truck project.
- 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; and
  - Fuel cell Class 8 trucks under Zero Emission Cargo Transport (ZECT) II Program.
- Electric and Hybrid Electric Vehicle Development and Demonstrations
  - Daimler Class 6 and 8 battery electric trucks with Penske and NFI;
  - Volvo Class 8 battery electric trucks with TEC Fontana, DHE, and NFI;
  - Hybrid electric delivery trucks with National Renewable Energy Laboratory (NREL), FedEx and UPS;
  - Plug-in hybrid work truck with Odyne Systems;
  - 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; and
- Peterbilt battery-electric drayage 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 2020 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 1 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 2020 Project

Summaries by Core Technologies contained within this report, as well as Table 4 which lists federal, state and local funding awarded to the South Coast AQMD in CY 2020 for RD^3 projects (which will likely result in executed project contracts in 2021).

Table 1: South Coast AQMD Major Funding Partners in CY 2020

Research Funding Organizations	Major Manufacturers/Technology Providers
California Air Resources Board	Landi Renzo USA Corporation
California Energy Commission	Volvo Technology of America LLC
Department of Energy	US Hybrid
National Renewable Energy Laboratory	Roush Cleantech, LLC
U.S. Environmental Protection Agency	**Local Entities & Utilities**
Southwest Research Institute	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 2020. 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 2020 include: (a) Evaluate Real-World Emissions and Fuel Usage for On-Road Medium- and Heavy- Duty Vehicles; (b) Development of a Pent-Roof Medium-Duty Spark-Ignited Natural Gas Engine in an Optimized Hybrid Vehicle System; and (c) Impact of Low Carbon Fuel Standard (LCFS) Regulation on Regional Air Quality, Emerging Vehicle Technologies, and Infrastructure.

Evaluate Real-World Emissions and Fuel Usage for On-Road Medium- and Heavy-Duty Vehicles

On-road heavy-duty engines are now subject to the 2010 U.S. EPA emissions standards of 0.01 g/bhp-hr PM and 0.20 g/bhp-hr NOx. However, engine manufacturers are using emissions credits which allow them to produce a mixture of engines certified at or below 0.20 g NOx and engines certified at a level higher than 0.20 g NOx to comply with the emissions standards on an average basis. These engines are broadly classified as natural gas stoichiometric engines with three-way catalysts and lean-burn engines with exhaust gas recirculation (EGR) and selective catalytic reduction (SCR) systems, high pressure direct injection dual-fuel engines equipped with SCR systems, diesel engines with advanced EGR and DPF technology, and diesel engines with diesel particulate filter (DPF) and urea-based SCR technology. While recent studies have shown NOx and PM emissions are reduced from heavy-duty vehicles powered by these modern-technology engines, emissions from heavy-duty vehicles still dominate the total basin-wide NOx and PM emissions. Therefore, additional assessment of in-use vehicle emissions remain a critical component for measuring the effectiveness of engine, fuel and aftertreatment technologies and improving emission inventories for air quality modeling and planning as well as developing effective strategies toward achieving the federal ambient air quality standards. Thus, reliable and accurate emissions inventory derived from real-world studies like this one is critical input to such plans.

South Coast AQMD, CEC, CARB and Southern California Gas Company (SoCalGas) have come together to co-fund one of the largest emissions studies on heavy-duty vehicles to-date. The objective of this project is to conduct in-use emissions testing, characterize fuel usage profiles, develop new or improve existing heavy-duty vehicle drive cycles, and assess the impact of current technology and alternative fuels on fuel consumption and in-use emissions from on-road heavy-duty vehicles with gross Vehicle Weight Rating (GVWR) greater than 14,000 lb. The project is designed to involve 200 on-road heavy-duty test vehicles used in transit, school bus, refuse, delivery and goods movement applications, and powered by engines fueled with alternative fuels (fossil fuel-based and renewable natural gas, propane, electric and hybrid), conventional and alternative diesel fuels, and a combination of diesel and natural gas (dual) fuels. The engines are categorized into six groups including:

- MY 2008 – 2015 natural gas engines certified at or below 0.20 g/bhp-hr NOx;
- Natural gas and propane engines certified to CARB optional standard at or below 0.02 g/bhp-hr NOx;
- MY 2010 and newer diesel engines certified at or below 0.20 g/bhp-hr NOx;
- Diesel engines with no SCR systems;
- Dual fuel engines; and
- Alternative fuel engines including electric and fuel cell

The test vehicles are shared equally between West Virginia University (WVU) and University of California Riverside/College of Engineering-Center for Environmental Research & Technology (UCR/CE-CERT) and instrumented with portable emissions measurement systems (PEMS), portable vehicle activity measurement systems (PAMS) and other hardware to monitor daily vehicle activities, fuel usage profiles and emissions. WVU and UCR will then use the PEMS' and PAMS' results to recommend whether to develop new or improved or retain existing vocation-based heavy-duty drive cycles. Moreover, the PEMS testing results represents the current heavy-duty in-use testing program and the emissions results can be correlated to later tasks as well as the emission standard.

Figure 4: PEMS Equipment Install on School Bus

From the PAMS task of data logging 200 trucks, engine and GPS data were logged for up to 12 month to develop new chassis duty cycles specific to Basin such as school bus, goods movement, and delivery. WVU and UCR performed chassis dynamometer tests of 60 test vehicles using the developed or

improved and existing drive cycles. The chassis results is more representative of the real world emissions for the purpose of inventory planning compare to the PEMS test. The chassis cycles were based on large amount of vehicle activity data where the PEMS test is only a snap shot of one working day which could be subjected to many day to day variations. The chassis testing is also using laboratory-grade equipment vs. portable equipment shown in Figure 5.

Figure 5: Chassis Dyno Setup for a Goods Movement Truck

The study also included testing of ten test vehicles used in delivery and goods movement applications with laboratory-grade test equipment to assess real-world in-use emissions, fuel usage profile and engine aftertreatment technology performance as the vehicles are driven over typical vocation routes. Four routes were developed specifically for this study. Due to the weight of the mobile labs, only Class 7 and Class 8 vehicles were evaluated for this portion of the study. The result for this part of the study supplements the gaps between the PEMS and Chassis task.

Figure 6: Real-World In-Use Emissions Testing with Lab-Grade Equipment

As of early 2021, majority of the testing has been completed and the analysis task are set to begin. The goal of the analysis are to develop deterioration factors for engine aftertreatment technologies employed on at least four test vehicles; and based on the test results and discussion with CARB, provide

recommendations to improve CARB EMFAC model, identify technology issues and how to mitigate them, prioritize South Coast AQMD and the CEC staff and financial resources to support advanced engine and aftertreatment technology research and demonstration programs, and match vehicle technologies to vocations for which technology benefits can be maximized.

Development of a Pent-Roof Medium-Duty Spark-Ignited Natural Gas Engine in an Optimized Hybrid Vehicle System

The South Coast AQMD has been supporting rapid deployment of near-zero natural gas engines for both medium-duty and heavy-duty vehicles that have been commercialized since 2015 and supporting alternative fuel light-duty passenger vehicles since early 2000s. With nearly two decades of operational experience in the Basin, natural gas technology is well on its way towards full commercialization achieving a Technology Readiness Level 9 (see summary table on page 15). However, there are ongoing concerns, such as the 2019 Feasibility Assessment for Drayage Trucks by Gladstein, Neandross & Associates, which highlights the need for higher efficiency, more powerful natural gas engines.

To help advance natural gas vehicle technologies, the South Coast AQMD partnered with DOE, NREL and CEC to launch a research effort to identify ways to increase efficiencies from natural gas medium- and heavy-duty engines and vehicles. In September 2018, as part of this ongoing effort, NREL issued an RFP offering funding of approximately $37 million for projects focusing on: (1) reducing the cost of natural gas vehicles; (2) increasing vehicle efficiency; and (3) advancing new innovative medium- and heavy-duty natural gas engine designs. Nine projects were selected for funding through this solicitation, four of which the South Coast AQMD helped cost-share with $1.7 million from the Clean Fuels Fund because they aligned well with AQMP priorities to reduce NOx and PM emissions from transportation sources.

One of those awards was to SwRI, to develop a pent-roof cylinder head version of a medium duty (MD) Isuzu diesel engine for operation on natural gas and integrate it into an Isuzu F-series truck chassis in combination with a hybrid drivetrain system as shown in Figure 7 to provide a demonstration of a highly optimized low GHG emission medium-duty truck.

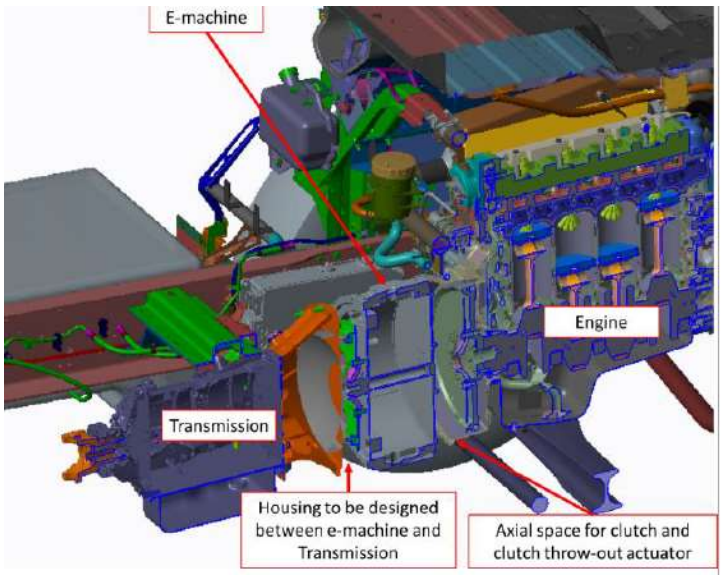


Figure 7: Hybrid Powertrain Integration Cutaway

Spark Ignition (SI) engines operating with stoichiometric combustion can use simple three-way catalysts to achieve low tailpipe emissions in comparison to more complex diesel fuel engines.

However, most SI engines are a compromised design for medium- and heavy-duty applications. They are either derived from an automotive application in which the engine is de-rated to provide for more durability or from a medium- or heavy-duty flat head diesel in which the flow field is compromised for SI combustion.

New technologies, such as cooled EGR, have recently been developed for stoichiometric SI engines which enable high efficiency and high brake mean effective pressure (BMEP) at low engine speeds. This enables torque curves comparable to diesel engines and therefore comparable operating conditions in vehicle, which enables diesel-like durability in an SI engine. SwRI seeks to improve natural gas engines and vehicle efficiency by applying a modern high-tumble combustion system to a medium-duty natural gas engine. Preliminary data from a first-generation prototype single cylinder engine (SCE) and computational fluid dynamic (CFD) studies indicate a very fast burn rate and high dilution tolerance for this combustion system, both of which are essential building blocks to developing an efficient SI multi cylinder engine (MCE). The addition of a high EGR combustion system will provide additional efficiency gains through the potential to increase the engine compression ratio and run with elevated levels of EGR dilution over the full operating map of the engine. Combining this efficient engine with an optimized hybrid system will offer even more efficiency gains, demonstrating the potential for a low NOX, low GHG medium duty truck applicable to real-world applications.

On the vehicle and hybrid system front, SwRI is recommending a mild hybrid architecture with a 100kW machine and 40kWh battery pack. Preliminary results shown in Figure 8 and Figure 9 indicate this hybrid powertrain has following benefits:

- Has a lower initial cost than the diesel powertrain
- Achieves 15% improvement on fuel economy and a 34% reduction in carbon dioxide (CO2) on a combination of Isuzu real world cycles
- Has the potential for 25% to 80% fuel economy improvement compared to the conventional diesel engine vehicle on the standard cycles (heavy-duty urban dynamometer driving schedule (HD-UDDS), heavy heavy-duty diesel truck (HHDDT) schedule transient and city suburban cycle (CSC))

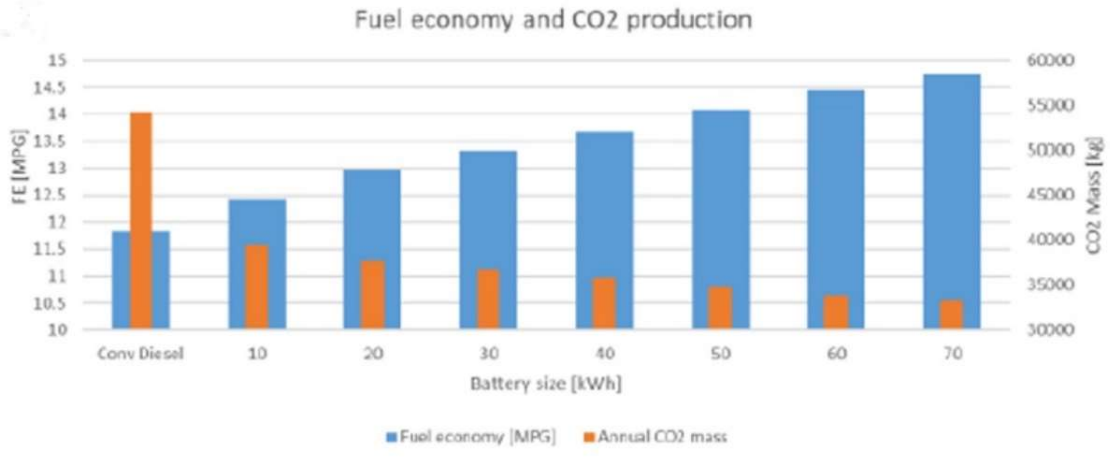


Figure 8: Effect of PHEV Battery CO2 Mass and Fuel Economy

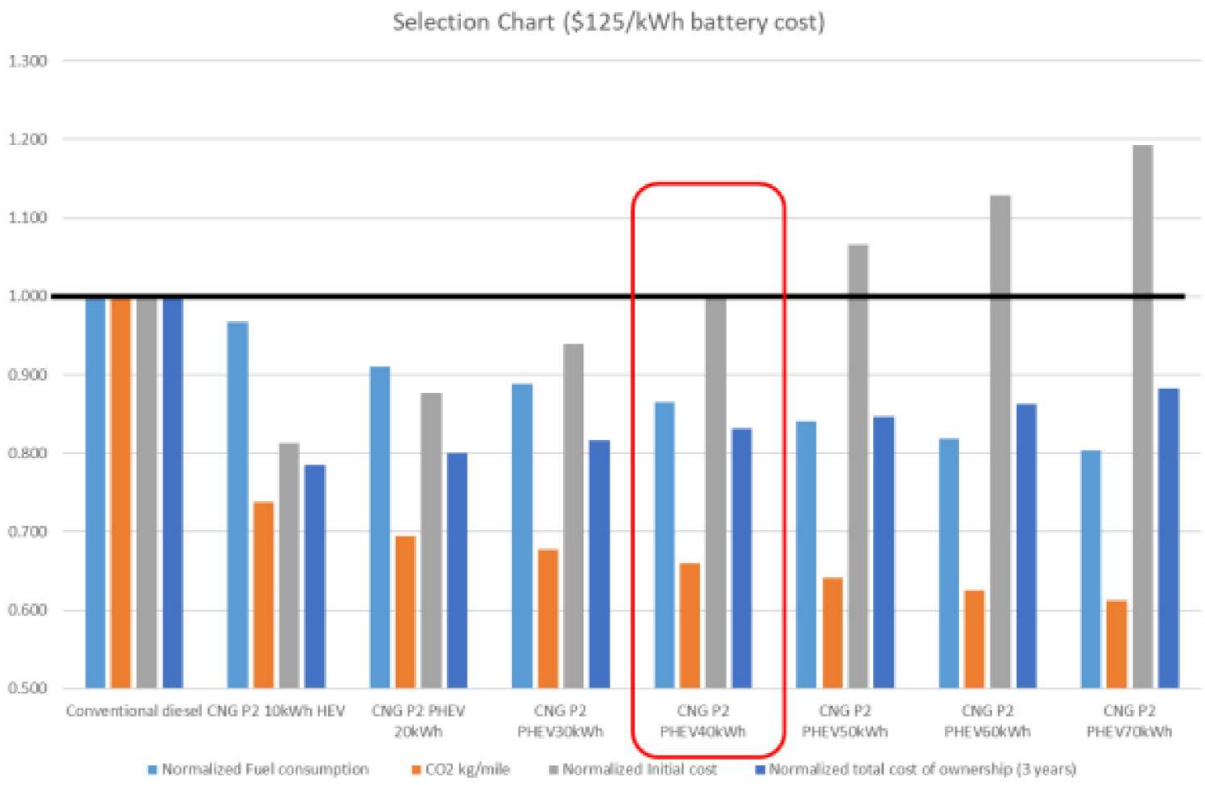


Figure 9: Hybrid Powertrain Selection

A packaging study was also completed using components representative of the hybrid powertrain selected and concluded that these components can be integrated in the base vehicle without compromising the cargo space and with minimal vehicle modifications.

On the engine development front, a new combustion system was designed and tested on a SCE, shown in Figure 9 to determine if the combustion system could achieve the requirements of the current project on an MCE platform. The test results showed that the Gen 2 combustion system met the requirements of the project and the improvements targeted with the system were achieved. These improvements included a reduction in pumping work of up to 0.1 bar pumping mean effective pressure, lower lumped efficiency losses and up to 10% higher EGR tolerance at high engine speeds. Additional analysis work was performed to support the multi-cylinder platform for the demonstration vehicle. The fired engine testing and analysis work were used to select and confirm the compression ratio of the MCE.

Impact of Low Carbon Fuel Standard (LCFS) Regulation on Regional Air Quality, Emerging Vehicle Technologies, and Infrastructure

The California Global Warming Solutions Act of 2006 (AB32) required California to reduce its overall GHG emissions to 1990 levels by 2020. With the transportation sector accounting for the largest source of emissions in California, including GHGs and criteria pollutants such as NOx and PM, CARB moved to adopt the Low Carbon Fuel Standard (LCFS) in 2009 to encourage the production and use of cleaner, low-carbon transportation fuels in California.

The LCFS program is a state-wide effort to reduce the carbon intensity in fuels used in California transportation. The original objective of the regulation was to achieve a 10% reduction in the carbon intensity (CI) of transportation fuels used in the state by 2020, relative to 2010 levels, which was followed in 2018 with a 20% reduction by 2030 under AB32. CI benchmarks for gasoline and diesel

decline each year to meet the 20% objective by 2030.[5] The federal equivalent of the LCFS is the Renewable Fuel Standard (RFS) program which Congress authorized under the Energy Policy Act of 2005 and expanded under the Energy Independence and Security Act of 2007 to reduce greenhouse gas emissions and expand the nation's renewable fuels sector while reducing reliance on imported oil. Both programs work collectively to reduce the State's dependency on fossil fuels and GHG emissions through regulation and incentives.[6]

A major component of these two programs is their respective credit markets and how these credits incentivize production and use of alternative fuels. For the LCFS, it is the LCFS Credit and for the RFS it is the RIN or Renewable Identification Number Credit. Both programs have obligated parties that need to meet certain standards for reducing GHGs and the credits provide a mechanism for meeting these standards. This brief, summarizes the benefits of the LCFS, and the reader is encouraged to explore the comparable benefits from the complimentary RFS and RIN credit programs as an incentive for alternative fuel transportation in California.

As previously mentioned, the LCFS program includes a LCFS credit market where low CI transportation fuels generate carbon reduction credits that can be sold to parties obligated to offset their carbon emissions. The LCFS affords three ways to generate credits: fuel pathways, projects, and capacity-based crediting. Under fuel pathway-based crediting, each transportation fuel has a CI score. The CI is calculated on a full life-cycle basis, indicating the full GHG emissions related to the fuel's production, transportation, storage, and use, and is measured in terms of grams of CO2 equivalent per megajoule of energy (gCO2e per MJ). The differences in energy efficiencies from one technology to a conventional technology is defined by Energy Economy Ratio (EER), i.e. EER for diesel is 1 whereas it is 5 for electricity. The EER can be a significant multiplier in LCFS credit generation. The LCFS credits cannot be generated if they are not real, quantifiable, and enforceable. As such, an LCFS fuel cannot generate credit until it is used as a transportation fuel, so both the fuel producer and the supplier/dispenser/consumer (user) are required to make the LCFS Credit real. Producer and user typically formalize this relationship through an "offtake agreement" that establishes a commitment to deliver and use the LCFS fuel. The actual fuel delivered and used is enforced through quarterly reporting to and accounting by CARB. Offtake agreements provide fuel producers with the security of a buyer and users with some certainty of lower fuel costs because offtake agreements typically delineate a percentage of the LCFS credits to the user. Hence, the LCFS program and the LCFS credit market play important roles in reducing the price of fuel to the consumer and incentivizing the adoption of alternative fuel transportation technologies. In addition, the LCFS credit system helps the alternative fuel producer offset capital and operating expenses associated with the production and transportation of these fuels to the market. [7]

Many low CI transportation fuels in the LCFS also help to reduce ground level air pollution by virtue of their production, their use in advanced zero and near-zero emission transportation technologies, and the associated displacement of conventional petroleum-based counterparts. These "clean alternative transportation fuels" result in little to no "tailpipe emissions" such as the ozone precursor NOx, PM2.5, VOC, and CO. Achieving air quality attainment standards for ozone and PM in the Basin relies significantly on reducing both NOx and PM emissions from the transportation sector. Over the last decades, several emissions and air quality modeling studies were performed to evaluate the air quality impact of increasing renewable fuels in the transportation sector. Research included the blend level of some biofuels in conventional gasoline or diesel or renewable natural gas with conventional gas, infrastructure compatibility, manufacturer warranties, evaporative or toxic emissions, and hydrogen or

[5] https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard
[6] https://www.epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard
[7] https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard/lcfs-credit-generation-opportunities

electric vehicle technologies and their respective infrastructure, specifically in the heavy-duty sector. The overall benefits that these low CI fuels can provide are numerous. [8,9,10]

The Clean Fuels Program mandates the funding of programs to help reduce criteria "transportation-based" emissions such as NOx and PM. Hence, the combined efforts of LCFS and Clean Fuels can synergistically advance both causes. Figure 10 provides examples of CI scores for some alternative fuels in the LCFS program.

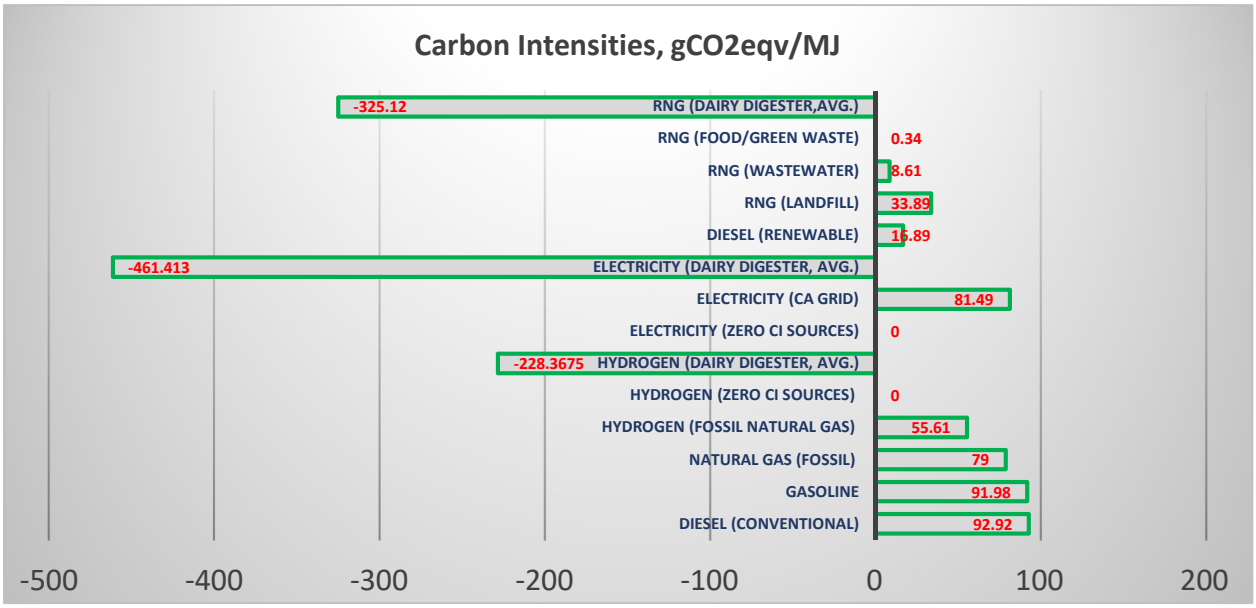


Figure 10: Examples of CI Scores (gCO2e/MJ) for Various LCFS Fuel Pathways (not EER Adjusted). RNG, Electricity, and Hydrogen from Dairy Digester is Averaged from Multiple Pathways in the LCFS.

Some low CI transportation fuels, e.g. electricity from wind, solar and hydro are inherently air pollution free from production to use. Others, such as RNG from the capture of fugitive, high Global Warming Potential methane (e.g. dairy operations, waste biomass that generate very low to negative carbon intensities) combined with cleaner combustion technologies such as advanced near-zero natural gas engines certified to the optional standard of 0.02g-NOx/bhp-hr or cleaner, can result in significantly reduced NOx emissions. However, the real-world benefit of this synergy is dependent on participation from the consumer market and the adoption of the emerging low CI fuel transportation technologies. The economics of adopting new technologies is significant and currently relies on government subsidies. Renewable, low CI projects funded through the Clean Fuels Program (CFP) require demonstrated reductions in criteria pollutants. Such projects include local production of RNG and its demonstrated use in near-zero NOx, RNG-powered heavy-duty vehicles.[11] Other projects that are expected to see CFP funding include renewable hydrogen partnered with fuel cell powered vehicles, or

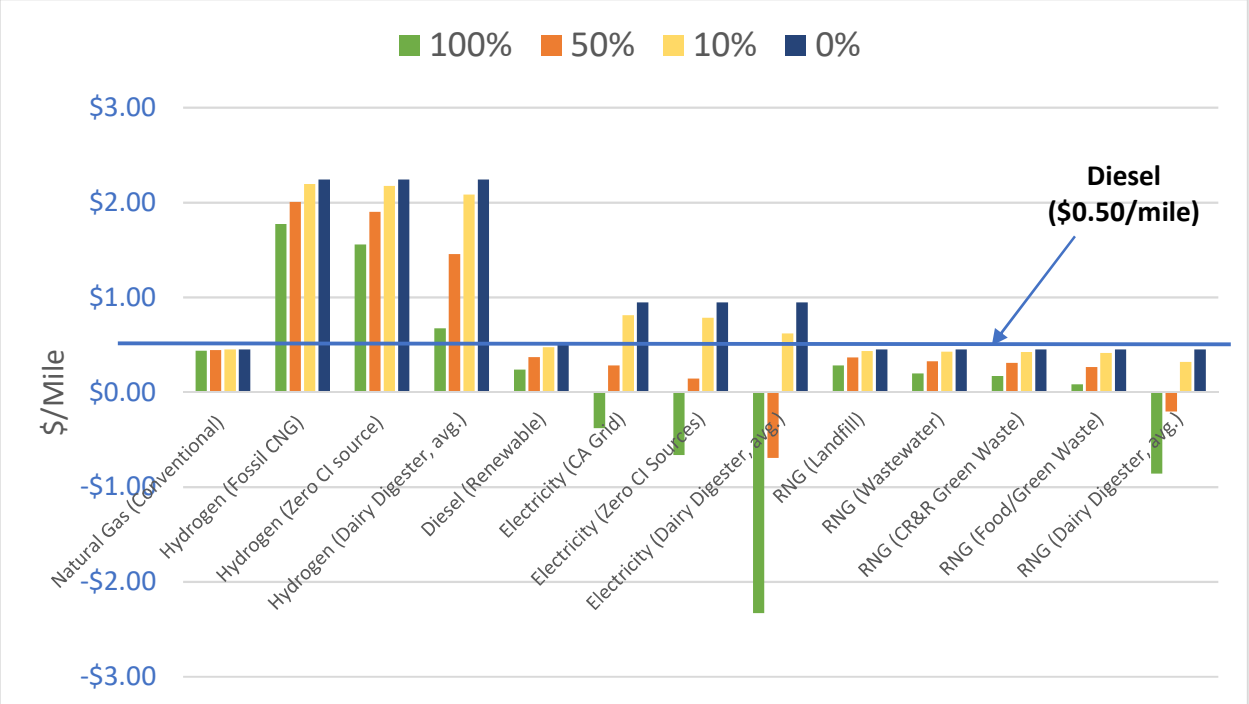
[8] Investigation of the Effect of Mid- and High-Level Ethanol Blends on the Particulate and the Mobile Source Air Toxic Emissions from a Gasoline Direct Injection Flex Fuel Vehicle, Yang et al., Energy Fuels, 2019

[9] Evaluation of the Impacts of Biodiesel and Second Generation Biofuels on NOx Emissions for CARB Diesel Fuels, Hajbabaei et al., Environmental Science and Technology, 2012

[10] Evaluating the regulated emissions, air toxics, ultrafine particles, and black carbon from SI-PFI and SI-DI vehicles operating on different ethanol and iso-butanol blends, Karavalakis et al., Fuel, 2014

[11] CR&R Anaerobic Digester, RNG, and NZE demonstration

renewable electricity used to power heavy-duty battery electric vehicles. The LCFS program and the LCFS Credit Market offer an opportunity to provide low cost, low carbon fuel and energy to these emerging alternative fuel-powered transportation technologies and support the lowering of the total cost of ownership and operation of these technologies. Economic drivers imbedded in the LCFS program could provide the necessary added incentive to accelerate the transformation of many petroleum fuel-powered fleets in the Basin. As the LCFS Credit system is reliant on both producer and user of these fuels the Clean Fuels Program is very interested in exploring outreach efforts with stakeholders in taking a broader look at how the LCFS credit market can further incentivize fleets in this region to adopt clean technologies earlier. In order to see the impact of LCFS credits on the fuel cost per mile, staff performed an analysis using the methodology that is elaborated in the LCFS regulation for calculating CI scores and EER ratios. Figure 11 summarizes the results of this effort, and shows the monetary impact associated with 10%, 50%, and 100% LCFS credits on final fuel cost per mile from various low CI transportation fuels using LCFS credit calculation methodology. As depicted in Figure 11, the greater the "share" of LCFS credit applied to the end user's fuel cost, the lower the cost of fuel per mile. Also, transportation fuels with lower CI scores have greater fuel cost reductions per mile. However, other factors such as total cost of vehicle ownership, cost to install and maintain fueling, or charging infrastructure, as well as the amount of energy consumed will also impact the TCO of these respective technologies. Figure 11 below shows the impact of receiving 10%, 50%, and 100% LCFS credits on final fuel cost per mile of various low CI transportation fuels using LCFS credit calculation methodology.



Note: Assumptions applied: LCFS credit value $180/MT, Diesel as reference fuel, and CI scores shown in Figure 2. Fuel pricing and fuel economies assumed for Class 8 trucks: $3.50 per gallon and 7 mpDGE for diesel; $2.85/DGE and 6.3 mpDGE for CNG; $0.45/kWh and 2.1 kWh/mi for electricity; and $15/kg and 7.5 miles/kg for hydrogen

Figure 11: Fuel Cost ($/mile) Assuming User Receives 10%, 50%, and 100% of the Respective Realized LCFS Credits. 0% Credit is Value of Fuel Assuming Full Retail Pricing.

CLEAN FUELS PROGRAM
2020 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 5), 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, 2020.

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, 2020, a total of 35 contracts/agreements, projects or studies that support clean fuels were executed or amended (adding dollars), as shown in Table 2. 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 12. 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 2020 reporting period are shown below with the total projected project costs:

- South Coast AQMD Clean Fuels Fund Contribution $4,137,895
- Total Cost of Clean Fuels Projects $28,944,841

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 2020-21 Budget on May 1, 2020, it included $1 million from Clean Fuels recognized in TAO's budget for technical assistance, workshops, conferences, cosponsorships 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, 2020, are included within this report. Any portion of the Clean Fuels Funds not spent by the end of Fiscal Year 2020-21 ending June 30, 2021, 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 $500,000 is listed within Table 3.

For Clean Fuels executed and amended contracts, projects and studies in 2020, the average South Coast AQMD contribution was leveraged with nearly $7 of outside investment. The typical historical leverage amount is $4 for every $1 of South Coast AQMD Clean Fuels funds, but from 2016 to 2020 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 2020, the distribution of funds for South Coast AQMD executed contracts, purchases and contract amendments with additional funding for the Clean Fuels Program totaling approximately $4.1 million are shown in the figure below.

Additionally, the South Coast AQMD continued to seek funding opportunities and was awarded an additional $45.8 million in CY 2020 for RD3 projects as listed in Table 4.

As of January 1, 2021, there were 106 open Clean Fuels Fund contracts. Appendix B lists these contracts by core technology.

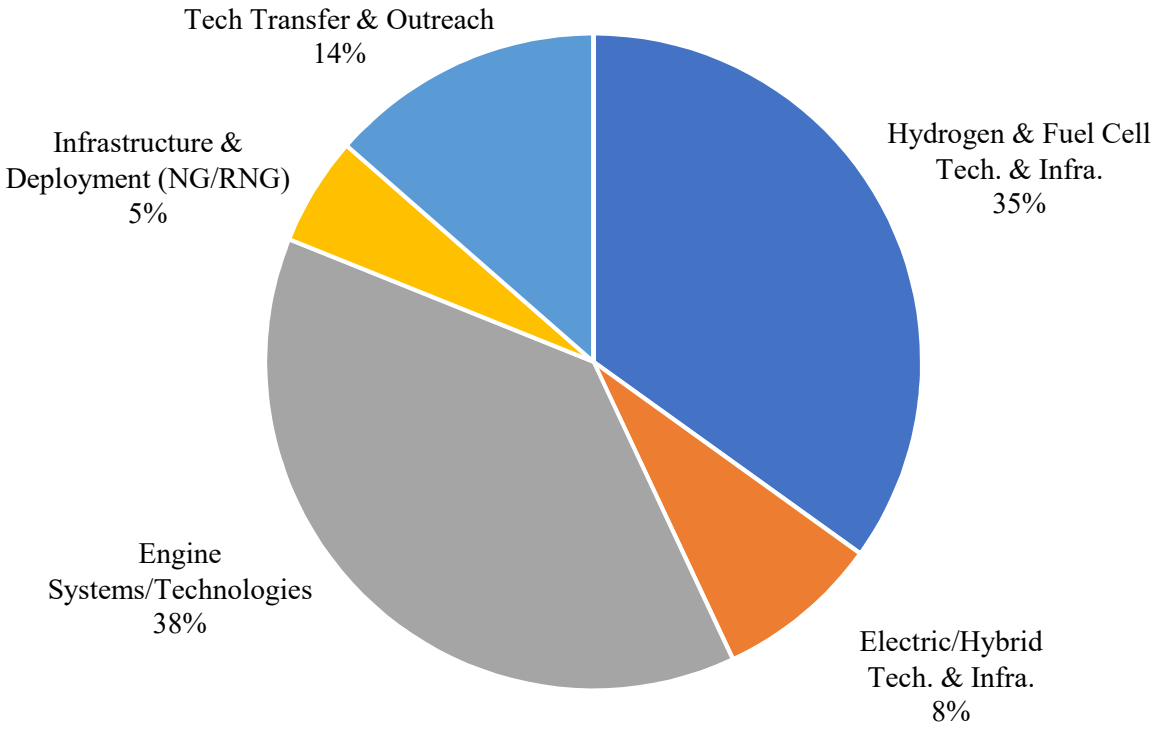


Figure 12: Distribution of Funds for Executed Clean Fuels Projects CY 2020 ($4.1M)

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, 2020, 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 35 new and continuing contracts/agreements, projects and studies that received South Coast AQMD funding in CY 2020 are summarized in Table 2 (beginning on the next page), together with the funding authorized by the South Coast AQMD and by the collaborating project partners.

Table 2: Contracts Executed or Amended (w/$) between January 1 & December 31, 2020

Contract	Contractor	Project Title	Start Term	End Term	SCAQMD $	Project Total $
Hydrogen/Mobile Fuel Cell Technologies and Infrastructure						
17317	American Honda Motor Co., Inc.	One-Year Extension of Three Year Lease of One Honda 2017 Clarity Fuel Cell Vehicle	3/22/17	3/22/21	4,816	4,816
17343	American Honda Motor Co., Inc.	One-Year Extension of Three Year Lease of One Honda 2017 Clarity Fuel Cell Vehicle	2/21/17	2/21/21	4,899	4,899
17385	American Honda Motor Co., Inc.	One-Year Extension of Three Year Lease of One Honda 2017 Clarity Fuel Cell Vehicle	5/17/17	5/17/21	4,981	4,981
20108	University of California, Irvine	Develop Optimal Operation Model for Renewable Electrolytic Fuel Production	6/17/20	6/16/21	100,000	500,000
19313	Equilon Enterprises LLC DBA Shell Oil Products	Construct & Operate Renewable Hydrogen Refueling Station	6/30/20	4/1/22	1,200,000	12,000,000
21092	Frontier Energy, Inc.	Participate in California Fuel Cell Partnership for Calendar Year 2020 and Provide Support for Regional Coordinator	1/1/20	12/31/20	120,000	1,300,000
Engine Systems/Technologies						
20092	Southwest Research Institute	Natural Gas Engine and Vehicles Research and Development - Pent-Roof Medium Duty Natural Gas Engine	10/14/20	4/13/24	475,000	6,000,000
20122	Landi Renzo USA Corporation	Develop and Commercialize a Near-Zero Natural Gas Conversion System for On-Road Medium-Duty Vehicles	1/17/20	7/31/21	600,000	1,455,072
20316	US Hybrid	NaturalGas Engine & Vehicles Research & Development - Plug-In Hybrid CNG Drayage Truck (PHET)	6/2/20	12/1/23	500,000	2,853,006
Electric/Hybrid Technologies and Infrastructure						
14184	Green Paradigm Consulting, Inc.	DC Fast Charging Network Provider	4/4/14	6/30/23	40,000	40,000
14375	National Renewable Energy Laboratory	Data Collection & Analysis of Zero-Emission Cargo Transportation (ZECT) Demonstration Trucks	6/26/01	3/31/21	20,000	20,000
17225	Volvo Technology of America LLC	Development and Demonstration of up to 2 Class 8 Battery Electric Drayage Trucks	6/9/17	12/31/21	353,000	353,000
17244	Kenworth Truck Company	Development & Demonstration of four Class 8 CNG Hybrid Electric Drayage Trucks	9/8/17	4/14/21	(1,184,369)	(3,251,501)
18075	Selman Chevrolet Company	Extension of Lease for Two 2017 Chevrolet Bolt All-Electric Vehicles for Three Years	8/18/17	2/18/21	4,068	4,068

Table 2: Contracts Executed or Amended (w/$) between January 1 & December 31, 2020 (cont'd)

Contract	Contractor	Project Title	Start Term	End Term	SCAQMD $	Project Total $
Electric/Hybrid Technologies and Infrastructure (cont'd)						
20097	Zeco Systems, Inc. DBA Greenlots	Operate, Maintain and Network the EV Chargers	2/14/20	2/13/23	155,664	155,664
20125	Roush Cleantech, LLC	Develop and Demonstrate Battery Electric Medium-Duty Truck	3/19/20	3/18/22	937,500	3,200,000
20248	Los Angeles County Economic Development Corp	Economic and Workforce Impact Analysis of Electric Revolution in Southern California	7/7/20	1/2/21	10,000	150,000
Fueling Infrastructure and Deployment (Natural Gas/Renewable Fuels)						
20178	Whittier Union High School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	2/21/20	11/30/34	196,500	1,052,500
Transfer	California Natural Gas Vehicle Partnership	Participation in the California Natural Gas Vehicle Partnership for Fiscal Years 2018-19 and 2019-20	7/1/20	6/30/22	25,000	170,000
Technology Assessment and Transfer/Outreach						
08210	Sawyer Associates	Technical Assistance on Mobile Source Control Measures and Future Consultation on TAO Activities	2/22/08	2/28/22	15,000	15,000
12376	University of California, Riverside	Technical Assistance with Alternative Fuels, Biofuels, Emissions Testing, and Zero-Emission Transportation Technology	6/1/14	5/31/22	150,000	150,000
19078	Green Paradigm Consulting, Inc.	Technical Assistance with Alternative Fuels, Evs, Charging & Infrastructure and Renewable Energy	9/7/18	9/30/21	211,800	540,300
20265	Eastern Research Group	Technical Assistance with Heavy-Duty Vehicle Emissions Testing, Analyses & Engine Development & Applications	6/17/20	6/16/22	50,000	50,000
Various	Various	Cosponsor 8 Conferences, Workshops & Events plus 3 Memberships	01/01/20	12/31/20	141,960	2,170,960
Direct Pay	Prizm Imaging	Procure Outreach Materials	01/01/20	12/31/20	1,848	1,848
Direct Pay	Various	Alternative Fuel Demonstration Vehicle Program Related Expenses	01/01/20	12/31/20	228	228
						$28,944,841

Table 3: Supplemental Grants/Revenue Received into the Clean Fuels Fund (31) in CY 2020

Revenue Agreement #	Revenue Source	Project Title	Contractor	SCAQMD Contract #	Award Total $
20132	Southern California Gas Company	Near-Zero Natural Gas Conversion System for On-Road Medium-Duty Vehicles	Landi Renzo USA Corporation	20122	300,000
19165	US EPA Airshed Grant	Near-Zero CNG School Buses	Whittier Union High School District	20178	196,500
Table 3 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 (2020).					**$496,500**

Table 4: Summary of Federal, State and Local Funding Awarded or Recognized in CY 2020

Awarding Entity or Program	Award (*) or Board Date	Purpose	Contractors	Award Total/ Fund
U.S. EPA DERA Grant	03/06/20	Fund up to 35% of Near Zero-Emission Trucks	Ecology Auto Parts	$1,601,523 Fund 17
Southern California Gas Company	04/03/20	Emissions Impacts of Hydrogen-Natural Gas Fuel Blends in Near Zero-Emission Heavy-Duty Natural Gas Engines	University of California, Riverside	$305,000 Fund 31
U.S. EPA DERA Grant	04/03/20	Truck Trade Down Program	Various	$789,581 Fund 31 $719,500 Fund 17
U.S. EPA SEPs	04/03/20	Install Air Filtration Systems at Schools	IQAir North America	$146,250 Fund 75
California Air Resources Board	04/03/20	Install Air Filtration Systems at Schools and Residences	IQAir North America	$1,205,300 Fund 75
Southern California Gas Company	04/03/20	Evaluation of Vehicle Maintenance Costs for On-Road Heavy-Duty Vehicles (HDVs)	West Virginia University	$150,000 Fund 31
US EPA Airshed Grant	09/04/20	Deploy Class 8 Battery Electric Trucks and EV Infrastructure	Volvo Group North America, LLC	$20,000,000 Fund 17
US EPA Airshed Grant	09/04/20	Deploy Fuel Cell Transit Buses	SunLine Transit Agency	$5,906,601 Fund 17
US EPA Section 105 CATI Grant	09/04/20	Demonstrate Additional Battery Electric Trucks for the Volvo LIGHTS Project	Volvo Group North America, LLC	$500,000 Fund 67

Table 4: Summary of Federal, State and Local Funding Awarded or Recognized in CY 2020 (cont'd)

Awarding Entity or Program	Award (*) or Board Date	Purpose	Contractors	Award Total/ Fund
US EPA Airshed Grant	09/04/20	Develop and Demonstrate Selective Catalytic Reduction Retrofit Technology for an Ocean-Going Vessel	MAN Energy Solutions USA Inc.	$11,414,700 Fund 83
San Pedro Bay Ports	09/04/20	Develop and Demonstrate Selective Catalytic Reduction Retrofit Technology for an Ocean-Going Vessel	MAN Energy Solutions USA Inc.	$300,000 Fund 83
Southern California Gas Company	10/02/20	Develop, Demonstrate and Commercialize the Ford 7.3 Liter Medium-Duty Natural Gas and Propane Conversion System	Agility Fuel Solutions	$154,325 Fund 31
U.S. EPA Clean Diesel Program	12/04/20	Replace Diesel Transportation Refrigeration Units (TRUs) with Electrified TRUs	Albertsons Companies	$2,240,721 Fund 31
California Air Resources Board	12/04/20	Install Air Filtration Systems at Schools and Residences	IQAir North America	$26,850 Fund 75
Table 4 provides a comprehensive summary of revenue awarded to South Coast AQMD during the reporting CY (2020) 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.				**$45,760,351**

Project Summaries by Core Technologies

The following summaries describe the contracts, projects and studies executed, or amended with additional dollars, in CY 2020. They are listed in the order found in Table 2 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.

Hydrogen/Mobile Fuel Cell Technologies and Infrastructure

17317: Three Year Lease of One Honda 2017 Clarity Fuel Cell Vehicle for TAO's Fleet Demonstration Program

Contractor: American Honda Motor Company, Inc.	South Coast AQMD Cost-Share	$ 4,816
Term: 03/22/17 – 03/22/21	Total Cost:	$ 4,816

South Coast AQMD has been working with American Honda and has participated in on-road testing of their fuel cell electric vehicles starting with research programs since 2004 when South Coast AQMD's first hydrogen station in Diamond Bar started fueling the first fuel cell car – the Honda FCX - in our fleet. Several fuel cell vehicle generations have resulted in the 2017 Honda Clarity Fuel Cell for retail lease through 12 specially trained dealerships near retail hydrogen fueling stations in California. The Honda Clarity fuel cell vehicle is a five-passenger sedan that travels 366 miles before refueling with 70 MPa gaseous hydrogen and has U.S. EPA estimated fuel economy of 67 mpge. The vehicle will be placed into South Coast AQMD's alternative fuel vehicle fleet to demonstrate new fuel cell vehicles to public and private organizations to promote zero emission technologies. This lease was extended one year to continue mileage accumulation until new model is available.

17343: Three Year Lease of One Honda 2017 Clarity Fuel Cell Vehicle for TAO's Fleet Demonstration Program

Contractor: American Honda Motor Company, Inc.	South Coast AQMD Cost-Share	$ 4,899
Term: 02/21/17 – 02/21/21	Total Cost:	$ 4,899

As noted, South Coast AQMD has been working with American Honda and has participated in on-road testing of their fuel cell electric vehicles starting with research programs since 2004 when South Coast AQMD's first hydrogen station in Diamond Bar started fueling the first fuel cell car – the Honda FCX - in our fleet. Several fuel cell vehicle generations have resulted in the 2017 Honda Clarity Fuel Cell for retail lease through 12 specially trained dealerships near retail hydrogen fueling stations in California. This second vehicle will also be placed into South Coast AQMD's alternative fuel vehicle fleet to demonstrate new fuel cell vehicles to public and private organizations to promote zero emission technologies. This lease was extended one year to continue mileage accumulation until new model is available.

17385: Three Year Lease of One Honda 2017 Clarity Fuel Cell Vehicle for TAO's Fleet Demonstration Program

Contractor: American Honda Motor Company, Inc.	South Coast AQMD Cost-Share	$ 4,981
Term: 05/17/17 – 05/17/21	Total Cost:	$ 4,981

This third Honda 2017 Clarity Fuel Cell will also be placed into South Coast AQMD's alternative fuel vehicle fleet to demonstrate new fuel cell vehicles to public and private organizations to promote zero emission technologies. Given the number of events the South Coast AQMD cosponsors and attends throughout the Basin, three of these vehicles were added to the Fleet Demonstration Program in 2017. This lease was extended one year to continue mileage accumulation until new model is available.

20108: Develop Optimal Operation Model for Renewable Electrolytic Fuel Production

Contractor: University of California, Irvine	South Coast AQMD Cost-Share	$ 100,000
	Cosponsors:	
	University of California, Irvine	350,000
	NREL	50,000
Term: 06/17/20 – 06/16/21	Total Cost:	$ 500,000

The University of California Irvine (UCI) through its Advanced Power and Energy Program is developing a roadmap for deployment of renewable electrolytic hydrogen production facilities in California. The proposed project leverages expertise and resources through NREL and adds a comprehensive analysis of a rapidly developing electrolysis technology, which portends to serve as one of the most promising pathways for the production of renewable hydrogen. The proposed project will analyze hypothetical scenarios of model electrolysis projects, including project location, production capacity, efficiency, source of electricity, footprint, dynamic operation characteristics, capital cost, operating cost and other parameters. Based on the modeling and analyses defined above, the project will extract findings on optimal economic dispatch of the electrolysis facilities and air quality impact.

19313: Construct and Operate Renewable Hydrogen Refueling Station

Contractor: Equilon Enterprises LLC DBA Shell Oil Products	South Coast AQMD Cost-Share	$ 1,200,000
	Cosponsors:	
	CEC ARFVTP, GFO-17-603	8,000,000
	Toyota	1,400,000
	Equilon	1,400,000
Term: 06/30/20 – 04/01/22	Total Cost:	$ 12,000,000

On April 6, 2018, the CEC awarded $8 million to Equilon Enterprises LLC for construction and operation of a renewable hydrogen refueling station. Equilon will own and operate the 1,000 kg/day truck refueling station on land at the Port of Long Beach, sub-leased from Toyota, which under a separate contract with Fuel Cell Energy, will generate hydrogen using a Tri-Generation system, using biogas, to produce up to 1.27 tons per day of renewable hydrogen. The station can also use delivered hydrogen. In addition to refueling Toyota vehicles at 700 bar, South Coast AQMD co-funding will be used to refuel vehicles at 350 bar, supporting various fuel cell demonstration vehicles by multiple operators in the local ports.

21092: Participate in California Fuel Cell Partnership for Calendar Year 2020 and Provide Support for Regional Coordinator

Contractor: Frontier Energy Inc	South Coast AQMD Cost-Share	$ 120,000
	Cosponsors:	
	7 automakers, 4 public agencies, 7 industry takeholders, 35 Full & Associate Members	1,180,000
Term: 01/01/20 – 12/31/20	Total Cost:	$ 1,300,000

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 2020, South Coast AQMD contributed $70,000 for Executive membership and $50,000 to continue support for Regional Coordinator activities.

Engine Systems/Technologies

20092: Natural Gas Engine and Vehicles Research and Development – Pent-Roof Medium-Duty Natural Gas Engine

Contractor: Southwest Research Institute	South Coast AQMD Cost-Share	$ 475,000
	Cosponsors:	
	US Dept. of Energy	2,525,000
	Southwest Research Institute, Isuzu Technical Center of America, Inc. and Southern California Gas Company	3,000,000
Term: 10/14/20 – 04/13/24	Total Cost:	$ 6,000,000

In April 2019, the South Coast AQMD board approved 4 projects under a natural gas vehicle research consortium made up with DOE, NREL, CEC, SoCalGas and South Coast AQMD totaling over $26 million. This project, SwRI along with Isuzu are set to develop and new cylinder head for a 4HK Isuzu gasoline engine (ongoing project at the time at SwRI) that enables the use of natural gas fuel and achieve near-zero NOx emissions as well as integrating the new engine into a medium-duty truck equipped with hybrid-electric powertrain. The technical targets of the project include casting and building new natural gas with optimized pent-roof, develop calibration and aftertreatment system to achieve 0.02 gram NOx, achieve combined fuel economy exceeding the diesel baseline as well as minimize cost by selection the best available hybrid powertrain. The project was kicked off in early 2020 and expect to go on for 37 months from project initiation.

20122: Develop and Commercialize a Near-Zero Natural Gas Conversion System for On-Road Medium-Duty Vehicles

Contractor: Landi Renzo USA Corporation	South Coast AQMD Cost-Share	$ 300,000
	Cosponsors:	
	Southern California Gas Company (received as pass-through funds into Fund 31)	300,0000
	Landi Renzo USA Corporation	855,0720
Term: 01/17/20 – 07/31/21	Total Cost:	$ 1,455,072

Optimization of the recently introduced Ford 7.3 liter natural gas engine for medium-duty vehicles. Develop a commercially available engine that is certified to the CARB optional low NOx standard of 0.02 g/bhp NOx. The optimization will include modification of controller software and the latest in catalyst technology to reach near-zero NOx. Once developed, the engine will be tested using both the Federal Test Procedure for emissions certification and non-certification test cycles representative of real-world use in different vocations that are prevalent in the Basin. The use of vocational-specific test cycles will provide additional insight towards the engine's real-life emission reduction potential at the desired increased efficiency.

20316: Natural Gas Engine & Vehicles Research & Development - Plug-In Hybrid CNG Drayage Truck (PHET)

Contractor: US Hybrid	South Coast AQMD Cost-Share	$ 500,000
	Cosponsors:	
	DOE	634,137
	CEC	860,000
	US Hybrid	858,869
Term: 06/02/20 – 12/01/23	Total Cost:	$ 2,853,006

The DOE, NREL, CEC, and South Coast AQMD partnered to launch a research effort to increase efficiency of natural gas engines for heavy-duty vehicles. Based on DOE projections, natural gas is poised to play a key role as a versatile, low-emissions and low GHG fuel. Advances in the ability to capture methane from waste streams such as landfills, wastewater treatment plants, municipal solid waste, and livestock operations for the production of Renewable Natural Gas (RNG) adds a robust renewable alternative to conventional fuels. This project will develop the next generation of a plug-in parallel hybrid heavy duty Class 8 platform based on the near-zero-emission 8.9-liter natural gas engine (L9N) from Cummins Westport (CWI). The L9N will be paired in parallel with a comparably powered battery-electric drivetrain to produce a powertrain comparable to much larger power systems. The resulting plug-in hybrid CNG truck will have improved efficiency, reduced criteria and GHG emissions, and smart geofencing and sufficient battery storage to operate zero emission miles in sensitive areas.

Electric/Hybrid Technologies and Infrastructure

14184: DC Fast Charging Network Provider

Contractor: Green Paradigm Consulting, Inc.	South Coast AQMD Cost-Share	$ 40,000
Term: 04/04/14 – 06/30/23	Total Cost:	$ 40,000

This contract was funded using CEC funds and Clean Fuels funds towards hardware and installation costs. Clean Fuel Connection, Inc. (CFCI) installed 10 DC fast chargers at seven sites including the Hollywood & Highland red line metro stop, Little Tokyo gold line metro stop, Westwood LADOT parking garage, La Kretz Center for Innovation, Victoria Gardens shopping mall in Rancho Cucamonga, and Mel's Diner in Santa Monica. These chargers are maintained and operated as part of the EVgo network and provide public charging to fill gaps in corridor charging in Los Angeles and San Bernardino counties.

14375: Data Collection & Analysis of Zero-Emission Cargo Transportation (ZECT) Demonstration Trucks

Contractor: National Renewable Energy Laboratory	South Coast AQMD Cost-Share	$ 20,000
Term: 06/26/01 – 3/31/21	Total Cost:	$ 20,000

NREL has provided data analysis to the US DOE's Zero Emission Cargo Transport (ZECT 1) program since its commencement in 2012. Under ZECT 1 two technology integrators developed three types of zero- and near-zero- emission Class 8 drayage truck technologies, consisting of two battery electric truck platforms, one CNG series-hybrid electric truck and one LNG parallel-hybrid platform. In June 2014, South Coast AQMD entered into a three-year contract with NREL to collect and analyze data on the performance of these zero- and near-zero-emission Class 8 tractors to provide consistent and objective evaluation. Delays in vehicle development required design adjustments that resulted in the DOE extending the project twice through March 2020. The protracted project required additional time and work effort by NREL that resulted in additional funding to complete this project.

17225: Develop and Demonstrate Up to Two Class 8 Battery Electric Drayage Trucks

Contractor: Volvo Technology of America, LLC	South Coast AQMD Cost-Share	$ 0
	Cosponsors	
	California Air Resources Board *(received as pass-through funds into Fund 67)*	353,000
Term: 06/09/17 – 12/31/21	Total Cost:	$ 353,000

Volvo is demonstrating a newer version of a PHEV diesel hybrid Class 8 truck developed under a South Coast AQMD/DOE grant to continue refinement towards commercialization, including integration of innovative and significant C-ITS efficiency measures through its Eco-Drive software, in cooperation with LA Metro and its miniburner aftertreatment technology. The PHEV diesel hybrid truck is designed to maximize operations in zero emission mode when traveling through disadvantaged communities.

17244: Develop and Demonstrate Up to Two Class 8 Battery Electric Drayage Trucks

Contractor: Kenworth Truck Company	South Coast AQMD Cost-Share	$ (1,184,369)
	Cosponsors	
	California Air Resources Board (reduced pass-through funds in Fund 67)	(2,067,132)
Term: 09/08/17 – 04/14/21	Total Cost:	$ (3,251,501)

Due to some technical challenges, Kenworth is only developing two instead of four Class 8 plug-in hybrid electric trucks with zero emission operation capability. These trucks have begun their demonstration in revenue drayage service at TTSI. The trucks will operate in all-electric and in conventional hybrid electric mode using a CNG engine. This will provide an opportunity to test the manufacturing processes for repeatability, optimize an architecture developed for this application and re-introduce field operations to this type of product. The power output of the electric drivetrain is comparable to standard Class 8 vehicles, but it will have a greater operating efficiency and improved fuel economy.

18075: Lease Two 2017 Chevrolet Bolt All-Electric Vehicles for Three Years for TAO's Fleet Demonstration Program

Contractor: Selman Chevrolet Company	South Coast AQMD Cost-Share	$ 4,068
Term: 08/18/17 – 02/18/21	Total Cost:	$ 4,068

The South Coast AQMD operates a number of alternative fuel vehicles (AFVs) in its Fleet Demonstration Program to support the use of zero emission vehicles and bring awareness to the public of their viability. The all-new 2017 Chevrolet Bolt EV is available in all 50 states and was selected as the Green Car Journal 2017 Green Car of the Year. It uses a 60 kWh LG Chem lithium ion (nickel-manganese-cobalt) low-profile battery pack for this five-passenger crossover, providing 238 miles U.S. EPA-estimated all-electric range, with improved passenger and cargo capacity. Increased safety technology includes a rear camera mirror with wide-angle rearview and overhead view. Use of DC fast chargers to replenish the battery up to an estimated 90 miles of range in 30 minutes will be demonstrated and evaluated during lease for broader fleet implementation. Carpool lane solo-access with red carpool sticker will be utilized when out in the community. These vehicle leases were extended six months to continue mileage accumulation.

20097: Operate, Maintain and Network the EV Chargers

Contractor: Zeco Systems, Inc. DBA Greenlots	South Coast AQMD Cost-Share	$ 155,664
Term: 02/14/20 – 02/13/23	Total Cost:	$ 155,664

Greenlots is providing three years of maintenance and operation services for 92 Level 2 EV charging ports for public and workplace charging at South Coast AQMD headquarters. This includes handling payment of EV charging sessions, monitoring of EV chargers, dispatching and handling routine maintenance, escalating charger issues, maintaining and periodically updating hardware and software updates, and providing reporting and analysis tools through its SKY networking platform.

20125: Develop and Demonstrate Battery Electric Medium-Duty Truck

Contractor: Roush Cleantech, LLC	South Coast AQMD Cost-Share	$ 937,500
	Cosponsors:	
	Roush Cleantech, LLC	2,062,500
	Penske Truck Leasing	200,000
Term: 03/19/20 – 03/18/22	Total Cost:	$ 3,200,000

Demand for commercially available heavy-duty battery electric trucks continues to increase, but availability is limited to a few suppliers. Roush CleanTech will develop a medium-duty battery electric Class 6-7 commercial vehicle and demonstrate the technology with local commercial fleets. These applications are local and regional goods movement, municipal fleets, utilities, a variety of transit and shuttle bus operations, and school buses. This project will develop and demonstrate three medium-duty electric trucks and these vehicles will be used to generate actual customer use-case data to help with validation cycle requirements, as well as to obtain customer feedback on usability and performance.

20248: Economic and Workforce Impact Analysis of Electric Revolution in Southern California

Contractor: Los Angeles County Economic Development Corporation	South Coast AQMD Cost-Share	$ 10,000
	Cosponsors:	
	Los Angeles County Economic Development Corporation and project partners	140,000
Term: 07/07/20 – 01/02/21	Total Cost:	$ 150,000

Los Angeles County Economic Development Corporation (LAEDC) conducted the Economic and Workforce Impact Analysis of Electric Mobility Revolution in Southern California. LAEDC was founded in 1981 as a nonprofit, public-benefit organization and focuses on economic impact studies, regional industry and cluster analysis and issue studies, particularly in workforce development and labor market analysis. This contract provided a comprehensive study on the electrification of mobility in Southern California, defined as the five counties of Los Angeles, Orange, Ventura, Riverside and San Bernardino. The research and resulting report from this analysis is expected to contribute to the following aims: business attraction to Southern California, workforce development in advanced mobility, and catalyze public debate and government action regarding legislation, regulation, urban planning, taxes and incentives surrounding electric mobility to demonstrate success in transportation electrification in the region.

Fueling/ Infrastructure and Deployment (Natural Gas/Renewable Fuels)

20178: Replace Diesel School Buses with Near-Zero Emissions CNG Buses

Contractor: Whittier Union High School District	South Coast AQMD Cost-Share	$ 0
	Cosponsors:	
	U.S. EPA *(received as pass-through funds into Fund 31)*	196,500
Term: 02/21/20 – 11/30/34	Total Cost:	$ 1,052,500

South Coast AQMD executed a grant for Whittier Union High School District to replace a total of five old pre-1994 diesel school buses with CNG school buses certified to meet the optional low NOx, near-zero standard of 0.02 g/bhp-hr. The award provided a total of $1,052,500 for the purchase of five Type D CNG school bus including sales tax. These school buses are partially funded by a U.S. EPA Airshed Grant, which were recognized into the Clean Fuels Fund. The grant award $1,052,500, compromised of $196,500 by the U.S. EPA Airshed Grant and $856,000 by South Coast AQMD's AB 923 funds. The Whittier Union High School District has taken possession of five 2019 CNG school buses.

Transfer: Participation in the California Natural Gas Vehicle Partnership for Fiscal Year 2020-21 and 2021-22

Contractor: California Natural Gas Vehicle Partnership	South Coast AQMD Cost-Share	$ 25,000
	Cosponsor	
	CNGVP Participating Members	155,000
Term: 07/01/20 – 06/30/22	Total Cost:	$ 180,000

The California Natural Gas Vehicle Partnership (CNGVP) was formed to accelerate the development of advanced natural gas vehicle technologies to provide a benchmark for lowering emissions from petroleum-based engines and to provide a pathway to hydrogen fuel cell use in the next two decades. The South Coast AQMD spearheaded the formation of this strategic alliance, which comprises state and federal air quality agencies, transportation and energy agencies, vehicle and engine manufacturers, fuel providers, and transit and refuse hauler organizations. Partnership Steering Committee members contribute monies to fund specific projects intended to achieve the goal of the Partnership. In September 2020 the South Coast AQMD approved $25,000 in biennial dues and South Coast AQMD's participation in the Steering Committee for the next two Fiscal years. Projects or efforts funded by the Partnership include event sponsorships such as the ACT Expo and the ReThink Methane Symposiums; enhancing and maintaining the Partnership's website; co-funding research papers to assess the in-state production of renewable natural gas and its overall carbon intensity relative to transportation fuel for new near zero NOx emission natural gas powered heavy-duty vehicles. The next two Fiscal year period is expected to result in significantly more effective and strategic messaging efforts from the Partnership.

Technology Assessment and Transfer/Outreach

08210: Technical Assistance on Mobile Source Control Measures and Future Consultation on TAO Activities

Contractor: Sawyer Associates	South Coast AQMD Cost-Share	$ 15,000
Term: 02/28/18 – 02/28/22	Total Cost:	$ 15,000

The Office of Science and Technology Advancement (STA) augments in-house expertise with consultants who perform through level-of-effort technical assistance contracts. Under this contract executed in 2008, Dr. Robert F. Sawyer provides technical assistance to further develop and refine the mobile source control measures. In addition, he provides assistance in air toxics control measures, review of South Coast AQMD programs such as the Clean Fuels projects, input to greenhouse gas and energy diversity policies, and state regulatory activities, such as the ZEV and ZBus regulations. Dr. Sawyer is the former Chairman of the California Air Resources Board and has over 50 years of domestic and international experience specializing in automotive emissions, alternative fuels, air pollution and

environmental issues. He has additional experience in air pollution regulatory policy advising. Dr. Sawyer is a Professor of the Graduate School and the Class of 1935 Professor of Energy Emeritus at the University of California at Berkeley and a Visiting Professor of Energy and Environment at University College London. Dr. Sawyer serves on the Clean Fuels Advisory Committee.

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	$ 150,000
Term: 06/13/14 – 05/31/22	Total Cost:	$ 150,000

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
	Cosponsors:	
	California Air Resources Board *(received as pass-through funds into Fund 67)*	161,800
Term: 09/07/18 – 09/30/22	Total Cost:	$ 211,800

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 is for technical and administrative support for the CARB Greenhouse Gas Reduction Fund (GGRF) Zero Emission Drayage Truck Project. In CY 2020, CARB funding was allocated to GPCI to assist in putting together quarterly progress reports, processing of invoices and supporting documentation, and reimbursement requests by funding agencies and partners.

20265: Technical Assistance with Heavy-Duty Vehicle Emissions Testing, Analyses & Engine Development & Applications

Contractor: Eastern Research Group	South Coast AQMD Cost-Share	$ 50,000
Term: 06/17/20 – 06/15/22	Total Cost:	$ 50,000

To promote, assess, expedite and deploy the development and demonstration of advanced, zero and near-zero emissions mobile and stationary technologies, South Coast AQMD relies on expert input and consultation. Eastern Research Group has experience and capabilities in conducting both dynamometer and in-use emissions measurements. As well as being a multi-service consulting firm that focuses on transportation, energy, environmental, economic and outreach solutions, Eastern Research Group has experienced staff with extensive qualifications in clean fuel transportation technology research, development, demonstration, planning and implementation, covering current and emerging alternative fuels and advanced propulsion technologies. Eastern Research Group has been providing support over three decades to transportation programs across the country seeking to improve air quality through advanced fuel and technology introduction, mitigation strategy implementation, and end user outreach and communication.

Various: Cosponsor 8 Conferences, Workshops and Events plus 3 Memberships

Contractor: Various	South Coast AQMD Cost-Share	$ 141,960
	Cosponsors	
	Various	2,029,000
Term: 01/01/20 – 12/31/20	Total Cost:	$ 2,170,960

The South Coast AQMD regularly participates in and hosts or cosponsors conferences, workshops and miscellaneous events. In CY 2020, South Coast AQMD provided funding for 8 conferences, workshops and events and 3 memberships in key stakeholder organizations, as follows: Clean Fuels Advisory Group Retreat in January and September 2020; the 2030 California Transportation Future Summit in March 2020; Hydrogen and Fuel Cells for Freight Workshop in March 2020; the PEMS Conference in March 2020; the ACT Virtual Event Series from August through November 2020; the Breath of Life Awards Virtual Gala in September 2020; the High Power Charging for Commercial Vehicles Event in September 2020; and the Renewable Gas 360 Symposium and Webinar Series from June 2020 through February 2021. Additionally, for 2020, three memberships were renewed for participation in the California Hydrogen Business Council, a member-based association representing a wide array of organizations that acts as a leading advocate for the hydrogen and fuel cell industry; Calstart, a nonprofit organization working nationally and internationally with businesses and governments to develop clean, efficient transportation solutions; 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	$ 1,848
Term: 01/01/20 – 12/31/20	Total Cost:	$ 1,848

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 2020, 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: Alternative Fuel Demonstration Vehicle Program Expenses

Contractor: Various	South Coast AQMD Cost-Share	$ 229
Term: 01/01/20 – 12/31/20	Total Cost:	$ 229

The South Coast AQMD alternative fuel vehicle demonstration program showcases new clean-fuel vehicles 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 vehicle technologies. This direct pay covers cost of service for one Honda Fuel Cell Clarity.

CLEAN FUELS PROGRAM
Progress and Results in 2020

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 6provides a list of 30 projects and contracts completed in 2020. Summaries of the completed technical projects are included in Appendix C. Selected projects completed in 2020 which represent a range of key technologies from near-term to long-term are highlighted below: (a) Low NOx Diesel Development Project; and (b) Assessment of the Air Quality and Greenhouse Gas Impacts of a Microgrid-Based Electricity System.

Low NOx Diesel Development Project

CARB initiated a three phase comprehensive study to support the current Omnibus legislation involving lower emissions standards for on-road heavy-duty vehicles and the EPA Cleaner Trucks Initiative. The original Stage 1 CARB Low NOx Demonstration Program provided an initial demonstration of the feasibility of technologies for achieving a target tailpipe NOx level of 0.02 g/hp-hr on a diesel engine platform. The second stage involved developing low- load cycles for heavy-duty diesel engines.

Phase 1 incurred a significant fuel penalty due to the engine architecture using a mini- burner and waste heat recovery. As a follow-up to these earlier programs, CARB and South Coast AQMD launched a second diesel demonstration program, the Stage 3 Low NOx Demonstration Program. The Stage 3 program focused on answering two major questions:

1. Could Low NOx levels be achieved at a smaller fuel consumption penalty?
2. Could a different and more efficient system be designed to target 0.02 NOx levels?

Significant contributions to the program came from the Port of Los Angeles, South Coast AQMD, MECA, CARB, and the US EPA.

The first task in the South Coast AQMD program was the development of a modified engine calibration that would enable an advanced aftertreatment system to reach Low NOx levels. This modified calibration was incorporated into cylinder deactivation (CDA) resulting in improved fuel efficiency and maintaining a significant increase in exhaust temperatures. Engine-out NOx during the aftertreatment warm-up period

was successfully controlled. Leveraging CDA allowed this to be done with only a small impact on cold-start GHG, while hot-start GHG levels showed a benefit compared to baseline. Following an extensive evaluation of candidate aftertreatment technologies and configurations, a final configuration was chosen, which is shown in Figure 13.

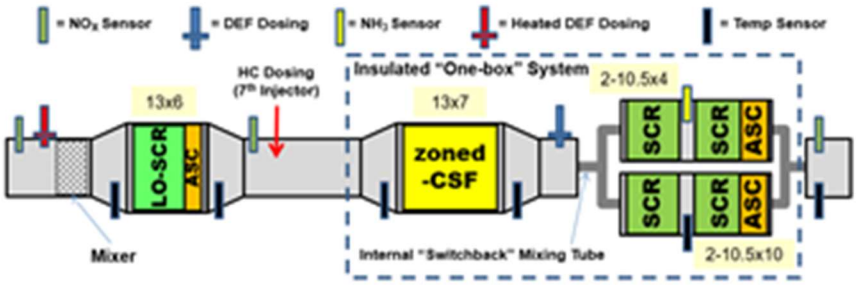


Figure 13: Final Stage 3 Aftertreatment Configuration Down-selected from Evaluation

This configuration employed both a close-couple light-off Selective Catalytic Reduction (LO-SCR) and a downstream system featuring dual Diesel Exhaust Fluid (DEF) dosers, including a heated upstream dosing unit. An advanced controls system was implemented on the engine including state-of-the-art model-based dosing controls, and an integrated state-based strategy controller. The final system was calibrated to minimize NOx emissions, while at the same time maximizing efficiency and controlling GHG emissions. The final calibration was demonstrated on a system that was hydrothermally aged to represent a full useful life of 435,000 miles. The resulting performance levels are shown in Figure 14. The system was able to reach tailpipe NOx levels below 0.02 g/hp-hr on the federal test procedure (FTP) and Ramped Modal Cycle Supplemental Emissions Test (RMC-SET), and at 0.06 g/hp-hr for the Low Load Cycle (LLC). Further testing is expected to lower these emissions further to achieve near- zero NOx certification.

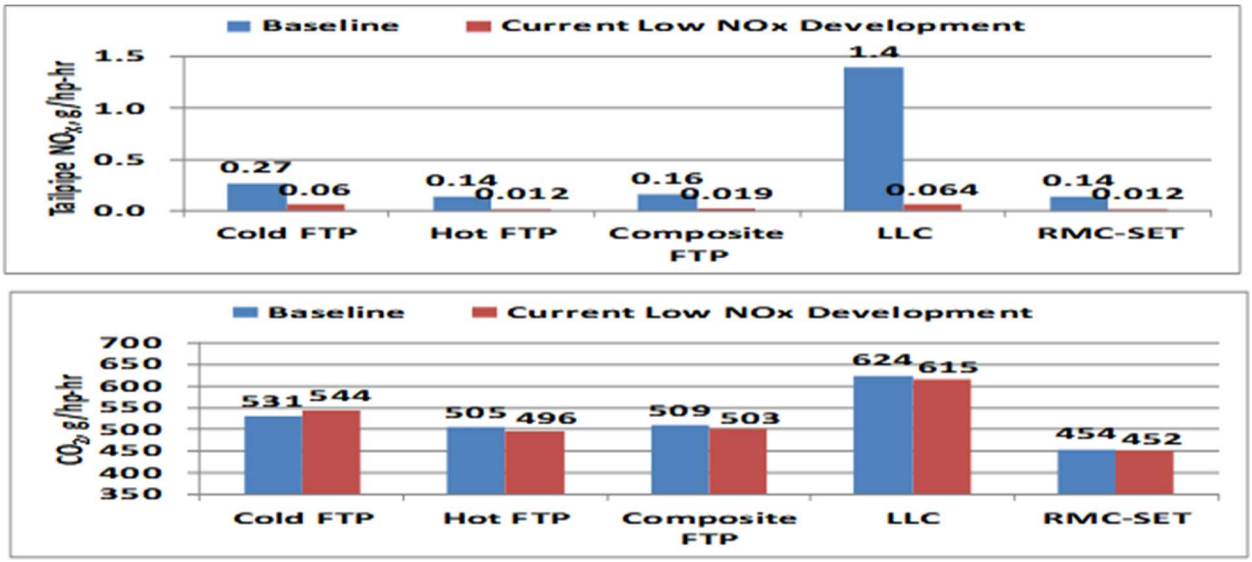


Figure 14: Performance Levels Demonstrated at the end of South Coast AQMD Funded Development on Hydrothermally Aged FUL parts (435,000 miles equivalent)

The Low NOx configuration developed in this program has been tested over current regulatory cycles, the new LLC, and field cycles. The system has shown the potential for NOx emission control under a wide variety of application cycles, while maintaining GHG emissions, and in some cases showing improvements. Several technology elements such as heated dosing and heated catalysts are now available for the engine and aftertreatment system and are likely to be incorporated in future on-highway engines to meet Low NOx standards.

Assessment of the Air Quality and Greenhouse Gas Impacts of a Microgrid-Based Electricity System

The development of microgrids is gaining attention as a means of increasing the resilience and reliability of the electricity system, reducing criteria pollutant and greenhouse gas emissions of the electricity and transportation sectors, and increasing the deployment of renewable power generation resources in serving the electric load demand. The provision of electric service through microgrids has a number of potential advantages, including but not limited to:

- Reducing transmission losses and the need for transmission capacity and additional transmission lines to connect external generation
- Taking advantage of co-/poly-generation methods such as combined heat and power or district heating and cooling
- Allowing usage of otherwise stranded assets such as biogas and biomass
- Maintaining electric service in the event of an external grid outage
- Serving as a hub for grid-to-vehicle (G2V) charging and vehicle-to-grid (V2G) services for battery
- Electric vehicles, and hydrogen fueling for fuel cell electric vehicles and V2G services for plug-in fuel cell electric vehicles.

As microgrids become prevalent, capacity for electricity generation which was previously outside the Basin will be retired and replaced with new capacity inside of the Basin. The potential of microgrids to substantially reduce the criteria pollutant emissions in southern California depend entirely on the design of the microgrids. When microgrids are used to support alternative transportation refueling (electric and hydrogen) the emission reduction benefits are increased. This project is the first to explore microgrid design features that facilitate zero emission of both criteria pollutant and greenhouse gasses with a focus on the following three tasks.

Task 1. Fuel Cell Technology for Industrial and Petroleum Refinery Microgrids

Two different types of fuel cells are considered in this work: Solid Oxide Fuel Cells (SOFC) and Molten Carbonate Fuel Cells (MCFC). Two approaches individually and in combination are considered: 1) greenfield applications where SOFC replace a productive process, e.g., power plant, steam methane reforming (SMR); and 2) retrofit applications, with MCFC assumed to be placed downstream of exhaust gas streams as a post-combustion system, which would involve every source of emissions.

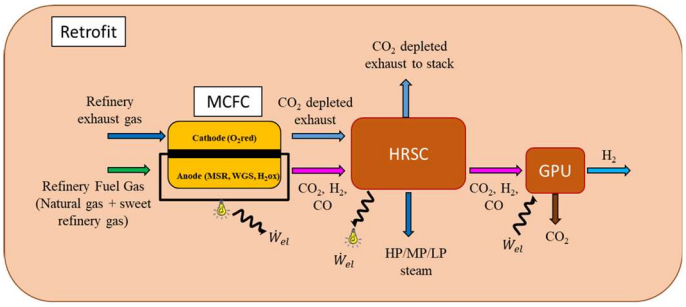


Figure 15: Retrofit configuration using MCFCs (HRSC: Heat Recovery Steam Cycle; GPU: Gas Processing Unit; MSR: Methane Stream Reforming; WGS: Water Gas Shift)

Scenarios are assessed using detailed thermodynamic models to determine the feasibility and performance within the scenario configurations including emission reductions for a given refinery deployment scenario. Emission changes are then mapped to a 2035 emissions inventory quantitatively, and spatially and temporally resolved for the location and activity of all refineries in California. The Community Multi-scale Air Quality model (CMAQ) is then used to simulate chemistry and transport within the atmosphere to resolve impacts on primary and secondary pollutant concentrations including ozone and fine particulate matter (PM2.5) from fuel cell deployment. Using CMAQ, summer and winter meteorological episodes are evaluated to analyze the effects of changing emissions during high pollutant formation conditions in California.

Fuel cell systems can feasibility be integrated into petroleum refineries in various ways to achieve emission reductions for both pollutants and GHG, although challenges related to the complexity and scale of existing refineries require further study. Emission reductions for the scenarios in this work scale with the aggressiveness of fuel cell deployment from relatively minor up to 66% of total refinery NOx for the widespread use of MCFC. When applied to all refineries, the largest NOx reductions occur in northern California with lesser impacts in Basin. Conversely, reductions in other pollutants including VOC are greater in Basin relative to NOx, and more equivalent to those in northern California. The trends have AQ implications as both are precursor emissions for ozone and secondary PM2.5. Emission reductions translate to a range of possible AQ impacts. For an aggressive MCFC deployment, ozone reductions peak at -2.6 ppb. Improvements in PM2.5 for summer are substantial, exceeding 8 μg/m3 in the Basin and occurring in other regions of the State. Similarly, improvements reach 10 μg/m3 in winter in Basin. highlighting the importance of VOC emissions in secondary PM2.5 formation pathways.

Task 2. Assess the Emissions and Air Quality Impacts of Renewable Fuel Blending in the Natural Gas System

Determining the change in emissions from a fuel composition shift to H2 blends requires assessment of impacted combustion devices. UCI has developed and demonstrated a platform using in-lab testing and numerical modeling to investigate emissions and stabilities with different fuel compositions for combustion equipment. The platform was used to analyze the formation of NOx and CO when burning mixtures of NG with H2 in industrial applications including different configurations of turbine combustors, boiler burners, radiant tubes, and porous burners. Additionally, the same method was used to assess the combustion performance of residential and commercial appliances including cooktop, oven and broiler burners, central forced air furnaces, and water heaters. Additional devices not included in the previous work were assessed using a detailed review of the literature. Numerous aspects complicate a clear understanding of how H2 addition may effect emissions including numerous potential pathways and quantities of H2 production, the size and complexity of the NG system, how the diverse range of end-use sources may be affected, lack of available data, and others. Thus, assumptions are made to feasibly develop scenarios and should be considered in interpreting the results including:

- Scenarios assume 5%, 16%, and 20% by volume H2 blending in the NG system
- Blends are perfectly mixed throughout the entire NG system in California
- End-use devices are not optimized for operation on H2/NG blends
- Only stationary sources are impacted
- Only NOx and CO are impacted

Emission changes are mapped to a 2035 emissions inventory quantitatively, and spatially and temporally resolved for the location and activity of end-use equipment. The Community Multi-scale Air Quality model (CMAQ) is then used to simulate chemistry and transport within the atmosphere to fully resolve impacts on primary and secondary pollutant concentrations including ozone and fine particulate matter (PM2.5) from H2 blending. Using CMAQ, summer and winter meteorological episodes are evaluated to analyze the effects of changing emissions during high pollutant formation conditions in California. In addition to the assumptions listed above, scenarios are defined by decisions regarding the mapping of NG-consuming boilers, steam generators, and equipment included in the emission inventory as “Other”. To establish a range of impacts (both positive and negative) a “Best Case” and “Worst Case” for each H2 blend level is established. Projected impacts on state-wide NOx range from a 6% decrease to a 4% increase demonstrating the range of effects from transitions in NG system fuel composition and the lack of current understanding of many important factors that will ultimately determine the real-world effects.AQ impacts follow suit, e.g., ozone changes vary from -2.4 to +1.6 ppb in the 20% Best and Worst Cases, respectively. Spatially, the largest impacts occur in the Basin with importance given the large populations and currently degraded AQ.

Similar impacts are noted for PM2.5 in winter and summer with peak changes in the Central Valley and Basin with similar importance.

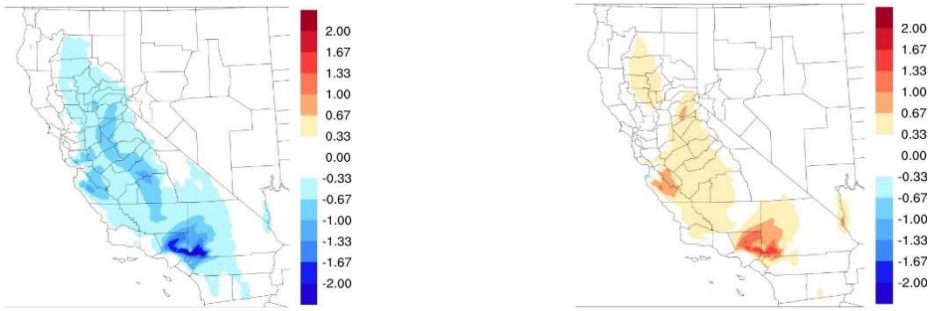


Figure 16: Difference in summer MD8H ozone (ppb) for the 20% Best Case(left) and the 20% Worst Case(right)

Task 3. Comparative Study on Environmental-Economic Impacts of Fuel Cell and Battery-Electric Buses within a Microgrid

As zero-emission vehicles increase, the development of microgrids is critical as a means of increasing the resilience and reliability of the electricity system, increasing the deployment of renewable power generation resources in serving the electric load demand, and serving as a hub for the merging of the electricity and transportation sectors, which together represent the major source of criteria pollutant emissions. The wider deployment of battery electric and fuel cell electric heavy-duty vehicles has already started, and it is expected that their penetration will increase energy demand for their operation. Therefore, it is essential to coordinate charging/fueling of these vehicles, especially integrate these zero-emission vehicles in microgrids. Microgrids can enable improving the overall energy efficiency and integrating more and more zero-emission vehicles for fleet operators.

Figure 17: Anteater Express Zero-Emission Buses

Anteater Express is the first fully zero-emission fleet in the state of California, and the first transit agency in the country to have a mix of zero-emission buses (ZEBs) in operation with 20 battery electric buses (BEBs) and one fuel cell electric buses (FCEBs). The simultaneous operation of battery electric and hydrogen buses provides a unique opportunity to develop an evaluation framework under consistent conditions. The data collected from the fleet enabled a comprehensive comparison of the two technologies and were used in statistical analysis to assess the performance of ZEBs and assess impact of various factors on overall performance of different bus technologies.

Multiple models were developed in the project to determine a driving cycle representative of Anteater Express routes which was then used in the fuel efficiency model to compare energy consumption of various bus powertrains. A detailed Life Cycle Assessment (LCA) analysis was done to assess economic and environmental impact of different ZEBs, and a strategy was developed to optimize the technology-mix of the a zero-emission in order to help transit agencies transition to a zero-emission fleet without impacting their service and routes.

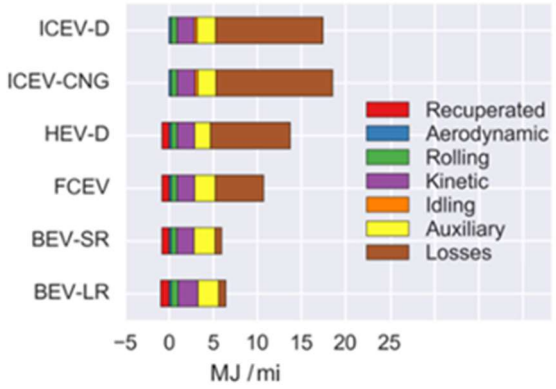


Figure 18: Energy Consumption per Mile for Various Powertrains

Results of the study include comparison of total cost of ownership, economic and environmental impacts, and overall assessment of FCEBs and BEBs. Environmental impacts included emissions criteria pollutants (NOx, PM) and greenhouse gases. Not only the tailpipe emissions are 100% eliminated the overall life-cycle emissions are also reduced with deployment of BEBs and FCEBs. The extend to reduction depends on the fuel pathways and delivery, but for similar pathways, BEBs have lower emissions.

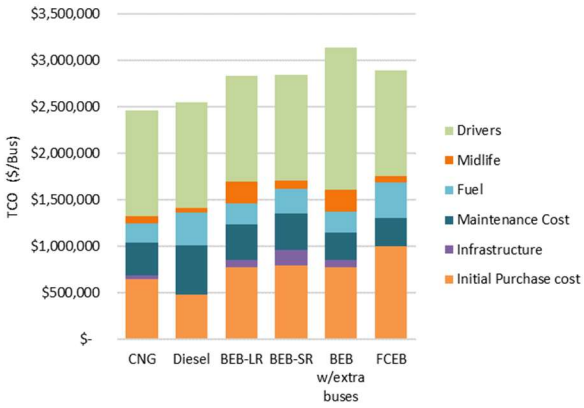


Figure 19: Total Cost Ownership for Various Powertrain Technology Buses

The use of fuel cell systems at industrial facilities can provide notable improvements in regional levels of ozone and PM2.5 which in turn will provide substantial benefits to human health within California. The addition of H2 may also provide important AQ co-benefits to sensitive urban regions. Conversely, care must be taken to avoid AQ worsening in those same areas. the overall criteria pollutant and greenhouse gases are reduced with the deployment of BEBs and FCEBs and has the potential to improve air quality as well as helping mitigate and reduce impacts of climate change.

Table 5: Projects Completed between January 1 & December 31, 2020

Contract	Contractor	Project Title	Date
Hydrogen/Mobile Fuel Cell Technologies and Infrastructure			
15609	ITM Power, Inc.	Installation of Riverside Rewenable Hydrogen Fueling Station	Jan 2020
15619	H2 Frontier, Inc.	Installation of Chino Renewable Hydrogen Station	Dec 2020
19191	University of California, Irvine	Development of Solid Oxide Fuel Cell and Gas Turbine (SOFC-GT) Hybrid Technology	Jun 2020
Engine Systems/Technologies			
17393	Southwest Research Institute	Development of an Ultra-Low Emission Diesel Engine for On-Road Heavy-Duty Vehicles	May 2020
18211	West Virginia University Innovation Corporation	Develop Thermal Management Strategy Using Cylinder Deactivation for Heavy-Duty Diesel Engines	Jun 2020
Electric/Hybrid Technologies and Infrastructure			
13433	US Hybrid Corporation	ZECT I : Develop and Demonstrate Two Class 8 Zero-Emission Electric Trucks	Mar 2020
14052†	Altec Capital Services, LLC	Lease of 2 PHEVs	Jan 2020
16022†	Gas Technology Institute	ZECT II - Develop & Demonstrate One Class 8 CNG Hybrid Electric Drayage Truck	Nov 2020
16046	Transportation Power, Inc.	ZECT I - Develop & Demonstrate Two Class 8 CNG Plug-In Hybrid Electric Drayage Trucks	Mar 2020
17029	University of California, Irvine	Demonstration and Evaluation of Plug-In Smart Charging at Multiple Electric Grid Scales	Dec 2020
18122	Clean Energy	Southern California Trucking Demonstration of Near-Zero ISX12N Beta Engines	Jan 2020
Fueling Infrastructure and Deployment (NG/RNG)			
12667	West Covina Unified School District	Upgrade CNG Fueling Station	Mar 2020
16075	City of Desert Hot Springs	Purchase 1 Heavy-Duty CNG Powered Truck	Mar 2020
16244†	CR & R, INC.	Renewable Natural Gas Production & Vehicle Demonstration Project	Mar 2020
Fuel/Emissions Studies			
15680	National Renewable Energy Laboratory	Develop Detailed Technology and Economics Based Assessment for Heavy-Duty Advanced Technology Development	Jun 2020
17277	University of Southern California	Conduct Market Analysis for Zero-Emission Heavy-Duty Trucks in Goods Movement	Feb 2020
18206	University of California, Irvine	Assess Air Quality and Greenhouse Gas Impacts of a Microgrid-Based Electricity System in Southern California	Jun 2020

Table 5: Projects Completed Between January 1 & December 31, 2020 (cont'd)

Contract	Contractor	Project Title	Date
Emissions Control Technologies			
17278	University of Southern California	Develop Freight Loading Strategies for Zero-Emissions Heavy-Duty Trucks in Goods Movement	Feb 2020
Technology Assessment and Transfer/Outreach			
12453†	TECH COMPASS	Technical Assistance with Alternative Fuels, Fuel Cells, Emissions Analysis, and Aftertreatment Technologies	May 2020
16200	California State University, Los Angeles	Cosponsor Regional Universities for US DOE EcoCAR 3 Competition	Apr 2020
20046†	RadTech International	Cosponsor the RadLaunch Program	Jun 2020
20098†	Coordinating Research Council, Inc.	Cosponsor the 30th Real World Emissions Workshop	Apr 2020
20104†	Gladstein, Neandross & Associates LLC	Cosponsor the 2020 Renewable Gas 360 Symposium	Feb 2020
20233†	California Hydrogen Business Council	Cosponsor the CA Hydrogen & Fuel Cell Summit	Mar 2020
20264†	CALSTART, Inc.	Cosponsor the 2030 California Transportation Future Summit	Jun 2020
21079†	Gladstein, Neandross & Associates LLC	Cosponsor 2020 ACT Virtual Event Series	Dec 2020
21093†	BREATHE California Of Los Angeles County	Cosponsor 2020 Breath of Life Awards Virtual Gala	Oct 2020

†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.

CLEAN FUELS PROGRAM

2021 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 Technology Advancement Program (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 2021 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 is updated approximately every four years, 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 ozone standards of 80 ppb and 75 ppb, respectively. The majority of these NOx reductions must come from mobile sources, both on- and off-road. Notably, South Coast AQMD is currently only one of two regions in the nation designated as an extreme nonattainment area (the other region is 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 standard ozone for Coachella Valley to "extreme" status. Hotter summer months and climate change in the region have presented challenges that require additional time to reach attainment.

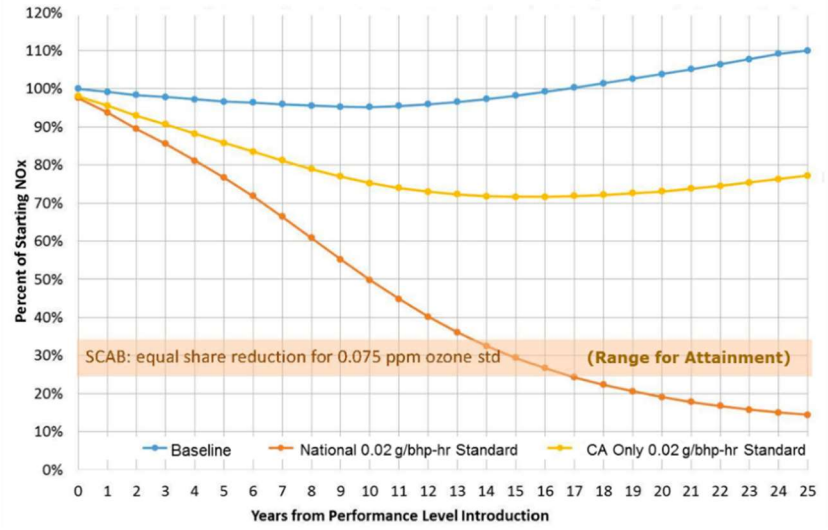
While current state efforts in developing regulations for on- and off-road vehicles and equipment are expected to reduce NOx emissions significantly, they will be insufficient to meet South Coast AQMD needs, particularly in terms of timing. The 2016 AQMP identified a means to achieving the NAAQS through 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.

On June 3, 2016, in light of the need for a more stringent national heavy-duty truck engine emissions standard to achieve mobile source emission reductions, South Coast AQMD petitioned the U.S. EPA to initiate rulemaking for a lower national NOx standard for heavy-duty engines. A national NOx standard (as opposed to a California standard) for on-road heavy-duty vehicles is estimated to result in NOx emission reductions from this source category from 70 to 90 percent in 14 to 25 years, respectively. While CARB has adopted more stringent in-use fleet rules which require older trucks and buses to upgrade to newer, cleaner engines meeting the 2010 standard of 0.2 g/bhp-hr by 2023, CARB estimates that 60 percent of total heavy-duty vehicle miles traveled in the Basin are from vehicles purchased outside of California. This points to the need for a more stringent federal as well as state standard for on-road heavy-duty vehicles.

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.

Figure 20 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 20: NOx Reduction Comparison: No New Regulations vs Low NOx Standard in California only vs National Standard

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. 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 starting as early as model year 2026. However, CARB forged ahead, announcing its own Low NOx Omnibus rule, which was adopted by CARB Board in summer 2020. The new regulation will require lower NOx standard starting in model year 2024 a goal harmonize with U.S. EPA Cleaner Truck Initiative of a national NOx stand of 0.02 g/bhp-hr in 2027, 90% below today's NOx standard. Although both are welcome news, the

timing is too late to help the South Coast AQMD meet its 2023 federal attainment deadline. So, despite the milestone progress, commercialization and deployment of cost-effective near-zero engines are still needed to meet near-term goals.

The findings from the MATES IV[12] study (May 2015), which included local scale studies near large sources such as ports and freeways, reinforced the importance of the need for transformative transportation technologies, especially near the goods movement corridor to reduce NOx emissions. 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. The MATES V report is expected to be finalized by early 2021. 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 being 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 $340 million toward projects exceeding $1.5 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, Community Air Protection Program and Voucher Incentive Program), currently with cumulative funding of $250 million annually. 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 serval emerging key technology 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.

[12] http://www.aqmd.gov/docs/default-source/air-quality/air-toxic-studies/mates-iv/mates-iv-final-draft-report-4-1-15.pdf?sfvrsn=7

Figure 21 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 21: Technology Readiness Levels

While the state continues to focus their attention on climate change (GHG reductions), South Coast AQMD remains committed to achieving NOx reductions. Many of the technologies that address the Basin's needed NOx reductions align with the state's GHG reduction efforts. In 2016, U.S. EPA noted that the transportation sector contributed 28 percent of overall GHG emissions. Due to these co-benefits, South Coast AQMD has been successful in partnering with the state and public/private partnerships to leverage its Clean Fuels funding extensively.

Program and Funding Scope

This 2021 Plan Update includes projects to research, develop, demonstrate and advance deployment (RD^3) 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 2021 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 might include findings from MATES V and revised emission inventories in EMFAC 2017.

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 2020, 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 2021 are expected to result in commercially available products in the 2023-2025 timeframe, and technologies being demonstrated generally are in the process of being 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 2021 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 2021-2025. 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 2026 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 2021 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 fuel 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 designated in CERPs by five 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 2021.

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. It is dedicated to assisting federal and state government programs to deploy light-, medium-, and heavy-duty fuel cell vehicles (FCV) 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 delivering its 2017 Honda Clarity FCV. Other commercially available FCVs include the Audi H-Tron Quattro, Chevrolet Colorado ZH2, Hyundai Nexo, Mercedes-Benz GLC F-Cell and Nissan X-Trail. 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 for light-duty vehicles 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 should enable 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 light-duty retail 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 CaFCP's 2030 Vision[13] 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.

As part of the $83 million Shore-to-Store project, for which the Clean Fuels Program committed $1 million, Toyota and Kenworth will deploy 10 Class 8 fuel cell trucks and Equilon (Shell) will build two large capacity hydrogen fueling stations in Wilmington and Ontario. Kenworth will leverage the development on the fuel cell truck demonstrated in South Coast AQMD's ZECT 2 project and integrate Toyota's fuel cells into the Kenworth trucks. These fuel cell trucks will be 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. In 2019, Toyota displayed a second

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

prototype Class 8 fuel cell truck at the Port of Long Beach, including plans for a new 1,000 kg/day heavy-duty hydrogen fueling station using hydrogen produced by a new tri-generation fuel cell.

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. Also, Volvo and Daimler this year announced a joint venture to develop fuel cell powered trucks. South Coast AQMD has created many alliances with the large OEM's and will continue to fund projects with these companies over the next year to develop heavy-duty fuel cell trucks.

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, the Center for Transportation and Environment (CTE) partnered with New Flyer, Trillium, and Orange County Transportation Authority (OCTA) to deploy 10 40-foot New Flyer XHE40 fuel cell transit buses and install 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). The transit buses were delivered in December 2019 and liquid hydrogen station was completed in January 2020, and the demonstration and data collection period for the buses and station started in February 2020. SunLine Transit Agency was the recipient 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 16 fuel cell and four battery electric transit buses and five buses that will be deployed by the end of 2020 as well as a recently upgraded 900 kg/day hydrogen station capable of supporting up to 30 fuel cell transit buses.

The 2021 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. plug-in hybrid fuel cell vehicles);
- 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 fuel cell vehicles 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 fuel cell vehicle OEMs to develop an understanding of their progress in overcoming barriers to economically competitive fuel cell vehicles 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, internal combustion engines (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, commercialization of the Cummins 8.9 liter (8.9L) natural gas engine achieving 90 percent below the existing federal standard was a game changer. The 8.9L engine works well in refuse and other vocational trucks as well as transit and school buses. In 2017, Cummins Westport Inc., 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 is a further game changer. 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 ensures viability of near-zero engine options for all market segments. For trucks that cannot utilize the Cummins near-zero emission engines, the 2021 Plan Update includes potential projects to develop, demonstrate and certify natural gas and propane engines in the 6-8L range. Although no near-zero emission diesel technology is commercially available today, South Coast AQMD has been working closely with CARB 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 Cycle Deactivation Project with West Virginia University. The 2021 Plan Update included 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 are feasible via advanced engine and aftertreatment or optimized engine design and calibration. 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 emission reductions using an optimized systems approach. 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 2021 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 eventual 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 off-road applications;
- evaluation of alternative engine systems such as hydraulic plug-in hybrid vehicles;
- development and demonstration of engine systems that employ advanced engine design features, cylinder deactivation, improved exhaust or recirculation systems, and aftertreatment devices; and
- development of low load and cold start technologies for hybrids and diesels where high-level emissions occur.

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

In an effort 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 technologies. South Coast AQMD supports projects to address concerns regarding cost, battery lifetime, 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. 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 electric vehicles (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 vehicles 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 vehicles has generally been with the CCS1 connector in North America, with Volvo and ABB obtaining UL certification of the CCS2 connector in 2020, which is a connector standard predominantly used in Europe and other parts of the world. 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 vehicles and off-road equipment, charging infrastructure to support these vehicles and equipment, and an ability to fund larger scale deployment projects for medium- and heavy-duty vehicles, equipment, and infrastructure.

This is especially important when the number of light-duty EVs continues to increase annually. As of Q2 2020, 723,045 and 1,556,058[14] new plug-in and battery electric vehicles were sold or leased in California and the U.S respectively. Greater adoption of EVs will increase significantly with the introduction of more vehicles with 200-plus mile range, such as the Tesla Model 3/S/X/Y, Jaguar i-PACE, Kia e-Niro, Hyundai Kona Electric, Mercedes Benz EQC, Audi e-tron, Nissan Leaf e Plus, Chevrolet Bolt, BMW i3, and Porsche Taycan Turbo.

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 a 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, near-zero emission locomotives (e.g., 90% below Tier 4), electric locomotives using battery electric tender cars and catenary systems, 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

[14]Veloz is a non-profit advocacy organization promoting light-duty electric vehicles. https://www.veloz.org/sales-dashboard/

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) deployment of 70 Volvo Class 8 battery electric drayage/freight trucks for the Switch-On project 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, 2) demonstration of two additional Class 8 battery electric drayage trucks as part of the Volvo LIGHTS project funded by a $500,000 U.S. EPA Clean Air Technology Initiative grant, 3) retrofit of six RTG cranes with hybrid electric engines at SSA Marine Terminal in the Port of Long Beach funded by a $2.5 million South Coast AQMD grant, and 4) Daimler Commercial Experience project to demonstrate eight Class 6 and 8 battery electric trucks and fast charging infrastructure funded by a $1 million South Coast AQMD grant.

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 LADWP include funding for medium- and heavy-duty vehicles and infrastructure, and there is an upcoming joint CARB-CEC heavy-duty drayage truck deployment and infrastructure solicitation for $40 million towards a 50-truck deployment at a single drayage fleet.

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 procedure 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 can be 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.

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;
- 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 or yard tractors;
- 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, and 3) put in place infrastructure that will ultimately be needed to accommodate transportation fuels with very low gaseous emissions.

Compressed and liquefied natural gas (CNG and LNG) refueling stations are being positioned to support both public and private fleet applications. 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 growing interest for partial or complete transition to renewable natural gas delivered through existing natural gas pipelines. Funding has been provided at key refueling points for light-, medium- and heavy-duty natural gas vehicle users traveling from the local ports, along I-15 and The Greater Interstate Clean Transportation Corridor (ICTC) Network. 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 cofunded for infrastructure development are:

- development and demonstration of renewable natural gas as a vehicle fuel from renewable feedstocks and biowaste;
- development and demonstration of advanced, cost effective methods for manufacturing synthesis gas for conversion to renewable natural gas;
- enhancement of safety and emissions reductions from natural gas refueling equipment;

- expansion of fuel infrastructure, fueling stations, and equipment; 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 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. 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.

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 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 (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
- 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 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. In 2020, South Coast approved comprehensive ethanol fuel study along with CARB and others to assess the emissions and secondary organic aerosol impacts on model year 2002 and up light duty vehicles. 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. In 2015, South Coast AQMD funded studies 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. 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. 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. 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 new lower level emissions trigger the need to perform a new in-use study focus on assessing the variability in-use, multiple proposals from CARB, EPA and other are under discussion to fulfill that need. 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.

One a large scale, Senate Bill 210 was signed in the law in 2019 which directs CARB to development 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 large population of trucks which is critical for success of this program. Remote sensing technology, which can be setup near road side and over passes has gain the spot light for enabling a new suite of technology for assess emissions in-use. South Coast AQMD staff is closing monitoring the CARB progress and see how it can help us better understand emissions inventory.

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. MATES V was launched in 2017 to update the emissions inventory of toxic air contaminants and modeling to characterize risks, including measurements and analysis of ultrafine particle concentrations typically emitted or converted from vehicle exhaust. In addition, staff are also performing additional advanced monitoring activities as an extension of 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 power-to-gas concept has renewed interest in hydrogen-fossil fuel blends where the emissions impact on latest ICE technologies needs to be reassessed. 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. 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, 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 currently installed on-road and off-road technologies. Existing diesel emissions can be greatly reduced with introduction of natural gas into the engine or via aftertreatment controls such as PM traps and 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 lowering the sulfur content or using additives with diesel fuel. Gas-to-Liquid (GTL) fuels, formed from natural gas or other hydrocarbons rather than petroleum feedstock and emulsified diesel, provide low emission fuels for use in diesel engines. As emissions from engines become lower and lower, the lubricant contributions to VOC and PM emissions become increasingly important.

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 the 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 disadvantaged communities, local governments, funding agencies, technical audiences). As part of Assembly Bill (AB) 617[15], which 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 adoption of cleaner technologies. Cleaner technologies such as zero emission heavy-duty trucks are now included in the Community Emission Reduction Plans (CERPs) 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 $17.9 million for all potential projects. The actual project expenditures for 2021 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 2021 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.

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

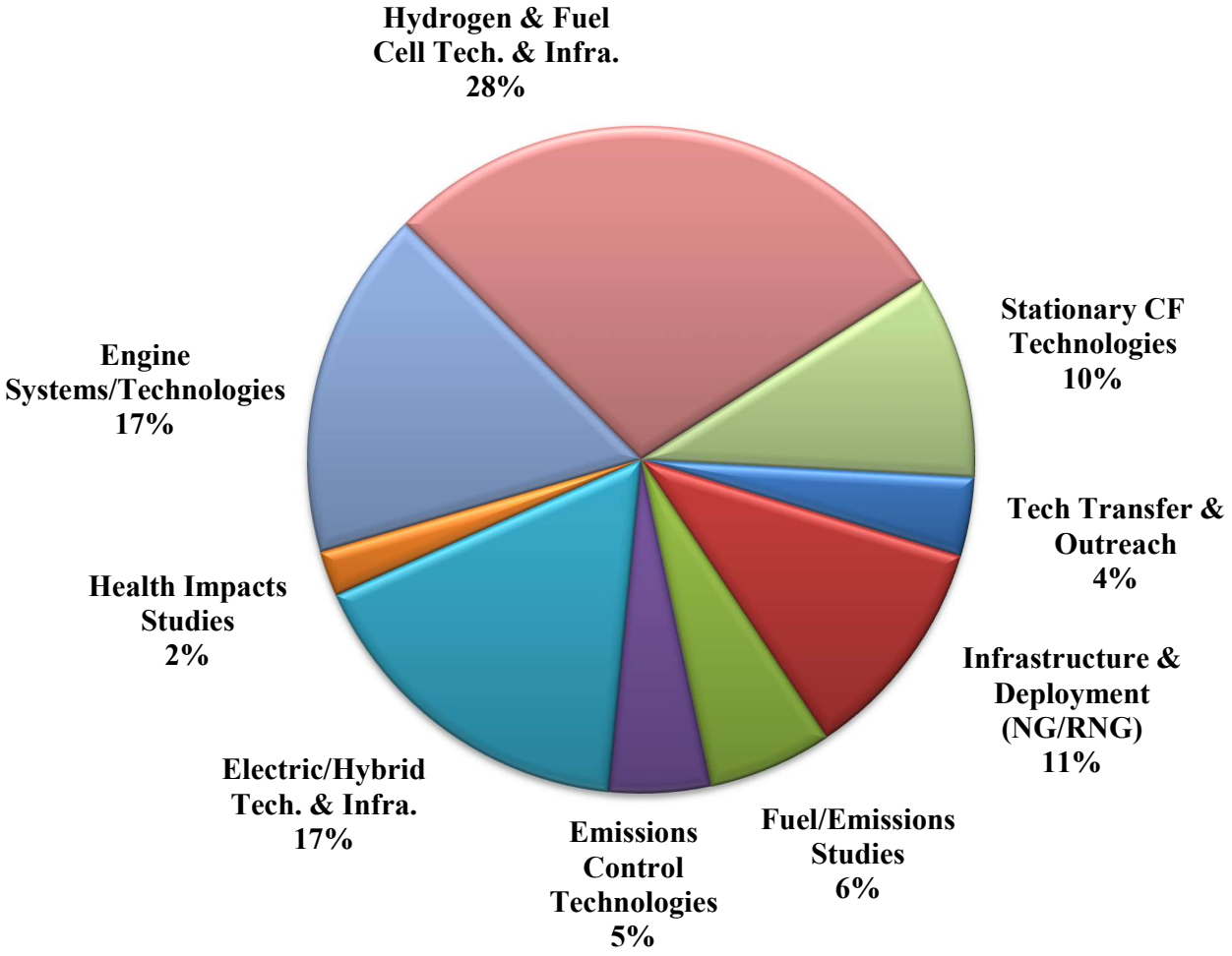


Figure 22: Projected Cost Distribution for Potential South Coast AQMD Projects in 2021 ($17.9M)

CLEAN FUELS PROGRAM
Program Plan Update for 2021

This section presents the Clean Fuels Program Plan Update for 2021. 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 6 summarizes potential projects for 2021 as well as the distribution of South Coast AQMD costs in some areas as compared to 2020. 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 2021 Draft Plan, 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 2021, 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 buses and 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 2020-21 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 6.

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 6: Summary of Potential Projects for 2021

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	90,000	1,800,000
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	75,000	75,000
Subtotal	$4,809,500	$20,375,000
Engine Systems/Technologies		
Develop and Demonstrate Advanced Gaseous- and Liquid-Fueled Medium- and Heavy-Duty Engines & Vehicle Technologies to Achieve Ultra-Low Emissions	2,750,000	10,000,000
Develop and Demonstrate Alternative Fuel and Clean Conventional Fueled Light-Duty Vehicles	176,300	1,000,000
Develop and Demonstrate Low Load and Cold-Start Technologies	176,300	1,000,000
Develop and Demonstrate Low Emissions Locomotive Technologies	176,300	1,000,000
Subtotal	$3,278,900	$13,000,000
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	600,000	30,790,000
Demonstrate Alternative Energy Storage	300,000	2,000,000
Demonstrate Light-Duty Battery Electric Vehicles	200,000	200,000
Subtotal	$3,500,000	$55,790,000
Fueling Infrastructure and Deployment (Natural Gas/Renewable Fuels)		
Demonstrate Near-Zero Emission Natural Gas Vehicles in Various Applications	500,000	2,100,000
Develop, Maintain and Expand Natural Gas Infrastructure	500,000	2,100,000
Demonstrate Renewable Transportation Fuel Manufacturing and Distribution Technologies	$1,000,000	$10,000,000
Subtotal	$2,000,000	$14,200,000
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	264,450	1,000,000
Subtotal	$1,264,450	$5,500,000

Table 6: Summary of Potential Projects for 2021 (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	200,000	1,000,000
Subtotal	$1,100,000	$4,500,000
Emissions Control Technologies		
Develop and Demonstrate Advanced Aftertreatment Technologies	250,000	1,000,000
Develop and Demonstrate Advanced Aftertreatment Catalyst Heating Technologies	250,000	1,000,000
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	350,000	800,000
Support Implementation of Various Clean Fuels Vehicle Incentive Programs	350,000	400,000
Subtotal	$700,000	$1,200,000
TOTALS FOR POTENTIAL PROJECTS	**$17,931,750**	**$120,165,000**

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: $90,000

Expected Total Cost: $1,800,000

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 in order 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. Currently, funded tasks 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. 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 Vision 2030 document released in July 2018 establishing a roadmap for future FCV and hydrogen refueling stations, including barriers that need to be overcome and CARB's Advanced Clean Truck Regulation adopted in June 2020.

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, in an effort 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 for stationary power generation are considered an enabling technology with the potential for costs 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 as a means to produce power and hydrogen from renewable feedstocks (e.g., biomass, digester gas) and store hydrogen in larger scales to support electric systems.

Innovative Refueling Appliances: Home or small scale refueling/recharging is an attractive advancement for alternative clean fuels for some potential applications. This project would evaluate a hydrogen innovative 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.

Projections for on-the-road FCVs counts are now 27,000 in 2023 and 48,900 in 2026 in California and the majority of these do not include medium- and heavy-duty vehicles that may be deployed in the Basin. To provide fuel for these vehicles, the hydrogen fueling infrastructure needs to be significantly increased and become more reliable in terms of availability. 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 any momentum created by the Governor's 2018 Executive Order to establish 200 stations by 2025 and adoption of CARB's Advanced Clean Truck Regulation.

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. 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 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 demonstration of 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 as a way of reducing costs and potentially enhancing 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 recently adopted Advanced Clean Truck and Fleet Regulations in addition to Innovative Clean Transit Bus Regulation as other drivers. Fleets are useful demonstration sites because economies of scale exist in central refueling, in training skilled personnel to operate and maintain the vehicles, in the ability to monitor and collect data on vehicle performance and for manufacturer technical and customer support. In some cases, medium- and heavy-duty FCVs could leverage the growing network of hydrogen stations, providing an early base load of fuel consumption until the number of passenger vehicles 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. More recently, the Clean Fuels Program cost-shared the development of transit buses at OCTA and will cost-share the demonstration of trucks and hydrogen stations to support the Port of Los Angeles project. More projects like these are anticipated as the OEMs come on board.

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. 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 emission 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 to demonstrate improvements to the reliability and durability of the powertrain systems and hydrogen storage system. 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 and higher density and lower cost batteries.

Proposed Project: Demonstrate Light-Duty Fuel Cell Vehicles

Expected South Coast AQMD Cost: $75,000

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 proton exchange membrane (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.

With the implementation of the California ZEV Action Plan, supplemented by the existing and planned hydrogen refueling stations in the Southern California area, light-duty limited-production FCVs are planned for retail deployment in early commercial markets near hydrogen stations by several OEMs. Fleets are useful demonstration sites because economies of scale exist in central refueling, in training skilled personnel to operate and maintain the vehicles, in the ability to monitor and collect data on vehicle performance and for 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 commercialized FCVs in California, and Toyota is redesigning the 2020 Mirai as a five-passenger sedan. The first commercial FCV leases are ending, and solo carpool lane access extends only for MY 2017 and later, encouraging new replacements. 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. 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: $2,750,000

Expected Total Cost: $12,500,000

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 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 cylinder deactivation (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 partially or fully convert engines and vehicles from petroleum fuels to alternative fuels; and
- 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

Anticipated fuels for these projects include but are not limited to alternative fuels (fossil fuel-based and renewable natural gas, propane, hydrogen blends, 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 combustion technologies. Serval key diesel engine development projects that have demonstrated the ability to achieve 0.02 g/bhp-hr NOx under laboratory conditions has reach on-road truck demonstrate stage. The truck integration and packaging is another critical step towards commercialization. The prototype trucks are typically placed in revenue service to collect real-world performance data and well as end user feedback for production engines.

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 are beginning to be introduced. However, vehicle range, lack or limited accessible public infrastructure, lack of experience with alternative fuel engine technologies and limited selection of appropriate alternative fuel engine products as well as high initial cost have made it difficult for more firms to consider significant use of alternative fuel vehicles. For example, in recent years, several large trucking fleets have expressed interest in using alternative fuels. However, at this time the choice of engines over 400 HP or more is limited. 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. Moreover, a developing trend of less incentive funding is occurring as certain alternative fuel engine technologies continue to reach full commercial readiness. Thus, continued development of cost-effective technologies that do not rely on incentives are key to drive additional market penetration and emissions reduction.

The 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. In 2020, CARB and EPA introduced new hybrid powertrain certification test procedures aiming to help hybrid powertrain certify to engine-based emission standards. The new test procedures utilize the equivalent vehicle based test cycles and real-time vehicle simulation to account for the fuel and emission benefits of hybrid vehicles under the traditional engine based test cycles. Cost effective hybrid technologies that offers 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 be achieve the CARB 2024-2026 NOx standard of 0.05 g/bhp-hr while maintain reasonable cost and feasible pathway to 0.02 g/bhp-hr. These low-NOx hybrid powertrains could be another pathway for near term emissions reduction strategy until the full commercialization of zero emission technologies. Furthermore, low-cost mild hybrid system that do not rely on incentive could drive up sales outside of California and gain additional emissions reduction from interstate commerce trucks. Due to limited time to attainment and the fast approach to the CARB 2024 NOx limit, continued development and demonstration efforts are needed in the medium- and heavy-duty sector in order to accelerate the commercialization of next generation hybrid technologies to market.

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, neat 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, clean diesel, modified biodiesel and ultra-low sulfur diesel, and other novel technologies. 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; and
- assessment of other clean technologies.

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 Load and Cold-Start Technologies

Expected South Coast AQMD Cost: $176,300

Expected Total Cost: $1,000,000

Description of Technology and Application:

Cold starts and low loads of internal combustion engines have a negative impact on the environment especially in urban areas like much of the Basin. The thermal efficiency of the internal combustion engine is significantly lower at cold-starts and lower loads. Diesel exhaust aftertreatment systems require a temperature of 250 degrees Celsius or higher to operate at the highest level of emissions reduction efficiency, furthermore diesel engines at cold start increase emissions as much as 10% compared to spark-ignited CNG engines. At low loads, an aftertreatment system often may operate at 150 degrees Celsius. It is also now known that the smaller and poorly integrated hybrid powertrain engines are experiencing similar warm-up issues due to the on-off drive cycles. In fact, the CARB and EPA low-NOx regulation all included a new low-load cycle as well as new in-use low-load operation "bins" that sets emissions limits (different than traditional limits) on low-load operations. The need for thermal efficiency at start- up has led to a variety of suggestions and trials. The primary goal is to reduce energy losses so that systems and components such as the catalytic converter system reach and maintain their intended operating temperature range as soon as possible after engine start. In most cases, adaptation of algorithms associated with fuel injection timing, cylinder deactivation, EGR fraction, turbo control, heated dosing, SCR pre-heaters and close coupled catalysts can be used to keep the catalyst at the correct operating temperature. This project is to investigate technology to improve catalyst temperature at start-up and low loads with minimal economic impact and time. This technology could be applied to a range of vehicles from hybrid-electric light-duty vehicles to heavy-duty trucks. Emphasis should be on steady temperature control at optimal degrees already proven and established through significant research. The following items are the most recently developed best practices with respect to cost and functionality. These engine-based technologies should be integrated closely with aftertreatment technologies to maximize the intended emissions benefit.

- Develop and demonstrate engine-based low-load and cold start technologies such as cylinder activation technology on heavy-duty applications; and
- develop control algorithms to ensure the engine exhaust maintains catalyst temperature throughout the duty cycle.

The project would be implemented, and fleet tested, and recorded over a minimum 12-month period. Further projects can develop from this technology and should be tested in regard to other liquid fuel burning engines.

Potential Air Quality Benefits:

The technology to reduce emissions at cold starts and low loads is beneficial to a broad spectrum of vehicles from hybrid electric, light-duty and heavy-duty engines in drayage long haul trucks. The advancement in this technology will directly contribute toward low NOx required as a result of U.S. EPA and CARB's heavy-duty engine standard and the current attainment policies in effect. Eliminating cold starting engine issues also directly creates a co- benefit of reducing fuel consumption.

Proposed Project: Develop and Demonstrate Low Emissions Locomotive Technologies

Expected South Coast AQMD Cost: $176,300

Expected Total Cost: $1,000,000

Description of Technology and Application:

The objective of this project is to support the development and demonstration of gaseous and liquid fueled locomotive engines. The requirements of locomotive engines as primary generators of electricity to power the locomotive poses serious challenges. 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 do not currently exist to power locomotives. The early stages of development of engines and systems to fill this need is currently on-going. Engines are expected to be below the current 0.2g/bhp-hr low 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 less maintenance costs and better reliability.

Potential Air Quality Benefits:

This project is expected to reduce emissions around 97 tons per year of NOx for each locomotive. The reduction of PM and CO2 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: $2,203,750

Expected Total Cost: $12,500,000

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. In 2018, the U.S. EPA[16] estimated that transportation was responsible for about 28 percent of the nation's carbon emissions, while the electricity sector emissions accounted for 27 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 4.8[17] percent of vehicles in the U.S. and drive 9.4[18] percent of all vehicle miles traveled each year yet are responsible for more than 38[19] 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 development 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 capable of zero emission operation and some leveraging advance concepts such as Geofencing to maximize emissions reduction in certain areas. Vehicle based hybrid system continue to progress for additional emissions reduction and efficiency improvements. Engine powertrain based hybrid system began to emerge since the introduction of the optional hybrid powertrain test procedures, The hybrid powertrain based projects are further described under engine systems.

Vehicle categories to be considered for potential or future demonstration and deployment projects include drayage/freight/regional haul trucks, utility trucks, 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, especially from renewable sources, LPG, hydrogen, GTL and hydrogen-natural gas blends, but conventional fuels such as gasoline, renewable diesel, or even modified biodiesel may be considered if the

[16] https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions
[17] https://www.bts.gov/content/number-us-aircraft-vehicles-vessels-and-other-conveyances
[18] https://www.bts.gov/content/us-vehicle-miles
[19] https://www.bts.gov/content/fuel-consumption-mode-transportation-1

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. Several manufacturers have released battery electric and hybrid equipment, and more are becoming commercially available. 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 and construction equipment);
- 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 broad 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: $220,375

Expected Total Cost: $1,250,000

Description of Technology and Application:

There is a critical need to address gaps in EV charging infrastructure availability. Almost half (47 percent) of the 1,556,058[20] EVs sold in the U.S. since 2010 were in California, and of those sales in California, almost half (44[21] percent) of CVRP rebates issued as of February 2020 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 agreed upon 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 vehicles 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 vehicles has generally been with the CCS1 connector in North America, with Volvo and ABB obtaining UL certification of the CCS2 connector in 2020, which is a connector standard predominantly used in Europe and other parts of the world. 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 vehicles and off-road equipment, charging infrastructure to support these vehicles and equipment, and an ability to fund larger scale deployment projects for medium- and heavy-duty vehicles, equipment, and infrastructure. As the deployment of medium- and heavy-duty vehicles and off-road equipment has increased, there is an increasing reliance on the use of standardized charging connectors and UL or Nationally Recognized Testing Laboratory (NRTL) charging infrastructure, as opposed to proprietary charging infrastructure and connectors which can only be used with vehicles 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 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

[20] Veloz is a non-profit advocacy organization promoting light-duty electric vehicles. https://www.veloz.org/sales-dashboard/
[21] https://cleanvehiclerebate.org/eng/rebate-statistics

EcoDrive 2.0 through the connector vehicle corridor in Carson that was set up as part of the CEC funded Eco FRATIS[22] 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;
- 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 impact 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.

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

Proposed Project: Demonstrate Alternative Energy Storage

Expected South Coast AQMD Cost: $176,300

Expected Total Cost: $1,500,000

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, maintainability and durability), gauge market preparedness, evaluate costs relative to current lithium-ion batteries and provide a pathway to commercialization.

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: $100,000

Expected Total Cost: $100,000

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.

Light-duty BEVs and PHEVs are available from most established OEMs and several new OEMs. Current legislation extends solo carpool lane access only for three years until September 2025.

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: **$**440,750

Expected Total Cost: $2,000,000

Description of Technology and Application:

Natural gas vehicles (NGVs) have been very successful in reducing emissions in the Basin due to the deployment by fleets and owners and operators of heavy-duty vehicles utilizing this clean fuel. Currently, on-road heavy-duty natural gas engines are increasingly being certified to CARB's optional low-NOx standards which are significantly lower in NOx 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.

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 Natural Gas Infrastructure

Expected South Coast AQMD Cost: $440,750

Expected Total Cost: $2,000,000

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: $881,500

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 to further efforts associated with landfill and waste diversion, greenhouse gas reduction, energy diversity and petroleum dependency. Locally produced renewable fuels further reduces 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 that can significantly reduce the price of fuel and hence the cost of operation of clean, alternative fuel vehicles and providing additional incentive for consumers to purchase and deploy clean, alternative renewable fueled 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) from various waste biomass feed stocks including municipal solid wastes, green waste, and biosolids from waste water treatment facilities, from technologies such as 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 provide supply to 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: $1,322,250

Expected Total Cost: $6,000,000

Description of Technology and Application:

CARB has proposed the Advanced Clean Truck Regulation which is part of a holistic approach to accelerate a large-scale transition of zero emission 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 the 2021-2022 timeframe to be introduced in Southern California. Both Daimler and Volvo, which are currently developing battery electric drayage trucks with the South Coast AQMD, are planning commercial products soon. Several fleet operators are planning large deployments of 50 to100 trucks, some at single site locations. Also, CARB is expected to announce in spring 2020 release of a solicitation that seeks projects to deploy 50 or more heavy-duty trucks at a single location. 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 (BET) each carrying 300+ kW hours of battery-stored energy or fuel cell trucks (FCT) 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 sold to the fleet through a power purchase agreement, the financial challenge of a 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 to 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 kW hours, batteries would require 30 MW hours/day of energy and for a 100-vehicle fleet of FCTs, 2000 kgs/day of hydrogen. 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 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 Renewables-Based Energy Generation Alternatives

Expected South Coast AQMD Cost: $264,450

Expected Total Cost: $1,000,000

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-fired pumps. Besides renewable technologies, electrolyzer technology could be used to generate hydrogen, a clean fuel. Hydrogen, when used in regular engines, can potentially reduce tail-pipe emissions, 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 user friendliness 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. To 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.

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: $500000

Expected Total Cost: $850,000

Description of Technology and Application:

Hybrid electric, hybrid hydraulic, plug-in electric hybrid and pure EVs 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 (now propane) technology penetrate the different segments, in-use assessment of real-world benefit is needed.

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. For the upcoming EMFAC 202x, a natural gas engine module is included for the first time with emissions data gathered from the 2017 South Coast AQMD funded in-use emissions characterization effort. The upcoming CARB and EPA low-NOx regulation focused on addressing the gap of in-use and certification values by introducing a new methodology that includes emissions from all operations. While staff do expect the in-use emissions from new engines perform closer to certification values, there are still significant population of the 2010+ legacy fleet expected to remain in service well over 2031. There is always a need to better assess real world truck emissions and fuel economy benefit 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 to 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.

Another proposed project would be the characterization of intermediate volatility organic compound (IVOC) emissions which is critical in assessing ozone and SOA precursor production rates. Diesel vehicle exhaust and unburned diesel fuel are major sources of and contribute to the formation of urban ozone and secondary organic aerosol (SOA), which is an important component of PM2.5.

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 Environmental Impacts

Expected South Coast AQMD Cost: $400,000

Expected Total Cost: $1,500,000

Description of Technology and Application:

The use of 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 in fact 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.

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 has 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 the emissions impact on latest ICE technologies needs to be reassessed. Hydrogen fueled ICE was studied heavily in the early 2000's and results has 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 NOx and low NOx standards. Therefore, emissions impact assessment is much needed on the latest engines.

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: $220,375

Expected Total Cost: $1,000,000

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. 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.

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
- 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 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

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 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.

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, waste haulers and transit buses. 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 and Demonstrate Advanced Aftertreatment Catalyst Heating Technologies

Expected South Coast AQMD Cost: $220,375

Expected Total Cost: $1,000,000

Description of Technology and Application:

The objective of this project is to support the demonstration and integration of aftertreatment systems incorporating technologies such as heated dosing and electrically heated catalysts used for on-road heavy duty vehicles. Current aftertreatment systems are required to maintain an operating temperature of 200 °C or higher for optimal performance. Diesel engines for heavy duty commercial vehicles have been discovered to operate at temperatures below 200 °C during specific parts of the driving cycle, such as low loads and cold starts. Emissions during the low-load and cold starts have been shown to increase up to 30% and PM up to 20%. Previous technologies, such as the mini burner, were successful mitigating the cold catalyst issue. There were draw backs in this technology due to increased CO2 emissions. The mini burner was not favorable as a successful approach because it increased fuel consumption. New aftertreatment technologies, coupled with advanced engine and hybrid technologies, have shown potential to reduce emissions up to 99% without a fuel penalty. Technologies such as:

- Close-coupled catalysts
- Dual-heated diesel-exhaust fluid dosing
- Electronically heated catalysts

Current aftertreatment design incorporates a close-coupled catalyst, Diesel particulate filter, dual SCR, and an ammonia–slip catalyst. Included in this design is a required heat source at low loads, cold starts and motoring conditions. The use of an electric heat source has become feasible due to advancements in electrical-powered applications and integration with the vehicle. These heating technologies has been demonstrated under lab based testing but issues reside with further commercialization effort as the new CARB and EPA regulation significantly lengthening the warranty and durability requirements which could increase the cost and ultimate limit adoption of new and unproven technologies. Thus, large scale, OEM and supplier sponsored demonstration effort is needed to move these technologies forward.

Potential Air Quality Benefits:

This project is expected to contribute to the total emission reductions in heavy-duty on road engines. Emission reductions of 80-90% in heavy-duty diesel long-haul trucks has already been proven when an advanced aftertreatment system, incorporating an additional heat source, along with advanced engine technology such as cylinder deactivation is used. The fuel savings benefit is especially attractive to long-haul fleet operations. In order to meet the ultra-low NOx air quality standards and promote a national low NOx standard for heavy-duty diesel engines, an advanced aftertreatment system incorporating heated catalyst technology is required.

Proposed Project: Develop Methodology and Evaluate Onboard Emission 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. In order 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 are 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.

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 require a repower (engine exchange) to only meet the same emissions standards as the engine being retired. Unfortunately, this does not take advantage of recently developed clean technologies.

Exhaust gas cleanup strategies, such as SCR, 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 in off-road applications including yard hostlers, switcher locomotives, gantry cranes, waste haulers and construction equipment;
- implementing lower emission engines in repower applications for both on-road and off-road applications; and
- applying stationary best available control technologies, such as SCR, scrubbers, 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.

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 Toxic Air Contaminants

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 and modeling to characterize risks, including measurements and analysis of UPM concentrations typically emitted or converted from vehicle exhaust. In addition, staff are also performing additional advanced monitoring activities as an extension of 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: $352,600

Expected Total Cost: $800,000

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: $264,450

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 the 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 1,500 rebates, totaling $416,087. 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 diesel 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
Vacant	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 19, 2021

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
Kevin Walkowicz	National Renewable Energy Laboratory
*Dwight Robinson	Mortimer & Wallace, Inc.

*Newly appointed member

[2] Members as of February 19, 2021

Appendix B

Open Clean Fuels Contracts as of January 1, 2021

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Contract	Contractor	Project Title	Start Term	End Term	South Coast AQMD $	Project Total $
Hydrogen and Mobile Fuel Cell Technologies and Infrastructure						
15366	Engineering, Procurement & Construction, LLC.	Operate and Maitain Publicly Accessible Hydrogen Fueling Station at SCAQMD's Diamond Bar HQs	10/10/14	04/09/21	0	0
15611	Ontario CNG Station, Inc.	Installation of Ontario Renewable Hydrogen Fueling Station	07/10/15	07/09/21	200,000	2,510,000
15618	FirstElement, Inc.	Installation of Eight Hydrogen Stations in Various Cities	02/05/16	02/04/21	1,000,000	16,442,000
16251	H2 Frontier Inc.	Develop & Demonstrate Commercial Mobile Hydrogen Fueler	05/06/16	05/05/21	200,000	1,665,654
17059	CALSTART Inc	Develop and Demonstrate Fuel Cell Extended Range Powertrain for Parcel Delivery Trucks	10/27/16	02/28/21	589,750	1,574,250
17312	Hydrogenics USA, Inc.	ZECT II - Develop Fuel Cell Range-Extended Drayage Truck	11/20/17	05/19/21	1,109,279	2,433,553
17317	American Honda Motor Company, Inc.	Three Year Lease of One Honda 2017 Clarity Fuel Cell Vehicle	03/22/17	03/22/21	22,120	22,120
17343	American Honda Motor Company, Inc.	Three Year Lease of One Honda 2017 Clarity Fuel Cell Vehicle	02/21/17	02/21/21	22,188	22,188
17385	American Honda Motor Company, Inc.	Three Year Lease of One Honda 2017 Clarity Fuel Cell Vehicle	05/17/17	05/17/21	22,285	22,285
18150	California Dept of Food and Agriculture, Division of Measurement Standards	Conduct Hydrogen Station Site Evaluations for Hydrogen Station Equipment Performance	06/28/18	02/27/21	100,000	805,000
18158	National Renewable Energy Laboratory	California Hydrogen Infrastructure Research Consortium H2 @ Scale Initiative	08/01/18	03/30/21	100,000	760,000
19172	Longo Toyota	Three Year Lease of Two 2018 Toyota Mirai Fuel Cell Vehicles	10/28/18	10/27/21	35,108	35,108
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
20038	University of California, Irvine	Expansion of the UCI Hydrogen Refueling Station	10/18/19	02/17/27	400,000	1,800,000
20108	University of California, Irvine	Develop Optimal Operation Model for Renewable Electrolytic Fuel Production	06/17/20	06/16/21	100,000	500,000
Engine Systems and Technologies						
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

Contract	Contractor	Project Title	Start Term	End Term	South Coast AQMD $	Project Total $
Engine Systems and Technologies (cont'd)						
20122	Landi Renzo USA Corporation	Develop and Commercialize a Near-Zero Natural Gas Conversion System for On-Road Medium-Duty Vehicles	01/17/20	07/31/21	300,000	1,455,072
20316	US Hybrid	Natural Gas Engine & Vehicles Research & Development - Plug-In Hybrid CNG Drayage Truck	06/02/20	12/01/23	500,000	2,853,006
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
Electric/Hybrid Technologies and Infrastructure						
14184	Green Paradigm Consulting, 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
17065	Green Paradigm Consulting, Inc.	EV Infrastructure Installer	12/02/16	12/31/21	805,219	805,219
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	12/31/21	2,341,184	9,811,447
17244	Kenworth Truck Company	Development & Demonstration of four Class 8 CNG Hybrid Electric Drayage Trucks	09/08/17	04/14/21	2,239,106	6,492,238
17316	Center for Transportation and the Environment	Develop and Demonstrate 10 Zero-Emission Fuel Cell Electric Buses	06/09/17	03/31/21	1,000,000	45,157,859
18075	Selman Chevrolet Company	Lease Two 2017 Chevrolet Bolt All-Electric Vehicles for Three Years	08/18/17	02/18/21	30,892	30,892
18129	Electric Power Research Institute	Versatile Plug-In Auxilary Power System Demonstration	06/28/18	10/31/21	125,000	273,000
18151	Rail Propulsion System	Develop & Demonstrate Battery Electric Switcher Locomotive	04/05/18	12/30/21	0	925,000
18232	Hyster-Yale Group Inc	Electric Top-Pick Development, Integration & Demonstration	09/14/18	09/13/21	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
18280	Honda of Pasadena	Three-Year Lease of One Honda 2018 Clarity Plug-In Vehicle	02/07/18	06/26/21	18,359	18,359
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

Contract	Contractor	Project Title	Start Term	End Term	South Coast AQMD $	Project Total $
Electric/Hybrid Technologies and Infrastructure (cont'd)						
18397	Port of Long Beach	Demonstrate Zero Emission Cargo Handling Vehicle at POLB	01/04/19	05/31/21	350,000	8,668,410
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	Disburse Donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	01/10/19	01/10/22	0	0
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
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	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	06/30/21	4,000,000	91,246,900
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-Benz 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

Contract	Contractor	Project Title	Start Term	End Term	South Coast AQMD $	Project Total $
Electric/Hybrid Technologies and Infrastructure (cont'd)						
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
19290	University of California, Riverside	Perform Data Collection, Analysis, and Reporting for CARB's ZANZEFF Project	02/15/19	06/30/21	836,258	836,258
19295	Ivan Garcia	Disburse donated Mercedes-Benz USA, LLC. Electric Vehicle Chargers	04/11/19	04/10/22	0	0
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	02/28/21	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
20248	Los Angeles County Economic Development Corp	Economic and Workforce Impact Analysis of Electric Revolution in Southern California	07/07/20	01/02/21	10,000	150,000
Fueling Infrastructure and Deployment (NG/RNG)						
17092	Kore Infrastructure LLC	RNG Production & Vehicle Demonstration	10/14/16	10/13/21	2,500,000	25,500,000
18336	Abc Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/05/18	11/30/34	117,900	676,500
18337	Alta Loma School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/05/18	11/30/34	78,600	423,000
18344	Bellflower Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	09/07/18	11/30/34	39,300	225,500
18346	Chaffey Joint Union High School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/05/18	11/30/34	235,800	1,269,000
18348	Cypress School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	09/07/18	11/30/34	39,300	211,500
18349	Downey Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	09/14/18	11/30/36	157,200	902,000
18350	Fountain Valley School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	09/07/18	11/30/34	39,300	211,500

Contract	Contractor	Project Title	Start Term	End Term	South Coast AQMD $	Project Total $
Fueling Infrastructure and Deployment (NG/RNG) (cont'd)						
18351	Fullerton Joint Union High School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/05/18	11/30/34	157,200	846,000
18355	Huntington Beach Union High School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/05/18	11/30/34	589,500	3,382,500
18363	Orange Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	09/14/18	11/30/34	39,300	225,500
18364	Placentia-Yorba Linda Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/05/18	11/30/34	235,800	1,353,000
18365	Pupil Transportation Cooperative	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/05/18	11/30/34	196,500	1,127,500
18367	Rialto Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/05/18	11/30/34	510,900	2,931,500
18368	Rim Of The World Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/05/18	11/30/34	513,600	676,500
18369	Rowland Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	11/02/18	11/30/34	117,900	770,000
18374	Upland Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/12/18	11/30/34	157,200	902,000
20178	Whittier Union High School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	02/21/20	11/30/34	196,500	1,052,500
Fuel/Emissions Studies						
17276	University of California, Riverside	Development of ECO-ITS Strategies for Cargo Containers	08/03/17	01/31/21	543,000	2,190,233
17352	California State University, Maritime Academy	Develop and Demonstrate Vessel Performance Management Software and Equipment	06/09/17	06/08/21	50,086	195,915
18090	University of California, Riverside	Study Secondary Organic Aerosol Formation from Heavy-Duty Diesel and Natural Gas Vehicles	12/05/17	02/28/21	85,000	85,000
19208	University of California, Riverside	Conduct Emission Study on Use of Alternative Diesel Blends in Off-Road Heavy Duty Engines	06/21/19	07/31/21	261,000	1,353,499
20058	University of California, Riverside	Evaluate Meteorological Factors and Trends Contributing to Recent Poor Air Quality in Basin	08/23/19	02/23/21	188,798	188,798
Technology Assessment 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

Contract	Contractor	Project Title	Start Term	End Term	South Coast AQMD $	Project Total $
Technology Assessment and Transfer/Outreach (cont'd)						
12376	University of California, Riverside	Technical Assistance with Alternative Fuels, Biofuels, Emissions Testing, and Zero-Emission Transportation Technology	06/01/14	05/31/22	225,000	225,000
16262	University of California, Davis-Institute of Transportation Studies	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	06/30/21	200,000	200,000
17358	AEE Solutions, LLC	Technical Assistance with Heavy-Duty Vehicle Emissions Testing, Analyses & Engine Development	06/09/17	05/31/21	200,000	200,000
19078	Green Paradigm Consulting, Inc.	Technical Assistance with Alternative Fuels, Evs, Charging & Infrastructure and Renewable Energy	09/07/18	09/30/22	200,000	540,300
19227	Gladstein, Neandross & Associates, LLC	Technical Assistance with Alternative Fuels & Fueling Infrastructure, Emissions Analysis & On-Road Sources	02/01/19	01/31/21	200,000	200,000
19302	Hydrogen Ventures	Technical Assistance with Hydrogen Infrastructure and Related Projects	04/24/19	04/23/21	50,000	50,000
20085	CALSTART, Inc	Technical Assistance for Development & Demonstration of Infrastructure and Mobile Source Applications	11/08/19	11/07/21	150,000	150,000
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
20348	Gladstein, Neandross & Associates, LLC	Cosponsor the 2021 Renewable Gas 360 Symposium and Webinar Series	07/21/20	03/31/21	35,000	150,000
21078	Charging Interface Initiative (CharIn) e.V.	Cosponsor High Power Charging for Commercial Vehicles Event	09/16/20	01/31/21	12,500	240,000

Appendix C

Final Reports for 2020

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South Coast AQMD Contract #15609 **January 2020**

Installation of Riverside Renewable Hydrogen Fueling Station

Contractor
ITM Power Inc.

Cosponsors
California Energy Commission (CEC)
South Coast AQMD

Project Officers
Patricia Kwon,
Lisa Mirisola

Background
This project saw a hydrogen refueling station installed in Riverside, CA. The hydrogen is produced in part by an on-site electrolyzer using renewable electricity to produce zero carbon fuel. This station will offset up to 250 gallons per day of gasoline therefore improving air quality and reducing greenhouse gasses (GHGs) in California.

Project Objective
The project objective was to build and install a publicly accessible hydrogen fueling station in Riverside, CA. A total of 33% of the maximum capacity of the station will be generated on site via renewable electrolysis. The station will be capable of delivering up to 100kg per day with a 35kg per hour peak fueling capacity. The dispenser will be compliant with California Division of Measurement Standards (DMS) requirements to sell hydrogen on a per kg basis. The station will also provide fill data collection in the National Renewable Energy Laboratory (NREL) template as approved by the California Energy Commission (CEC).

Technology Description
The station uses an on-site electrolyser to split water using renewable electricity therefore producing zero carbon fuel for use in hydrogen fuel cell vehicles. The hydrogen is compressed and stored in high pressure tubes and dispensed to vehicles in both 350 and 700 Bar pressures.

This station produces 33% of its capacity using electrolysis and 67% of the gas is provided by delivered tube trailer. This allows the site to be expanded easily in the future and allows up to 33kg of hydrogen per day to be generated from renewable sources.

Status
The project is currently deemed open to the public which means that the following milestones have been reached:

1. Installation of all station equipment and sign off by equipment provider
2. Installation of all security fences, bollards & signage to allow for unattended operation
3. Energize all equipment and run the system to enable the storage tanks to be filled with hydrogen
4. Carry out initial inspection by local fire and electrical officials
5. Carry out test fills from the vehicle dispenser to confirm fuel protocol compliance
6. Carry out a fuel gas sample to confirm compliance with fuel quality standards
7. Open to public and dispense fuel

Figure 1: Installed Dispenser at Site

Results
The station has been installed and commissioned and has been operational for 3+

years.

The station hydrogen has been sampled and analyzed multiple times in accordance with Society of Automotive Engineers J2719 and found to be within tolerance.

To date the station has dispensed over 34,800kg of fuel

Benefits

This station has the capacity to displace 250 gallons of gasoline per day.

This is the only hydrogen station in the Inland Empire and provides a basis for vehicle original equipment manufacturers (OEMs) to deploy hydrogen cars in the region. It also provides a refueling stop for customers wishing to travel as far as Palm Springs, Joshua Tree and beyond.

Project Costs

The CEC project costs met the original budget parameters of $2,125.000. Below is the final cost breakdown.

Project Funding:

California Energy Commission	$2,125,000
South Coast AQMD	$200,000
Match Funding	$409,184
Total	$2,734,184

Commercialization and Applications

The technology utilized in this project relied entirely on vehicle deployment. Vehicle OEMs have begun deployment of fuel cell vehicles in the local area and ITM Power, Inc. has already contacted several early adopters for the technology. ITM Power, Inc. has also begun to reach out to local fleet operators to try to increase fuel at the site and boost the commercialization of this station.

The site would benefit from the creation of a large expansion space to accommodate a larger electrolyser. It would also benefit from the installation of rooftop PV to generate electricity on the site.

Figure 2: Fuel Site Entrance Sign

South Coast AQMD Contract #15619 **December 2020**

Installation of Chino Renewable Hydrogen Station

Contractor

H2 Frontier Inc
PowerTech Labs
ITM Power

Cosponsors

California Energy Commission (CEC)
South Coast AQMD
Hyundai R&D

Project Officer

Lisa Mirisola

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 the transition of the mobile transportation sector which will help promote zero emission technologies. These new technologies are necessary to attain the federal criteria pollutant standards as well as the state greenhouse gas targets. As part of this transition, hydrogen refueling facilities for these vehicles must be expanded to satisfy the impending vehicle roll-out by the automakers.

Project Objective

The goal of this project was to establish a hydrogen station having both 350 Bar and 700 Bar dispensing capabilities utilizing a renewable source of fuel, with the flexibility to meet the anticipated demand of the future. To achieve this goal, it would be necessary to deploy a station in a high value area while creating a cost-effective design. The station would need to use a 100% renewable source of hydrogen fuel and provide the ability to sell hydrogen thru a Point-of-Sale terminal at the dispenser location while providing a system design that would be easily upgradable to meet future demand.

Technology Description

It was determined that the 100% renewable energy credits will be purchased over a three-year period to provide the electricity to generate hydrogen by electrolysis. While this is not groundbreaking technology, the high discharge pressure is. The electrolyser provider, ITM Power, promised to deliver an 80 Bar discharge pressure system from the four Proton Exchange Membrane (PEM) stack. This higher pressure is well above the industry standard of 30 Bar. This improvement in pressure allows the station design to use one less compressor to reach 950 Bar storage pressure. Less compressors mean a smaller equipment footprint and less maintenance/operational costs. This helps reduce overall capital costs. These costs are currently extremely high and are a hindrance in propelling this technology to the mainstream public.

Due to the nature of electrolysis and its high demand for reverse osmosis in the form of deionized water (where two-thirds of the flow stream is rejected and not used), a 600-gallon subterranean water tank was installed, with a pump to collect and use this water for both street sweepers and irrigation at the facility.

Compression, storage and dispensing (CSD) equipment was provided by PowerTech Labs. The equipment consisted of a 26’ container housing a Hydropac compressor, a control/data room and a chiller for the compressor. Hydrogen is stored in one large buffer tank between the electrolyser and compressor, consisting of six 950 Bar Fiba brand high-pressure tubes. Overall storage of less than 100 kilograms was required by the local fire department. Since the electrolyser is an on-demand generator, the smaller storage system helps reduce cost and footprint. The dispenser has both 350 and 700 Bar nozzles at -40C, dispensing to light duty and forklift fuel cell vehicles using the latest Society of Automotive Engineers (SAE) J 2601 standard. This system design can produce 100 kg/day with 35 kgs peak per hour reliably.

Status

Compression, storage and dispensing equipment has been purchased, installed and commissioned to SAE J2601 and SAE 2719 standards. The dispensing system has provided many successful fills for Hyundai’s VIP dignitaries on multiple

occasions. This has been achieved using hydrogen (H2) tube trailer delivery.

The fire department's final permit has been signed off on as has the electrical permit. The final building permit is waiting for the remainder of generation equipment.

A specification of 80 Bar discharge pressure was originally offered by ITM Power but has not been delivered. Powertech engineered their equipment (CSD) to meet the 35kg/hr requirement based on the 80 Bar discharge pressure. It allowed us to have one less compressor. Without this higher 80 Bar discharge pressure, the station design cannot meet the 35 kilograms back to back dispensing requirement. The original design pressure of 80 Bar was reduced to 50 Bar due to the inability of ITM to meet certain standards. Currently the ITM website shows only 20 Bar for their PEM stacks so this modified offer of 50 Bar is still questionable.

A revised Factory Acceptance Test with 10 hot starts (already at temp and pressure) and 10 cold starts (ambient temp and pressure) with 2 weeks continuous runtime data would be sufficient to accept a lower performance stack, but tests yielded only 2 cold starts, plenty of warm starts and only 8 continuous hours of runtime data.

There was enough money remaining in the budget to purchase a 30 Bar electrolyser and install it before contract expiration date. A letter requesting this change was sent to the CEC, but CEC immediately issued a stop work order. Any change of electrolysis vendors would require us to complete the project with private investment.

All ownership and assets of the Chino station returned to the CEC who reduced the performance criteria from 35 kgs peak to just 20 kgs peak and awarded the station to ITM. It has been almost a year since then and no visible progress has been seen onsite.

Benefits

In addition to criteria emission reductions, this project represents an investment in clean economical FCEV transportation to help meet California's climate goals. The project was designed to reduce emissions of greenhouse gasses (GHG) by lowering the carbon content of transportation fuels in California. The hydrogen fuel cell environmental footprint is much smaller than the gasoline baseline and achieves 100% GHG emission reduction using renewable electricity and on-site electrolysis. The on-site system removes the requirement for a diesel vehicle to deliver hydrogen, which means that this system is essentially zero carbon. In summary a 100 kg per day station that is operating at full usage could be expected to offset 200 gallons of petrol per day and therefore 24,000MJ of energy and 2,300 kg's of C02 per day. At 100% capacity it is estimated that the annual savings would be 839.5 metric tons of C02.

Project Costs

This project was not completed within the proposed budget. There were many delays and cost overruns. On November 19, 2012, the CEC released a competitive Grant Solicitation PON-12-606 entitled "Hydrogen Fuel Infrastructure" under the Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP).

Organization	Funding
CEC	$3,000,000
South Coast AQMD	$ 200,000
H2Frontier, PowerTech and ITM Power	$1,414,384
Total	$4,614,384

Commercialization and Applications

This project would not have been profitable, assuming Renewable Energy Credits (REC's) at $0.18 per KW and 65 Kw per kilogram results in $11.70 per kg just for hydrogen generation. The cost of electricity to operate adds another $0.25 per kg for compression cooling and dispensing. This cost estimate would be $4.50 + $11.70=$16.20 cost per kg. Not including cost of water, the retail sale of hydrogen would have to be above $18 just to break even without counting maintenance costs. A 100% renewable station perhaps was a little early in the commercialization of retail hydrogen. Without profit margins, this industry will not attract private investors and will remain dependent on funding to advance this technology.

South Coast AQMD Contract # 19191 **June 2020**

Development of Solid Oxide Fuel Cell and Gas Turbine (SOFC-GT) Hybrid Technology

Contractor

University of California, Irvine

Cosponsors

UC Irvine Advanced Power and Energy Program
U.S. Department of Energy (DOE)

Project Officer

Seungbum Ha

Background

Improving air quality in urban areas requires the reduction of criteria pollutant emissions across several sectors. The power sector for both stationary and mobile applications is of particular interest, in part due to the local emissions in disadvantaged and rural communities and its significant contribution to criteria pollutant and greenhouse gas emission compared to other sectors. To meet state energy and environmental goals, interest is growing in fuel cell – gas turbine (FC-GT) hybrid technology as a continuous power generation technology given the unique combination of ultra-high efficiency, ultra-low criteria pollutant emissions, and ability to operate on zero-carbon renewable hydrogen (H_2).

In this project, the optimization of 10 MW class SOFC-GT hybrid power plant technology is addressed for both stationary power generation in the South Coast Air Basin for operating on natural gas (NG), biogas (BG) and renewable H_2 sourced from excess solar and wind. In addition, the optimization of two cases for a 50 MW hybrid power generation plant is addressed, one with carbon capture (CCS) and one without. Finally, both a 3.5 MW SOFC-GT hybrid long-haul locomotive and a tugboat are evaluated as candidates for land-based and marine-based mobile applications respectively, both fueled by liquefied natural gas (LNG) and utilizing the LNG as a low temperature heat sink to increase the overall system efficiency. The Total Plant Cost (TPC) and the Cost of Electricity (COE) are provided for the stationary applications.

Project Objective

The goals of the project were to develop overall system FC/GT simulations and optimize both stationary and mobile applications as a technology candidate to replace existing sources of major NOx and particulate emissions today in the South Coast Air Basin, and to provide techno-economic analyses for the stationary applications to assess feasibility. The project objectives were to:

1) Develop integration models to fully realize the potential of hybrid SOFC-GT systems for disturbed power in the 10 to 50 MW range fueled by NG, BG, and renewable H_2,
2) Develop integration models to fully realize the potential of hybrid SOFC-GT systems in the 3.5 MW range fueled by LNG for mobile applications including long-haul locomotives and tugboats.
3) Conduct a techno-economic analysis for the stationary applications.

Technology Description

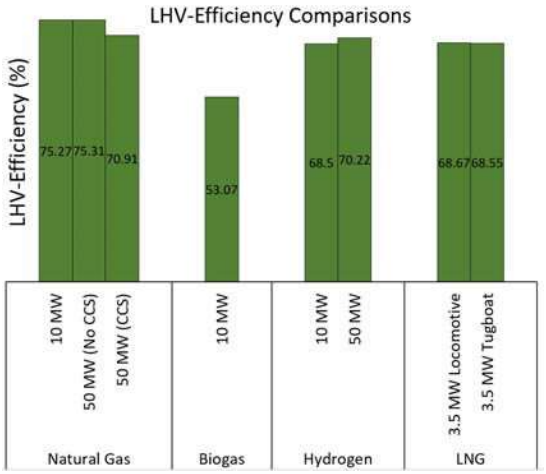
The approach was to first develop 10 MW SOFC-GT hybrid system configurations for a distributed power plant appropriate for wide scale deployment in the South Coast Air Basin that can be operated on NG and BG with the potential to operate on renewable H2. Second, a 50 MW SOFC-GT was selected as a candidate for a large power generation resource in the Basin including service as a Transmission Integrated Grid Energy Resource (TIGER) station operating on NG and renewable H2. Finally, for two major mobile applications, a 3.5 MW LNG-fueled was analyzed for long-haul locomotive and marine-based tugboat applications, the latter of which with a specialized GT air filter to remove the salt content from the ambient air and thereby mitigate compressor blade corrosion.

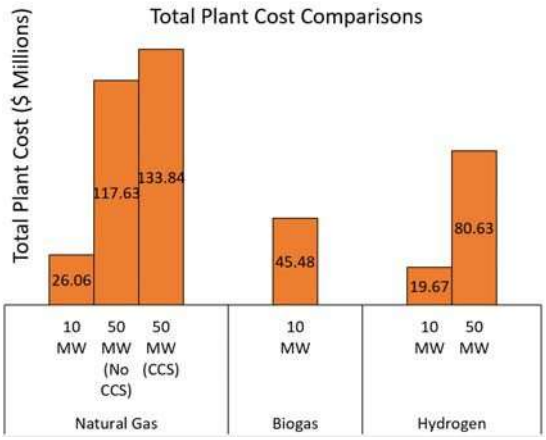
The project leveraged a five-year U.S. Department of Energy (DOE) U.S./China "Clean Energy Research Center (CERC)" water-energy nexus initiative wherein APEP conducted a study with the Chinese Academy of Sciences (CAS) on water efficient 100 MW class SOFC-GT integrated gasification fuel cell (IGFC) systems operating on pulverized coal.

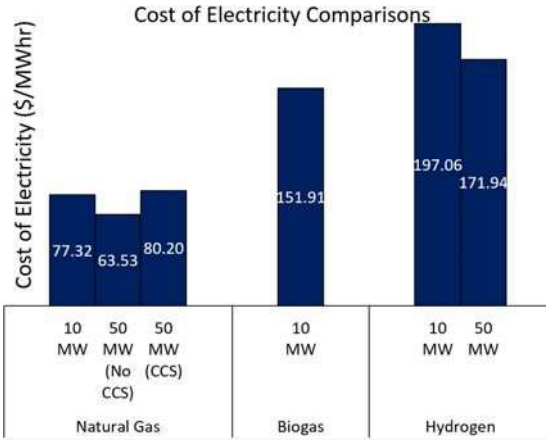
Results

For the 10 MW stationary hybrids, the NG-fueled case resulted in the highest efficiency at 75.27%

(LHV) followed by the H2-fueled case at 68.50%







and the BG-fueled case at 53.07%. At the 50 MW scale, the NG-fueled case without CCS efficiency is 75.31% and with CCS is 70.91% followed by the H2-fueled at 70.22%. The TPC for the 10 MW NG-fueled hybrid is $26,063,604 with a COE at $77.32/MWhr, BG-fueled is $45,483,880 with a COE at $151.91/MWhr, and H2-fueled is $19,671,000 with COE at $197.06/MWhr. When moving to the 50 MW scale, the TPC for the NG-fueled hybrid without CCS and with CCS is $117,628,563 with COE at $63.53/MWhr and $133,835,172 with COE at $80.20/MWhr, respectively. The TPC for the 50 MW H2-fueled hybrid is $80,626,000 with COE at $171.94. For the mobile applications, the 3.5 MW long-haul locomotive has an average LHV-efficiency at 68.67% and, for the tugboat, 68.55%.

Commercialization and Applications

The project proved the feasibility and efficacy of SOFC-GT hybrid technology for both stationary and mobile applications with the following salient conclusions:

- **The results reveal promise for economically viable implementation.** The ultra-high efficiencies and reasonable COE of stationary hybrids portend a promising future market.
- **Stationary applications are more ready for commercialization than mobile**. The stationary application for distributed power generation has a less demanding duty cycle than the application for mobile applications.
- **Operating SOFC-GT hybrids with anode recirculation.** Among anode, cathode, and no recirculation, anode recirculation yields the highest power output/electrical efficiency.
- **The utilization of LNG in mobile applications is beneficial**. LNG provides a higher stored power and energy density, and a higher efficiency given its cryogenic nature as a heat sink.
- **A reduction in renewable H_2 cost is required to enable H_2 as a fuel for distributed generation.** While the TPC for a renewable H_2-fueled SOFC/GT is the lowest at both scales, **t**he current cost of renewable H_2 (due to the price of electricity to power electrolyzers from solar and wind) results in the most expensive COE among the three fuels.

Project Cost

The cost of the one-year project was $900,000, comprised of $200,000 in support from the South Coast AQMD and $700,000 of match funding from the DOE CERC initiative that included cost share from Southern California Edison and Southern California Gas and collaboration with CAS and the Chinese Ministry of Science and Technology.

South Coast AQMD Contract # 17393 **May 2020**

Development of an Ultra-Low Emission Diesel Engine for On-Road Heavy-Duty Vehicles

Contractor

Southwest Research Institute

Cosponsors

South Coast AQMD
U.S. Environmental Protection Agency (EPA)
California Air Resources Board (CARB)
Manufacturers of Emissions Controls (MECA)

Project Officer

Joseph Lopat

Background

The original Stage 1 CARB Low NOx Demonstration Program provided an initial demonstration of the feasibility of technologies for achieving a target tailpipe NOx level of 0.02 g/hp-hr on both a diesel and natural gas engine platform. The diesel demonstration platform was a 2014 Volvo MD13TC EU6 engine, and that program, along with the supplemental Stage 1b durability program funded by South Coast AQMD, demonstrated the feasibility and durability of a system which reached NOx levels near the 0.02 g/hp-hr level. However, due to the low exhaust temperatures of the MD3TC engine created by a turbo-compound for waste heat recovery, there was a significant fuel consumption penalty. CARB later expanded this original demonstration with the Stage 2 program, which focused on Low Load operations typical of urban and vocational applications.

As a follow-up to these earlier programs, CARB and South Coast AQMD launched a second diesel demonstration program, the Stage 3 Low NOx Demonstration Program. The Stage 3 program focused on answering two major questions:

1. Could Low NOx levels be achieved at a smaller fuel consumption penalty?
2. Could a different and more efficient system be designed to target 0.02 NOx levels.

During the Stage 3 program, an additional effort was launched. Designated Stage 3b, it will continue an on-going effort examining the use of additional engine technologies to further improve fuel consumption and green house gas (GHG) emissions while maintaining Low NOx levels. The Low Load Cycle (LLC) target would be developed based off examining the balance of NOx and GHG emissions.

The portion of the program funded by South Coast AQMD and their funding partner, The Port of Los Angeles, involved the development of the modified engine calibrations, the screening and selection of aftertreatment hardware options, and the final development of the down-selected technology package for the engine-aftertreatment system.

Status

The South Coast AQMD Stage 3 development effort was completed January 2020. Futher stages involving improvements in technologies to lower NOx, including testing renewable diesel, will be ongoing. CARB Stage 3b is currently in progress and is expected to be completed in July 2021.The final report for Stage 3b will be submitted at that time.

Results

The first task in the South Coast AQMD program was the development of a modified engine calibration that would enable an advanced aftertreatment system to reach Low NO_X levels. This modified calibration was later supplemented by the Stage 3b engine hardware work, which resulted in a modified engine calibration that incorporated cylinder deactivation (CDA) as a level to improve fuel efficiency and maintain aftertreatment system temperatures. The final engine calibration shows the impact of the modifications on the early part of the cold-start Federal Test Procedure (FTP) cycle. The engine modifications resulted in a significant increase in

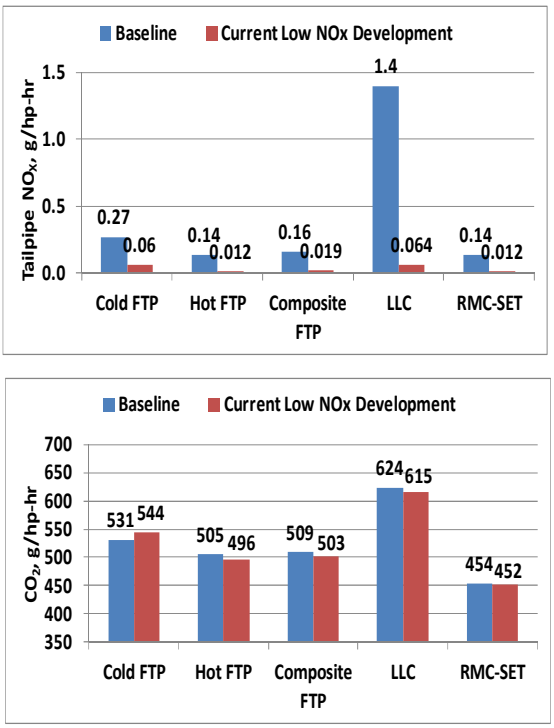


Figure 1: Performance Levels Demonstrated at the End of South Coast AQMD Funded Development on Hydrothermally Aged FUL parts (435,000 miles equivalent)

exhaust temperatures while also controlling engine-out NO_X during the aftertreatment warm-up period. Leveraging CDA allowed this to be done with only a small impact on cold-start GHG, while hot-start GHG levels showed a benefit compared to baseline. Following an extensive evaluation of candidate aftertreatment technologies and configurations, a final configuration was chosen, which is shown in Figure . This configuration employed both a close-couple light-off Selective Catalytic Redution (LO-SCR) and a downstream system and featured dual Diesel Exhaust Fluid (DEF) dosers, including a heated upstream dosing unit. An advanced controls system was implemented on the engine including state-of-the-art model-based dosing controls, and an integrated state-based strategy controller with multiple thermal management modes. The final system was calibrated to minimize NO_X emissions, while at the same time maximizing efficiency and controlling GHG emissions. The final calibration was demonstrated on a system that was hydrothermally aged to represent a full useful life of 435,000 miles. The resulting performance levels are shown in Figure . The system was able to reach tailpipe NO_X levels below 0.02 g/hp-hr on the FTP and Ramped Modal Cycle Supplemental Emissions Test (RMC-SET), and at 0.06 g/hp-hr for the LLC. At the same CO_2 levels of the FTP and LLC were better than the baseline engine by 1 to 1.5%, while the Low NO_X configuration was fuel consumption neutral on the RMC-SET compared to the baseline.

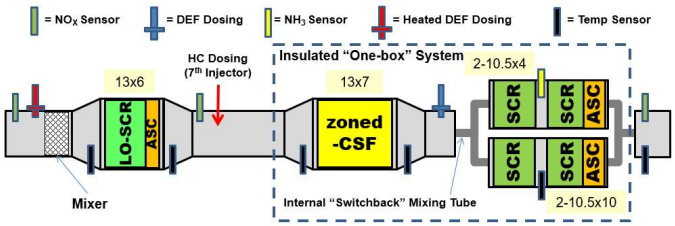


Figure 2: Final Stage 3 Aftertreatment Configuration Down-selected from Evaluation

Project Costs

The funding for Stage 3 is shown in Table 1.

CARB	$750,000
South Coast AQMD	$287,500
Port of Los Angeles	$287,500
Total stage 3	$1,325,000

Table 1: Funding for Stage 3

An additional $1,375,000 was provided in Stage 3b by EPA, MECA, and the SwRI-run CHEDE-VII industry consortium. In total, considering both Stage 3 and the Stage 3b supplement, the overall program has been funded to nearly $2,700,000.

Commercialization and Applications

The Stage 3 program is a critical data point supporting the development of new Low NO_X regulations for both CARB and EPA. Data from this program will support both the ARB Omnibus Low NO_X Rule and the EPA Cleaner Trucks Initiative NPRM.

The Low NOX configuration developed in this program has been tested over current regulatory cycles, the new LowLoad Cycle, and field cycles. The system has shown the potential for NO_X emission control under a wide variety of application cycles, while maintaining GHG emissions, and in some cases showing improvements.

Several technology elements of the engine and aftertreatment system are likely to be incorporated in future on-highway engines to meet Low NO_X standards.

South Coast AQMD Contract #18211 **June 2020**

DEVELOP THERMAL MANAGEMENT STRATEGY USING CYLINDER DEACTIVATION FOR HEAVY-DUTY DIESEL ENGINES

Contractor

West Virginia University Innovation Corporation (WVUIC)

Co-Sponsors

Environmental Canada, US EPA, Jacobs Vehicle Systems (JVS), Cummins Inc.

Project Officer

Joseph Lopat

Background

Cylinder deactivation (CDA) was shown to reduce pumping losses in spark ignited engines. The concept of CDA has recently gained interest in the heavy-duty diesel (HDD) engine segment as a pathway to a fuel-efficient thermal management strategy and, in some cases, for improvements to brake thermal efficiency (BTE). Certain vocational duty cycles that are characterized by frequent stop-and-go (urban delivery, refuse truck, port drayage) and extended idle and creep mode operations (port drayage vehicles), are plagued by higher NOx emissions due to increased cooling of the exhaust aftertreatment system. Operations are typically below the 30% power curve of the engine and account for a major fraction of the engine operation in regions characterized by high vehicle traffic density.

Project Objective

The thermal management strategies currently employed are associated with a fuel penalty. It is imperative, therefore, to adopt a strategy that results in a minimal to no fuel penalty. Recent studies have shown that a CDA approach in a heavy-duty 6-cylinder engine can result in close to a 63ºC increase in post turbine exhaust gas temperature with no change in brake-specific fuel consumption (BSFC), while a 13ºC increase in post turbine exhaust gas temperature can be realized with a 25% reduction in BSFC.

Technology Description

West Virginia University, Center for Alternative Fuels, Engine and Emissions (WVU-CAFEE), JVS and Cummins Inc. propose this collaborative effort that will integrate cost-effective cylinder deactivation hardware, developed by JVS, in a 15 L Cummins ISX HDD engine platform with suitable engine controls and calibration for improving BTE and selective catalytic reduction (SCR) thermal management at engine loads below 30%. The proposed JVS cylinder deactivation technology has been developed as a cost-effective integration into current technology HDD engines. JVS has demonstrated the ability to deactivate independently all six cylinders at any given point of time. However, a complete system integration, which addresses noise vibration and harshness (NVH) issues, seamless transition of CDA to baseline and calibration of active cylinders has not been realized.

Status

In the final phase of the project, two thermal management strategies were tested: CDA while motoring (stay-hot) and early exhaust valve opening (EEVO) (get-hot). The stay hot strategy was tested on steady state motoring points as well as on a transient California Air Resources Board (CARB) low-load cycle (LLC). The EEVO was tested on idle conditions as a quick warmup strategy.

Results

Figure 1 shows motoring operation at 1,200 rpm for operation with one cylinder, two cylinders and three cylinders disabled. The results show that compared to the baseline cooldown profile of the exhaust gas at inlet of SCR, the time taken for the SCR inlet temperature to reach below SCR activation increases with the increasing number of

cylinders disabled. The increase in temperature is primarily due to lowering the air flow across the aftertreatment system during no-fueling and motoring operation. The results show that by disabling three cylinders, the SCR inlet temperature takes over a minute to reach 150°C. This is a viable option to reduce the increased NOx options after a down-hill operation.

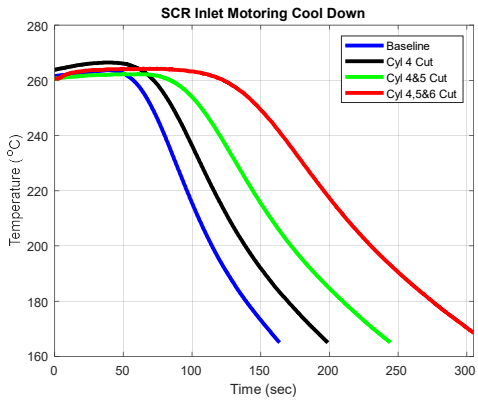


Figure 1: 1,200 rpm SCR Inlet Temperature Profile for Various Cylinder Cut-Off

Figure 2 shows the results of the temperature profiles for CDA operation during the CARB LLC cycle. Six-cylinder CDA while motoring during the LLC cycle can keep the SCR inlet temperature above the 150°C threshold.

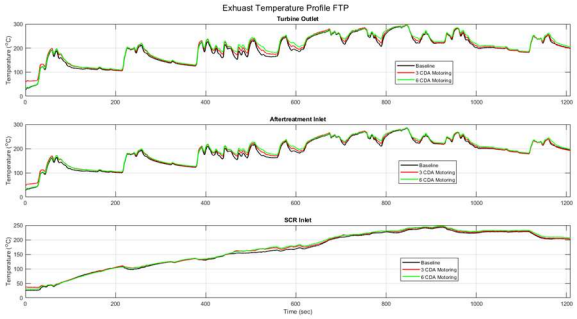


Figure 2: CDA Motoring Operation over the CARB LLC Cycle

It was decided to use EEVO for all load points below 1000 ft-lbs and to use an increased idle speed to increase the fueling and mass flow rate of air. The results show that the get-hot strategy can reach the 150°C threshold two minutes faster than the baseline warm-up strategy and sustained conducive SCR temperatures are observed during the LLC cycle.

During the warm-start the get-hot strategy is found to be far-more effective with NOx emissions temperatures at the inlet of SCR reaching over 200°C. The get-hot strategy can potentially lower cold-start NOx emissions. It may also be effective during frequent start-stop operations. The downside of the EEVO get-hot strategy is the fuel penalty that is incurred during the EEVO operation. However, with smart engine calibration this fuel penalty can be lowered from the current 10-15% compared to baseline.

Benefits

Near-zero NOx from HD diesel engines can reduce NOx nationally from the 11 million commercial diesel trucks on road. Reduction of NOx by 90% can significantly improve air quality nationally.

Project Cost

Funding for the project is listed in the following table.

Environmental Canada	$100,000
South Coast AQMD	$250,000
US EPA	$250,000
Cummins and JVS (in kind)	$100,000
Total	$700,000

Commercialization and Applications

WVU is continuing to work on the development of smart calibrations to optimize fuel consumption. Optimization of the CDA operation can potentially yield fuel savings that can offset the increased fuel consumption from EEVO operation. WVU is also partnering with Tula Technologies to further advance the CDA control for optimal firing patterns. The continuous work on this project is expected to have a good chance for commercialization compared to the success of other CDA platforms used by General Motors and others. CDA supports the need for low NOx diesel engines soon to be required by CARB and the US EPA.

South Coast AQMD Contract #13433 **March 2020**

Zero Emission Cargo Transport (ZECT-I): Develop and Demonstrate Two Class 8 Zero-Emission Electric Trucks

Contractor
US Hybrid Corporation

Cosponsors
US Hybrid Corporation
U.S. Department of Energy (US DOE)
South Coast AQMD
University of California, Riverside

Project Officer
Phil Barroca

Background
On-road heavy-duty diesel trucks are a significant source of diesel particulate matter and NOx emissions with adverse health effects. The impact on public health is more pronounced in the communities adjacent to goods movement corridors near the Ports of Los Angeles (POLA) and Long Beach (POLB) and major freeways in Southern California. Recognizing the significant impact diesel trucks have on air quality and public health, the South Coast AQMD has been working with regional stakeholders, including the POLA and POLB, to promote and support the development and deployment of advanced zero emission cargo transport technologies in the South Coast Air Basin. This project was one of four zero emission drayage truck technologies South Coast AQMD that received a grant under the Department of Energy's (DOE's) Zero Emission Cargo Transport (ZECT) Demonstration program.

Project Objective
The objective of this project was to develop and build two zero emission Class 8 battery electric drayage trucks (BETs) for demonstration in real world drayage service to promote and accelerate the use of electric transportation technologies in cargo transport operations. US Hybrid's BETs were referred to as eTrucks™.

Upon completion, the eTrucks™ were planned to be demonstrated in real world drayage service for two years in partnership with a South Coast AQMD-approved fleet in Basin.

Technology Description
The demonstration eTrucks™ were built on a Navistar ProStar Model 8600 chassis with 80,000-lbs Gross Combined Weight Rating (GCWR). The eTrucks™ are powered by a 320-kW electric drive system which has been developed mainly for on-road eTrucks™ applications. The electric motor is an induction type design, free of high cost rare-earth permanent magnet materials making it commercially cost effective. The motor is powered by a proven traction motor inverter rated at 420-kVA at 600V-DC. An energy management system was employed to ensure efficiency and reliability of the lithium-ion cells. Truck one (eTruck™ 1) was fabricated and operated using EnerDel lithium-iron-phosphate (LFP) battery packs with 180 kWh of total capacity. This initial battery platform demonstrated inadequate range, power, and life cycle. US Hybrid's eTruck™ 2 used 280 kWh of A123 lithium nickel-manganese-cobalt (NMC) battery chemistry which provided sufficient power and energy density and durability (cycle life). eTruck™ 2 provided an approximate 100-mile range under normal operating conditions (80% depth-of-discharge). To support the eTruck™ acceleration requirements, the energy storage system was set up to meet the required power density at low state of charge and to accept the regenerated power at a higher state of charge. In addition, a proprietary eTruck™ control system optimizes eTruck™ efficiency, maximizing battery life, and protecting key components such as batteries and power electronics from excessive temperatures, voltage spikes, and current surges.

Figure 1: eTruck™ 2 at South Coast AQMD January 2020

Status

The ZECT I project was completed March 31, 2020. On March 24, 2015, eTruck™ 1 was successfully demonstrated at TTSI's facility with 80,000-lbs. GCWR. eTruck™ 2 was delivered to TTSI in June 2019 for demonstration.

Figure 2: eTruck™ 1 with 80,000 lbs GCWR Trailer

Results

Two battery electric trucks were designed, developed, and deployed for demonstration at the POLA and the POLB by US Hybrid. TTSI was the primary demonstrating fleet at the ports. The drivers really liked the smooth truck operation especially at low speed as they engage with the trailers and maneuver in the lot with virtually no operating noise. Drivers and operators still have range anxiety even when we increased the battery capacity by 55% for an effective range of 100 miles in full load real world operation.

The eTrucks™ powertrain system performance was well within the design parameters and there were no issues during the demonstration for both trucks. The auxiliary systems were updated from the first truck to the second to be 30% more efficient. The biggest lesson learned in this project was how difficult it was to deal with battery suppliers, both in technical performance (power density, energy density, life degradation), and charge profiling to extend battery life. US Hybrid was able to validate its cost model for small (100), medium (200), and large volume (500) units per year. It requires more production and supply chain experience to validate the cost models for thousands of annual units. We were able to develop a price matrix/indicator of $/mile-range for battery electric trucks for drayage applications. Furthermore, US Hybrid was able to develop a Utilization Factor Indicator for the eTrucks™ that is a composite of loss of payload due to added weight of large battery box and the loss of utilization due to charge time based on double shift (16 hours) operation.

Overall, the electric traction system is capable of meeting drayage performance demands. The main issue with electric-powered trucks is life cycle cost, and most importantly the capital cost associated with the truck purchase, including the battery replacement (estimated in 4 years) in the 8-year typical life operation. US Hybrid calculated an operation cost ($/mile) for the eTruck™ based on Southern California Edison rates at its facility in Torrance, CA of $0.15/kWh (net) and $0.39/kWh (gross), taxes and demand charges, and a diesel truck getting 6 mile/gal, and fuel cost at $2.80/gal or $0.46/mile, equating diesel fuel to electric energy at $0.15/kWh and assuming 3 kWh/mile AC power. When compared to natural gas at 4 miles/GGE and $1.60/GGE, the break-even electricity rate should be $ 0.13/kWh. This is in contradiction with most reported sales literature. Special electrical rates of less than $0.15/kWh is needed to have a break-even operation cost if electric trucks are to compete with diesel and natural gas fuels. The operation cost data does not include any cost for infrastructure or utilization of on-board charges (eTruck™ cost) or DC off-board charger, facility cost, etc.

Project Costs

Total project cost was $2,116,323, with $943,810 from South Coast AQMD/US DOE and $1,172,513 from US Hybrid. Original cost share was projected at $1,043,811.

Commercialization and Applications

Based on the development and operation of the two eTrucks™, the following is the best estimate of commercial viability economics of incremental cost $/mile-range and productivity of the truck. Not accounting for container weight capacity reduction, heavy battery, and time allocated to charge a large battery pack, the eTruck™ energy efficiency is about $2.8kWh/mile. The battery cost used for the calculations is $498/kWh including BMS, packaging for heavy duty shock and vibration, and IP67 rating and protection.

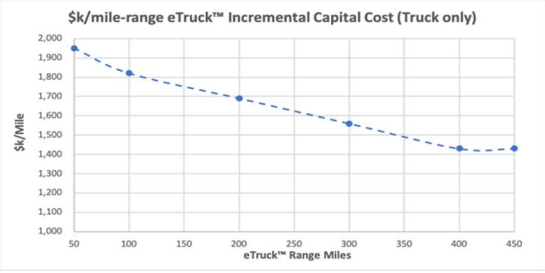


Figure 3:Incremental Capital Cost (truck only) ($/mile range)

South Coast AQMD Contract #16046 **March 2020**

Zero Emission Cargo Transport (ZECT-I) Develop and Demonstrate Two Class 8 CNG Plug-In Hybrid Electric Drayage Trucks

Contractor

Transportation Power, Inc. (TransPower)

Cosponsors

California Energy Commission (CEC)
U.S. Department of Energy (DOE)

Project Officer

Phil Barroca

Background

On-road heavy-duty diesel trucks are a significant source of diesel particulate matter and NOx emissions that can create serious health effects. The impact on public health in Southern California is more pronounced in communities along the goods movement corridors near the Ports of Los Angeles and Long Beach, and next to major freeways. Recognizing the significant impact diesel trucks have on air quality and public health, the South Coast AQMD has been working with other regional stakeholders, including the Ports of Los Angeles and Long Beach, to promote and support the development and deployment of advanced zero emission cargo transport technologies in the South Coast Air Basin. Deployment of zero emission trucks in this region may also be a future requirement for conforming with rules, regulations, and mandates of the South Coast AQMD, California Air Resources Board (CARB), Environmental Protection Agency (EPA), and DOE, while also helping to foster economic development in the region.

Project Objective

The overarching goal of this ZECT project was to develop a hybrid-electric drive system using a natural gas engine as a range extender and to demonstrate two Class 8 drayage trucks using this system in service with Total Transportation Services, Inc. (TTSI) at the Ports of Los Angeles and Long Beach. This project was one of four zero emission drayage truck technologies funded by a grant from the DOE under the ZECT Demonstration Program. The vehicles were intended to be demonstrated in near-dock drayage service for two years in partnership with Transportation Services, Inc. or other South Coast AQMD approved fleets in the basin. A specific project objective was to determine if a very small compressed natural gas (CNG) engine could provide sufficient power to work as a range-extender for locally-driven trucks, while also being capable of operating intermittently in a zero emissions mode, solely on battery power with the engine turned off.

Technology Description

The TransPower ElecTruck™ drive system uses a unique combination of two 150 kW permanent magnet motors that were originally developed for the Fisker Karma hybrid passenger car. The demonstration vehicles (one of which is pictured above) were equipped with inverter-charger units (ICU) that combine the functions of the vehicle inverter and battery charger. This innovation minimizes external charging infrastructure and charges each truck in less than 4 hours, providing operational flexibility and reducing capital costs. An automated manual transmission uses proprietary software to control a transmission shift mechanism, enabling operation in multiple gears to maximize vehicle efficiency. High-energy lithium ion battery modules were installed on both trucks providing 30-40 miles of all-electric (battery-only) range under normal operating conditions. Lithium-iron-phosphate cells were installed on the first

Figure 1: TransPower CNG Series Hybrid Truck No. 2

truck and nickel-manganese-cobalt on the second truck. A proprietary vehicle control system controls the CNG auxiliary power unit (APU), optimizes vehicle efficiency, maximizes battery life, and protects key components such as batteries and power electronics from excessive temperatures, voltage spikes, or current surges.

Status

The ZECT project was successful in demonstrating the proof-of-concept of a CNG hybrid configuration to meet the basic load-carrying requirements of an 80,000-pound Class 8 truck. The innovative dual motor configuration selected for the trucks provided adequate performance and high reliability in a package that cost less and was more compact than competing motive drive options. The ICUs performed up to expectations and enabled the trucks to be safely recharged with minimal external infrastructure. Battery energy storage capacity exceeded contract specifications. The major unanticipated problem encountered during the project was that the Ford 3.7-liter engine selected for the APU, when limited to Stationary Trim mode, was incapable of supplying more than 60 kilowatts (kW) of power, making it impossible to carry full loads at freeway speeds for more than about 50-60 miles. Limitations of the chosen engine control strategy also resulted in higher APU emissions than desired. In addition, the experimental battery product selected for the first prototype truck had severe quality problems that limited use of this truck and forced the use of a different battery in the second truck, which delayed its deployment. Despite these challenges, operators of these trucks commented that they were the best electrically-driven trucks they had driven at the time. On-going advances in engine control and battery technology are expected to address the range limitation and emissions issues, making hybrid-electric trucks of this type a practical alternative.

Results

The two prototype CNG hybrid trucks accumulated approximately 5,000 miles of test operation, including several long-distance trips of 100 miles or more while unloaded. They were put through two years of intermittent use in commercial drayage operations carrying full loads, along with a series of dynamometer tests at the University of California, Riverside (UCR). Results of the UCR dynamometer testing, shown in the bar graph below, indicate NOx emissions of more than 7 g/bhp-hr. across the four duty cycles tested. The higher-than-anticipated emissions were the result of TransPower's inability to obtain a certified automotive engine configuration that was expected to be provided by Ford. This forced TransPower to use a CNG engine designed for stationary power generation, whose control could not be optimized to minimize automotive emissions within project budgetary constraints.

Benefits

Cycle	Ave Speed	Duration	Distance	Net Total Energy	Net Generator Energy	Net Battery Energy	Total Energy usage	Generator energy usage	Battery Energy usage	SOC usage
n/a	mi/hr	sec	mi/cycle	kWhr	kWhr	kWhr	kWhr/mi	kWhr/mi	kWhr/mi	%
SG1 Hill	40.79	448	5.07	22.95	4.37	18.58	4.53	0.86	3.66	11
UDDS	18.39	1061	5.42	15.02	12.34	2.67	2.77	2.28	0.49	2
UDDS	18.48	1061	5.45	14.97	12.83	2.14	2.75	2.36	0.39	1
DTP 3	23.98	4229	26.65	56.52	50.20	6.32	2.12	1.88	0.24	5
UDDS (No APU)	18.31	1061	5.40	17.15	0.00	17.15	3.18	0.00	3.18	10
SG1 (No APU)	33.15	427	3.93	19.04	0.00	19.04	4.85	0.00	4.85	12
UDDS	18.46	1061	5.44	15.49	11.87	3.62	2.85	2.18	0.67	2
UDDS	18.59	1061	5.48	14.65	12.09	2.56	2.67	2.21	0.47	2

Figure 2: Summary Across All Cycles for Chassis Dyno Testing for Truck No. 2

By demonstrating the proof-of-concept of using a CNG engine to augment a battery pack in a Class 8 truck application, this project established a foundation for future work, which could yield emissions and energy efficiency benefits by utilizing larger CNG engines with more typical automotive controls. This technology could reduce air pollutants while helping to address global warming if utilized for goods movement, which is seen as one of the leading sources of criteria pollutants and carbon emissions.

Project Costs

The total cost of the TransPower hybrid project was $2.68 million, exceeding the projected $2.1 million. South Coast AQMD funded over $1.15 million. TransPower's cost share was $1,529,065, exceeding the original $900,000.

Commercialization and Applications

Evidence is mounting that electrification of Class 8 trucks has great commercial potential, and the size of the locally-driven U.S. electric Class 8 truck market is in the tens of thousands of trucks per year. Improvement in CNG hybrid technology could enable application to long-haul trucks, which could expand the addressable market to hundreds of thousands of trucks per year.

South Coast AQMD Contract #17029 **December 2020**

Demonstration and Evaluation of Plug-in Smart Charging at Multiple Electric Grid Scales

Contractor

University of California, Irvine (UCI)

Cosponsors

UCI Advanced Power and Energy Program (APEP)
US Department of Energy
Hyundai
Southern California Edison

Project Officer

Seungbum Ha

Background

Improving air quality in urban areas requires the reduction of criteria pollutant emissions across several sectors. The transportation sector is of particular interest due to the local emissions in disadvantaged communities and the regional contribution to criteria pollutants and greenhouse gas emissions. To meet State energy and environmental goals, the deployment of alternative vehicles including plug-in electric vehicles (PEV) and fuel cell electric vehicles has increased in recent years and it is expected to increase further. Since these vehicles are connected to the electric grid, their interaction with the electricity sector and grid is of utmost importance. For PEVs to contribute to emissions reductions, plug-in vehicles must interface with the electric grid such that 1) their usage of renewable energy is maximized and 2) charging behavior does not cause the grid to violate its ability to adhere to reliability criteria and balance the electric load demand at all grid scales. To coordinate and control charging of PEVs, smart charging strategies should be implemented.

In this project, a previously developed smart charging strategy was implemented, deployed, and demonstrated on the UCI Microgrid Solar CarShade nanogrid using a fleet of 10 battery PEVs. This project increases understanding on how PEVs should be managed on the electric grid distribution system so that their deployment can become a valuable asset for electric grid operation and the microgrid, renewable resource utilization, and emission reduction.

Figure 1: KIA Soul EVs

Project Objective

The purpose of the project was to implement a smart charging algorithm previously developed by the UCI Advanced Power and Energy Program (APEP) on a fleet of PEVs and demonstrate the smart charging strategy on a nanogrid located on the UCI Microgrid. The project goals were to:

1) Further develop an existing smart charging algorithm so that it can be tuned by balancing area operators, investor-owned utilities, and third parties (e.g., microgrid operators) for their specific needs and implementation in their specific domains; and

2) Successfully demonstrate the effectiveness of the developed algorithm on the UCI Microgrid Solar CarShade nanogrid with specially equipped PEVs.

Approach

A smart charging algorithm previously developed was modified to enable implementation on a small scale at the distribution level on a nanogrid. The Solar CarShade nanogrid includes a building, 48 kW of photovoltaic (PV) panels, a 100kW/100 kWh battery and 20 level 2 electric vehicle (EV) chargers. The smart charging strategy is a decentralized valley-filling optimization where the charging profile of each vehicle is optimized individually and independent of the rest of the fleet and based on a cost profile, price signal, or load profile (cost load). The cost profile is then updated with the vehicle's

charging profile, and the updated cost profile is then used for upcoming vehicles. Several scenarios were developed and first simulated using different cost load profiles based on data collected from the UCI Microgrid.

A strategy was developed to implement the smart charging algorithm on the CarShade nanogrid using 10 KIA Soul EVs. This strategy included several components including a driver portal for the participating drivers to enter their travel plan, and communication with the vehicles to poll their status and enable sending charging ON/OFF commands to the vehicles. This strategy was then deployed and demonstrated in the nanogrid

Results

The smart charging algorihtm was deployed on the nanogrid and demonstrated. More than 80 days of testing and demonstration were conducted with different cost profiles and various scenarios. The smart charging results were recorded, and data was collected and recorded including vehicle status, commands sent, nanogrid load, PV generation, as well as data from the chargers.

Overall, the demonstration was successful with the qualification that communication was periodically interrupted due to network connectivity issues.

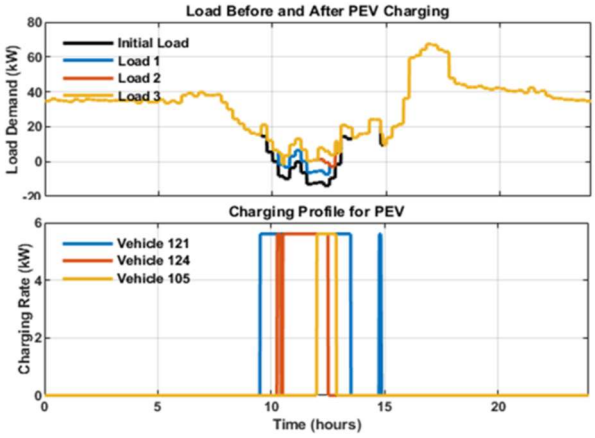


Figure 2: Load Demand and Charging Profile

Project Costs

The total cost of the project was $750,000. South Coast AQMD provided $250,000 of the total cost. Match funding of $500,000 was provided by UCI, the U.S. Department of Energy, Southern California Edison, and Hyundai.

Commercialization and Applications

The demonstration proved feasibility and efficacy of the smart charging algorithm deployed on a nanogrid. Below are some observations and lessons learned from the project:

- **Demonstration results reveal promise for large-scale implementation in the future.** All components and strategies developed in the project can be scaled up for a larger fleet.
- **The strategy can be implemented and deployed on parking structures**. The strategy can be deployed on parking structures at workplaces as well as retail centers with minimum infrastructure upgrade.
- **Standards should be developed for communications with the vehicles and charging infrastructure.** To reduce upfront cost and effort for fleets with EVs of different make and model, standards should be developed.
- **Required communication rate with the fleets might be higher than expected originally.** To identify issues and to ensure customer satisfaction, communication with the vehicles is required.
- **Negative impacts of high rate of communication with the vehicles should be addressed.** The auxiliary battery is depleted with a high rate of communication. The issue can be addressed in the design of the vehicles.
- **Strategies must be developed to incentivize PEV drivers to participate in smart charging programs**
- **Load forecasting helps improve the outcome of smart charging for larger fleets.** While impact of forecasting is small for smaller fleets, it can significantly improve the smart charging results for larger fleets.

South Coast AQMD Contract # 18122 **January 2020**

Southern California Trucking Demonstration of Near-Zero ISX12N Beta Engines

Contractors

Clean Energy
Cummins Westport Inc.

Co-Sponsors

South Coast AQMD
California Energy Commission (CEC)

Project Officer

Phil Barroca

Background

The Ports of Los Angeles and Long Beach rank drayage trucks as the second largest source of NOx and the largest source of greenhouse gas (GHG) emissions from port-related activities.

Replacing the almost 8,000 oldest diesel port trucks with trucks powered by the Cummins Westport (CWI) ISX12N ultra low-NOx engine and fueled with renewable natural gas (RNG) is one of the best opportunities for air quality improvement in Southern California.

One of the key barriers to adoption of the ISX12N engine among drayage fleets is the lack of experience with the engine operating in the port drayage application. Skepticism about the technology is amplified by the unsatisfactory experience of some truckers with the first-generation natural gas technologies that were deployed in port drayage over 10 years ago in response to the first Clean Truck Program.

Project Objective

Clean Energy and CWI initiated this project to demonstrate 20 trucks repowered with pre-commercial ("beta") versions of the ISX12N engine for one-year periods. Beta engines were used to allow the project to be performed in parallel with CWI efforts to finalize ISX12N engine development and secure California Air Resources Board (CARB) certification to the lowest optional low NOx standard of 0.02g-NOx/bhp-hr. This parallel approach was intended to shorten the traditional time between the initial commercial launch and the market prove-out of the new engine.

Technology Description

CWI developed the ISX12N engine with funding support from South Coast AQMD, CEC, and others to be certified to the CARB optional low NOx standard of 0.02g-NOx/bhp-hr. This certification is 90% cleaner than the current new truck engine manufacturing standard, and over 98% cleaner than the emissions standard of almost 8,000 of the oldest port trucks. When fueled with RNG, climate pollutants can be reduced by 50% to over 500% compared to diesel. These percentages are dependant on the carbon intensity of the RNG source under the CARB Low Carbon Fuel Standard (LCFS) program.

Figure 1:Cummins Westport ISX12N Ultralow-NOx Engine

The ISX12N also eliminates 100% of the toxic diesel particulate matter and diesel petroleum use of a diesel truck. The ISX12N is also far quieter than diesel engines, reducing noise pollution.

Status

Seven trucking companies from port drayage and regional trucking participated in the project by running the demo trucks in their actual operations. Participating companies were TTSI, 4Gen, Pacific 9 Transportation (Pac 9), NFI, Green Fleet Systems, CR&R, and Orange Avenue Express. Demonstrations started in September of 2017 and ended on June 30, 2019. Each of the seven participating fleets ran their trucks for a 12-month period commencing at staggered starting dates. The trucks traveled a total of 567,603 miles

during the demonstration and as of mid-August had run over 750,000 miles.

Results

The engine performed exceptionally well for this project with an engine availability of 98% during the demonstration. Trucks traveled to all the routine destinations and routes in southern California for port trucks and regional trucks including near the port, along the 710 corridor, and to the Inland Empire, San Diego, and Central Valley. The ISX12N has proven to reliably perform port drayage and regional hauling services throughout southern California and even beyond.

Drivers and fleet operators found the ISX12N to be suitable for the job. Six of the operators have either acquired, or are planning to acquire, trucks with the commercial ISX12N. These near-term orders involve approximately 140 trucks with over 70 delivered in 2019.

Benefits

The 20 demonstration trucks displaced 129,674 gallons of diesel fuel and reduced 4.02 tons of NOx over the course of the project. Because the trucks were powered by 100% RNG, GHG emissions were reduced by 887 tons.

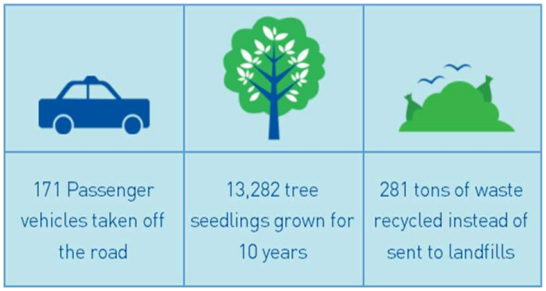


Figure 2:Greenhouse Gas Reduction Equivalencies

Figure 3:Pac 9 Class 8 with ISX12N Refueling with CNG

Project Costs

The project budget and the actual project costs are shown in the table below. Funding provided by CEC of $2,845,000 and South Coast AQMD of $650,000 matched the project budget. Cost share costs incurred by the project contractors and participating fleets totaled $2,717,007, which was $217,007 more than the project budget of $2,500,000. The higher cost incurred by participants was due to higher used truck acquisition and repair costs (unrelated to the beta engine and associated CNG and LNG fuel systems) and high project management costs due to the overall duration of the project.

Project Budget		Actual Costs
South Coast AQMD	$650,000	$650,000
CEC	$2,845,000	$2,845,000
Cost Share	$2,500,000	$2,717,007
Total	$5,995,000	$6,212,007

Commercialization and Applications

This project helped demonstrate the capability of the ISX12N engine in routine port drayage and regional trucking applications. The ISX12N is CARB certified and commercially available and in 2020 received a Technology Readiness Level (TRL) 9 in an Addendum to the Port's Clean Air Action Plan.

South Coast AQMD Contract #12667 **March 2020**

Upgrade CNG Fueling Station

Contractor
West Covina Unified School District (WCUSD)

Cosponsor
South Coast AQMD

Project Officer
Phil Barroca

Background
In 2012 West Covina Unified School District initiated participation in the South Coast AQMD's Lower-Emission School Bus Replacement Program with a desire to replace its fleet of older diesel-powered school buses with alternative fueled vehicles. To date, the district has replaced 9 Type D diesel-powered school buses with comparable compressed natural gas (CNG)-powered school buses. Currently, the district's school bus fleet is composed of 19 buses as follows:

Type of School Bus	No.
CNG	9
Gasoline	3
Diesel	7

Of the 7 diesel-powered school buses, 6 were manufactured prior to 2004 and are scheduled to be replaced with CNG-powered school buses as South Coast AQMD grant funding becomes available.

The first CNG-powered school buses acquired by the district were fueled by outdated temporary refueling equipment that worked poorly. As additional CNG-powered school buses were acquired, fiduciary and safety responsibility dictated that the district should install a new and permanent time-fill CNG fueling facility.

Project Objective
The objective of this project was to construct a slow-fill CNG refueling facility for the district to refuel its natural gas school buses on-site, both to meet present and projected future needs. The station would be located at 1717 W. Merced Avenue in West Covina. This objective was completed in October 2018 with the installation of fueling posts and a slow-fill fueling station. The district hired and worked with Jaycox Construction who installed both the fueling posts and station.

Technology Description
The new station is comprised of two 7.2 standard cubic feet per minute (scfm) BRC FuelMaker model FMQ-8-36 compressors, gas conditioning equipment, controls and all ancillary equipment, two 33.5 cubic feet CNG storage spheres, and 9 time-fill fueling posts. The dual compressor unit dispenses CNG at 6.7 gasoline gallon equivalent (GGE)/hr. WCUSD buses average 30 miles of daily travel and consume about 10 GGE at an average fuel efficiency of 3 mpGGE. Concurrent refueling of all nine buses requires 13-14 hours or 1.5 hours per bus. Field trips of 150 miles requires 8 hours of refueling using both compressors. The dual compressor design is meeting the district's demands.

Figure 1: BRC FuelMaker FMQ-8-36

Status
In 2012, the district was awarded a grant by South Coast AQMD to construct a CNG refueling station. The contract for this project was extended from December 2017 through March 2020 following a no cost time extension request from the district in 2017. While designing the new fueling station the district encountered an issue with the available electrical power required to power the

compressors. This issue was resolved in partnership with Southern California Edison and required an upgrade to the main electrical service to provide the necessary electrical power for the new CNG compressors and station. The district issued a request for quotes on the project in 2017 and awarded the job to Jaycox Construction which commenced construction in 2018.

Figure 2: Type D CNG Bus Refueling

Results

The station displaces more than 12,000 gallons of diesel fuel annually. The station was first commissioned in late summer of 2018. The chart below provides a monthly throughput amount in GGEs per month and seasonal fueling patterns for the first full calendar year of operation in 2019. From January to December 2019, a total of 15,784 CCFs (hundred cubic foot) were consumed. Using

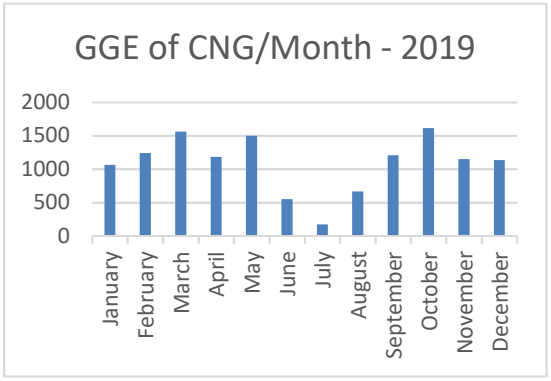


Figure 3: Throughput in GGE/month-2019

a conversion formula of 1.212 CCFs per gallon of gasoline, and 1.115 gallons of gasoline per gallon of diesel, the CNG station saved 13,023 gallons of gasoline fuel or 11,679 of diesel. In terms of NO_x and particulate matter (PM) emissions, 1.23 tons of nitrogen oxides were taken out of the air and particulate matter has been reduced as well.

Benefits

In addition to the air quality benefits achieved, e.g., reduced NO_x and PM emissions, by switching from diesel to natural gas, construction of the fueling facility has allowed the district's transportation services to significantly cut operational costs. Fuel and labor cost savings to the district equal $12,000 annually and is anticipated to exceed twice that once the district replaces the current fleet of pre-2004 diesel-powered school buses with CNG-powered school buses.

Project Costs

Projected bid costs were anticipated at approximately $100,000. Actual project costs were $84,915 as follows:

Actual Project Cost	
100% Payment and Performance Bond	$2,500
Installation of slow-fill CNG refueling station	$77,806
Sales Tax	$4,609
Total Station Cost	**$84,915**

Of this $84,915, the South Coast AQMD funded $60,000 and the district contributed $24,915.

Commercialization and Applications

The West Covina Unified School District Time-Fill CNG fueling systems is comprised of two BRC FuelMaker FMQ-8-36 CNG compressors, producing 6.7 GGE/hr @3600 psig, with nine connector hoses to fill 9 Type D CNG school buses concurrently. The buses average 3 miles/GGE, and 30 miles/day and 1.5 hours of dedicated fuel time or nearly 14 hours for all nine. Field trips can be 150 miles and require 8 hours of dedicated fill time typically over the weekend. Jaycox Construction provides monthly servicing of the system. The system continues to meet the district's needs and the dual compressor system provides the district with redundancy to be able to conduct maintenance on one compressor and still have CNG fueling available. WCUSD recently secured a renewable natural gas (RNG) agreement and will earn dividends from the Low Carbon Fuel Standard and federal Renewable Fuel Standard programs to help lower operating expenses.

South Coast AQMD Contract #16075 **March 2020**

Purchase One Heavy-Duty CNG Powered Truck

Contractor
City of Desert Hot Springs

Cosponsors
South Coast AQMD
Mobil Source Review Committee (MSRC)

Project Officer
Phil Barroca

Background
In 2009, the Mobil Source Review Committee (MSRC) awarded the city of Desert Hot Springs $25,000 in match funds to purchase a heavy-duty dedicated compressed natural gas (CNG)-powered stakebed truck estimated to cost $50,000. Due to the financial impact of the 2008-2015 recession, the City's budget was unable to include the necessary cost share for the grant funds. By 2014, MSRC was informed that the City was not able to meet its cost share, making indefinite the purchase of the vehicle. In October of 2015, with the assistance of a coordinator for the Clean Cities Coachella Valley Region, Mr. Richard Cromwell, Desert Hot Springs was able to secure Clean Fuels Funds (CFF) from the South Coast AQMD as a cost share in addition to the already secured funds approved by MSRC. To cover the increased price of the vehicle ($50,000 in 2009 to $63,000 in 2015) the City was awarded an additional $38,000 in matching CFF funds.

Project Objective
In 2015, the South Coast AQMD approved match funding with the MSRC to support the purchase one new heavy-duty CNG truck for the city of Desert Hot Springs. The purchase of this new cleaner natural gas-powered truck would be countered with the removal of a comparable truck with higher emissions. The new CNG vehicle would be placed into service with the City's Public Works Department. The CNG-powered vehicle would provide the City with a clean, alternative fuel heavy-duty vehicle to help lower criteria pollutants and greenhouse gas (GHG) emissions. The vehicle would be domiciled at the City yard. Refueling would be provided at the upgraded CNG refueling station owned and operated by Clean Energy at the Mission Springs Water District in the city of Desert Hot Springs. Clean Energy dispenses low carbon intensity renewable natural gas (RNG) under the name Redeem™. The City, in turn, would remove a 2007 gasoline powered Ford pick-up from their fleet.

The South Coast AQMD's Air Quality Management Plan relies on accelerated implementation of advanced technologies within Southern California to achieve federal and state ambient air quality standards and further reductions in air toxic exposure. Conversion of high mileage gasoline or diesel-powered vehicles to natural gas-powered vehicles can significantly reduce criteria pollutants, GHG emissions, and the use of petroleum-based fuel.

Figure 1: F-450 CNG Stakebed Truck

Technology Description
The technology employed in this project includes the conversion of a new 2016 original equipment manufacturer (OEM) gasoline-powered heavy-duty 6.8-liter V-10 spark-ignited engine to a dedicated CNG engine using a California Air Resources Board (CARB) certified CNG conversion system that includes pressure regulators, injectors and on-board high pressure CNG storage tanks and fuel lines. The OEM truck is a 2016 Ford F-450 2x4 stakebed truck chassis with a gross vehicle weight rating (GVWR) of 16,500 lbs. The CNG conversion system is a 2016 CARB-certified Impco system with 31 gasoline gallon equivalent (GGE) @ 3600 psig of onboard CNG storage. The CNG storage system is comprised of two identical high pressure Type 3 gas cylinders positioned behind the cab. The CARB

Executive Order for the Impco system is A-328-0033 which is certified to the 0.2g-NOx/bhp-hr heavy-duty on-road NOx standard. All conversions were performed prior to vehicle delivery and under the supervision of Miramar Truck Center, San Diego, CA. The vehicle is fueled by CNG or low carbon intensity renewable natural gas (RNG) that is dispensed at the local Clean Energy station under the tradename Redeem™.

Status

Desert Hot Springs took delivery of a new 2016 heavy-duty CNG-powered Ford F-450 stakebed on April 28, 2016. This vehicle was funded through the South Coast AQMD and the MSRC. To acknowledge the efforts of those involved in this project, the City issued a press release on May 26, 2016 announcing the vehicle's delivery. In addition to acknowledging the funding partners, special recognition was made to two representatives from the Clean Cities of the Coachella Valley Region, Mr. Richard Cromwell and Mr. Jack Hogan.

Under the contracts for this project, the City concurrently and permanently removed a 2007 gasoline-powered Ford F-150 pick-up with 25,459 miles. This vehicle was dismantled by Dick's Auto Wrecking in Fontana, CA. The new CNG-powered heavy-duty truck is deployed by the City's Public Works Department and has accrued about 5,000 miles. The vehicle is fueled with low carbon intensity RNG from the Clean Energy natural gas refueling station located in the city on Park Lane and on the Mission Springs Water District property. This station was upgraded with funding through AB1318.

Results

The city of Desert Hot Springs has deployed the heavy-duty CNG truck under this project with the Department of Public Works (DPW). The City's DPW assigns a work truck to each staff person. Because of the current configuration in the flatbed, the truck is being used to haul signs to notify drivers of pending and ongoing road work and road closures. The vehicle is also utilized to place barricades when requested by the City's police department. As these work efforts are less frequent, this truck sees somewhat limited daily driving. The DPW recognizes the truck is capable of much more and expects to use it more in the field for green waste and trash removal citywide. The vehicle's 31 GGE of fueling provides approximately 300 miles of range. City staff and vehicle operators are satisfied with the vehicle's ability to perform.

Figure 2: CNG F-450 Being Deployed

Benefits

The CNG powered Ford F-450 is powered by low carbon intensity RNG supplied at the local Clean Energy station on Park Lane and the engine system is certified to federal on-road heavy-duty NOx standard of 0.2g-NOx/bhp-hr. The City estimates that the CNG vehicle is generating 30% less NOx than a comparable diesel-fueled vehicle and the use of low carbon intensity RNG is contributing to lower GHG emissions. Use of the vehicle reduces immediate air pollution exposure to the residents of and visitors to the City.

Project Costs

Purchase and registration of the CNG truck cost $61,387.98. The vehicle was funded with $25,000 by the MSRC, and $36,387.98 from the South Coast AQMD. Costs to insure and operate this vehicle were paid for by the city of Desert Hot Springs.

Commercialization and Applications

The city of Desert Hot Springs acquired this vehicle in 2016 and has continued to operate this vehicle in limited but necessary public works activities. The vehicle continues to meet the City's performance standards and has not incurred any major issues that has prevented its routine usage. The vehicle has been maintained by Palm Springs Motors. Maintenance costs associated with this technology has been comparable to conventional fueled vehicles used in comparable applications. The vehicle also performs well and without incidence during the extreme high summer temperatures in the Coachella Valley.

South Coast AQMD Contract # 15680 **June 2020**

Develop Detailed Technology and Economics Based Assessment for Heavy-Duty Advanced Technology Development

Contractor

National Renewable Energy Laboratory (NREL)
Ricardo Strategic Consulting (Ricardo)

Cosponsors

Southern California Gas Company

Project Officer

Phil Barroca

Background

In August 2015, the South Coast AQMD, with co-funding from the Southern California Gas Company (SoCalGas), executed a contract with the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) to develop a detailed technology and economics-based assessment for the deployment of advanced heavy-duty vehicle technologies suitable in commercial fleet applications. This project, commonly referred to as ComZEV, analyzed six technologies which included a 2010 compliant diesel, a 0.02g-NO_x/bhp diesel, a 0.02g-NO_x/bhp-hr compressed natural gas (CNG) alone as well as with a hybrid electric, battery-electric, and battery-electric with fuel cell range extender. The additional technologies were six vehicle vocations including Class 5-6 medium-duty delivery vehicles, Class 8 port drayage, short haul, and long-haul trucks and Class 8 refuse and transit buses.

COMZEV Key Technology and Vocation Analysis Matrix

Technology / Vocation	Class 5-6 Medium Duty Delivery	Class 8 Port Drayage	Class 8 Short haul	Class 8 Long Haul	Class 8 Refuse Truck	Class 8 Transit Bus
Conventional Diesel	✓	✓	✓	✓	✓	✓
Diesel .02g NOx	✓	✓	✓	✓	✓	✓
CNG SI .02g NOx	✓	✓	✓	✓	✓	✓
CNG SI .02g NOx Hybrid	✓	✓	✓	✓	✓	✓
Battery Electric	✓	✓	X	X	✓	✓
H2 Fuel Cell (Gaseous Storage)	✓	✓	✓	✓	✓	✓

Figure 1 – Final Technology/Vocation Matrix

Project Objective

NREL and Ricardo developed a detailed technology and economics-based roadmap for the adoption of advanced commercial vehicle technologies to reduce nitrogen oxides (NO_x) and greenhouse gas (GHG) emissions through 2050, with an emphasis on the years 2023 and 2032 to correspond to the Federal Clean Air Act (CAA) 8-hour ozone standards attainment deadlines. The ComZEV study was to identify barriers and opportunities to match advanced technology options to key commercial medium- and heavy-duty vehicle vocations in Southern California.

Technology Description

Ricardo developed Total Cost of Ownership (TCO) and Adoption-Rate models and applied data from NREL's Fleet DNA vocational vehicle and duty-cycle database. The Adoption Rate model forecasts technology adoption based on both economic and non-economic factors that influence buying decisions by fleet owners. The model compares and contrasts potential adoption rates for zero- and near-zero emission truck technologies and can help assess the benefits and costs of various incentives or mandates, analyze short- and long-term total cost of ownership between technologies and identify key factors that create "tipping points" for widespread adoption. It can also asses the importance of sales volumes and scalability, barriers in early commercialization and options to address these, sensitivity to fuel prices and other external factors. Technology adoption rates enable quantifying NO_x and GHG emission reductions and goals through 2050. The Technology Adoption Scenario is enhanced through feedback from industry and governmental stakeholders and the incorporation of non-economic and non-technical market drivers and barriers.

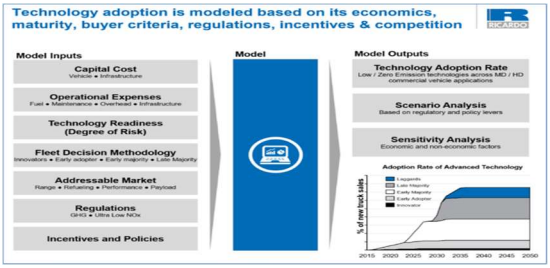


Figure 2: Modeling Framework

Status

A detailed technology and economics-based roadmap for the adoption of advanced commercial vehicle technologies was developed with the focus of quantifying key technological, market, and policy barriers to alternative vehicle adoption. Vehicle adoption modeling was completed using detailed choice-modeling methodology and the resulting impacts on NO_x and GHG emissions through 2050 were evaluated for the South Coast Air Basin in California.

Results

Results indicate that there are many drivers of vehicle adoption that involve cost. The key drivers appear to be economies of scale and fuel cost. Results also indicate that all technologies play an important role in reducing both NO_x and GHG emissions. CNG is the dominant alternative over diesel near-term for short-haul, long-haul, transit bus and refuse truck markets due to having the lowest cost. Battery-electric is the most economically attractive for low range applications with battery-electric hydrogen fuel cells offering the most attractive economics of all technologies for medium- and long-range applications. Key barriers to adoption of the advanced vehicle technologies include limited refueling infrastructure in the case of CNG. Hydrogen range limitations or payload restrictions are barriers in battery-electric trucks, and high costs are barriers for hydrogen fuel and hydrogen fuel cell technology.

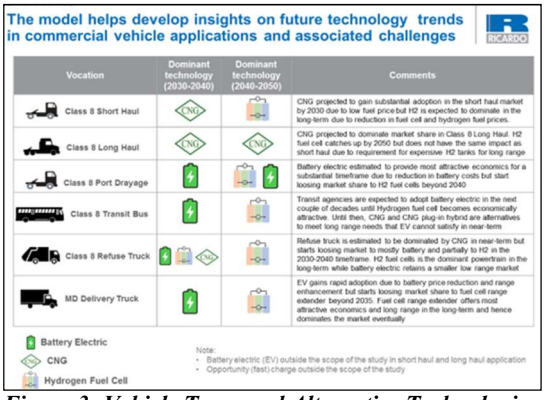


Figure 3: Vehicle Types and Alternative Technologies

Benefits

The key benefit of this study is the development of a roadmap for near-zero and zero-emission technologies calibrated to South Coast AQMD air quality attainment objectives that comprehends NO_x and GHG reductions and the economics of deployment.

The model showed that there are three vocations that comprise most of the GHG and NOx emission reductions through 2050 for the Southern California fleet. The three include the Class 8 Long Haul, the Class 8 Drayage, and the Class 5-6 MD Delivery. The Class 8 Long Haul emissions are primarily a function of the high travel requirement for this vocation combined with the improved diesel fuel economy and high CNG and hydrogen adoption by 2050. The Class 8 Drayage emissions are significant due to the vocation's high emission rate (poor aftertreatment) combined with early adoption of battery electric technology. The Class 5-6 MD is included due to delivery emissions caused by a large vehicle population combined with the adoption of battery electric technology, hydrogen technology, and improved diesel fuel efficiency. All powertrain technologies contribute to different market applications and timing, providing significant reductions in NO_x (60-62%) and tailpipe CO_2 (37-39%) emissions reduction by 2050 relative to the business-as-usual scenario.

Project Costs

The total project costs are noted below with payouts shared equally by South Coast AQMD and SoCalGas.

Task	NREL	Ricardo	Total
Total	$230,000	$270,000	$500,000

Commercialization and Applications

The addressable market is expected to grow as refueling infrastructure develops to provide sufficient coverage and battery price and energy density improves to provide more range. Hydrogen fuel cell and fuel costs are expected to reduce dramatically beyond 2035 due to synergies with light-duty fuel cell vehicle manufacturing and adoption.

The roadmap provided Total Cost of Ownership and Adoption-Rate models to estimate adoption rate projections and the resulting fleet emission impacts based on best available data on economic, governmental and societal drivers at the time of the study. This tool and methodology can be updated with the latest information and be used to conduct additional sensitivity analysis as technologies mature and the economics continue to evolve providing a guide for future California funding incentives.

South Coast AQMD Contract #17277 **February 2020**

Conduct Market Analysis for Zero-Emission Heavy-Duty Trucks in Goods Movement

Contractor
University of Southern California

Cosponsors
US Department of Transportation
Volvo Research and Education Foundation
Majestic Realty

Project Officer
Seungbum Ha

Background
Achievement of a zero emissions (ZE) vehicle fleet is part of the long range plans for California, the South Coast AQMD, and more recently the San Pedro Bay Ports and many local jurisdictions. The use of ZE heavy duty trucks (HDTs) for freight movement remains a challenge particularly in the heavy duty sector.

Project Objective
This research examines the potential for ZE or near-ZE vehicles with respect to freight operations, economic impacts and environmental benefits. The focus is on HDTs used in short-haul drayage services, one of the most promising market segments for early adoption. Drayage service is defined as short haul pickup/delivery of goods to/from ports, warehouse and distribution centers, and intermodal facilities. To provide a comprehensive assessment of the market potential for ZE and near-ZEHDTs, several dimensions of their costs and benefits were considered.

Technology Description
ZEHDTs have different performance characteristics than conventional diesel HDTs, namely range, load capacity, and refueling time. For a given set of pickups/deliveries, the number of trucks required depends on the range of the vehicle and its load capacity. These in turn determine miles traveled (including associated labor costs) and refueling time costs. Near ZE HDTs, such as hybrid electric, have similar performance characteristics to conventional diesel.

A simulation model and actual drayage trip data were used to generate a set of simple drayage demands to be accomplished over a single eight-hour shift day. The simulation model optimized routes so that total costs are minimized. Using an all diesel fleet as the base case, the simulation model was used to estimate the number of trucks required to meet demands. ZE trucks were incrementally introduced into the fleet with subsequent model runs. The model was run until the maximum possible number of ZE trucks was reached.

Three target years, 2020, 2025, and 2030, and three vehicle technologies: diesel, natural gas hybrid, and battery electric were considered. Performance attributes for 2020 are based on data from field tests; attributes for 2025 and 2030 are based on most recently available data on expected improvements in the various technologies.

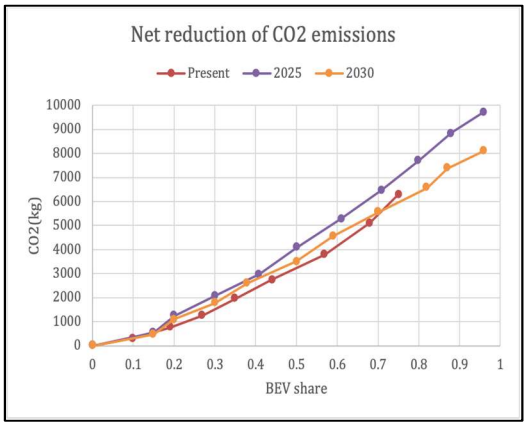
Two case studies were conducted of short haul firms to test the potential penetration of ZEHDTs with more realistic truck activity. The case study data considers both range and charging constraints, as well as the additional effect of the gross vehicle weight restriction.

The simulation and case study research were supplemented with two rounds of interviews and a stated preference survey to gather information on trucking industry perspectives. Interviews were conducted with OEMs as well as drayage firm owners and operators. A market analysis of drayage activity concentrations was also conducted.

Status
This project has been completed and the final report published in December 2020 on the METRANS website:
https://www.metrans.org/research/developing-markets-for-zero-emission-vehicles-in-short-haul-goods-movement.

Results
Results show a clear trade-off between emissions reductions and larger BEV fleet size. In 2020, the maximum possible share of BEVs is 75% and requires a near doubling of the fleet. In 2025 and 2030, the maximum possible share rises to 96%, and the vehicle fleet increases by about one third in 2025 and 20% in 2030. Increased fleet size adds to costs, leading to clear tradeoffs between emissions reductions and drayage costs. Figure 1 compares the net reduction of CO2 for the three target years.

Figure 1: BEV Share and Net CO2 Reductions



Simulation results were used to generate four scenarios: all diesel, all NG hybrid, midpoint ZE, and maximum ZE. Diesel and hybrid trucks have similar range and refueling requirements, so differ only in emissions and costs. Annualized emissions savings relative to diesel were estimated. See Table 1. Max ZE has the greatest emissions net savings for all but NOX in 2020.

Table 1: Net Annualized Emissions Savings

Net Emissions Savings	All NG Hybrid	Midpoint ZE	Max ZE
PM 2.5 (g)			
2020	2350	3525	8075
2025	1175	3150	7525
2030	1175	3275	7525
NOX (kg)			
2020	2725	675	1550
2025	1225	600	1425
2030	1225	625	1425
CO2 (kg)			
2020	1311500	687750	1576500
2025	1160500	1019750	2429500
2030	1040500	880500	2024000

The annualized cost per unit of emissions removed relative to diesel HDTs was estimated. Capital, vehicle operations, and driver costs were included. The all hybrid alternative is the least cost alternative for all emissions and all target years. This is due to the lower operating costs of hybrids and lower emissions relative to diesel. At the same time, the hybrid alternative does not require additional vehicles, and therefore has much lower capital costs than the ZE alternatives. The max ZE alternative generates modest savings in 2030, but of much lower magnitude than the hybrid alternative. Results illustrate the contrast between possible policy objectives. If reducing emissions is the most important objective, ZEHDTs meet that objective, but at very high cost relative to other alternatives.

Benefits

The main benefit of this project is incorporating freight operations into assessments of the market for ZEHDTs in the short-haul market. The project provides a set of findings and recommendations that can provide guidance for policy makers and regulators.

Finding 1: Current state of BEV technology-BE ZEHDTs have limited application in the short haul heavy truck market. *Recommendation*: State / local policy should take into account the full impacts of ZEHDTs on freight operations and costs

Finding 2: NG hybrid near zero vehicles are preferred in the short term. *Recommendation:* State / local policy should be more flexible and consider hybrid technologies as viable near and middle term options for GHG and other emissions reductions

Finding 3: The medium-term market is promising and depends critically on the rate of improvement of battery technology and rate of decline in vehicle price. *Recommendation:* Continue to promote and invest in battery technology improvements

Finding 4: The medium-term market depends on charging infrastructure and energy availability. *Recommendation:* Develop a comprehensive investment plan for public charging stations and identify a funding source

Finding 5: The medium-term market depends on subsidies. *Recommendation*: Develop a comprehensive subsidy and incentive program to promote ZE and near-ZE purchase and use and fund at a sufficiently high level

Project Costs

SCAQMD	$350,000
Caltrans	$126,000
Volvo Research and Education Foundation	$25,000
Majestic Realty	$23,000
Total	**$524,000**

Commercialization and Application

The results of this project can be applied to current and future rulemaking on emissions reductions in the heavy duty vehicle sector. The research should be extended to consider weight limits, a broader set of operating conditions, infrastructure costs and availability and full life cycle costing.

South Coast AQMD Contract #18206 **June 2020**

Assess Air Quality and Greenhouse Gas Impacts of a Microgrid-Based Electricity System in Southern California

Contractor

University of California, Irvine (UCI)

Cosponsors

UCI Advanced Power and Energy Program
National Science Foundation,
Southern California Gas Company

Project Officer

Seungbum Ha

Background

The development of microgrids is gaining attention as a means of increasing the resilience and reliability of the electricity system, reducing criteria pollutant and greenhouse gas emissions of the electricity and transportation sectors, and increasing the deployment of renewable power generation resources in serving the electric load demand. As microgrids become prevalent, capacity for electricity generation, previously outside the basin, will be retired and replaced with new capacity inside of the Southern California Air Basin (Basin). The potential of microgrids to substantially reduce the criteria pollutant emissions in Southern California depend entirely on the design of the microgrids.

Project Objective

This project is the first to explore microgrid design features that facilitate zero emission of both criteria pollutant and greenhouse gasses with a focus on the following three tasks:

Task 1. Commercial, Industrial and Petroleum Refinery Microgrids: Assess fuel cell technology to mitigate pollutant and greenhouse gas emissions.

Task 2. Renewable Fuel Blending: Assess the emissions impacts of renewable fuel blending in the natural gas system.

Task 3. Public Mobility: Compare battery electric buses and hydrogen fuel cell electric buses.

Technology Description

Task 1. Two approaches individually and in combination were considered: 1) greenfield applications where SOFC replace a productive process, e.g., power plant, SMR; and 2) retrofit applications, with MCFC assumed to be placed downstream of exhaust gas streams as a post-combustion system, which would involve every source of emissions. Scenarios were assessed using detailed thermodynamic models to determine the feasibility and performance within the scenario configurations including emission reductions for a given refinery deployment scenario

Task 2. Determining the change in emissions from a fuel composition shift to H2 blends requires assessment of impacted combustion devices. UCI has developed and demonstrated a platform using in-lab testing and numerical modeling to investigate emissions and stabilities with different fuel compositions for combustion equipment and assessed the combustion performance of residential and commercial appliances including cooktop, oven and broiler burners, central forced air furnaces, and water heaters. Numerous aspects complicate a clear understanding of how H2 addition may affect emissions including numerous potential pathways and quantities of H2 production, the size and complexity of the NG system, how the diverse range of end-use sources may be affected, lack of available data, and others.

Task 3. The simultaneous operation of battery electric and hydrogen buses provides a unique opportunity to develop an evaluation framework under consistent conditions. The data collected from the fleet enabled a comprehensive comparison of the two technologies and were used in statistical analysis to assess the performance of ZEBs and assess impact of various factors on overall performance of different bus technologies. A detailed life cycle assessment analysis was done to assess economic and environmental impact of different ZEBs, and a strategy was developed to optimize the technology-mix of the a zero-emission to help transit agencies transition to a zero-emission fleet without impacting their service and routes.

Results

Task 1. Emission reductions were identified for the scenarios in this work scale with the aggressiveness of fuel cell deployment from relatively minor up to 66% of total refinery NO_x for the widespread use of MCFC. When applied to all refineries, the largest

NO_x reductions occur in northern California with lesser impacts in Basin. Emission reductions translate to a range of possible air quality impacts. For an aggressive MCFC deployment, ozone reductions peak at -2.6 ppb. Improvements in $PM_{2.5}$ for summer are substantial, exceeding 8 µg/m^3 in the Basin and occurring in other regions of the state. Similarly, improvements reach 10 µg/m^3 in winter in the Basin. highlighting the importance of VOC emissions in secondary $PM_{2.5}$ formation pathways.

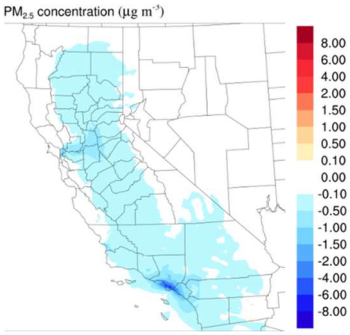


Figure 1: Summer 24-h PM2.5 from Reference Case for Widespread Use of MCFC in California Refineries

Task 2. Projected impacts on state-wide NOx range from a 6% decrease to a 4% increase demonstrating the range of effects from transitions in NG system fuel composition and the lack of current understanding of many important factors that will ultimately determine the real-world effects. Air quality impacts follow suit, e.g., ozone changes vary from -2.4 to +1.6 ppb in the 20% best and worst cases, respectively. Similar impacts are noted for PM2.5 in winter and summer with peak changes in the Central Valley and Basin with similar importance.

Task 3. Results of the study include comparison of total cost of ownership, economic and environmental impacts, and overall assessment of fuel cell electric buses (FCEBs) and battery electric buses (BEBs).

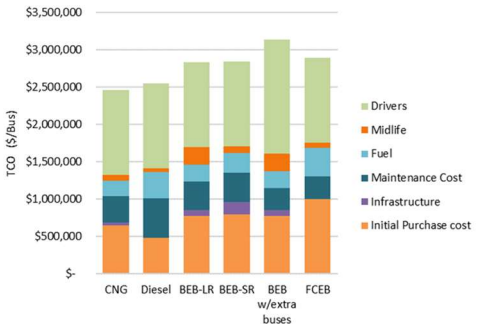


Figure 2: Total Cost of Ownership comparison

Commercialization and Applications

The following are main conclusions from this work:

- Impacts on ozone follow trends for NO_x and are most prominent downwind of refineries in northern California. Peak MD8H reductions range from -2.6 ppb to -0.55 ppb depending on the scenario.
- Impacts on $PM_{2.5}$ are substantial in summer and winter, i.e., potentially exceeding 8 ug/m^3 and 10 ug/m^3 respectively. Peak improvements are in Basin, and reductions occur in the S.F. Bay Area and Central Valley.
- Impacts on total statewide NO_x include 6% decreases to 4% increases demonstrating the wide range of possible impacts depending on blend level, equipment assumptions, and others
- FCEB total cost of ownership is comparable to that of BEB-Long range
- For BEBs, the total cost of ownership is impacted by the pricing strategies and tariffs set by the utility or microgrid
- Results of MCDA indicate that FCEB and BEBs-Long Range (BEB-LR) with plug-in charging are preferred over BEBs-Short Range (BEBs-SR) with on-route charging

Benefits

The use of fuel cell systems at industrial facilities can provide notable improvements in regional levels of ozone and $PM_{2.5}$ which in turn will provide substantial benefits to human health within California. The addition of H2 may also provide important AQ co-benefits to sensitive urban regions. Conversely, care must be taken to avoid AQ worsening in those same areas. the overall criteria pollutant and greenhouse gases are reduced with the deployment of BEBs and FCEBs and has the potential to improve air quality as well as helping mitigate and reduce impacts of climate change.

Project Costs

The cost of the project was $450,000. South Coast AQMD provided $250,000 and $200,000 of match funding was provided by a combination of UCI, the National Science Foundation, and Southern California Gas Company.

South Coast AQMD Contract #17278 **July 2020**

Develop Freight Loading Strategies for Zero-Emissions Heavy-Duty Trucks in Goods Movement

Contractor

University of Southern California (USC)

Cosponsors

National Science Foundation
Volvo Research and Education Foundation

Project Officer

Seungbum Ha

Background

Recent advances in sensing and navigation technologies make it easier to route vehicles from origin to destination based on traffic characteristics obtained from historical and available real time traffic data. Current applications however do not distinguish between different classes of vehicles and associated dynamics which often have a big impact on travel time and traffic flow characteristics. The lack of coordination among different shippers, along with their lack of a coordinated exchange of information makes it difficult to predict changes in travel times as it relates to upcoming freight loads. In general, the current freight transportation system is full of inefficiencies leading to imbalances in traffic with respect to space and time, and these imbalances have significant individual and environmental costs. Information technologies, software and hardware technologies as well as the emergence of battery electric trucks offer a strong potential for dramatic improvements in balancing freight loads in multimodal networks.

Project Objective

The objective of this project is to develop a methodology to reduce inefficiencies in the current freight system by using a centrally coordinated load balancing system to provide routes to users that benefit the overall system. This load balancing system should lead to system and user benefits in terms of mobility and environmental impact for mixed fleets of diesel and zero-emission freight vehicles (ZEFV) as well as taking into consideration concepts such as empty container reuse.

Technology Description

The developed freight load balancing system is based on a co-simulation optimization approach that combines real time traffic simulators with a route optimization algorithm in a feedback configuration as shown in the figure below.

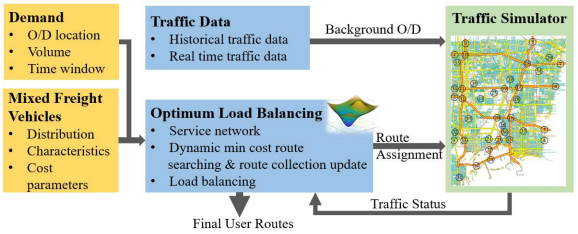


Figure 1: Co-Simulation Optimization Method

The advantage of the proposed approach is that it makes use of available software tools and fast computers to evaluate the impact on travel times of the initially generated optimized load balancing routes and then makes the necessary changes taking into consideration the nonlinear impact of loads on travel time. The impact of loads on travel times is something that current routing systems do not consider which often leads to possible unintended load imbalances. The technology assumes a "system manager" that receives all user requests for route planning and allocates loads to time, space, and mode windows to minimize an overall system cost. The load balancing system is developed for one type of truck (diesel) and was then extended to two type of trucks, diesel and battery electric. The use of mixed fleet of diesel and electric trucks introduces additional constraints and cost criteria. Electric trucks have a higher capital cost, shorter range, and longer refueling time than diesel trucks. The proposed technology is shown to be flexible to include additional freight technologies and concepts such as the empty container reuse that aims to reduce the empty container trips.

Status

The project was officially completed February 2, 2020 with the final report submitted to South Coast AQMD at the end of January 2020.

Results

The proposed centrally coordinated freight load balancing system has potential for improvements in balancing freight loads across the road and rail networks. All simulated scenarios showed consistent improvements in fuel economy and emissions. Electric trucks can be incorporated in the proposed load balancing system despite the added constraints of range and charging times.

Based on models of diesel and electric engines and tests with different speed cycles the electric engines are found to consume less energy than diesel except during congestion. The figures below an example of how fuel consumption and emissions change as the number of electric trucks increases in a heavy traffic scenario.

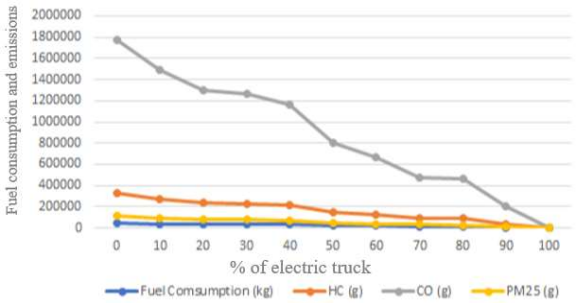


Figure 2a: Reduction of Fuel Consumption and Emissions (HC, CO, PM25) as Percent of Electric Truck

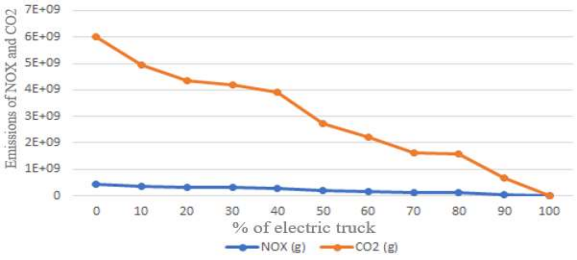


Figure 2b: Reduction of Emissions (NOx, CO2) as Percent of Electric Truck

In a mixed fleet of diesel and electric vehicles the total energy cost without including charging cost decreases as the percentage of electric vehicles increases. Charging, however, during driver working times adds to the overall costs and makes the overall cost higher as the percent of electric trucks increases. The concept of empty container reuse and other technologies and concepts can be easily incorporated in the proposed load balancing approach.

Benefits

A centrally coordinated freight load balancing system can reduce inefficiencies of freight movements in complex surface networks by achieving a better distribution of freight loads in time and space and reducing the overall cost in terms of mobility under various traffic conditions as shown in the figure below.

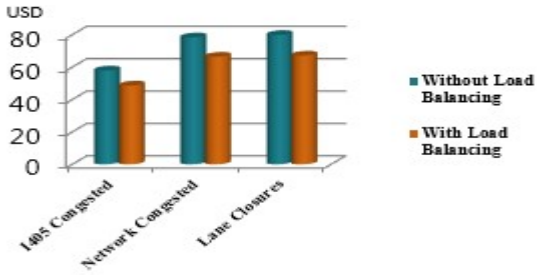


Figure 3: Cost Benefits under Different Conditions

The benefits on fuel consumption and emissions (HC, CO, NOx, CO2, PM25) in the case of diesel trucks gained by load balancing generated using the Environmental Protection Agency model MOVEs are of the order of about 5% under light, 9% under medium traffic conditions and 22% under heavy traffic conditions when compared with no load balancing.

Project Costs

The total project cost was $1,001,000. South Coast AQMD's share was $200,000 with the remaining $801,000 contributed by the National Science Foundation and the Volvo Research and Education Foundation.

Commercialization and Applications

Shippers are very sensitive to costs and, in general, open to new technologies if they can see the benefit. The proposed centrally coordinated freight load balancing system shows the potential benefits of central coordination for freight routing and offers a strong incentive for commercialization.

South Coast AQMD Contract #16200 **April 2020**

Cosponsor Regional Universities for US Department of Energy EcoCAR3 Competition

Contractor

California State University, Los Angeles

Cosponsors

US Department of Energy (DOE)
General Motors (GM)
California State University Los Angeles

Project Officer

Lisa Mirisola

Background

EcoCAR 3 is a four-year advanced plug-in hybrid passenger vehicle design-and-build competition sponsored by the United States Department of Energy (DOE) and General Motors and managed by Argonne National Laboratory. Of the 16 North American universities chosen to participate, California State University of Los Angeles (Cal State LA) is the only competitor from California. In keeping up with Los Angeles history and current needs, the team elected to design a police themed vehicle with a pursuit capability for this EcoCAR 3 competition.

Project Objective

Each team redesigned a stock gasoline Chevrolet Camaro into a hybrid vehicle that reduced the environmental impact while retaining performance, safety, and consumer appeal. The cornerstone goal of the program is the creation of the next generation of engineers by providing them with real-world research experience in the development of extremely complex advanced vehicle technologies.

Technology Description

The Cal State LA team designed a Parallel Post Transmission Plug-in Hybrid Electric Vehicle based on a 2016 V6 Chevrolet Camaro.

The engine selected was the GM 182 Hp 2.4L Ecotec engine that utilizes renewable ethanol fuel for reduced overall emissions. The 135 kWh UQM Power Phase electric motor used was also deployed for regenerative braking. The electric motor is fed from a 12.6 kWh, battery pack. A new control system was designed to control the hybrid functionality and the new components.

Status

Year 4 of the competition was dedicated to completing the design-and-build project resulting in a vehicle in performing condition. This included updating multiple systems including installation of the air conditioning and on-board battery charger. In addition to addressing the technical development, the vehicle was appropriately dressed in the police "uniform", as in Figure 1.

Figure 1. Fully Assembled Cal State LA Police Vehicle

Results

The engineering subteams throughout the year produced eleven technical reports and presentations recording the design and vehicle integration updates. In addition to working on all vehicle systems, the engineering vector was applied to the design of the control software and autonomous driving technology.

Two graduated students working in the vehicle controls area authored two papers: "MPC-Based Power Management Strategy to Reduce Power Loss in Energy Storage System of HEV – Improved Model" and "Neuroevolution Based Optimization of Hybrid Transmission Shift Points". These papers were presented at the 6th Annual IEEE SusTech Conference 2018 in Long Beach, CA.

The communications team produced eleven reports and presentations, performed outreach events, created videos and blogs and updated the team website and social media. The EcoCAR team

organized two workshops for about 150 -200 middle-school students. Throughout the year the team hosted several hundred students from local schools in the EcoCAR garage. Ethnically diverse members shared their life experiences to inspire students to pursue a college education.

In addition, the EcoCAR team has participated in numerous public outreach events where members displayed the vehicle and engaged the public.

Figure 2. Cal State LA Team Conducts a Quiz on Hybrid Cars to Los Angeles Sheriff Department Officers, Diamond Bar, CA, April 2018

This included the Car Classic Auto Show hosted by the Art Center College of Design held at the Angel City Brewery, the Diamond Bar City Birthday Fair (see Figure 2), and the final competition at the Fontana Speedway.

Benefits

About forty students participated on the team in Year 4. Several students graduated, securing jobs in the automotive and high-tech sectors, including five new engineers at General Motors. Participation in EcoCAR has resulted in opening doors to team participants from disadvantaged communities such as East Los Angeles and providing them with the opportunity to obtain employment in high-pay engineering jobs at such coveted giants as GM, Boeing, and Northrop Grumman

In recognition of the team's outreach and public education accomplishments, Cal State LA has received the 2018 Clean Air Award from South Coast AQMD (see Figure 3).

Figure 3. Cal State LA EcoCAR Team Accepts the Clean Air Award, October 2018

Project Costs

Project Partner	Funding
US DOE, Argonne National Lab, CARB	$200,000
Chevrolet Camaro: GM **Sponsorship Training:** MathWorks, Siemens NX, and Autonomie, **Components/Software:** General Motors, MathWorks, Freescale, BOSCH, ETAS, Siemens, GKN Driveline, Woodward, EnerDel, Ricardo, New Eagle, and A123 Systems.	$250,000
CSULA	$250,000
South Coast AQMD	$100,000
Total (approximate)	$800,000

Commercialization and Applications

The police-oriented vehicle fuses the unique law enforcement needs and plug-in hybrid capabilities. Hybrid functionality saves fuel and provides financial savings to police departments. It has three distinct modalities: stakeout mode – the engine is off when parked, with the air conditioning and equipment run via battery pack; patrol mode – the car is driven in full electric mode and releases no emissions, and lastly, pursuit mode – both its electric motor and its engine are operating, optimizing energy consumption, even during high-speed chases.

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

Criteria Pollutant Emission Reduction potential continues to receive the highest priority for projects that facilitate the 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 is able to leverage funds available through several state and federal programs, as well as overall health benefits in reducing exposure to Ozone and PM2.5, especially along 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 assessed importance of a particular technology. Some key metrics that can be considered include Infrastructure Constructability that would evaluate the potential of fuel or energy for the technology and readiness of associated infrastructure, Technology Readiness that includes not only the research and development of the technology, but potential larger scale deployments that consider near-term implementation duty and operational compatibility for the 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 the technology research, development, demonstration and deployment projects. Therefore, in an effort to accelerate the demonstration and deployment, especially some pre-commercialization technologies, incentive programs such as those available from local, state and federal programs are key, but may be underfunded for larger scale deployments.

Staff has developed an approach to evaluating the 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 state 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 it is noted that 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 Poor to Good for Technology Maturity & 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 Trucks	◓	◓	●	◓	○	○	◒	◒	●
Medium- and Heavy-Duty Buses	●	◓	●	◓	○	◒	○	◒	◒
Light-Duty Vehicles	◓	◓	●	◓	◓	◓	◓	○	◒
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 emissions Heavy-Duty Engines	◓	◓	◓	●	○	○	●	◓	○
Alternative Fuel Medium- and Heavy-Duty Vehicles	◓	◓	◓	●	◓	◓	●	◓	○
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

AB—Assembly Bill
AC—absorption chiller
ADA—American with Disabilities Act
AER—all-electric range
AFRC—air/fuel ratio control
AFVs—alternative fuel vehicles
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
BEB—battery electric bus
BET—battery electric truck
BEV—battery electric vehicle
BSNOx—brake specific NOx
BMEP – brake mean effective pressure
BMS—battery management system
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
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
CPUC—California Public Utilities Commission
CRDS—cavity ring-down spectroscopy
CRT—continuously regenerating technology
CSC—city suburban cycle
CVAG—Coachella Valley Association of Governments
CWI—Cummins Westport, Inc.
CY—calendar year
DC—direct connection
DCFC—direct connection fast charger
DCM—dichloromethane
DEF—diesel exhaust fluid
DEG—diesel equivalent gallons
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
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
EGR—exhaust gas recirculation
EIA—Energy Information Administration
EIN—Energy Independence Now
EMFAC—Emission FACtors
EPRI—Electric Power Research Institute
E-rEV—extended-range electric vehicles
ESD—emergency shut down
ESS—energy storage system
EV—electric vehicle
EVSE—electric vehicle supply equipment
FCEB – fuel cell electric bus
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

LIST OF ACRONYMS (cont'd)

GGE—gasoline gallon equivalents
GGRF—Greenhouse Gas Reduction Relief Fund
GHG—greenhouse gas
GNA—Gladstein, Neandross & Associates, LLC
GPU—gas processing unit
GREET- Greenhouse Gasses, Regulated Emissions and Energy Use in Transportation
GTL—gas to liquid
GVWR—gross vehicle weight rating
H&SC—California Health and Safety Code
HCCI—Homogeneous Charge Combustion Ignition
HCNG—hydrogen-compressed natural gas (blend)
HD – heavy duty
HDDT—highway dynamometer driving schedule
HD-FTP—Heavy-Duty Federal Test Procedure
HD-OBD—heavy-duty on-board diagnostics
HHDDT—heavy heavy-duty diesel truck schedule
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
ICU—inverter-charger unit
ICTC—Interstate Clean Transportation Corridor
IVOC—intermediate volatility organic compound
kg—kilogram
LACMTA—Los Angeles County Metropolitan Transit Authority
LADOT—City of Los Angeles Dept. of Transportation
LADWP—Los Angeles Department of Water and Power
LCA—life cycle assessment
LCFS—Low Carbon Fuel Standard
Li—lithium ion
LIMS—Laboratory Information Management System
LLC—low load cycly
LLNL—Lawrence Livermore National Laboratory
LNG—liquefied natural gas
LO-SCR— light-off selective catalytic reduction
LPG—liquefied petroleum gas or propane
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
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
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
NHTSA—Natural Highway Traffic Safety Administration
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
NSPS—new source performance standard
NSR—new source review
NZ—near zero
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

LIST OF ACRONYMS (cont'd)

PAH—polyaromatic hydrocarbons
PbA—lead acid
PCM—powertrain control module
PEMFC—proton exchange membrane fuel cell
PEMS—portable emissions measurement system
PEV—plug-in electric vehicle
PHET—plug-in hybrid electric truck
PHEV—plug-in hybrid vehicle
PM—particulate matter
PM2.5—particulate matter ≤ 2.5 microns
PM10—particulate matter ≤ 10 microns
POS—point of sale
ppm—parts per million
ppb—parts per billion
PSI—Power Solutions International
PTR-MS—proton transfer reaction-mass spectrometry
RD&D—research, development and demonstration
RDD&D (or RD3)—research, development, demonstration and deployment
RFP—Request for Proposal
RFS—renewable fuel standards
RI—reactive intermediates
RMC-SET— ramped modal cycle supplemental emissions test
RNG—renewable natural gas
RTP/SCS—Regional Transportation Plan/Sustainable Communities Strategy
SAE—Society of Automotive Engineers
SB—Senate Bill
SCAB—South Coast Air Basin or "Basin"
SCAQMD—South Coast Air Quality Management District
SCFM—standard cubic feet per minute
SCE – single cylinder engine
SCE—Southern California Edison
SCR—selective catalytic reduction
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
SOAs—secondary organic aerosols
SoCalGas—Southern California Gas Company (A Sempra Energy Utility)
SOFC – solid oxide fuel cells
SULEV—super ultra-low emission vehicle
SUV—sports utility vehicle
TAO—Technology Advancement Office
TAP— (Ports') Technology Advancement Program
TC—total carbon
TEMS—transportable emissions measurement system
THC—total hydrocarbons
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
$\mu g/m^3$—microgram per cubic meter
ULEV—ultra low emission vehicle
UPS—United Postal Service
U.S.—United States
U.S.EPA—United States Environmental Protection Agency
V2B—vehicle-to-building
V2G—vehicle-to-grid
V2G/B—vehicle-to-building functionality
VMT—vehicle miles traveled
VOC—volatile organic compounds
VPP—virtual power plant
WGS – water gas shift
WVU—West Virginia University
ZEB – zero-emission bus
ZECT—Zero Emission Cargo Transport
ZEV—zero emissions vehicle