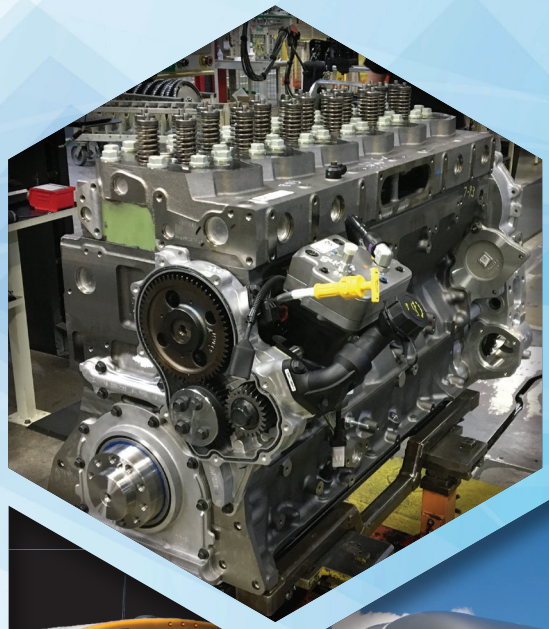
March 2019

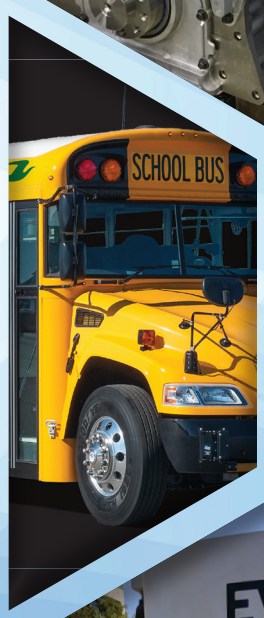
Clean Fuels Program

2018 Annual Report & 2019 Plan Update

Technology Advancement Office

Leading the way to zero and near-zero emission technologies





South Coast AQMD

South Coast
Air Quality
Management District

Cover Photo Credits

Top Row:

- Cummins' ultra-low emissions 12-liter natural gas engine for on-road heavy-duty vehicles
- Pre-pilot Hyster® 1150-CH electric container top handler being demonstrated at the ports
- Hyundai Nexo fuel cell SUV fueling up at SCAQMD's Diamond Bar hydrogen station

Middle Row:

- Propane Bluebird school bus
- Daimler Freightliner Class 8 electric truck, part of their Class 6-8 battery electric truck and fast charging demonstration project
- Volvo Class 8 truck with all electric range developed under GGRF, precursor to electric truck development under the ZANZEFF-funded Volvo LIGHTS project
- Mobile monitoring van deployed by SCAQMD contractor FluxSense for the Multiple Air Toxics Exposure Study V (MATES V)

Bottom Row:

- EVgo fast charging unit at SCAQMD's Diamond Bar headquarters
- TransPower Class 8 CNG hybrid truck developed under the Zero Emission Cargo Transport (ZECT) demonstration

South Coast Air Quality Management District

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Council Member, City of Lake Forest
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Wayne Nastri

*Technology Committee Members (as of 2/15/19) **Technology Committee Chairman

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This year's Annual Report and Plan Update
are dedicated to

Dr. Fritz R. Kalhammer

Founding Member of the SB 98 Clean Fuels Advisory Group
Serving from 1999 to 2018,
As a scientific community representative.

Dr. Kalhammer has been an independent consultant in energy and process technology since 1995, prior to which he worked at EPRI and served on the National Research Council Committee. A native of West Germany, he recently relocated permanently to Germany and resigned from the Advisory Group. We thank him for his nearly 20 years of dedicated service and input to our program.

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South Coast Air Quality Management District

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EXECUTIVE SUMMARY

Introduction

The South Coast Air Quality Management District (SCAQMD) 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 all of the South Coast Air Basin plus 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.

Last year marked the 30th year of the Clean Fuels Program. It was in 1988 that 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 SCAQMD's effort to achieve the significant NOx reductions called for in the 2016 AQMP because it affords the SCAQMD the ability to fund research, development, demonstration and accelerated deployment of clean fuels and transformative transportation technologies.

Last year also marked another significant milestone for TAO, the 20th year of the Carl Moyer Program. The two programs produce a unique synergy, with the Carl Moyer Program (and other incentive programs) providing the necessary incentives to push market penetration of the technologies developed and demonstrated by the Clean Fuels Program. This synergy enables the SCAQMD to act as a leader in both technology development and commercialization efforts targeting reduction of criteria pollutants.

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, natural gas engines and infrastructure, battery electric vehicles, plug-in hybrid electric vehicles and related fueling infrastructure including renewable fuels. A key strategy of the Program, which allows significant leveraging of the Clean Fuels funding (typically $3-$4 to every $1 of Clean Fuels funds), is its public-private partnership with private industry, technology developers, academic institutions, research institutions and government agencies. From 1988 to 2018, the Clean Fuels Program leveraged $321 million into $1.5 billion in projects.

While SCAQMD aggressively seeks to leverage funds to accomplish more with every dollar, it also strives to be a leader in technology development and commercialization to accelerate the reduction of criteria pollutants. As a result, the TAO Clean Fuels Program has traditionally supported a portfolio of technologies, in different stages of maturity, to provide a continuum of emissions reductions and health benefits over time. This approach provides the greatest flexibility and enhances the region's chances to achieve the National Ambient Air Quality Standards (NAAQS).

California Code, 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, the cost-effectiveness of emissions 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 district. The

Legislature recognized the need for flexibility that allows focus on a broad range of technology areas, including cleaner fuels, which can help SCAQMD in achieving its clean air goals.

H&SC 40448.5.1 requires the SCAQMD to prepare, and submit to the Legislative Analyst each year, 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, essentially re-calibrating the technical emphasis of the Program. Preliminary review and comment by SCAQMD's Governing Board, advisory groups, technical experts and other interested parties are incorporated into the final Plan Update, along with the Clean Fuels Annual Report, which are due to the Legislative Analyst by March 31 of every year.

Setting the Stage

The overall strategy of TAO's Clean Fuels Program is based, in large part, on emissions reduction technology needs identified in the Air Quality Management Plan (AQMP) and the SCAQMD Governing Board's directives to protect the health of the approximately 17 million residents (nearly half the population of California) in the South Coast Air Basin (Basin). The AQMP, which is updated approximately every four years, is the long-term regional "blueprint" that relies on fair-share emissions reductions from all jurisdictional levels (e.g., federal, state and local). The 2016 AQMP, which was adopted by the SCAQMD Governing Board in March 2017, is composed of stationary and mobile source emissions 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 emissions 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 lower-emitting mobile and stationary advanced technologies in the Basin to achieve health-based air quality standards. The 2016 AQMP projects that an approximate 45 percent reduction in NOx is required by 2023 and an additional 55 percent reduction by 2031. Figure 1 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 SCAQMD is currently only one of two regions in the nation designated as an extreme ozone nonattainment area (the other is San Joaquin Valley). 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 especially noteworthy because in the South Coast Air Basin the primary driver for ozone formation is NOx emissions, and mobile sources contribute approximately 88 percent of the NOx emissions in this region, as shown in Figure 2. 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 ($\mu g/m^3$)].

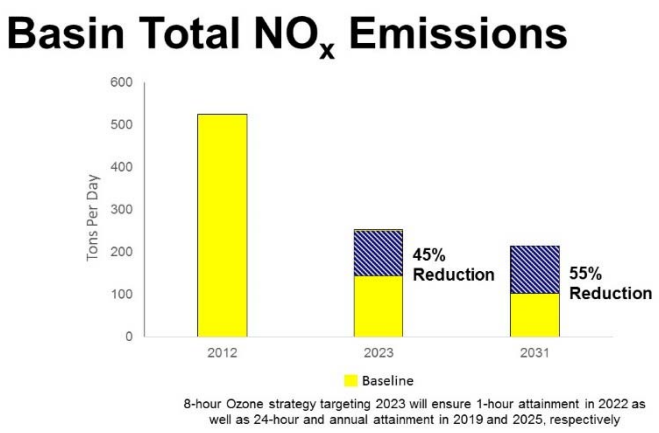


Figure 1: Total NOx Reductions Needed

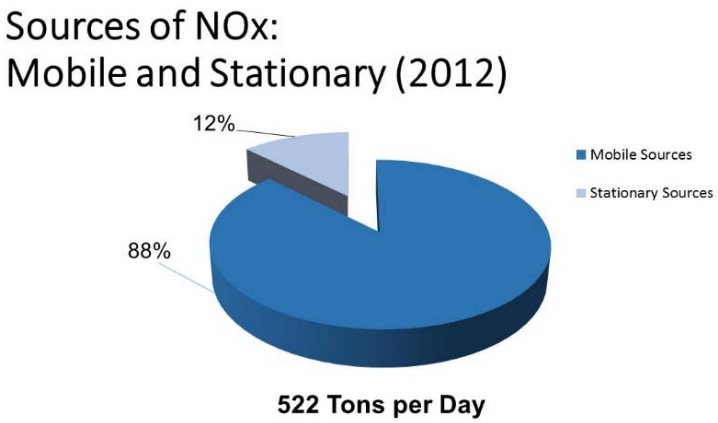


Figure 2: Sources of NOx 2012 Base Year

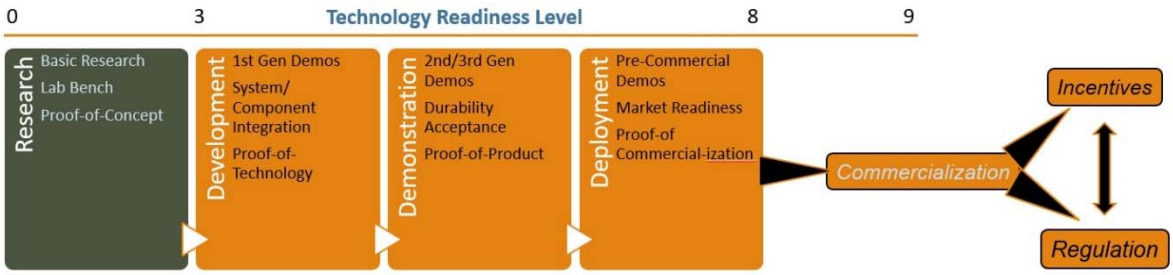
For the first time, the 2016 AQMP identified a means to achieving the federal standards through regulations and heavy incentives for near-zero and zero emissions technologies that are commercial or nearing commercialization. This strategy however, requires a national, lower heavy-duty truck emissions standard, significant additional financial resources, and accelerated fleet turnover on a massive scale.

Clean Fuels Program

Due to these daunting challenges to reduce NOx and PM2.5 to meet health-based air quality standards, the Clean Fuels Program is more important than ever to encourage and accelerate the advancement and commercialization of clean fuel and transportation technologies, especially with Original Equipment Manufacturers (OEMs).

Figure 3 provides a conceptual design of the wide scope of the Clean Fuels Program and the relationship with incentive programs. As mentioned in the Core Technologies section (page 6), various stages of technology projects are funded not only to provide a portfolio of emissions technology choices but to achieve emissions reduction benefits in the nearer as well as over the longer term. The SCAQMD 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 brief summary of the contents of the 2018 Clean Fuels Program Annual Report and 2019 Plan Update. Every Plan Update is reviewed by two advisory groups--the Clean Fuels Advisory Group and the Technology Advancement Advisory Group. These two groups meet approximately every six months to provide expert analysis and feedback on potential projects and areas of focus. They are also briefed and comment on the accomplishments of the prior year in the context of the annual report. The membership of these two bodies is in Appendix A. For more information on this review process, refer to Program Review (page 2). Further review of the Clean Fuels Program is detailed under the Strategy and Impact section (page 15).

2018 Annual Report

In CY 2018, the SCAQMD Clean Fuels Program executed 74 new contracts, projects or studies and modified 1 continuing project adding dollars toward research, development, demonstration and deployment (RD^3) projects as well as technology assessment and transfer of alternative fuel and clean fuel technologies.

Table 2 (page 32) lists the 75 projects or studies, which are further described in this report. The SCAQMD Clean Fuels Program contributed nearly $27 million in partnership with other governmental organizations, private industry, academia and research institutes, and interested parties, with total project costs of more than $85 million. The $27 million includes $12.3 million recognized into the Clean Fuels Fund as pass-through funds from project partners to facilitate project administration by the Clean Fuels Program. This $12.3 million, which is about double the typical amount recognized into Clean Fuels on an average year, included $3.1 million from a U.S. EPA Airshed Grant for near-zero CNG school buses, with the remaining incoming revenue from a U.S. EPA DERA Grant, CEC and the Ports as stakeholder partners. Table 3 (page 35) provides information on this outside funding received into the Clean Fuels Fund. Additionally, in CY 2018, the Clean Fuels Program continued to leverage other outside funding opportunities, securing new awards totaling $54.5 million from federal, state and local funding opportunities. Table 4 (page 35) provides a comprehensive summary of these federal, state and local revenues awarded to the SCAQMD during CY 2018. Similar to the last couple of years, the significant project scope of a few key contracts executed in 2018 resulted in higher than average leveraging of Clean Fuels dollars. Typical leveraging is $3-$4 for every $1 in Clean Fuels funding. In 2017, leveraging was more than $1:$6; in 2018, SCAQMD continued this upward trend with nearly $6 leveraged for every $1 in Clean Fuels funds. Leveraging dollars and aggressively pursuing funding opportunities are more important than ever given the magnitude of needed funding identified in the 2016 AQMP to achieve federal ozone air quality standards.

The projects or studies executed in 2018 included a diverse mix of advanced technologies. The following core areas of technology advancement for 2018 executed contracts (in order of funding percentage) include:

1. 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);
2. Engine Systems/Technologies (emphasizing alternative and renewable fuels for truck and rail applications);
3. Fueling Infrastructure and Deployment (predominantly natural gas and renewable fuels);
4. Technology Assessment and Transfer/Outreach;
5. Fuel/Emissions Studies;
6. Hydrogen and Mobile Fuel Cell Technologies and Infrastructure; and
7. Emissions Control Technologies.

The pie chart on page 30 shows the distribution by percentage of executed agreements in 2018 across these core technologies.

During CY 2018, the SCAQMD supported a variety of projects and technologies, ranging from near-term to long-term RD^3 activities. This "technology portfolio" strategy provides the SCAQMD 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 75 executed contracts and projects, 21 RD[3] projects or studies and 24 technology assessment and transfer contracts were completed in 2018, as listed in Table 5 (page 54). Appendix C comprises two-page summaries of the technical projects completed in 2018. As of January 1, 2019, 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, 2019, after approval by the SCAQMD Governing Board.

2019 Plan Update

Every year, staff re-evaluates the Clean Fuels Program to develop a Plan Update based on a reassessment of the technology progress and direction for the agency. The Program continually seeks to support the development and deployment of lower-emitting technologies with an increasing collaboration with OEMs. The design and implementation of the Program Plan must balance the needs in the various technology sectors with technology readiness, emissions reduction potential and cofunding opportunities. As the state continues to focus a great deal of its attention to climate change and petroleum reduction goals, the SCAQMD has necessarily remained committed to developing, demonstrating and commercializing technologies that reduce criteria pollutants, specifically NOx and toxic air contaminants (TACs). Fortunately, many, if not the majority, of these technologies that address the Basin's need for NOx and TAC reductions also garner reductions in greenhouse gases (GHG) and petroleum use. Due to these "co-benefits," the SCAQMD has been successful in partnering with the state, which allows the Clean Fuels Program to leverage its funding extensively.

To identify technology and project opportunities where funding can make a significant difference in deploying progressively cleaner technologies in the Basin, the SCAQMD employs a number of outreach and networking activities. These activities range from close involvement with state and federal collaboratives, partnerships and industrial coalitions, to the issuance of Program Opportunity Notices to solicit project ideas and concepts as well as issuance of Requests for Information (RFIs) to determine the state of various technologies and the development and commercialization challenges faced by those technologies. Potential development, demonstration and certification projects resulting from these outreach and networking activities are included conceptually within the Draft 2019 Plan Update.

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

- reducing emissions from port-related activities, such as cargo handling equipment and container movement technologies, including demonstration and deployment of zero emissions drayage trucks;
- developing and demonstrating ultra-low emissions liquid fuel larger displacement engines and zero emissions heavy-duty vehicles;
- developing, demonstrating and deploying advanced (increased efficiency) natural gas engines and vehicles as well as near-zero and zero emissions technologies for high horsepower applications;
- mitigating criteria pollutant increases 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 hybrid) technologies across light-, medium- and heavy-duty platforms; and
- establishing large-scale hydrogen refueling and EV charging infrastructures to help accelerate the introduction of zero emissions vehicles into the market.

Table 6 (page 71) lists the potential projects across nine core technologies by funding priority:

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

These potential projects for 2019 total $16.9 million, with anticipated leveraging of more than $4 for every $1 of Clean Fuels funding for total project costs of $73.7 million. Some of the proposed projects may also be funded by revenue sources other than the Clean Fuels Program, especially VOC and NOx mitigation and incentive projects.

CLEAN FUELS PROGRAM
Background and Overview

Program Background

The South Coast Air 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 all of the South Coast Air Basin plus small portions of the Mojave Desert and Salton Sea Air Basins, is home to approximately 17 million people (nearly half the population of California). Due to these confluence of factors which present unique challenges, the state legislature enabled the SCAQMD to implement the Clean Fuels Program to accelerate the implementation and commercialization of clean fuels and advanced mobile source technologies.

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 emissions 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 district. The Legislature recognized the need for flexibility that allows focus on a broad range of technology areas, including cleaner fuels, which can help SCAQMD in achieving its clean air goals.

Last year marked the 30th year of the Clean Fuels Program. It was in 1988 that 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 SCAQMD's effort to achieve the significant NOx reductions called for in the 2016 AQMP. From 1988 to 2018, the Clean Fuels Program leveraged $321 million into $1.5 billion in projects. This approach has enabled the SCAQMD to historically leverage public funds with outside investment in a ratio of about $4 of outside funding to every dollar of Clean Fuels funding.

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 SCAQMD 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 SCAQMD 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 SCAQMD'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 SCAQMD;
3. A description of projects funded by the SCAQMD, 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 SCAQMD 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 helps review the Clean Fuels Program every year.

Program Review

In 1990, the SCAQMD initiated an annual review of its technology advancement program by an external panel of experts. That external review process has evolved, in response to SCAQMD policies and legislative mandates, into two external advisory groups. The Technology Advancement Advisory Group (one of six standing Advisory Groups that make up the SCAQMD 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 SCAQMD 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 SCAQMD Governing Board. Also in 1999, in light of the formation of the SB 98 Clean Fuels Advisory Group, the SCAQMD 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 SCAQMD Board while changes to the Technology Advancement Advisory Group are reviewed by the SCAQMD 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 will be considered by the SCAQMD Board and its Technology Committee, respectively, as part of consideration of the 2018 Annual Report and 2019 Plan Update. The current members of the SB 98 Clean Fuels Advisory Group and Technology Advancement Advisory Group are listed in Appendix A, with proposed changes duly noted, subject to either SCAQMD 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 SCAQMD Board; 5) a public hearing of the Annual Report and Plan Update before the full SCAQMD 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 & Clean Fuels

Achieving federal and state clean air standards in Southern California will require emissions reductions from both mobile and stationary sources beyond those expected using current technologies. The need for advanced mobile source technologies and clean fuels is best illustrated by Figure 1 below, which identifies just how far NOx emissions must be reduced to meet federal standards by 2023 and 2031.

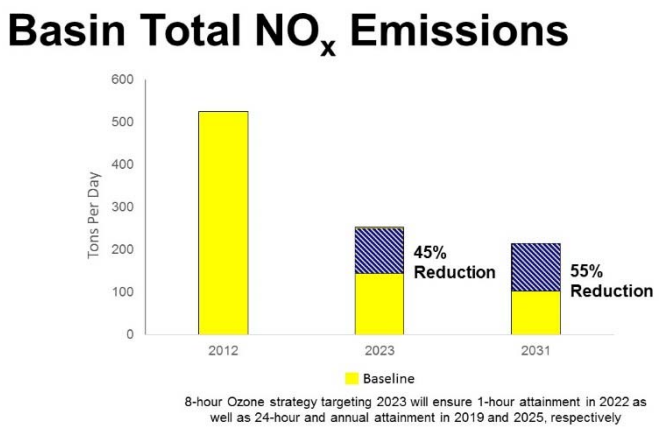


Figure 1: Total NOx Reductions Needed

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. EPA, are projected to require additional long-term control measures for both NOx and VOC. The 2016 AQMP's estimate of needed NOx reductions will require the SCAQMD Clean Fuels Program to encourage and accelerate advancement of clean transportation technologies that are used as control strategies in the AQMP. Of note is another significant milestone in 2018 for TAO, the 20th year anniversary of the Carl Moyer Program. The two programs produce a unique synergy, with the Carl Moyer Program (and other incentive programs) providing the necessary incentives to push market penetration of the technologies developed and demonstrated by the Clean Fuels Program. This synergy enables the SCAQMD to act as a leader in both technology development and commercialization efforts targeting reduction of criteria pollutants. Health studies also indicate a greater need to reduce NOx emissions and toxic air contaminant emissions. For example, the goal of SCAQMD'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 2017, SCAQMD 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 typically emitted or converted from vehicle exhaust, and the carcinogenic risk from exposure of air toxics.

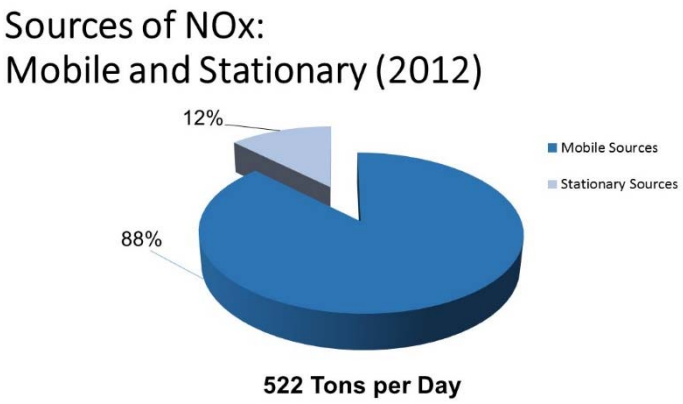


Figure 2: Sources of NOx 2012 Base Year

In the South Coast Air Basin, the primary driver for ozone formation is NOx emissions, and mobile sources contribute approximately 88 percent of the NOx emissions in this region, as shown in Figure 2. Given this contribution, significant cuts in pollution from these sources are needed, therefore the proposed mobile source strategy calls for establishing requirements for cleaner technologies (both near-zero and zero) and deploying these technologies into the fleet, requiring cleaner and renewable fuels, and ensuring continued clean performance in use.

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 SCAQMD's jurisdiction; to reduce long-term dependence on petroleum-based fuels; and to support a more sustainable energy future. Conventional strategies and traditional supply and consumption need to be retooled in order to achieve the federal air quality goals. To help meet this need for advanced, clean technologies, the SCAQMD Board continues to aggressively carry out the Clean Fuels Program and promote alternative fuels through its Technology Advancement Office.

The Clean Fuels Program is intended to assist in the accelerated development and deployment of progressively lower-emitting technologies and fuels through innovative public-private partnership. As previously noted, since its inception, SCAQMD's TAO has cofunded projects in cooperative partnerships with private industry, technology developers, academic and research institutions and local, state and federal agencies. In 2018, with projects initiated with two of the largest heavy-duty truck OEMs on electric trucks, this process is well underway to not only demonstrating these technologies with local fleets, but to scale the commercialization of these technologies.

The following sections describe program funding, provide a 2018 overview and describe core technologies of the Clean Fuels Program.

Program Funding

The Clean Fuels Program is established under California 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 Program is funded through a $1 fee on motor vehicles registered in the SCAQMD. 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 SCAQMD. This revenue is typically about $13.5 million and $350,000, respectively, every year. For CY 2018, the funds available through each of these mechanisms were as follows:

- Mobile sources (DMV revenues) $13,644,642
- Stationary sources (emission fee surcharge) $344,198

The SCAQMD Clean Fuels Program also receives grants and cost-sharing revenue contracts from various agencies, on a project-specific basis, that supplement the SCAQMD program. Historically, such cooperative project funding revenues have been received from CARB, the CEC, the U.S. EPA, 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 (page 35) lists the supplemental grants and revenues totaling $12.3 million for contracts executed in CY 2018.

Table 4 (page 35) lists the federal and state revenue totaling nearly $54.5 million awarded to the SCAQMD in 2018 for projects that will be part of the overall Clean Fuels Program's RD^3 efforts, even if for 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 SCAQMD. This indirect source is the cost-sharing provided by private industry and other public and private organizations. Historically, the Technology Advancement Office has been successful in leveraging its available public funds with $3 to $4 of outside funding for each $1 of SCAQMD funding. For 2018, the Clean Fuels Program leveraged each $1 to nearly $6 of outside funding. Similar to last year, this atypical leverage was the result of a few key contracts with significant project scopes executed in 2018, such as the $31 million project with Daimler Trucks North America, the Southern California Sustainable Freight demonstrations, and the opposed piston engine development project with CALSTART funded in large part by CARB (see the Project Summaries by Core Technologies for more information on these key projects, as well as the project highlights in the Strategy and Impact section starting on page 16). Through these public-private partnership, the SCAQMD 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 SCAQMD aggressively seeks leverage funds to accomplish more with every dollar, it also strives to be a leader in technology development and commercialization in an effort 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 the magnitude of additional funding identified in the 2016 AQMP to achieve federal ozone air quality standards. The SCAQMD'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 2018 are listed in Table 1 (page 16).

2018 Overview

This report summarizes the progress of the SCAQMD Clean Fuels Program for CY 2018. The SCAQMD Clean Fuels Program cost-shares projects to develop and demonstrate low, near-zero and zero emissions clean fuels and advanced technologies, to push the state-of-the-technology, and to promote commercialization and deployment of promising or proven technologies in Southern California. 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 SCAQMD Clean Fuels Program in CY 2018. During the period between January 1 and December 31, 2018, the SCAQMD executed 74 new contracts/agreements, projects or studies and modified 1 continuing project adding dollars during CY 2018 that support clean fuels and advanced zero, near-zero and low emission technologies. The SCAQMD Clean Fuels Program contribution for these projects was approximately $27 million, inclusive of $12.3 million received into the Clean Fuels Fund as cost-share for contracts executed in this reporting period. Total project costs exceed $85 million. These projects 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, page 35), but also funds awarded to the SCAQMD for projects that fall within the scope of the Clean Fuels Program's RD^3 efforts but may have been recognized (received) in another special revenue fund for financial tracking purposes ($54.5 million in 2018, see Table 4). Notably, the SCAQMD was awarded $44 million by CARB as project partner with Volvo on their Low Impact Green Heavy Transportation Solutions (LIGHTS) Project, which has a total project cost of over $100 million and will advance and hopefully commercialize electric truck technology. More details on this financial summary can be found later in this report. The SCAQMD will continue to pursue federal, state and private funding opportunities in 2019 to amplify leverage, while acknowledging that support of a promising technology is not contingent on outside cost-sharing and affirming that SCAQMD will remain committed to being a leader 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 of 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/Fuel Cell Technologies and Infrastructure (especially large-scale refueling facilities)
- Electric/Hybrid Vehicle Technologies and Infrastructure (emphasizing electric and hybrid electric trucks and container transport technologies with zero emission operation)
- Engine Systems/Technologies (emphasizing heavy-duty alternative and renewable fuel engines for truck and rail applications)
- Fueling Infrastructure and Deployment (predominantly natural gas and renewable fuels)
- Fuel and Emissions Studies
- Stationary Clean Fuels Technologies
- Emission Control Technologies
- Health Impacts Studies, and
- Technology Assessment and Transfer/Outreach

At its January 2019 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 2019.

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

1. Low, near-zero and zero 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 SCAQMD 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 SCAQMD program is significant, national and international activities affect the direction of technology trends. As a result, the SCAQMD program must be flexible in order to leverage and accommodate these changes in state, national and international priorities. Nonetheless, while the state and federal governments have in recent years turned a great deal of their attention to climate change, SCAQMD has remained committed to developing, demonstrating and commercializing near-zero and 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 SCAQMD has been successful in partnering with the state and federal government. Even with the leveraged funds, the challenge for the SCAQMD 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 SCAQMD will need to continue to employ a number of outreach and networking activities as well as evaluate new ways to expand these activities. Typical activities range from intimate involvement with state and federal collaboratives, partnerships and industrial coalitions, to the issuance of Program Opportunity Notices to solicit project ideas and concepts as well as the issuance of Requests for Information to determine the state of various technologies and the challenges faced by those technologies for commercialization. While employing a number of creative outreach and networking activities to try to overcome these challenges, SCAQMD's TAO annually develops a comprehensive plan to encourage and accelerate the development and demonstration of cleaner technologies. Every year TAO staff re-evaluates the Clean Fuels Program to develop a comprehensive plan (referred to as the 2019 Plan Update within this document) to essentially re-assess the technology progress and direction for the agency.

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 power-trains 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 on recent years has been on near-zero and zero emission technologies 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 SCAQMD 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.

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 SCAQMD programs that meet both the funding constraints as well as 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 numerous others have plans to commercialize their own in the near future. 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 production of a plug-in fuel cell model GLC for 2018, with U.S. availability approximately late 2019. 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 2018, partially funded by SCAQMD for those in our region, there are four non-retail and 39 retail operational in California, but most if not all 65 are expected to be operational by the end of 2019 with capacity for more than 10,000 fuel cell vehicles. AB 8 also requires CARB to annually assess current and future FCVs and hydrogen stations in the marketplace. *The Joint Agency Staff Report on Assembly Bill 8: 2018 Annual Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California*[1] released in July 2018 reporting on 2018 findings states that there were 4,411 fuel cell vehicles registered in California by May 2018. However, CARB's 2017 Annual Evaluation projects 13,400 FCEVs in California by 2020 and 37,400 by the end of 2023. Additionally, CaFCP's *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 identifying the need to expand the market with heavy-duty technologies and their infrastructure. Clearly, the SCAQMD must continue to support the infrastructure required to refuel retail fuel cell vehicles and the nexus to medium- and heavy-duty trucks including their lower cost fueling infrastructure. To that end, SCAQMD is also actively engaged in finding alternatives to reducing the cost of hydrogen (e.g., large-scale hydrogen refueling stations) and potential longer term fuel cell power plant technology.

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 passenger vehicles and more recently plug-in electric vehicles (PEVs) by almost all of the automakers and increased public attention on global warming, as well as several Executive Orders issued by Governor Brown over the last couple of years. The Governor's most recent Executive Order, which was issued on January 26, 2018, calls for 5 million ZEVs by 2030.

EV adoption surpassed a huge milestone in 2017, selling more than 360,000 cumulative electric vehicles in California, according to Veloz (formerly the PEV Collaborative), with increasingly more announcements by international automakers (e.g., Mercedes-Benz, Volkswagen-Audi-Porsche,

[1] http://www.energy.ca.gov/2017publications/CEC-600-2017-011/CEC-600-2017-011.pdf

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 Tesla Model 3 to longer electric ranges and faster charging, the 2017 Chevy Bolt EV, with an estimated EPA range of 238 miles and an affordable price after incentives, was a best seller. However, what is now needed is technology transfer to the medium- and heavy-duty vocations. As with hydrogen and fuel cell technologies SCAQMD is actively pursuing research, development and demonstration projects for medium and heavy-duty electric vehicles ad their commercialization.

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 TAC. Furthermore, according to CARB, trucks and buses are responsible for 37 percent of California's greenhouse gases and criteria emissions. Furthermore, 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.

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 SCAQMD, 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.

In connection with the challenge to develop cleaner engine systems, on June 3, 2016, SCAQMD petitioned the EPA to initiate rulemaking for a lower NOx national standard for heavy-duty engines. The 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. The EPA announced the Cleaner Truck Initiative on November 13, 2018, to reduce NOx emissions from on-road heavy-duty trucks, but the proposed NOx rule is anticipated in early 2020. Although welcome news, this timing is still too late to help the SCAQMD meet its 2023 federal attainment deadline. So despite progress, commercialization and deployment of near-zero engines are still needed in the interim.

Fueling Infrastructure and Deployment (NG/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% by 2020 and 50% by 2030 as required by SB 350 (chaptered October 2015), the objectives of the SCAQMD are to expand the infrastructure to support near-zero and zero emission vehicles through the development, demonstration and installation of alternative fuel vehicle refueling technologies. However, this category is predominantly targeted at natural gas 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.

Health Impacts, Fuel and Emissions Studies

The monitoring of pollutants in the Basin is extremely important, especially when focused on (1) a particular 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 emission 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.

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 near zero-emission technologies, such as solar, 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. 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.

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 the majority of 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 non-road mobile sources lies primarily with the U.S. EPA and CARB.

Low-emission and clean-fuel technologies that appear promising for on-road mobile sources should be effective at reducing emissions from a number of non-road sources. For example, immediate benefits are possible from particulate traps and selective catalytic reduction (SCR) 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 non-road applications. 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.

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 essential to its success. 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. Technology transfer efforts also include support for various clean fuel vehicle incentive programs. The other spectrum of this core technology is information dissemination to educate the end user and increase awareness. While SCAQMD's Public Affairs office oversees and carries out the majority of such education and awareness efforts on behalf of the entire agency, TAO cosponsors and occasionally hosts various technology-related events to complement their efforts. These efforts range from general outreach and partnerships to convening or cosponsoring events. Some examples include: 1) SCAQMD's Making Sense of Sensors International Conference in September 2017; 2) the annual spring ACT Expo, which SCAQMD cosponsors and attends; 3) the inaugural Electrification 2018 International Conference held in summer 2018 at which SCAQMD was a speaker and exhibitor; 4) CALSTART's 2030 Summit on clean transportation this past fall; 5) partnerships for national events such as Drive Electric Week; and 6) hosting tours of SCAQMD's clean fuel vehicle fleet and their respective fueling platforms.

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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 SCAQMD 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 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 SCAQMD 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 projects, the benefits are difficult to quantify since their full emission 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.

➢CNG Engine Development for Heavy-Duty Vehicles

- Cummins Westport: low-NOx natural gas ISL G 8.9L and 12L engines (0.2 & 0.02 g/bhp-hr);
- Detroit Diesel: Series 60G (CNG/LNG), Series 50G (CNG/LNG); and
- Clean Air Partners/Power Systems (Caterpillar): 3126B (Dual Fuel), C-10 (Dual Fuel), C-12 (Dual Fuel).
- Kenworth CNG Hybrid Electric Drayage Truck project;

➢Fuel Cell Development and Demonstrations

- Kenworth Fuel Cell Range Extended Electric Drayage Truck project;
- Ballard Fuel Cell Bus (first of its kind);
- Retail light-duty passenger fuel cell vehicles (Toyota Mirai, Hyundai Tucson, Honda Clarity);
- Orange County Transportation Authority GGRF Fuel Cell Bus project;
- SunLine Transit Agency Advanced Fuel Cell Bus projects;
- Commercial stationary fuel cell demonstration with UTC and SoCalGas (first of its kind);
- Orange County Sanitation District hydrogen and combined heat and power generation from biogas using molten carbonate fuel cell technology (as well as their renewable hydrogen station);
- New Flyer and El Dorado Transit Bus at OCTA;
- 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

- Hybrid electric delivery trucks with NREL, FedEx and UPS;
- Siemens Catenary Electric Truck project;

- Proterra battery electric transit bus and fast charging system;
- South Bay City Council of Governments' electric vehicle project;
- EVI/UPS electric truck;
- Plug-in hybrid work truck with Odyne Systems;
- Plug-in hybrid van and pickup with VIA Motors;
- BYD all-electric transit bus and trucks (yard hostlers and drayage);
- LACMTA 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
- PACCAR (Kenworth and Peterbilt) battery-electric and plug-in hybrid 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
- Southwest Research Institute development of aftertreatment for medium-duty diesel engines

SCAQMD 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 research, development, demonstration and deployment process.

Strategy and Impact

In addition to the feedback and input detailed in Program Review (page 2), the SCAQMD 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 SCAQMD 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, National Association of Fleet Administrators (NAFA), major local transit districts, local gas and electric utilities, the San Pedro Bay Ports and several universities with research facilities, including but 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 SCAQMD coordinates research and development activities also includes organizations specified in H&SC Section 40448.5.1(a)(2).

In addition, the SCAQMD holds periodic meetings with several organizations specifically to review and coordinate program and project plans. For example, the SCAQMD 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 California Fuel Cell Partnership (CaFCP), the California Stationary Fuel Cell Collaborative, the California Natural Gas Vehicle Partnership (CNGVP), the Electric Power Research Institute (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, which is part of the National Clean Diesel Campaign. The coordination efforts with these various stakeholders have resulted in a number of cosponsored projects.

Descriptions of some of the key contracts executed in CY 2018 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 SCAQMD 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 SCAQMD program. These partners are identified in the more detailed 2018 Project Summaries by Core Technologies (beginning page 37) contained within this report.

Table 1: SCAQMD Major Funding Partners in CY 2018

Research Funding Organizations	Major Manufacturers/Providers
California Air Resources Board	Achates Power, Inc.
California Energy Commission	Clean Energy
Department of Energy	Cummins Westport, Inc.
Environment Canada	Daimler Trucks North America
National Renewable Energy Laboratory	Hyster-Yale Group, Inc.
U.S. Environmental Protection Agency	Peterbuilt Motors Company
Local Air Districts & Utilities	Ports of Los Angeles & Long Beach
San Joaquin APCD	Rail Propulsion Systems
Sacramento Metropolitan AQMD	University of California Riverside/CE-CERT
Southern California Edison	Velocity Vehicle Group
Southern California Gas Company	Volvo Technology of America LLC

The following two subsections broadly address the SCAQMD's impact and benefits by describing specific examples of accomplishments including commercial or near-commercial products supported by the Clean Fuels Program in CY 2018. 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 SCAQMD research and development coordination efforts in 2018 include: (a) Clean Fuels Program Strategy for Commercialization of Zero Emissions Drayage Trucks; (b) Demonstration of Near-Zero and Zero Emissions Drayage Trucks and Cargo Handling Equipment; and (c) Development of Alternative Heavy-Duty Diesel Engine Technologies.

Clean Fuels Program Strategy for Commercialization of Zero Emissions Drayage Trucks

The Clean Fuels Program strategy for the commercialization of zero emissions technology in the heavy-duty truck sector emerged around 2010. A key element of the strategy was to engage major original equipment manufacturers (OEMs) in the development and demonstration and eventual commercialization of zero emissions technologies. The heavy-duty truck OEMs have the ability to

design, develop, manufacture, market and service large volumes of vehicles, and large volume is the key to meeting the Basin's emissions reduction goals. SCAQMD initially engaged small startups and vehicle integrators interested in developing and demonstrating zero emissions technologies. Most of the Clean Fuels projects were a small number of proof-of-concept trucks like the first ZECT project that developed and demonstrated battery electric and hybrid electric trucks. The second ZECT project included Kenworth, a major truck OEM, as a partner developing two vehicles–a fuel cell range extended truck and a CNG-hybrid drayage truck.

With an award of approximately $4.2 million in 2012 from DOE's first ZECT solicitation, coupled with some cost-share from Clean Fuels, SCAQMD contracted with two local EV integrators, TransPower and US Hybrid, to develop and demonstrate a total of 11 zero and near-zero emissions capable heavy-duty drayage trucks (Figure 4), based on two different architectures, consisting of battery electric vehicles and plug-in hybrid electric drivetrains with all electric range capability. These trucks were deployed in real-world drayage operations with fleet partners operating at the Ports of Los Angeles and Long Beach for demonstration up to two years. Vehicle performance and operational data is being collected and analyzed by NREL to evaluate both technical feasibility and market viability of the technologies to support drayage operations.

Figure 4: TransPower & US Hybrid ZECT 1 Trucks

In August 2014, the SCAQMD received an award of approximately $9.7 million from DOE for the second ZECT solicitation to develop and demonstrate seven zero and near-zero emissions drayage trucks in real-world drayage operations at the Ports of Los Angeles and Long Beach. Six of the trucks are fuel cell range-extended and the seventh truck is a hybrid electric drive platform using a CNG auxiliary power unit (Figure 5). Project partners included Kenworth, a major OEM, and US Hybrid, Hydrogenics and TransPower, vehicle integrators. The TransPower ElecTruck™ design, which was first deployed in ZECT I successfully performing short-haul drayage operations, was converted with a fuel cell range-extender in ZECT II.

In 2016, SCAQMD received an award of approximately $23.6 million to develop and demonstrate zero emissions drayage trucks under CARB's California Climate Initiative's Low Carbon Transportation Greenhouse Gas Reduction Fund (GGRF). In this project, TransPower teamed up with Peterbilt/TransPower taking the ElecTruck™ design and productionizing it, bringing it a step closer to commercialization. Peterbilt and TransPower are in the process of building 12 battery electric drayage trucks and will demonstrate them across a variety of real-world drayage applications in and around the Ports of Long Beach, Los Angeles, Oakland, Stockton and San Diego.

Figure 5: Kenworth CNG-Hybrid Truck

Figure 6: Kenworth Fuel Cell Truck

Kenworth Trucks, along with BAE Systems and other partners, developed a CNG hybrid and fuel cell powered truck for the ZECT II Project, and it is now in demonstration at the San Pedro ports. Kenworth and BAE Systems developed a plug-in hybrid electric truck (PHET) with a CNG-range extender. The technology is capable of providing a well-balanced blend of all electric and CNG-based hybrid operations. The electric drivetrain is based on BAE Systems HybriDrive® Series (HDS) propulsion system hardware currently used in transit buses. Kenworth will continue to develop that truck platform and bring it closer to commercialization in the SCAQMD's GGRF project.

The fuel cell truck that Kenworth and BAE Systems demonstrated in ZECT 2 (Figure 6) will be further developed with Toyota and their partner the Port of Los Angeles and an award from CARB's California Climate Initiative with SCAQMD cofounding. The project will demonstrate Kenworth's fuel cell drayage truck and will include Toyota's fuel cell integrated into ten of their trucks along with hydrogen infrastructure to support the demonstration.

Another OEM, BYD, a global company with over $9 billion in revenue and 180,000 employees, including an assembly plant in Lancaster, CA, will develop 25 T9 battery electric drayage trucks for SCAQMD's GGRF project. The T9 truck is optimized to serve near-dock and short regional drayage routes within a range of 100 miles, supported by 300 kWh batteries on hand. The truck is designed to provide similar operating experience compared to equivalent diesel and CNG trucks with matching or exceeding power and torque. The T9 is a Class 8 truck with 80,000 pounds Gross Combined Weight Rating, powered by two 180 kW traction motors. BYD will utilize 200 kW AC on-board charger for these trucks.

Figure 7: Volvo Hybrid Electric Truck

In July 2012, SCAQMD was awarded $1.2 million from the DOE Office of Science to develop a diesel hybrid drayage truck with Volvo Technologies of America (Figure 7). Coupled with cost-share from Clean Fuels, the objective of this project was to develop, build and demonstrate a prototype Class 8 heavy-duty plug-in hybrid drayage truck with significantly reduced emissions and fuel use. Volvo's approach leveraged the group's global knowledge and experience in designing and deploying electro-mobility products. The proprietary hybrid driveline selected for this proof of concept was integrated with multiple enhancements to the complete vehicle in order to maximize the emissions and energy impact of electrification. Volvo then teamed up with Siemens and SCAQMD for another project to develop and demonstrate overhead catenary electric trucks. A pantograph that allows a truck to connect to overhead power lines was integrated into the Volvo hybrid. The Volvo truck was successfully demonstrated on the Siemens eHighway in Carson, CA. To bring the hybrid vehicle architecture closer to the commercial stage,

Figure 8: Volvo's Battery Electric Truck

Volvo then joined SCAQMD in the GGRF project funded by CARB and key air districts across California to further develop its hybrid and their emissions reduction technologies.

In October 2018, SCAQMD was awarded $44.8 million from CARB's California Climate Initiative under their ZANZEFF (zero and near-zero efficient freight facilities) solicitation for our OEM partner Volvo to take the next step in electrification of its heavy duty trucks with the Volvo LIGHTS Project. Along with CARB funds, SCAQMD's Clean Fuels Program provided $4 million with Volvo and partners providing over $41 million for a total project cost of nearly $90 million to develop, demonstrate and commercialize electric heavy-duty trucks. The project will feature a system of moving cargo from the ports to customers with zero emissions. Volvo's battery-electric drayage truck will haul containers from the San Pedro Bay Ports to the Inland Empire where they will be staged by an electric yard tractor and then unpacked by zero emissions forklifts. When the cargo is repacked, a portion of it will be delivered locally by Volvo's battery-electric urban distribution trucks and the remainder will be hauled regionally by another Volvo electric truck. The warehouses will also have solar energy to provide charging via smart charging infrastructure that minimizes grid impacts and cost. At the end of the project, Volvo intends to produce a commercial vehicle.

Daimler Trucks North America LLC (DTNA), the world's leader in heavy-duty truck sales, proposes to implement the Daimler Zero Emission Trucks and EV Infrastructure Project. Under the project, DTNA will develop battery-electric heavy-duty trucks and demonstrate them in real-world commercial fleet operations in and around environmental justice communities within the SCAQMD's jurisdiction to gather data and information from the end-users including performance under specific duty-cycle applications. DTNA will utilize the data and information to move toward commercial production. DTNA will supply ten Class 6 trucks with a gross vehicle weight rating (GVWR) up to 26,000 pounds and ten Class 8 trucks with a GVWR up to 80,000 pounds, including associated EV charging infrastructure. (Figure 9 & 10). Fleet partners, including Penske Leasing, will be identified and the trucks integrated into a range of services and applications to gather operational data to improve each charging and utilization scheme, with seven of the Class 8 trucks to be used in port drayage operations.

Having two of the largest truck manufacturers in the world--Daimler and Volvo--developing heavy-duty electric trucks in the South Coast Air Basin, an effort that was formulated nearly ten years ago, demonstrates the impact and strategy of SCAQMD's Clean Fuels Program. As the trucks that these OEMs are developing and demonstrating become commercial, SCAQMD's involvement will move to facilitate market penetration of these technologies through incentive programs administered by SCAQMD's Technology Advancement Office.

Demonstrate Near-Zero and Zero Emissions Drayage Trucks and Cargo Handling Equipment

Mobile sources in goods movement sectors make up the large portion of NOx and PM2.5 emissions in the Basin. Cargo handling equipment and drayage trucks have been identified as two of the most significant sources with adverse impact on air quality and public health, particularly in Environmental Justice communities adjacent to the Ports of Los Angeles and Long Beach that are disproportionately impacted by goods movement operations and activities, and resultant emissions of ozone precursors, toxic air contaminants and greenhouse gases. In order to mitigate these port-related emissions, SCAQMD strongly supports accelerated deployment of zero and near-zero emissions technologies in cargo transport and handling operations. Both the Ports of Los Angeles and Long Beach have also supported these technologies pursuant to a Zero Emissions Technologies Roadmap with an established plan for technologies to pursue to advance zero emissions technology development.

In partnership with key industry partners, SCAQMD will demonstrate zero and near-zero emissions technologies in cargo handling and drayage applications. Under this project, SCAQMD will demonstrate a zero emissions "top handler" using a wireless charging system in cargo handling operations. In addition, SCAQMD will deploy and demonstrate four drayage trucks, three units using

a natural gas engine certified at the 0.02 g NOx/bhp-hr in a plug-in hybrid platform, and one battery electric platform.

Electric Top Handler Development, Integration and Demonstration

This battery electric cargo handling demonstration project is specifically targeting top handler equipment. With the continued growth of global container cargo, there is a commensurate growth in cargo handling equipment. Top handlers represent the largest size class of mobile cargo handling equipment (CHE) at California ports and therefore represent one of the highest remaining sources of emissions, particularly NOx and PM. Top handlers themselves represent the highest emissions source of mobile equipment per unit, and second highest equipment volumes, at the San Pedro Ports. With more than 360 units, they exceed the emissions of all other equipment for NOx and PM, and are second only to yard hostlers in carbon emissions (Figure 10). And, on a per-unit basis, they actually emit much more pollution given the large size of their engines and high utilization duty cycles.

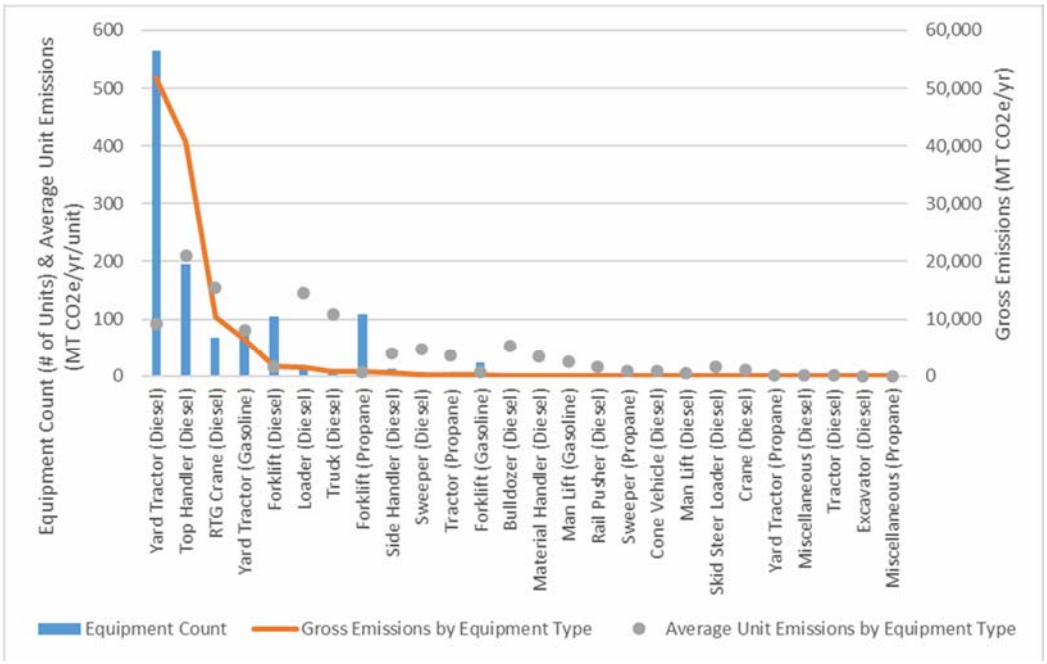

Figure 10: Emissions Profile of Cargo Handling Equipment: Gross Emissions and Average Unit Emissions (Source: PCEVB Research Report)

Hyster-Yale Group, Inc. (HYG), is a world leader in electrified mobile lift equipment. Together with project partners, WAVE and CALSTART, HYG will scale their already prototyped modular electrified power systems to validate and demonstrate a pre-pilot Hyster® 1150-CH electric container handler – known as a Top Handler - at POLA's APM Terminals (Figure 9). The equipment will be driven via electric power and all lifting functions will be powered by electric motors engaging hydraulic pumps. The 384 kWh battery will use high-powered wireless opportunity charging to match terminal operations. While retrofits have been performed, fully electrified off-road heavy cargo handling equipment is not available today in this weight class from a major OEM. The introduction of such equipment represents a major step forward in emissions-free options for port operators. Top Handlers are one of the largest

Figure 9: Hyster Top Handler

contributors of NOx and greenhouse gas emissions from mobile source goods movement equipment used at the San Pedro Bay Ports.

Southern California Advanced Sustainable Freight Demonstration

The zero emissions electric trucks and near-zero natural gas hybrid trucks demonstrated in this project will target the heavy-duty Class 8 truck market--and specifically trucks in short-haul and regional applications, which will are and will continue to one of the highest source of NOx emissions.

These trucks generally operate for port drayage, food and beverage processing and distribution, wholesale and retail and less-than-truckload. In California, they represent only 8 percent of the total truck population of the state, but are responsible for significant NOx and about 18 percent of medium- and heavy-duty greenhouse gas emissions because of their high daily mileage and low fuel economy. In the South Coast Air Basin, it is estimated that the heavy-duty diesel truck and off-road mobile equipment comprise about 200,000 and 150,000 units, respectively. This segment of the truck market is an excellent target for electrification as it covers operation in dense urban areas where pollution is concentrated and has the most negative impact. The average duty cycle is also well suited for this project, with a higher percentage of stops and idle compared to over-the-road Class 8 trucks. Lastly, trucks usually return to the same location at the end of the day, which is convenient for recharging.

In this project, Velocity Vehicle Group, one of the nation's largest truck dealerships, will partner with Freightliner Trucks, the leading truck OEM for Class 8 trucks, and Efficient Drivetrains, Inc. (EDI), which was recently acquired by Cummins Inc., a global leader and innovator of advanced, high-efficiency plug-in hybrid electric vehicles (PHEVs) and full battery electric vehicle (EV) drivetrains, to develop and demonstrate three PHEV Class 8 drayage trucks and one EV Class 8 drayage truck. EDI's PowerDrive™ 8000 technology is based on an intelligent four-mode, series-parallel drivetrain and provides full performance in both EV and PHEV configurations and no range limitations in PHEV configuration. The EDI PowerDrive™ 8000 EV drivetrain (Figure 11) can drive up to 100 miles in all-electric and zero emissions operation for short-haul vocations. The range extended plug-in hybrid version, the EDI PowerDrive™ 8000 PHEV drivetrain, delivers up to 35 miles of all-electric driving and a 300-plus mile series-parallel hybrid driving range before refueling is required. Successful demonstration of these technologies could provide significant benefits to the region in the form of reduced NOx and diesel PM emissions from the goods movement sector. The primary project locations are all located in disadvantaged communities. Each of these locations suffers from elevated levels of PM2.5 and other diesel-related emissions connected with goods movement activity. The project will displace activity of diesel-fueled equipment and replace it with technologies that completely eliminate diesel consumption and provide zero or near-zero emissions performance in these communities. In addition, the on-road drayage truck projects will reduce diesel-related emissions in the many other communities throughout the South Coast Air Basin that these trucks travel through.

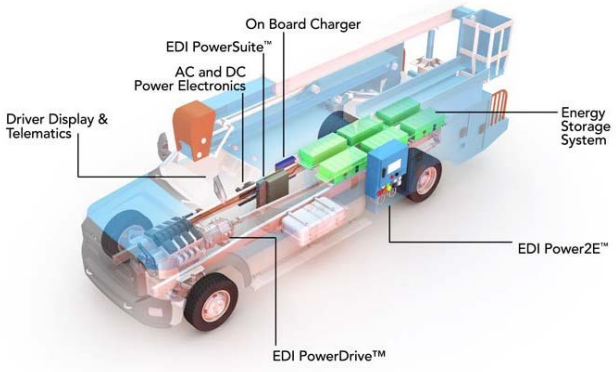

Figure 11: EDI PowerDrive™ Powertrain System

Development of Alternative Heavy-Duty Diesel Engine Technologies

Heavy-duty vehicles still dominate the total basin-wide NOx and PM emissions. An increase in available heavy-duty engine technologies is needed to reach attainment. This project is intended to

accelerate the adoption and commercial deployment of heavy-duty near-zero emissions technologies by developing and deploying opposed piston engine (OP) technology trucks for long-haul applications. Project partners include Achates Power, Inc. (API), Peterbilt Motors Company, Walmart Logistics, Tyson Foods, Inc., San Joaquin Valley Air Pollution Control District, Sacramento Metropolitan Air Quality Management District, and SCAQMD. Walmart and Tyson Foods will demonstrate the trucks in revenue service regional long haul routes within California, including disadvantaged communities located in Sacramento, San Joaquin Valley, SCAQMD, and San Diego County. CALSTART and API received a grant award under a CARB issued grant solicitation for the Fiscal Year 2016-17 Low Carbon Transportation and Fuels Investments and the Air Quality Improvement Programs for On-Road Advanced Technology Demonstrations. CALSTART, which will administer and provide oversight for this project, has previously worked with numerous manufacturers and fleets engaged in publicly funded programs to develop and deploy near-zero and zero emissions heavy-duty vehicles. SCAQMD's Clean Fuels Program is providing $1 million in cost-share for this $15.55 million project.

The OP engine Class 8 demonstration will deploy and validate an engine design that will demonstrate near-zero NOx levels (0.02 g/bhp-hr), while simultaneously providing equivalent torque and power and a 15-20 percent increase in fuel efficiency compared to existing larger displacement engines. This will be the first demonstration in the U.S. of a high-efficiency and low-NOx engine powertrain vehicle in Classes 7-8 applications.

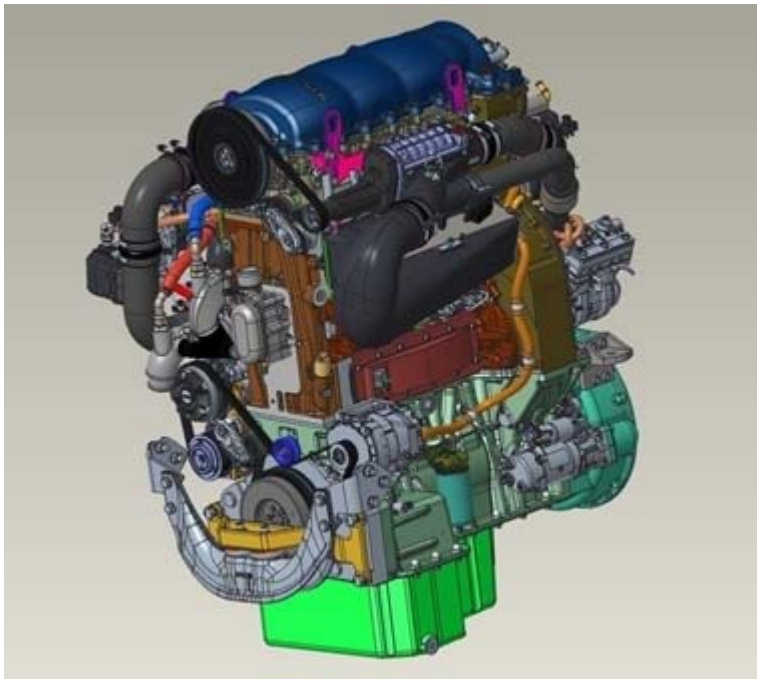

Figure 12: Heavy-Duty Opposed Piston Diesel Engine

Specifically, API will develop four 10.6-liter OP engines (Figure 12), including three aftertreatment systems, and install them into two Class 8 trucks provided by Peterbilt. Peterbilt will also perform integration services and support and perform vehicle calibration and testing. Subsequently, the trucks will be placed in revenue service with Walmart and Tyson Foods for a minimum of three months as part of the field demonstration, which will include the use of renewable diesel.

The overall goal of the project is to realize near- and long-term certification and commercialization goals and establish higher efficiency, near-zero emissions, liquid fueled engines as an industry standard.

Technology Deployment and Commercialization

One function of the Clean Fuels Program is to help expedite the deployment and commercialization of low and zero emission technologies and fuels needed to meet the requirements of the AQMP control measures. In many cases, new technologies, although considered "commercially available," require assistance to fully demonstrate the technical viability to end-users and decision-makers.

It is important to note here that SCAQMD's Technology Advancement Office (TAO) administers not only the Clean Fuels Program but also the Carl Moyer Program. While the Clean Fuels Program marked

its 30th year in 2018, the Carl Moyer Program[2] also achieved a milestone in 2018, marking its 20th year. These two programs produce a unique synergy, with the Carl Moyer Program (and other incentive programs) providing the necessary incentives to push market penetration of the technologies developed and demonstrated by the Clean Fuels Program. This synergy enables the SCAQMD to act as a leader in both technology development and commercialization efforts targeting reduction of criteria pollutants.

This report, however, is required to detail the accomplishments and achievements of the Clean Fuels Program. (1) One example during CY 2018 is the deployment of near-zero emissions CNG school buses, which resulted from SCAQMD's Clean Fuels Program investing in development and demonstration of an ultra-low NOx emissions 8.9-liter natural gas engine. (2) Another example is Clean Fuels Program support of efforts by the California Department of Food & Agriculture, Division of Measurement Standards, Energy Independence Now, the California Fuel Cell Partnership and other hydrogen fuel cell stakeholders towards opening commercial retail hydrogen stations.

Near-Zero Emissions CNG School Buses

The Lower-Emission School Bus Program, which began in 2001, replaces dirty diesel school buses with cleaner alternative fuel school buses and retrofits newer diesel buses with PM traps. To date, SCAQMD has provided more than $280 million in state and local funds to replace over 1,600 pre-1994 publicly owned diesel school buses and retrofit 3,400 newer diesel school buses.

In 2015, the SCAQMD awarded funding to Cummins Westport Inc. (CWI) to develop and demonstrate an ultra-low NOx emissions 8.9-liter natural gas engine. CARB and U.S. EPA certified the engine at CARB's Optional Low NOx 0.02 gram standard, although actual results were lower than CARB's Optional Low NOx standard. The resulting engine has a reduction of over 90 percent NOx from current federal standards. This was a game changer for this engine class. Since then, CWI has put the engine into full production. To help accelerate market penetration of this engine as well as reduce local exposure to students and the communities they live in, SCAQMD applied for U.S. EPA Airshed grant funding to replace the large Type D diesel school buses with the 8.9-liter natural gas engine, targeting disadvantaged communities or environmental justice (EJ) areas. The SCAQMD was successful in its application and was awarded $3.1 million.

In May 2018, the SCAQMD Board approved awards to 42 school districts for a total of 206 school buses in the amount of $35,638,000. Of these awards, 79 school buses for 18 (of the 42) school districts included funds allocated from the U.S. EPA Airshed grant. The U.S. EPA Airshed funds, which were recognized into the Clean Fuels Fund, totaled $3,104,700, with the Carl Moyer Program (AB 923 funds) providing $32,533,300. Additionally, school districts had to provide a $15,000 match for each CNG school bus.

Using CalEPA's CalEnviroScreen mapping tool, which helps identify disadvantaged communities in California, over 76 percent of the school districts that were awarded funds for school bus replacements were in disadvantaged communities. The 2018 awards overall will fund 115 Type D CNG school buses certified to meet the optional low NOx standard of 0.02 g/bhp-hr and 91 Type C propane school buses certified to meet the optional low NOx standard of 0.05 g/bhp-hr for a total of 206 replacements.

[2]For more information about the Carl Moyer Program and other SCAQMD incentive programs, visit this link: http://www.aqmd.gov/home/programs/business/business-detail?title=heavy-duty-engines&parent=vehicle-engine-upgrades

The table below summarizes the grants partially funded with the U.S. EPA Airshed grant:

School District	No. of CNG Buses	U.S. EPA Funds Allocated	School District (Match)
ABC USD	3	$117,900	$45,000
Alta Loma SD	2	$78,600	$30,000
Bellflower USD	1	$39,300	$15,000
Chaffey Joint Union HSD	6	$235,800	$90,000
Cypress SD	1	$39,300	$15,000
Downey USD	4	$157,200	$60,000
Fountain Valley SD	1	$39,300	$15,000
Fullerton Joint Union HSD	4	$157,200	$60,000
Hemet USD	5	$196,500	$75,000
Huntington Beach UHSD	15	$589,500	$225,000
Orange USD	1	$39,300	$15,000
Placentia-Yorba Linda USD	6	$235,800	$90,000
Pupil Transportation Coop.	5	$196,500	$75,000
Rialto USD	13	$510,900	$195,000
Rim of the World USD	3	$117,900	$45,000
Rowland USD	3	$117,900	$45,000
San Jacinto USD	2	$78,600	$30,000
Upland USD	4	$157,200	$60,000
Total	**79**	**$3,104,700**	**$1,185,000**

The above 79 buses collectively are estimated to reduce annual emissions of 0.8 tons per year of PM2.5, 17.7 tons per year of NOx and 4.1 tons per year of CO emissions through replacement with CNG-powered buses (Figure 13). Use of renewable natural gas to fuel these buses can significantly increase the CO2 reductions also achieved. This project achieves immediate and ongoing improvement in air quality and public health, particularly in communities where the residents are disproportionally impacted by the adverse effects of high levels of emissions, and the U.S. EPA Airshed grant accelerated and increased volume of replacements to eligible EJ communities.

Figure 13: CNG Type D bus certified at 0.02 g/bhp-hr NOx

The successful implementation of this Program provides less polluting and safer transportation for school children and reduces public exposure to toxic diesel PM emissions. Also, it will reduce air pollution in low-income, high-diesel and high-PM10 exposure areas as well as enhance the objectives of the Environmental Justice and Children's Health Initiatives adopted by the SCAQMD Board. In addition, the reduction of NOx and PM through deployment of these buses will enable us to take another step forward in meeting the goals called out in our AQMP.

The 2016 AQMP seeks to achieve and maintain all state and federal air quality

standards within attainment deadlines by the earliest date achievable to comply with federal Clean Air Act requirements. In order to meet these goals, the 2016 AQMP includes an integrated control strategy addressing multiple objectives for a more efficient path in meeting all clean air standards. Deployment and commercialization projects like this one will be crucial to help reduce costs for near-zero emission technologies and reduce emissions in impacted areas.

Progress for Hydrogen Infrastructure and Fuel Cell Vehicles

Support for the California Department of Food & Agriculture, Division of Measurement Standards (DMS) Metrology testing is one valuable component to opening commercial retail hydrogen (H2) stations.

Certificates of Approval allow the specific dispenser design type and model to be placed in service at multiple hydrogen stations throughout the state as an approved device, which has facilitated the growth of retail hydrogen fueling stations.

The National Conference on Weights and Measures has adopted a single accuracy class for hydrogen gas measuring devices, incorporating input from DMS. This single class with increased acceptance tolerance of 5.0 percent and increased maintenance tolerance of 7.0 percent supports the early adoption of expanding accuracy classes by California. With the new tolerances published in the National Institute of Standards and Technology Handbook 44, California can now align its specifications with this new national model standard and facilitate marketplace consistency across the country.

Clean Fuels Program cofunding continues to support DMS for retail hydrogen station equipment performance (HyStEP) testing to ensure safe, fast and complete hydrogen fills before retail stations are open for customers.

Energy Independence Now (EIN) released the Renewable Hydrogen Roadmap3, which explores strategies that are currently most cost-effective and scalable, including production technologies and feedstocks, and lays out the eight high priority policy and stakeholder recommendations for California. The EIN Renewable Hydrogen Roadmap is one of several efforts that helped set the stage for changes to the CARB's LCFS regulation in 2018 that are expected to encourage renewable hydrogen production.

Former California Governor Jerry Brown issued an executive order (#B-48-18 dated 1/16/18) calling for increasing the deployment of zero emission vehicles and developing 200 hydrogen refueling stations. While public cofunding for additional hydrogen stations was not included in the latest California budget, recent changes to CARB's LCFS regulation should help to facilitate larger capacity stations.

For 2018, numerous fuel and hydrogen programs include:

- More than 5,000 consumers and fleets have purchased or leased passenger category fuel cell vehicles from Hyundai, Toyota and Honda since they entered the commercial market starting in 2015. Fuel cell passenger vehicle deployment is dependent on increasing coverage and capacity of retail hydrogen stations.
- Transit agency members have 25 fuel cell electric buses currently in operation and more than 27 additional buses are funded for future deployment.
- There are 39 retail and four other non-retail hydrogen fueling stations in operation in California, an additional 25 in development, with the majority in the Southern California area (Figure 14).

[3] Energy Independence Now (EIN) *Renewable Hydrogen Roadmap* https://einow.org/rh2roadmap/, May 17, 2018.

- Staff and members of the California Fuel Cell Partnership (CaFCP) continue to conduct outreach and education in communities throughout California.
- The CaFCP, the Governor's Office of Business and Economic Development (GO-Biz) and the California Energy Commission continue advising and responding to city staff across the state of California to optimize station permitting.
- The CaFCP created and maintains the Station Operational Status System (SOSS) that hydrogen stations in the U.S. use to report status. This data, in turn, feeds real-time information (address, availability, etc.) to consumers through a CaFCP mobile-friendly website and several other apps and systems that support consumers.

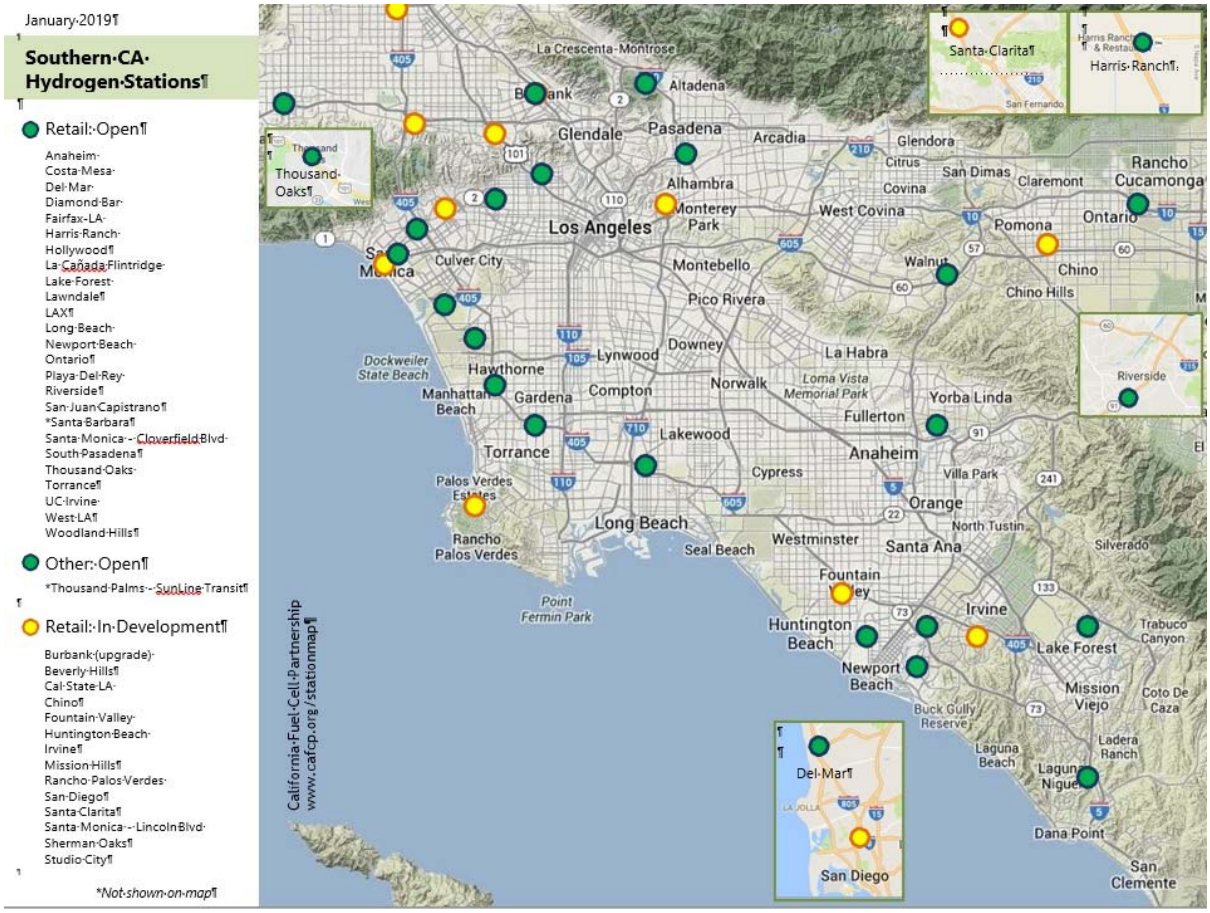

Figure 14: SoCal Hydrogen Stations (Source: CaFCP)

Since 1999, the CaFCP and its public and private members have jointly and separately worked to accelerate many aspects of fuel cell vehicle and hydrogen station development and commercialization. Building on many collaborative documents, such as the CaFCP Roadmap, Bus Roadmap and Medium & Heavy-Duty Fuel Cell Electric Vehicle Action Plan, the CaFCP released The California Fuel Cell Revolution, A Vision for Advancing Economic, Social and Environmental Priorities4 (Vision 2030) in 2018. These roadmaps and other studies provided technical support for public cofunding of hydrogen fueling stations, including heat maps for placement of stations that can support heavy-duty fuel cell

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

vehicles. Vision 2030 goes beyond current requirements, but builds on several of Former Governor Brown's Executive Orders.

The CaFCP is pursuing a network of 1,000 hydrogen stations to support a fuel cell vehicle population upwards of 1,000,000 vehicles in 2030, and the CaFCP is developing implementation strategies to enable Vision 2030. While adoption of fuel cell light duty vehicles is dependent on the deployment of hydrogen stations yet station operators find it difficult to execute a successful business plan without the load of increased vehicles. Now access to CARB's LCFS credits by station operators can help them get over the periods of low utilization; and of course more viable stations equals more vehicles. The CaFCP's goals relate to preparing for and supporting market launch through coordinated individual and collective effort. While research by multiple entities will be needed to reduce the cost of fuel cells and improve fuel storage, transport and infrastructure, the CaFCP has played a vital role in demonstrating fuel cell vehicle reliability and durability, fueling infrastructure and storage options, and increasing public knowledge and acceptance of the vehicles and fueling. The next couple of years should continue to achieve huge strides in fuel cell vehicle technology and hydrogen infrastructure growth, supporting a variety of vehicles.

The SCAQMD's 2016 AQMP and Clean Fuels Program 2019 Plan Update identify fuel cells for on- and off-road applications as a core technology for attaining and maintaining cleaner air quality. SCAQMD plans to continue to be a leader in this core technology area.

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CLEAN FUELS PROGRAM
2018 Funding & Financial Summary

The SCAQMD 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 4), the SCAQMD 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 SCAQMD Board.

As projects are approved by the SCAQMD 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, 2018.

Funding Commitments by Core Technologies

The SCAQMD 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, 2018, a total of 75 contracts/agreements, projects or studies that support clean fuels were executed or amended, as shown in Table 2 (page 32). 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 15 (page 30). This wide array of technology support represents the SCAQMD'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 2018 reporting period are shown below with the total projected project costs:

- SCAQMD Clean Fuels Fund Contribution $26,939,641
- Total Cost of Clean Fuels Projects $85,373,116

Traditionally every year, the SCAQMD Governing Board approves funds to be transferred to the General Fund Budget for Clean Fuels administration. For 2018, the fund transfer from Clean Fuels to the General Fund was handled through the annual budget process. Thus, when the Board approved the SCAQMD's FY 2018-19 Budget on June 1, 2018, 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, 2018, are included within this report. Any portion of the Clean Fuels Funds not spent by the end of Fiscal Year 2018-19 ending June 30, 2019, will be returned to the Clean Fuels Fund.

Partially included within the SCAQMD contribution are supplemental sponsorship revenues from various organizations that support these technology advancement projects. This supplemental revenue for pass-through contracts executed in 2018 totaling $12.3 million is listed within Table 3 (page 35). This $12.3 million, which is about double the typical amount recognized into Clean Fuels on an average

year, included $3.1 million from a U.S.EPA Airshed Grant for near-zero CNG school buses, with the remaining incoming revenue from a U.S. EPA DERA Grant, CEC and the Ports as stakeholder partners.

Appendix B lists the 106 Clean Fuels Fund contracts that were open and active as of January 1, 2019.

For Clean Fuels executed and amended contracts, projects and studies in 2018, the average SCAQMD contribution is approximately 17 percent of the total cost of the projects, identifying that each dollar from the SCAQMD was leveraged with nearly $6 of outside investment. The typical leverage amount is $3-$4 for every $1 of SCAQMD Clean Fuels funds, but from 2016 to 2018 there were several significant contracts, significant both in funding and in the impact they hopefully will make in strides toward developing and commercializing clean transportation technologies.

During 2018, the distribution of funds for SCAQMD executed contracts, purchases and contract amendments with additional funding for the Clean Fuels Program totaling approximately $27 million are shown in the figure below.

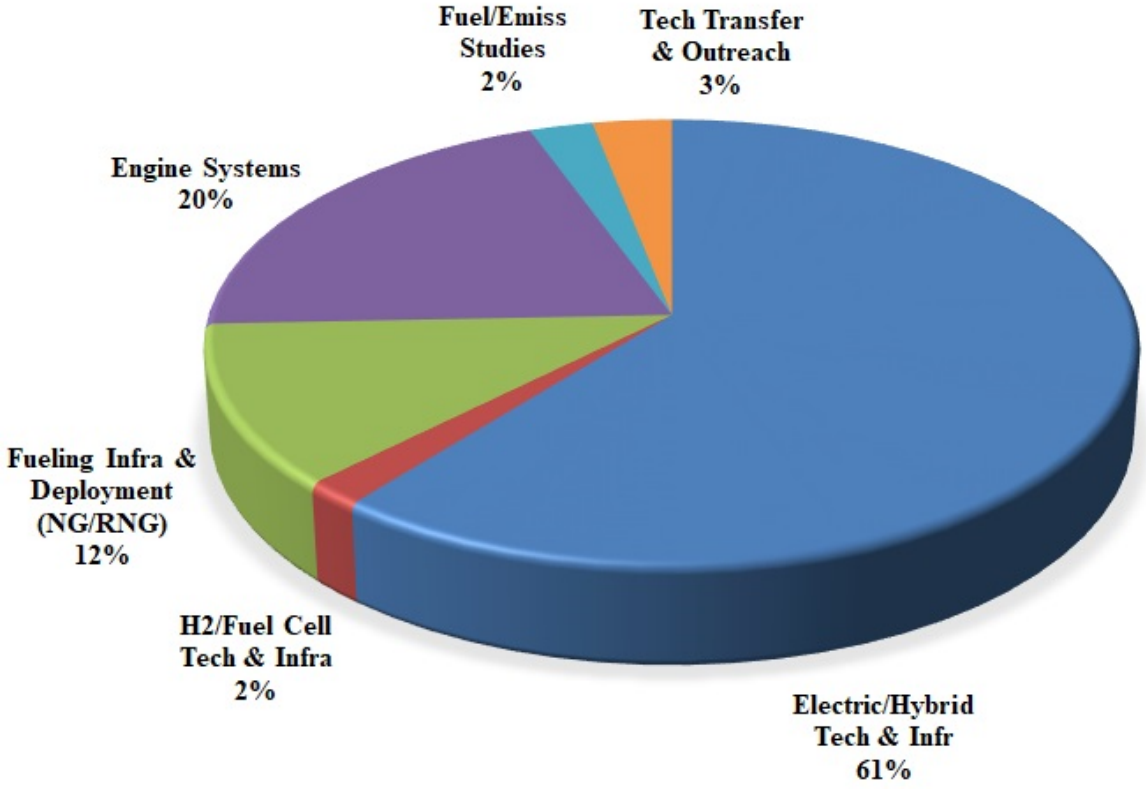


Figure 15: Distribution of Funds for Executed Clean Fuels Projects CY 2018 ($27M)

Table 2 (page 32) provides a breakdown of this $27 million in executed contracts. Table 3 (page 35) provides information on outside funding recognized and received into the Clean Fuels Fund ($12.3 million) for contracts executed in CY 2018. Additionally, the SCAQMD continued to seek funding opportunities and Table 4 (page 35) lists the additional $54.5 million awarded in 2018 for RD^3 projects.

Review of Audit Findings

State law requires an annual financial audit after the closing of each SCAQMD'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, 2018, 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 SCAQMD financial statements, which include the Clean Fuels Program revenue and expenditures. BCA Watson Rice, LLP, gave the SCAQMD an "unmodified opinion," the highest obtainable. Notably, the SCAQMD has achieved this rating on all prior annual financial audits.

Project Funding Detail by Core Technologies

The 75 new and continuing contracts/agreements, projects and studies that received SCAQMD funding in 2018 are summarized in Table 2, together with the funding authorized by the SCAQMD and by the collaborating project partners.

Table 2: Contracts Executed or Amended (w/$) between Jan. 1 & Dec. 31, 2018

Contract	Contractor	Project Title	Start Term	End Term	SCAQMD $	Project Total $
Hydrogen/Mobile Fuel Cell Technologies and Infrastructure						
18150	California Department of Food & Agriculture, Division of Measurement Standards	Conduct Hydrogen Station Site Evaluations for Hydrogen Station Equipment Performance (HyStEP) Project	06/28/18	02/27/20	100,000	805,000
18158	Alliance for Sustainable Energy, LLC (on behalf of National Renewable Energy Laboratory)	Participate in California Hydrogen Infrastructure Research Consortium H2 @ Scale Initiative	08/31/18	03/30/20	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
19213	Frontier Energy Inc.	Participate in California Fuel Cell Partnership for CY 2018 and Provide Support for Regional Coordinator	01/01/18	07/01/19	245,000	1,253,491
Electric/Hybrid Technologies and Infrastructure						
14062	Siemens Industry Inc.	Develop and Demonstrate Catenary Zero Emissions Goods Movement System and Develop and Demonstrate Diesel Catenary Hybrid Electric Trucks	07/14/14	12/31/18	430,000	430,000
14184	Clean Fuel Connection Inc.	DC Fast Charging Network Provider	04/04/14	06/30/20	350,000	350,000
18072	Electric Power Research Institute	Study Electrification Options of Energy Services for Environmental Justice Communities and Non-Attainment	06/08/18	06/07/20	150,000	1,558,657
18129	Electric Power Research Institute	Versatile Plug-In Auxiliary Power System Demonstration	06/28/28	06/27/20	125,000	273,000
18151	Rail Propulsion System	Develop and Demonstrate Battery Electric Switcher Locomotive	04/05/18	12/30/19	210,000	925,000
18232	Hyster-Yale Group Inc.	Electric Top-Pick Development, Integration and Demonstration	09/14/18	09/13/21	2,931,805	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	3,568,300	4,198,000
18280	Honda of Pasadena	Three-Year Lease of One Honda 2018 Clarity Plug-In Vehicle	02/07/18	02/96/21	18,359	18,359
18287	EVgo Services LLC	Charging Station and Premises Agreement for Installation of One DC Fast Charger at SCAQMD Headquarters	06/27/18	06/26/28	0	0

Table 2: Contracts Executed or Amended (w/$) between Jan. 1 & Dec. 31, 2018 (cont'd)

Contract	Contractor	Project Title	Start Term	End Term	SCAQMD $	Project Total $
Electric/Hybrid Technologies and Infrastructure (cont'd)						
19190	Daimler Trucks North America	Zero Emission Trucks and EV Infrastructure Project	12/18/18	06/20/22	8,230,072	31,340,144
Purchase Order	Zeco Systems, Inc., dba Greenlots	Procure Greenlots SKY Enterprise Software License with Load Management for One Year	12/13/18	12/13/18	55,200	55,200
Direct Pay	Clean Fuel Connection Inc.	Install DC Fast Charger at SCAQMD Headquarters	05/29/18	05/29/18	59,134	59,134
Engine Systems/Technologies						
17393	Southwest Research Institute	Development of an Ultra-Low Emissions Diesel Engine for On-Road Heavy-Duty Vehicles	05/30/18	07/31/19	575,000	1,325,000
18194	CALSTART Inc.	Develop and Demonstrate Near-Zero Emissions Opposed Piston Engine	095/30/18	07/31/20	1,000,000	15,550,000
18122	Clean Energy	Southern California Trucking Demonstration of Near-Zero ISX12N Beta Engines	01/05/18	01/04/20	3,459,000	5,995,000
18211	West Virginia University Innovation Corporation	Develop Thermal Management Strategy using Cylinder Deactivation for Heavy-Duty Diesel Engines	06/08/18	06/07/20	250,000	700,000
Fueling Infrastructure and Deployment (NG/Renewable Fuels)						
Transfer	California Natural Gas Vehicle Partnership	Participation in the California Natural Gas Vehicle Partnership for Fiscal Years 2018-19 and 2019-20	07/06/18	07/05/20	25,000	170,000
18336	ABC Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/05/18	11/30/34	117,900	162,900
18337	Alta Loma School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/05/18	11/30/34	78,600	108,600
18344	Bellflower Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	09/07/18	11/30/34	39,300	54,300
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	325,800
18348	Cypress School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	09/07/18	11/30/34	39,300	54,300
18349	Downey Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	09/14/18	11/30/34	157,200	217,200
18350	Fountain Valley School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	09/07/18	11/30/34	39,300	54,300
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	217,200
18354	Hemet Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/05/18	11/30/34	196,500	271,500

Table 2: Contracts Executed or Amended (w/$) between Jan. 1 & Dec. 31, 2018 (cont'd)

Contract	Contractor	Project Title	Start Term	End Term	SCAQMD $	Project Total $
Fueling Infrastructure and Deployment (NG/Renewable Fuels) (cont'd)						
18355	Huntington Beach Union High School	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/05/18	11/30/34	589,500	814,500
18363	Orange Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	09/14/18	11/30/34	39,300	54,300
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	325,800
18365	Pupil Transportation Cooperative	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/05/18	11/30/34	235,800	325,800
18367	Rialto Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/05/18	11/30/34	510,900	705,900
18368	Rim of the World Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/05/18	11/30/34	117,900	162,900
18369	Rowland Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	11/02/18	11/30/34	117,900	162,900
18370	San Jacinto Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	09/14/18	11/30/34	78,600	108,600
18374	Upland Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/12/18	11/30/34	157,200	217,200
Fuel/Emissions Studies						
18206	University of California Irvine	Assess Air Quality and Greenhouse Gas Impacts of a Microgrid-Based Electricity System	04/06/18	04/05/20	660,000	1,300,000
Emissions Control Technologies						
17367	Southwest Research Institute	Develop and Evaluate Aftertreatment Systems for Large Displacement Diesel Engines	02/28/18	06/30/19	400,000	480,00
Technology Assessment and Transfer/Outreach						
16262	University of California Davis-Institute of Transportation Studies	Support Sustainable Transportation Energy Pathways (STEPs)	01/05/18	01/04/22	240,000	5,520,000
18253	Three Squares Inc.	Identify and Secure a "Futurist" Clean Transportation or Goods Movement Technologies Expert	04/05/18	05/31/18	11,845	11,845
19078	Clean Fuel Connection Inc.	Technical Assistance with Alternative Fuels, EVs, Charging and Infrastructure, and Renewable Energy	09/07/18	09/06/20	100,000	100,000
Direct Pay	Various	Cosponsor 26 Conferences, Workshops & Events plus 5 Memberships	01/01/18	12/31/18	470,118	4,192,470

Table 3: Supplemental Grants/Revenue Received into the Clean Fuels Fund (31) in CY 2018

Revenue Agreement #	Revenue Source	Project Title	Contractor	SCAQMD Contract #	Award Total $
#17055	US EPA CATI	Develop and Evaluate Aftertreatment Systems for Large Displacement Diesel Engines	Southwest Research Institute	#17367	290,000
#17055	US EPA CATI	Develop and Demonstrate Battery Electric Switcher Locomotive	Rail Propulsion System	#18151	210,000
#18022	Port of Angeles	Develop Ultra-Low Emissions Diesel Engine for On-Road Heavy-Duty Vehicle	Southwest Research Institute	#17393	287,500
#18098	California Energy Commission	Demonstrate Zero and Near-Zero Emissions Drayage Trucks and Cargo Handling Equipment	Clean Energy	#18122	2,845,000
#18098	California Energy Commission	Demonstrate Zero and Near-Zero Emissions Drayage Trucks and Cargo Handling Equipment	Hyster-Yale Nederland BV	#18232	2,564,004
#18098	California Energy Commission	Demonstrate Zero and Near-Zero Emissions Drayage Trucks and Cargo Handling Equipment	Velocity Vehicle Group	#18277	2,985,995
#19165	US EPA Air Shed Grant	Near-Zero CNG School Buses	18 School Districts	Various	3,104,700
Table 3 lists revenue received by SCAQMD into the Clean Fuels Fund (31) only if the SCAQMD pass-through contract was executed during the reporting CY (2018).					**$12,287,199**

Table 4: Summary of Federal, State and Local Funding Awarded or Recognized in CY 2018

Awarding Entity or Program	Award(*) or Board Date	Purpose	Contractors	Award Total/ Fund
U.S. EPA Air Shed Grant	*07/09/18	Near-Zero Emissions School Bus Replacement Project	18 School Districts	$3,184,875 Fund 31
U.S. EPA Air Shed Grant	*7/09/18	Battery Electric Shuttle Bus Replacement Project	Phoenix Motorocars #19166	$3,184,875 Fund 31
San Pedro Bay Ports	07/06/18	Develop and Demonstrate Zero Emissions Trucks and EV Infrastructure	Daimler Trucks North America #19190	$2,000,000 Fund 61
U.S. EPA FY 18 Section 105 CATI	*09/14/18	Develop and Demonstrate Zero Emissions Trucks and EV Infrastructure	Daimler Trucks North America #19190	$500,000 Fund 61

Table 4: Summary of Federal, State and Local Funding Awarded or Recognized in CY 2018 (cont'd)

Awarding Entity or Program	Award(*) or Board Date	Purpose	Contractors	Award Total/ Fund
Schneider National, Inc.	*10/23/18	Install Air Filtration Systems at Schools	IQ Air North America #19169	$350,000 Fund 75
Old Dominion Freight Line, Inc.	*09/27/18	Install Air Filtration Systems at Schools	IQ Air North America #19170	$225,000 Fund 75
CARB ZANZEFF	*10/08/18	Zero and Near-Zero Emissions Freight Facilities (ZANZEFF) Project: Develop and Demonstrate Zero Emissions Heavy-Duty Trucks, Freight Handling Equipment, EV Infrastructure and Renewable Energy (LIGHTS Project including Data Analysis)	Volvo Technology of America, LLC/ University of California Riverside/CE-CERT #TBD	$44,839,686 Fund 67
Rainbow Transfer/Recycling, Inc.	11/02/18	Install Air Filtration Systems at Schools	IQ Air North America #19188	$250,000 Fund 75
Table 4 provides a comprehensive summary of revenue awarded to or recognized by SCAQMD during the reporting CY (2018) if it will be considered part of, or complementary to, the Clean Fuels Program, regardless of whether the SCAQMD pass-through contract has been executed.				**$54,534,436**

Project Summaries by Core Technologies

The following represents summaries of the contracts, projects and studies executed, or amended with additional dollars, in CY 2018. 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; SCAQMD cost-share, cosponsors and their respective contributions; contract term; and a description of the project.

Hydrogen/Mobile Fuel Cell Technologies and Infrastructure

18150: Conduct Hydrogen Station Site Evaluations for Hydrogen Station Equipment Performance (HyStEP) Project

Contractor: California Dept. of Food & Agriculture, Division of Measurement Standards	SCAQMD Cost-Share	$ 100,000
	Cosponsors	
	California Fuel Cell Partnership	100,000
	California Air Resources Board (cash & in-kind)	405,000
	California Energy Commission	100,000
	Other Partners (cash and/or in-kind)	100,000
Term: 06/28/18 – 02/27/20	Total Cost:	$ 805,000

The HyStEP equipment, which is owned by Sandia National Laboratories, was assembled, mounted on a trailer by Powertech, and was validation tested by NREL in Phase I, which was separately funded. Phase II, California implementation, overseen by a California task force, includes representatives from CARB, CEC, Division of Measurement Standards (DMS), the California Fuel Cell Partnership (CaFCP), SCAQMD, Toyota, Mercedes, BMW, Air Liquide, NREL and Sandia. The equipment validation device will be loaned for the California implementation portion. The total cost for Phase II is estimated to be approximately $805,000, with $100,000 each in cofunding already committed from both the CaFCP and the CEC. CARB is contributing $100,000 for a tow vehicle and in-kind assistance for a staff Air Resources Engineer. Successful testing in California may ultimately lead to certification and/or listing by nationally recognized testing laboratories, reduced time for hydrogen station commissioning and increased deployment of zero emissions vehicles in our region. Some automakers may still choose to conduct their own additional hydrogen station test program, especially in the early years of station development.

18158: Participate in California Hydrogen Infrastructure Research Consortium H2 @ Scale Initiative

Contractor: Alliance for Sustainable Energy, LLC (on behalf of National Renewable Energy Laboratory)	SCAQMD Cost-Share	$ 100,000
	Cosponsors	

	National Renewable Energy Laboratory	540,000
	California Energy Commission	100,000
	GO-Biz/California Governor's Office of Economic Development (in-kind)	20,000
Term: 08/31/18 – 03/30/20	Total Cost:	$ 760,000

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, a hydrogen research consortium has been organized to combine and collaborate. The proposed joint tasks include data collection from operational stations, component failure fix verification (i.e., nozzle freeze lock), analysis of data to optimize new fueling methods for medium- and heavy-duty applications, and ensuring hydrogen quality is maintained. These projects will also be managed in detail (e.g., schedule, budget, roles, milestones, tasks, reporting requirements) in a hydrogen research consortium project management plan. The joint application to the DOE H2 @ Scale Program to leverage national lab capabilities was not fully funded, so CARB and CEC also have separate agreements for those tasks.

19172: Three-Year Lease of Two 2018 Toyota Mirai Fuel Cell Vehicles

Contractor: Longo Toyota	SCAQMD Cost-Share	$ 35,108
Term: 10/28/18 – 10/27/21	Total Cost:	$ 35,108

The SCAQMD operates a number of alternative fuel vehicles, including electric vehicles, fuel cell vehicles and plug-in hybrid-electric vehicles. The primary objective of having these vehicles as part of the SCAQMD demonstration fleet is to continue to support the use of zero emissions vehicles. The Toyota Mirai fuel cell vehicles provide about 312 miles total range refueling with gaseous hydrogen.

19213: Participation in California Fuel Cell Partnership for CY 2018 and Provide Support for Regional Coordinator

Contractor: Frontier Energy, Inc. (formerly BKi)	SCAQMD Cost-Share	$ 245,000
	Cosponsors	
	7 automakers, 4 public agencies, 2 industry stakeholders, 28 Full & Associate Members	$ 1,008,491
Term: 01/01/18 – 07/01/19	Total Cost:	$ 1,253,491

In April 1999, the CaFCP was formed with eight members; SCAQMD joined and has participated since early 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. (previously Bevilacqua-Knight, Inc. or BKi) for their portion of the CaFCP's administration. In 2018, SCAQMD contributed

$70,000 for Executive membership, $50,000 to continue support for a Regional Coordinator and $125,000 for support of fuel cell truck and bus codes and standards coordination, such as SAE J2600, J2601-2 revision sponsorship, first responder training updates, and truck and bus task force facilitation and outreach.

Electric/Hybrid Technologies and Infrastructure

14062: Develop and Demonstrate Catenary Zero Emissions Goods Movement System and Develop and Demonstrate Diesel Catenary Hybrid Electric Trucks

Contractor: Siemens Industry Inc.	SCAQMD Cost-Share	$ 430,000
Term: 07/14/14 – 12/31/18	Total Cost:	$ 430,000

Siemens Industry Inc. designed and demonstrated a catenary truck technology, eHighway, in Germany on a European truck chassis. For this project with SCAQMD, Siemens brought the eHighway technology to Southern California with their partner Volvo and developed and demonstrated a catenary plug-in hybrid electric truck technology. The hybrid drive system extended the operating range of the truck beyond the all-electric range of the catenary system, enabling the truck to perform regional drayage operations and bridge gaps in catenary infrastructure as it is deployed on a regional level. The additional costs added to the contract through this contract modification were to cost-share safety barriers required by the City of Carson for the above-ground foundations for the catenary poles. Further details on this catenary truck technology project are available in the Key Projects Completed section.

14184: DC Fast Charging Network Provider

Contractor: Clean Fuel Connection Inc.	SCAQMD Cost-Share	$ 350,000
Term: 04/04/14 – 06/30/20	Total Cost:	$ 350,000

This contract was previously funded using CEC funds recognized into the Clean Fuels Fund (31). However in June 2018, CEC issued a stop work order and reversed a previous decision to allow for installation costs to be funded by the CEC grant. Staff received approval by the Governing Board in October 2018 to substitute Clean Fuels funds for CEC revenue funds towards installation costs. In June and July 2018, 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 part of the EVgo network and are provided needed public charging to fill gaps in corridor charging in Los Angeles and San Bernardino counties.

18072: Study Electrification Options of Energy Services for Environmental Justice Communities and Non-Attainment Areas

Contractor: Electric Power Research Institute	SCAQMD Cost-Share	$ 150,000
	Cosponsors	
	California Energy Commission	799,444
	Electric Power Research Institute	609,213
Term: 06/08/18 – 06/07/19	Total Cost:	$ 1,558,657

This study is to model the effects on air quality of a scenario that aggressively pursues GHG emissions reductions through electrification, including passenger vehicles, heavy-duty trucks, residential and commercial heat pumps, and industrial electrification. Air quality modeling has shown that electrification has significant potential to improve air quality, above emissions reductions expected from current regulations. Electrification of on-road and off-road vehicles leads to widespread reductions in smog in summer and winter throughout the South Coast Air Basin. The electrification study is in its final stages of completion, and a draft final report will be available early 2019. The current study results found some pollutants increased in coastal areas near the Los Angeles/Long Beach port complex, but this increase was offset by decreases in other pollutants. This is due to an effect similar to the 'weekend effect,' where a reduction in emissions can lead to an increase in some pollutants. The study results to date also found that residential space heating and water heating is a very significant opportunity for improvement in winter pollution. This is due to two factors: 1) emissions intensity for wood-fired sources is high and 2) current regulations do not address remaining sources for space and water heating. Overall, the study has indicated that electrification provides a cost-effective opportunity to simultaneously address GHG and air quality targets.

18129: Versatile Plug-In Auxiliary Power System Demonstration

Contractor: Electric Power Research Institute, Inc.	SCAQMD Cost-Share	$ 125,000
	Cosponsors	
	Southern California Edison (in-kind)	128,000
	Invited Partners: Utility/Military/Police/Fire	20,000
Term: 06/28/18 – 06/27/20	Total Cost:	$ 273,000

In December 2015, the Board awarded a contract to the Electric Power Research Institute, Inc., (EPRI) to cosponsor development and demonstration of a Versatile Plug-In Auxiliary (VAP) System. Based on the Phase I testing results, systems from alternative suppliers were evaluated and the scope of the project has expanded to include systems for portable power and portable DC fast charging. EPRI will use the previously approved cost-share for the second phase of the VAP System demonstration to evaluate the emissions and fuel usage benefits and impacts of electric auxiliary power in various on-board and stationary applications. Up to three units will undergo baseline tests at Southern California Edison's EV Technical Center prior to field demonstration within SCAQMD.

18151: Develop and Demonstrate Battery Electric Switcher Locomotive

Contractor: Rail Propulsion System	SCAQMD Cost-Share *(received as pass-through funds)*	$ 210,000
	Cosponsor	
	Rail Propulsion Systems (in-kind)	715,000
Term: 04/05/18 – 12/30/19	Total Cost:	$ 925,000

This project is to develop and demonstrate a zero emission, battery electric switcher locomotive. Rail Propulsion Systems will perform the following: 1) design and fabricate a battery pack and rack system; 2) modify an existing switcher locomotive to integrate the battery pack and rack system as well as electronic control systems; 3) install charging infrastructure for the locomotive; and 4) perform substantial validation and durability testing to confirm the robustness of their design. Once the locomotive is developed, Rail Propulsion Systems will test and optimize the locomotive in preparation

for a field demonstration. The project will ultimately conclude after the locomotive has been placed in a typical switcher locomotive operation at the Coast Rail Services rail yard to fully validate its performance, durability and reliability. The technology transfer will be the valuable information gathered in order to develop pathways to the needs and type of charging structures which will be required in a rail yard. The project supports the implementation of advanced alternative fuel technology that could potentially be used to further reduce NOx emissions from locomotives. In addition, the development and successful deployment of these zero emission switcher locomotives will promote their acceptance by railroads and facilitate their deployment at rail yards in the South Coast Air Basin as well as assist the SCAQMD to attain its clean air goals. This contract is fully funded through a U.S. EPA CATI grant the SCAQMD is administering.

18232: Electric Top-Pick Development, Integration and Demonstration

Contractor: Hyster-Yale Group Inc.	SCAQMD Cost-Share *(partially received as pass-through funds)*	$ 2,931,805
	Cosponsor	
	Hyster-Yale Group Inc.	746,203
Term: 09/14/18- 09/13/21	Total Cost:	$ 3,678,008

Hyster-Yale in partner with WAVE and CALSTART will scale their already prototyped modular electrified power systems to validate and demonstrate a pre-pilot Hyster® 1150-CH electric container handler – known as a Top Handler - at POLA's APM Terminals (APM). The equipment will be driven via electric power and all lifting functions will be powered by electric motors engaging hydraulic pumps. The 384 kWh battery will use high-powered wireless opportunity charging to match terminal operations. While retrofits have been performed, fully electrified off-road heavy cargo handling equipment is not available today in this weight class from a major OEM. The introduction of such equipment represents a major step forward in emissions-free options for port operators. Top Handlers are one of the largest contributors of NOx and greenhouse gas (GHG) emissions from mobile source goods movement equipment used at the San Pedro Bay Ports. This contract includes $2,564,004 in pass-through revenue from CEC.

18277: Southern California Advanced Sustainable Freight Demonstration

Contractor: Velocity Vehicle Group DBA Los Angeles Truck Centers LLC	SCAQMD Cost-Share *(partially received as pass-through funds)*	$ 3,568,300
	Cosponsor	
	Velocity Vehicle Group DBA Los Angeles Truck Centers LLC	629,700
Term: 09/07/18 – 03/06/22	Total Cost:	$ 4,198,000

Velocity Vehicle Group will partner with Freightliner Trucks, the leading truck OEM for Class 8 trucks, and Efficient Drivetrains, Inc. (EDI), a global leader and innovator of advanced, high-efficiency plug-in hybrid electric vehicle (PHEV) and full battery electric vehicle (EV) drivetrains, to develop and demonstrate three PHEV Class 8 drayage trucks and one EV Class 8 drayage truck. EDI's PowerDrive™ 8000 technology is based on an intelligent four-mode, series-parallel drivetrain and provides full performance in both EV and PHEV configurations and no range limitations in PHEV configuration. The EDI PowerDrive™ 8000 EV drivetrain can drive up to 100 miles in all-electric and zero-emission operation for short-haul vocations. The range extended plug-in hybrid version, the EDI

PowerDrive™ 8000 PHEV drivetrain, delivers up to 35 miles of all-electric driving, and a 300+ mile series-parallel hybrid driving range before refueling is required. This contract includes $2,985,995 in pass-through revenue from CEC.

18280: Three-Year Lease of One Honda 2018 Clarity Plug-In Vehicle

Contractor: Honda of Pasadena	SCAQMD Cost-Share	$ 18,359
Term: 02/07/18 – 02/06/21	Total Cost:	$ 18,359

The SCAQMD operates a number of alternative fuel vehicles, including electric vehicles, fuel cell vehicles and plug-in hybrid-electric vehicles. The primary objective of having these vehicles as part of the SCAQMD demonstration fleet is to continue to support the use of zero emissions vehicles. The Honda Clarity Plug-In Hybrid provide up to 47 miles all electric range with about 340 miles total range including gasoline.

18287: Charging Station and Premises Agreement for Installation of One DC Fast Charger at SCAQMD Headquarters

Contractor: EVgo Services LLC	SCAQMD Cost-Share	$ 0
Term: 06/08/18 – 06/07/19	Total Cost:	$ 0

Through a CEC-funded project to install DC fast chargers throughout the South Coast Air Basin, EVgo and Clean Fuel Connection Inc. were tasked with installing a DC fast charger at SCAQMD's headquarters. This no-cost agreement provided access to the headquarters' premises for installation of the charger. The 50 kW fast charger has CHAdeMO and CCS connectors to charge the majority of American, European and Asian fast charging vehicles. The fast charger has been installed in the parking lot close to the front lobby entrance and adjacent to a cluster of Level 2 charging stations. These charging stations serve the needs of staff (78 registered EV drivers), visitors and the general public. EVgo will continue to operate and maintain the fast charger for a minimum of five years.

19190: Zero Emission Trucks and EV Infrastructure Project

Daimler Trucks North America	SCAQMD Cost-Share *(transferred from Clean Fuels into Fund 61)*	$ 8,230,072
	Cosponsors	
	State Emissions Mitigation Fund *(transferred to Advanced Technology Goods Movement Fund 61)*	4,440,000
	Daimler Trucks North America	15,670,072
	San Pedro Bay Port *(received into Fund 61)*	2,000,000
	U.S. EPA *(received into Fund 61)*	500,000
Term: 12/18/18 – 6/19/22	Total Cost:	$ 31,340,144

Daimler Trucks North America (DTNA) will develop battery-electric heavy-duty trucks and demonstrate them in real-world commercial fleet operations in and around environmental justice communities for a period of two years within SCAQMD's jurisdiction. DTNA will gather data and

information from the end-users including performance under specific duty-cycle applications during the demonstration. DTNA will utilize the data and information to move toward the commercial production and sales phase. DTNA will supply five Class 6 trucks with a gross vehicle weight rating (GVWR) up to 26,000 pounds and fifteen Class 8 trucks with a GVWR up to 80,000 pounds, including associated EV charging infrastructure. Fleet partners will be identified and the trucks integrated into a range of services and applications to gather operational data to improve each charging and utilization scheme, with seven of the Class 8 trucks to be used in port drayage operations, supporting the goods movement industry.

Purchase Order: Procure Greenlots SKY Enterprise Software License with Load Management for One Year

Contractor: Zeco Systems, Inc., dba Greenlots	SCAQMD Cost-Share	$ 55,200
Term: 12/13/18 – 12/13/18	Total Cost:	$ 55,200

The second phase of SCAQMD's EV charger project is to implement load management capabilities to manage demand from the EV chargers at SCAQMD headquarters in order to minimize facility demand charges from electricity bills for the building. The purchase order covers an annual subscription for the Greenlots load management and networking software. The networking software handles payment transactions for collection of EV charging revenue. The purchase order also covers the cost of meters and site controllers to meter the demand from the EV chargers, and enable the load management software to ramp down or turn off power to the EV chargers based on overall facility demand for peak demand shaving.

Direct Pay: Install DC Fast Charger at SCAQMD Headquarters

Contractor: Clean Fuel Connection Inc.	SCAQMD Cost-Share	$ 59,134
Term: 05/29/18 – 05/29/18	Total Cost:	$ 59,134

As part of a CEC funded project to install ten DC Fast Chargers in the South Coast Air Basin to further support a public fast charging network, these fast chargers were located in Los Angeles and San Bernardino counties. The CEC grant covered the cost of hardware and required cost-share covered the five year operation and maintenance costs, but did not cover installation costs. The direct pay covers the cost of installation for one fast charger at SCAQMD headquarters on the EVgo network, which serves staff, visitors and the general public.

Engine Systems/Technologies

17393: Development of an Ultra-Low Emissions Diesel Engine for On-Road Heavy-Duty Vehicles

Contractor: Southwest Research Institute	SCAQMD Cost-Share *(partially received as pass-through funds)*	$ 575,000
	Cosponsor	
	California Air Resources Board	750,000
Term: 05/30/18 – 07/31/19	Total Cost:	$ 1,325,000

This is Stage 3 of a comprehensive project to develop the low load cycles and application of aftertreatment and engine controls to mitigate emissions in the most critical areas of a heavy-duty engine cycle typical in the Los Angeles basin. Cylinder deactivation (CDA) hardware, in combination with a modified aftertreatment system, have shown potential in modeling to reach 0.02 NOx per bhp-hr. A heavy-duty 15-liter engine will be modified and tested with the CDA and extensive engine control algorithms will be investigated. The aftertreatment will include components, such as a mini burner and a passive-NOx adsorber, as well as a possible close coupled catalyst to reach the desired near–zero NOx. This contract includes $287,500 in pass-through revenue from the Port of Los Angeles.

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

Contractor: CALSTART Inc.	SCAQMD Cost-Share	$ 1,000,000
	Cosponsors	
	California Air Resources Board	7,000,000
	Achates Power, Inc.	6,550,000
	San Joaquin Air Pollution Control District	1,000,000
Term: 05/30/18 – 07/31/120	Total Cost:	$ 15,550,000

This project takes an old concept to launch a new beginning. The opposed piston engine in combination with modern computer modeling and aftertreatment systems shows potential to be an entirely new option in internal combustion engines. Lower emissions and higher efficiency is expected. This project is for the complete development of a heavy-duty diesel engine and demonstration in class 8 trucks. The engine will have the same power rating requirements as the conventional engine of similar displacement. This project offers another pathway to providing a near-zero NOx engine for use in class 8 trucks.

18211: Develop Thermal Management Strategy using Cylinder Deactivation for Heavy-Duty Diesel Engines

Contractor: West Virginia University Innovation Corporation	SCAQMD Cost-Share	$ 250,000
	Cosponsors	
	Environment Canada	100,000
	U.S. Environmental Protection Agency	250,000
	Jacobs Vehicle Systems, Inc. (in-kind)	50,000
	Cummins Inc. (in-kind)	50,000
Term: 06/08/18 – 06/07/20	Total Cost:	$ 700,000

This project is to study the potential benefits of cylinder deactivation on a heavy-duty diesel engine. The benefits of NOx s and possible GHG reductions make this an important study in the pathway to near-zero emissions for heavy-duty diesel engines. The hardware will be installed and tested for noise, vibration, harshness and reliability as well as emissions on the dynamometer in a lab setting.

18122: Southern California Trucking Demonstration of Near-Zero ISX12N Beta Engines

Contractor: Clean Energy	SCAQMD Cost-Share *(partially received as pass-through funds)*	$ 3,495,000
	Cosponsor	
	Clean Energy (in-kind)	2,500,000
Term: 01/05/18 – 01/04/20	Total Cost:	$ 5,995,000

The SCAQMD and Clean Energy partnered to develop a project that was awarded CEC funds under the 2016 Sustainable Freight Transportation Grant Funding Opportunity. The project scope includes repowering 20 existing 12-liter heavy-duty (HD) natural gas-powered vehicles with the new Beta version of Cummins-Westport's ISX12N engine and demonstrating this technology with seven local freight movement fleets. Each fleet operator is deploying their demonstration vehicle into routine service, thereby allowing operators and fleet managers the opportunity to get "first-hand" experience with the new HD natural gas engines. The expected outcome is to alter the negative perception of prior HD natural gas engines. Upon completion of the one year demonstration each vehicle's engine and exhaust treatment systems will undergo minimal changes from the Beta version to the fully commercialized version and will be certified to CARB's optional low NOx standard of 0.02g NOx/bhp-hr. Demonstrations are expected to conclude in Q3 2019. Fleet operator are expected to continue operating each vehicle in the South Coast Air Basin for their normal useful life. This contract includes $2,845,000 in pass-through revenue from CEC and $650,000 in cost-share funds from SCAQMD.

Fueling Infrastructure and Deployment (NG/Renewable Fuels)

Transfer: Participation in the California Natural Gas Vehicle Partnership for Fiscal Year 2018-19 and 2019-20

Contractor: California Natural Gas Vehicle Partnership	SCAQMD Cost-Share	$ 25,000
	Cosponsor	
	CNGVP Participating Members	145,000
Term: 07/06/18 – 07/05/20	Total Cost:	$ 170,000

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 SCAQMD spearheaded the formation of this strategic alliance, which comprises state and federal air quality, 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 July 2018 the SCAQMD approved $25,000 for the SCAQMD's participation in the Steering Committee for the next two 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; and, co-funding a white paper study to assess the business case of renewable natural gas with new near zero emission natural gas powered heavy-duty vehicles.

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

Contractor: 18 School Districts	SCAQMD Cost-Share *(received as pass-through funds)*	$ 3,104,700
	Cosponsor	
	School Districts (match)	1,185,000
Term: Varies (all executed in CY 2018)	Total Cost:	$ 4,289,700

In 2018, SCAQMD executed grants with 18 school districts to replace a total of 79 old pre-1994 diesel school buses with Type D CNG school buses certified to meet the optional low NOx, near-zero standard of 0.02 g/bhp-hr. The awards will provide up to $192,000 for each Type D CNG school bus including sales tax. These school buses are partially funded by a U.S. EPA Airshed grant, the funds from which were recognized into the Clean Fuels Fund. Out of the $192,000 per bus provided under the grant, $39,300 is provided by the U.S. EPA Airshed grant. The remaining funds were provided by SCAQMD's AB 923 funds totaling $13,286,800 (not listed in the table above). School districts are also required to provide a match of $15,000 per CNG bus.

Fuel/Emissions Studies

18206: Assess Air Quality and Greenhouse Gas Impacts of a Microgrid-Based Electricity System

Contractor: University of California Irvine	SCAQMD Cost-Share	$ 660,000
	Cosponsors	
	University of California Irvine, in partnership with U.S. Department of Energy, Southern California Gas Company and National Science Foundation (in-kind)	640,000
Term: 04/06/18 – 04/05/20	Total Cost:	$ 1,300,000

The University of California Irvine (UCI) through its Advanced Power and Energy Program proposes to perform three projects to evaluate air quality and greenhouse gas impacts. These projects will focus on potential fuel cell technology applications for industrial operations and petroleum refineries, assess impacts of renewable hydrogen blending in existing natural gas infrastructure and equipment, and compare economic performance of a fuel cell and battery-electric bus operating in a microgrid.

Emissions Control Technologies

17367: Develop and Evaluate Aftertreatment Systems for Large Displacement Diesel Engines

Contractor: Southwest Research Institute	SCAQMD Cost-Share *(partially received as pass-through funds)*	$ 400,000

	Cosponsor	
	Manufacturers of Emission Controls Association	80,000
Term: 02/28/18 – 06/30/19	Total Cost:	$ 480,000

This project is in response to a request to continue a CARB-funded project developing new test cycles for emissions certification. Complications were discovered in the original project aftertreatment and the data was found inconclusive. Therefore, project partners agreed to run the test again to get definitive results from the aged aftertreatment system. The aftertreatment was aged for 1,000 hours and data collected and analyzed at different load cycles similar to that which would be found in the Los Angeles air basin. This contract includes $290,000 in pass-through revenue from the U.S. EPA.

Technology Assessment and Transfer/Outreach

16262: Support Sustainable Transportation Energy Pathways (STEPs)

Contractor: University of California Davis-Institute of Transportation Studies	SCAQMD Cost-Share	$ 240,000
	Cosponsors	
	7 Energy Companies	1,680,000
	10 Automotive Companies	2,400,000
	5 Government Agencies	1,200,000
Term: 01/05/18 – 01/04/22	Total Cost:	$ 5,520,000

The Sustainable Transportation Energy Pathways (STEPS) Program at the U.C. Davis-Institute of Transportation Studies is continuing their multidisciplinary research consortium that brings together the world's leading automotive manufacturers, energy companies and government agencies to understand sustainable vehicle and energy solutions. The four explicit program goals of the STEPS 2015-2018 Program are to: 1) optimize scenarios for mass transition to alternative fuels and vehicles in California, 2) model evolving relationships between future sources of mobile energy and the existing oil and gas industry, 3) describe current trends and inform policymakers of strategies for Global Urban Sustainable Transport, and 4) continue development of a wide range of models in order to progress research and improve trend recognition.

18253: Identify and Secure a "Futurist" Clean Transportation or Goods Movement Technologies Expert

Contractor: Three Squares Inc.	SCAQMD Cost-Share	$ 11,845
Term: 04/05/18 – 05/31/18	Total Cost:	$ 11,845

Three Squares Inc. (TSI), one of the nation's leading green event production and marketing firms specializing in producing environmentally sustainable high profile events, assisted SCAQMD in identifying and securing a recognized leading expert in clean transportation and technologies. TSI has experience leading large-scale event production efforts across the globe and has demonstrated the capacity to secure event speakers to attract international audiences of environmental leaders, corporate executives, academic researchers, technology developers and clean tech financiers. Through these events, TSI has established a wide network of contacts and prestigious speakers. This expert identified as a 'futurist' presented at the SCAQMD Board Retreat on May 10, 2018.

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

Contractor: Clean Fuel Connection, Inc.	SCAQMD Cost-Share	$ 100,000
Term: 09/07/08 – 09/06/20	Total Cost:	$ 100,000

SCAQMD relies on expert input, consultation and support to manage a number of programs conducted under the Clean Fuels Program and incentive programs. Clean Fuel Connection, Inc., 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 to enable the range of activities involved in implementing the Clean Fuels Program and associated complimentary programs as needed.

Direct Pay: Cosponsor 26 Conferences, Workshops & Events plus 5 Memberships

Contractor: Various	SCAQMD Cost-Share	$ 470,118
	Cosponsors	
	Various	3,722,352
Term: 01/01/18 – 12/31/18	Total Cost:	$ 4,192,470

The SCAQMD regularly participates in and hosts or cosponsors conferences, workshops and miscellaneous events. In CY 2018, SCAQMD provided funding for 26 conferences, workshops and events and 5 memberships in key stakeholder organizations, as follows: Hydrogen and Fuel Cells Ports Briefing in December 2017 (executed in 2018); Clean Fuels Advisory Group Retreats in September 2017 and January 2018; Rethink Methane in February 2018; NREL's Natural Gas Vehicle Technology Forum in February 2018; ICEPAG in March 2018; CALSTART Clean Transportation Summit "California:2030" in March 2018; 28th Real-World Emissions Workshop in March 2018; Portable Emissions Measurement Systems Conference & Workshop in March 2018; ACT Expo in April 2018; Hydrogen and Fuel Cell On-Road Freight Workshop in April 2018; California Passenger Rail Summit in April 2018; Special Awards at the California State Science Fair in April 2018; CARB's 50th Anniversary Technology Symposium and Showcase in May 2018; Advanced Transportation Symposium & Expo in June 2018; Women in Green Forum in August 2018; Electrification 2018 International Conference & Expo in August 2018; 2018 Air Sensors International Conference in September 2018; Los Angeles National Drive Electric Week "ChargeUp LA" in September 2018; Santa Monica AltCar Expo & Conference in October 2018; CALSTART's 26th Annual Symposium in November 2018; CalETC 2018 Los Angeles Auto Show events in November 2018; West Coast Collaborative Partners Meeting in October 2018; Power of Waste: Renewable Natural Gas (RNG) for California Workshop in October 2018; Annual Women in Trade Event in November 2018; and Mobile Source Air Toxics Workshop in February 2019. Additionally, for 2018, four memberships were renewed for participation in the California Hydrogen Business Council, California Stationary Fuel Cell Collaborative; CALSTART Board; and Veloz (subsumed California PEV Collaborative). SCAQMD also joined a new organization, the Los Angeles Cleantech Incubator's Transportation Electrification Partnership, which issued the ZE 2028 Roadmap in fall 2018.

CLEAN FUELS PROGRAM
Progress and Results in 2018

Key Projects Completed

A large number of emission sources contribute to the air quality problems in the South Coast Air Basin. Given the diversity of these sources, there is no single technology or "silver bullet" that can solve all of the region's problems. Accordingly, the SCAQMD continues to support a wide range of advanced technologies, addressing not only the diversity of emissions sources, but also the time frame to commercialization of these technologies. Projects cofunded by the SCAQMD's Clean Fuels Program include emission reduction demonstrations for both mobile and stationary sources, although legislative requirements limit the use of available funds primarily to on-road mobile sources.

Historically, mobile source projects have targeted low emissions technology developments in automobiles, transit buses, medium- and heavy-duty trucks and off-road applications. The last few years the focus has shifted to near-zero and zero emissions technologies for medium- and heavy-duty trucks, especially those in the goods movement industry.

Table 5 (page 54) provides a list of 45 projects and contracts completed in 2018. Summaries of the completed technical projects are included in Appendix C. Selected projects completed in 2018 which represent a range of key technologies from near-term to long-term are highlighted below: (a) Develop, Integrate and Demonstration Ultra-Low Emissions 12-Liter Natural Gas Engine for On-Road Heavy-Duty Vehicles; (b) Demonstrate Catenary Zero Emissions Goods Movement System; and (c) Secondary Organic Aerosol Forming Potential from Light-Duty Gasoline Direct Injection Vehicles.

Develop, Integrate and Demonstrate Ultra-Low Emissions 12-Liter Natural Gas Engine for On-Road Heavy-Duty Vehicles

The 12-liter (12L) natural gas engine project was a follow-on to the 8.9L natural gas engine development and certification project to address needs of larger displacement engines. The 12L natural gas engine was certified at near-zero NOx achieving a 0.02 gram bhp-hr rating and went into full production in February 2018. The Cummins Westport ISX12N (the "N" designation is for near-zero emissions) is a larger-displacement natural gas engine suitable for a variety of heavy-duty vehicles, including regional-haul truck/tractor, vocational and refuse applications. With a displacement of 11.9 liters and up to 400 horsepower and 1,450 lbs. per foot of torque, the ISX12N operates on 100 percent natural gas, which can be carried on the vehicle in either compressed (CNG) or liquefied (LNG) form. The ISX12N can also run on renewable natural gas (RNG). Sales have been increasing nationally with over 2 million miles tested on the road.

An extensive process was undertaken to design and develop the 12L natural gas engine and aftertreatment to meet the 0.02 gram NOx level. Utilizing learnings from previous technology development, the existing stoichiometric-cooled EGR spark-ignited combustion was selected as the platform to complement with the following additions/changes:

- Implementation of a closed crankcase ventilation (CCV) system with additional pressure sensor;
- Aftertreatment size increased, improved formulation and O2 sensor location changed;
- Redesigned fuel system for improved fuel delivery accuracy and responsiveness; and
- Improved software with various emissions optimizing control strategies and addition of heavy-duty on-board diagnostics (OBD).

The combination of increased aftertreatment size and improved formulation increases the overall conversion efficiency of the catalyst and thereby reduces emissions.

The recommended maximum gross container vehicle weight (GCVW) for line-haul applications is 80,000 lbs. (36,287 kg). The recommended gearing to optimize fuel economy is 1,400-1,475 rpms at cruise speed for line-haul applications and 1,450-1,600 rpms for vocational applications.

The ISX12 N engine has been certified at 0.02 g/bhp-hr current 2010 CARB optional low NOx standards and the U.S. EPA GHG and U.S. Department of Transportation fuel consumption regulations. The figure below shows the first Class 8 truck with a 1SX12 engine delivered to a customer.

Figure 16: Class 8 Tractor with 12-Liter NG Engine

Demonstrate Catenary Zero Emissions Goods Movement System

Siemens Industry Inc. has designed and demonstrated a catenary truck technology, eHighway, in Germany on a European truck chassis. For this project with SCAQMD, Siemens proposed to bring the eHighway technology to Southern California with their partner Volvo and develop and demonstrate a catenary plug-in hybrid electric truck technology. The hybrid drive system will extend the operating range of the truck beyond the all-electric range of the catenary system, enabling the truck to perform regional drayage operations and bridge gaps in catenary infrastructure as it is deployed on a regional level.

For SCAQMD, the infrastructure portion of the project was built along Alameda Street in the City of Carson. The approximate one mile segment extends north to south from East Lomita Blvd to the Dominguez Channel. Corresponding with the operational range of the pantographs, two parallel catenary wires were installed above the roadway one mile in each direction. The height of the system was designed to be above standard vehicle dimensions and clearances. The horizontal position of the overhead contact line along the roadway is supported by tensioning devices installed inside the poles supporting the overhead catenary system. The connection to the grid occurred at the middle of the system where a power supply was placed.

The Alameda Corridor where the eHighway system was demonstrated is a highly congested urban industrial area with several refineries, railyards and facilities associated with petroleum refining. Nearly two years of delays were encountered for the construction portion of the project. Because of the many underground utilities, some known on city maps and others not identified in any city or county records, placement of the planned pole foundations was affected. The obstructions prevented Siemens from

going forward with their original design and they had to redesign the foundations to above ground. The design change caused further delays due to requirements by the City of Carson to install safety barriers and the encroachment onto the roadway of the foundations (Figure 17). Additional delays prior to the start of demonstration were encountered because the system power supply was placed over a high pressure gas line.

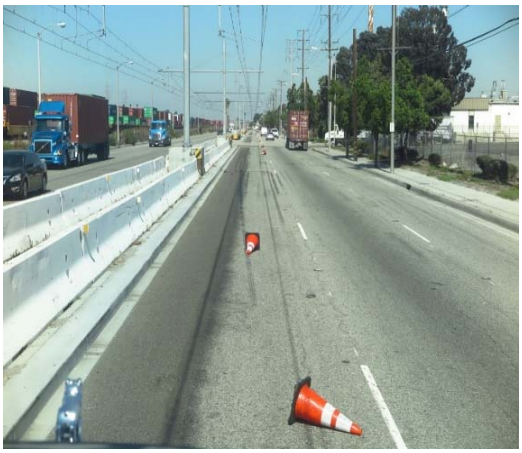


Figure 17: eHighway Infrastructure on Alameda Street

The demonstration period had to be reduced from one year to six months because of the issues outlined above. The demonstration was successful in proving out the operation of the vehicles and infrastructure. At the end of the six-month demonstration, Siemens decommissioned the system and returned the area to its original condition.

The SCAQMD conducted several independent studies that included: Determining Owner Operator for Catenary System; Total Cost of Ownership: Catenary Trucks vs Battery Electric Trucks; and Grid Impact Study and Business Case for eHighway. The studies were presented to the funding partners in the project and discussions of the technology and the project were conducted. The recommendations of the viability of the technology are as follows:

- Catenary systems may work in specific duty cycles with high concentrations of traffic on specific routes;
- Vehicles are tied to catenary technology and route;
- Having dual propulsion technologies on a vehicle is complex and expensive for limited utilization;
- Technologies not tied to wayside power are more versatile and flexible in their application for multiple duty cycles;
- Further R&D work and steps towards higher technology readiness level (TRL) must be taken;
- Commercialization and robustness of the pantographs is needed and optimized electric hybrid drivetrains; and
- Technology improvements and lower costs are needed for vehicles and infrastructure to impact economic feasibility.

In addition to the findings of the results of the catenary demonstration, other zero emissions technologies, such as battery and fuel cells, have improved dramatically in durability, reliability, energy density and lower costs.

Figure 18: Volvo Truck Operating on eHighway

Lesson learned and benefits of this project:

- Wayside power for zero emissions cargo transportation was difficult to implement in an urban industrial environment where it is needed most for reducing criteria pollutants. Sweden did a similar project but the system was constructed in a "green field" without utilities or obstructions to interfere with the construction; the Swedish objective was GHG reductions. The catenary technology may be viable in environments where it is being implemented in Sweden and Germany.
- Siemens was able to design and develop other alternatives for constructing their system infrastructure.
- Constructing infrastructure in the public right of way has many challenges and obstacles to overcome. Implementing such infrastructure, whether it is EV, hydrogen or wayside power, requires a more intensive site survey and risk analyses and risk mitigation plans need to be conducted before putting a shovel to the ground.
- Truck technologies, such as Volvo's hybrid electric platform, continue development of what was used in the Siemens project in two other major projects SCAQMD is administering: 1) the GGRF drayage truck project, and most recently: 2) the Volvo LIGHTS project. In these projects, we are seeing Volvo transition from diesel hybrid to battery electric trucks. SCAQMD's work with Volvo on these projects contributed to the realization of the benefits and viability of zero emissions transportation.

Secondary Organic Aerosol Forming Potential from Light-Duty Gasoline Direct Injection Vehicles

Gasoline direct injection (GDI) vehicles are known for higher fuel 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 forming potential from these vehicles as it could lead to further impact on the ambient PM concentration in the South Coast Air Basin (Basin).

The University of California Riverside (UCR)/CE-CERT evaluated the primary emissions and SOA production from eight current technology GDI vehicles over the LA92 test cycle. This program had three distinct goals (or separate exercises): 1) evaluate primary emissions and SOA formation from conventional GDI vehicles; 2) evaluate particulate emissions, toxic pollutants and SOA formation from GDI vehicles with and without gasoline particle filters (GPFs); and 3) examine the impact of fuel composition on the tailpipe emissions and SOA formation from GDI flexible fuel vehicles (FFVs). For the first exercise, four 2015 to 2016 model year GDI vehicles were tested. Results showed that PM, black carbon (BC) and particle number (PN) emissions increased markedly during accelerations and the cold-start phase.. PN and BC emissions showed large reductions during the urban and hot-start phases. Aged exhaust emissions resulted in distinct secondary aerosol emissions that varied significantly in physical and chemical structure. Two of the four vehicles produced considerable

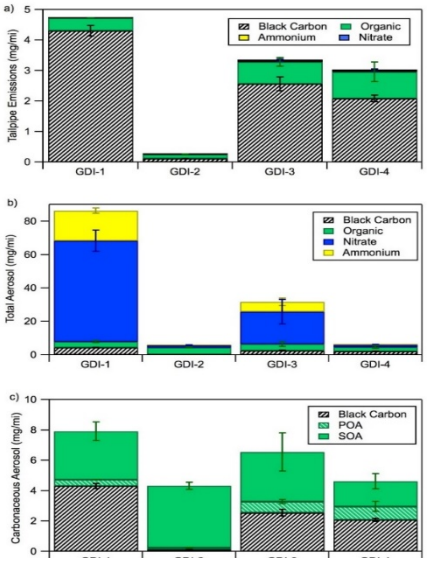


Figure 19: Chemical composition of primary organic aerosol (a-top panel), secondary organic aerosol after irradiation (b-middle panel), and primary and secondary carbonaceous aerosol (c-bottom panel).

amounts of inorganic aerosol, thereby modifying secondary aerosol volatility and hygroscopicity (Figure 19b). Primary PM emissions from all vehicles in this study met their certification requirements for their respective model years (Figure 19a); however, all vehicles exhibited potential to form a considerable amount of secondary aerosol with different composition (Figure 19c).

For the second exercise, two 2016 model year GDI vehicles were evaluated for the effects of catalyzed GPF addition to GDI vehicles. The use of catalyzed GPFs greatly reduced the toxic polycyclic aromatic hydrocarbons and their nitrated derivatives (nitro-PAHs), as well as dramatically reduced PM, PN and BC emissions. Gaseous emissions of NOx, total hydrocarbons (THC) and non-methane hydrocarbons (NMHC), and production of SOA was reduced with GPF addition.

For the third exercise, two GDI FFVs were tested with four fuels of different ethanol blend levels: E10 with high aromatics, E10 with low aromatics, intermediate E30 and high E78 blend. Vehicles fueled with E30 and E78 exhibited reductions in THC, NMHC, CO and NOx emissions compared to the high aromatics E10. As the ethanol content increased, the secondary aerosol formation potential decreased in both FFVs, due to reduction in SOA precursors (i.e., NMHC). In general, this study found that high ethanol content is not only effective in the reduction of tailpipe PM, but also has the potential to greatly decrease SOA formation potential of the emitted exhaust.

As shown in Figure 20, results from this study were compared to earlier peer-reviewed studies exploring SOA formation from gasoline vehicles. The comparison showed that SOA formation dropped as the emissions certification standards became more stringent.

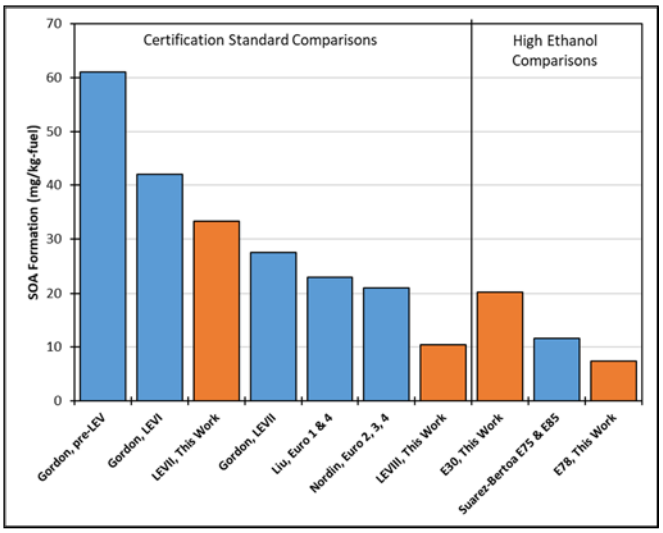


Figure 20: Comparison of SOA formation from GDI vehicles in this study and from gasoline vehicles in earlier peer-reviewed studies

In summary, this study showed that higher aromatics will increase SOA, while higher ethanol blends will reduce SOA formation. The results also showed that SOA formation increased with increasing NMHC emissions, suggesting that further reductions in NMHC emissions are necessary from current technology GDI vehicles. Catalyzed GPFs may help to reduce SOA productions from GDI vehicles.

This study will enhance our ability to model the formation of SOA from GDI vehicles, helping to close the gap between atmospheric measurements and model predictions of PM concentrations. Models equipped with these SOA formation processes could then be used to help formulate science-based policy for the reduction of ambient PM concentrations.

Table 5: Projects Completed between January 1 & December 31, 2018

Contract	Contractor	Project Title	Date
Hydrogen/Mobile Fuel Cell Technologies and Infrastructure			
12057	Linde, LLC	Expand Hydrogen Fueling Infrastructure	Oct-2018
14684	California Department of Food and Agriculture, Division of Measurement Standards	Conduct Hydrogen Station Site Evaluations for Site Certifications for Commercial Sale of Hydrogen	Feb-2018
15641†	Hardin Hyundai	Three-Year Lease of 2015 Tucson Fuel Cell Vehicle	Jun-2018
16171†	Longo Toyota	Three-Year Lease of 2015 Toyota Mirai Fuel Cell Vehicle	Dec-2018
17394	Energy Independence Now	Provide Analysis of Renewable Hydrogen Pathways, Economics and Incentives	Mar-2018
Electric/Hybrid Technologies and Infrastructure			
13426	Transportation Power, Inc.	Develop and Demonstrate Catenary Class 8 Trucks (1 Electric & 1 CNG Platform)	Jul-2018
13439†	City of Carson	MOU for Catenary Zero Emissions Goods Movement Project	Jul-2018
14062	Siemens Industry Inc.	Develop and Demonstrate Catenary Zero Emissions Goods Movement System and Develop and Demonstrate Diesel Catenary Hybrid Electric Trucks	Dec-2018
15382	ChargePoint, Inc.	Install Electric Charging Infrastructure	Jan-2018
15650	University of California San Diego	Develop and Demonstrate Warehouse Rooftop Solar System with Storage and EV Charging	Jan-2018
16047	US Hybrid Corporation	ZECT I: Develop and Demonstrate Three Class 8 LNG Plug-In Hybrid Electric Drayage Trucks	Sep-2018
Engine Systems/Technologies			
15632	Gas Technology Institute	Develop Ultra-Low Emission Natural Gas Engine for On-Road Medium-Duty Vehicles	Jun-2018
16205	Cummins Westport, Inc.	Develop, Integrate and Demonstrate Ultra-Low Emission 12-Liter Natural Gas Engines for On-Road Heavy-Duty Vehicles	Jun-2018
Fueling Infrastructure and Deployment (NG/Renewable Fuels)			
09364†	Rim of the World Unified School District	Construct and Install a CNG Fueling Station and Perform Garage Upgrades	Oct-2018
12851	Clean Energy	Install, Operate and Maintain Three Natural Gas Fueling Stations	Dec-2018

Table 5: Projects Completed between January 1 & December 31, 2018 (cont'd)

Contract	Contractor	Project Title	Date
Fueling Infrastructure and Deployment (NG/Renewable Fuels) (cont'd)			
12852	City of Corona	Upgrade Existing CNG Fueling Station at City Corporate Yard	Jan-2018
12853	Rainbow Disposal Co., Inc.	Upgrade CNG Fueling Station	Dec-2018
12854	Waste Management, Inc.	Upgrade LNG Fueling Station at Baldwin Park Facility	Dec-2018
15438	United Parcel Service (UPS)	Refurbish Ontario LCNG Fueling Facility	Jun-2018
Fuel/Emissions Studies			
15625	University of California Riverside/CE-CERT	Evaluate SOA Formation Potential from Light-Duty GDI Vehicles	Jun-2018
17060†	University of California Riverside	Bailment Agreement – Equipment Use for In-Use Emissions Testing of Heavy-Duty Inspection and Maintenance Program	Oct-2018
Technology Assessment and Transfer/Outreach			
12381†	Integra Environmental Consulting Inc.	Technical Assistance Related to Emissions Inventories, Goods Movement and Off-Road Sources	Apr-2018
14185	Three Squares Inc.	Conduct Education Outreach for the Basin DC Fast Charging Network Project	Jun-2018
15516†	Cordoba Corporation	Technical Assistance with Construction of Zero Emissions Goods Movement Demonstration Project	Mar-2018
17037†	Clean Fuel Connection, Inc.	Technical Assistance with Alternative Fuels, Electric Vehicles, Charging and Fueling Infrastructure and Renewable Energy	Nov-2018
17282†	CALSTART, Inc.	Cosponsor CALSTART's 25th Anniversary Symposium	Jan-2018
17336	Three Squares Inc.	Conduct Education Outreach for the Basin DC Fast Charging Network Project	Jun-2018
18120†	Burke Rix Communications	Cosponsor the Southern California Energy Water + Green Living Summit 2018	Feb-2018
18145†	Gladstein, Neandross & Associates LLC	Cosponsor Rethink Methane 2018	Feb-2018
18155†	University of California Davis-Institute of Transportation Studies	Cosponsor 2018 Air Sensors International Conference	Oct-201
18163†	CALSTART, Inc.	Cosponsor the CALSTART 2018 Clean Transportation Summit *California: 2030*	Apr-2018
18199†	National Renewable Energy Lab	Cosponsor NREL's Natural Gas Vehicle Technology Forum	Apr-2018

Table 5: Projects Completed between January 1 & December 31, 2018 (cont'd)

Contract	Contractor	Project Title	Date
Technology Assessment and Transfer/Outreach (cont'd)			
18219†	Coordinating Research Council, Inc.	Cosponsor the 28th Real World Emissions Workshop	Apr-2018
18235†	Southwest Rail Passenger Association	Cosponsor 2018 California Passenger Rail Summit	Apr-2018
18245†	University of California Riverside	Cosponsor the 2018 Portable Emissions Measurement Systems Conference & Workshop	Apr-2018
18249†	University of California Riverside	Cosponsor CARB's 50th Anniversary Technology Symposium and Showcase	May-2018
18253†	Three Squares Inc.	Identify and Secure a 'Futurist' Clean Transportation or Goods Movement Technologies Expert	May-2018
18282†	California Hydrogen Business Council	Cosponsor the Hydrogen and Fuel Cell On-Road Freight Workshop	May-2018
18290†	Sustain OC	Cosponsor the 2018 Advanced Transportation Symposium & Expo	Jul-2018
18382†	Three Squares Inc.	Cosponsor the 2018 Women in Green Forum	Nov-2018
19040†	Plug In America	Cosponsor the Los Angeles National Drive Electric Week 2018	Sep-2018
19041†	Green Technology (Foundation for Advancements in Science and Education)	Cosponsor Green California Schools and Community Colleges Summit and Exhibition	Dec-2018
19090†	Electric Power Research Institute	Exhibit at Electrification 2018 International Conference & Exposition	Aug-2018
19112†	Platia Productions	Cosponsor the 2018 Santa Monica AltCar Expo & Conference	Nov-2018
19154†	California Electric Transportation Coalition	Cosponsor the CalETC 2018 Los Angeles Auto Show Events	Dec-2018

†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
2019 Plan Update

As noted earlier, 2018 marked the 30th year of the SCAQMD's Clean Fuels Program. The funding source for the Clean Fuels Program is a $1 motor vehicle registration surcharge that, like the Program, 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 has continued to fund a broad array of technology applications spanning near- and long-term implementation. More recently, the focus has been and will continue to be to support the development and deployment of zero and near-zero emissions technologies. Similarly, planning has been and will remain an ongoing activity for the Program, which must remain flexible to address evolving technologies as well as the latest progress in the state-of-technologies, new research areas and data.

Every year the SCAQMD re-evaluates the Clean Fuels Program to develop a Plan Update based on a reassessment of the technology progress and direction of the SCAQMD's Board. This Plan Update for CY 2019 targets several projects to help achieve near-term emissions reductions needed for the South Coast to meet health-based air quality standards.

Overall Strategy

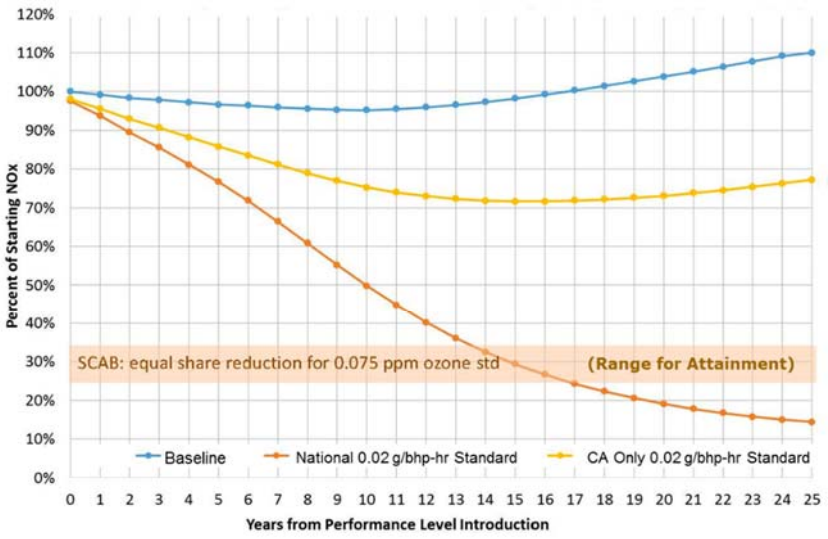
The overall strategy of the TAO's Clean Fuels Program is based, in large part, on emissions reduction technology needs identified through the AQMP process and the SCAQMD Board's directives to protect the health of the approximately 17 million residents (nearly half the population of California) in the South Coast 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 emissions 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 emissions 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 lower-emitting mobile and stationary advanced technologies in the Basin to achieve air quality standards. The 2016 AQMP projects that an approximate 45 percent reduction in oxides of nitrogen (NOx) is required by 2023 and an additional 55 percent reduction by 2031. The majority of these NOx reductions must come from mobile sources, both on- and off-road. Notably, the SCAQMD is currently only one of two regions in the nation designated as an extreme ozone nonattainment area (the other is San Joaquin Valley). Ground level ozone (a key component of smog) is created by a chemical reaction between NOx and volatile organic compound (VOC) emissions in the presence of sunlight. This is especially noteworthy because in the South Coast Air Basin the primary driver for ozone formation is NOx emissions, and mobile sources contribute approximately 88 percent of the NOx emissions in this region. 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 ($\mu g/m^3$)].

In June 2016, SCAQMD and 10 co-petitioners requested the U.S. EPA Administrator to undertake rulemaking to revise the national on-road heavy-duty engine exhaust NOx emission standard from 0.2 g/bhp-hr to 0.02 g/bhp-hr. It was recommended that the regulation be implemented by January 2022 or if not feasible, by January 2024, with a phase-in starting in January 1, 2022. A national standard (as opposed to only a California standard) is estimated to result in NOx emission reductions from this

source category from 70 to 90 percent in 14 to 25 years, respectively. Given that the Basin must attain the 75 ppb ozone NAAQS by 2031 (within the next 13 years), a new on-road heavy-duty engine exhaust emissions standard for NOx is critical given the time needed for such standards to be adopted, for manufacturers to develop and produce compliant vehicles, and for national fleet turnover to occur. In November 2018, U.S. EPA initiated the process to update the existing heavy-duty engine standards to lower NOx emissions.

Figure 21 shows the difference in NOx reductions from heavy-duty trucks between baseline emissions (no new regulations) in blue, a low NOx standard adopted only in California in yellow, and lastly, the orange line shows reductions if the same low NOx standard is implemented nationally.



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

The findings from the MATES IV[5] (released May 2015), which included local scale studies near large sources such as ports and freeways, reinforce the importance of the need for transformative transportation technologies, especially near the goods movement corridor to reduce NOx emissions. In recognition of these impacts, the SCAQMD added as a key element to its strategy a concerted effort to develop and demonstrate zero and near-zero emissions' goods movement technologies, including electric trucks, plug-in hybrid trucks with all-electric range, zero emission container transport technologies. In 2017, SCAQMD 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 typically emitted or subsequently formed from vehicle exhaust. CARB is also updating its EMFAC model, which assesses emissions from on-road vehicles including cars, trucks and buses.

California currently has several incentive programs to help implement cleaner technologies, and while some additional financial resources have also recently been identified to offset the higher procurement costs of emerging clean technologies (i.e., Volkswagen Environmental Mitigation Trust which allocated $423 million to California), significant additional resources are still needed for the scale necessary to achieve the air quality standards for this region. This is where the Clean Fuels Program can help make a significant impact. A key strategy of the Clean Fuels Program is its public-private partnership with private industry, technology developers, academic institutions, research institutions and government agencies. This public-private partnership has allowed the Program to leverage its

[5] 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

funding on average with $3-$4 of spending on R&D projects to every $1 of SCAQMD funds. The SCAQMD aggressively seeks leverage funds to accomplish more with every dollar. Over its 30-year life, from 1988 to 2018, the Clean Fuels Program provided $320.5 million toward projects totaling $1.5 billion. TAO's RD[3] and implementation programs have helped develop and commercialize numerous technologies, subsequently providing incentives to offset the incremental cost of the technologies. With the success of this process, the 2016 AQMP included control measures to develop indirect source regulations and strengthen the fleet rules that can take advantage of incentives provided, as a method of compliance to further accelerate the emissions reductions.

CY 2018 also marked another milestone in TAO–the 20th year of the Carl Moyer Program. The Carl Moyer Program (CMP) provides partial funding to owners of diesel engines and equipment to go beyond regulatory requirements by retrofitting, repowering or replacing their engines with newer and cleaner models. The CMP has been a successful and popular statewide air pollution reduction program enacted through legislation and plays a complementary role to California's regulatory program by providing incentives to expedite the transition to cleaner technology to obtain early or extra NOx, PM and ROG emissions reductions. The Carl Moyer Program provides the necessary incentives to facilitate penetration of the technologies developed and demonstrated by the Clean Fuels Program. Together these two synergistic programs allow the SCAQMD to be a leader in technology development and implementation to accelerate the reduction of criteria pollutants.

Figure 22 provides a conceptual design of the wide scope of the Clean Fuels Program and the relationship with incentive programs, as well as the regulatory approaches included in the 2016 AQMP. The SCAQMD's Clean Fuels Program funds various stages of technology projects, typically ranging from Technology Readiness Levels 3-8, to provide a portfolio of emissions technology choices but to achieve emissions reduction benefits in the nearer as well as over the longer term.

Figure 22: Technology Readiness Level Stages

While the state continues to focus their attention to climate change (CO2 reductions), the SCAQMD remains committed to being a leader in achieving NOx reductions. Toward this end, SCAQMD focuses on developing, demonstrating and commercializing zero and near-zero emissions technologies and renewable fuels that provide concurrent CO2 reduction benefits. Fortunately, many of the technologies that address the South Coast Basin's needed NOx reductions align with the state's GHG reduction efforts. Furthermore, the U.S. EPA noted that the transportation sector contributed 28 percent of overall GHG emissions in 2016. Given this, coupled with their Cleaner Trucks Initiative in development, the SCAQMD is confident it can successfully partner on state and federally funded projects that promise NOx and GHG co-benefit emissions reductions.

Program and Funding Scope

This 2019 Plan Update includes projects to develop, demonstrate and commercialize 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 getting ready for commercialization and deploying ready technologies; and
3) continued development of near-term cost-effective approaches and longer-term technology development.

The overall scope of projects in the 2019 Plan Update also needs to remain sufficiently flexible to address new challenges and measures that are identified in the 2016 AQMP, consider dynamically evolving technologies, and take into account new research and data. The latter, for example, might include initial findings from MATES V and revised inventories in EMFAC 2017.

Within the core technology areas defined later in this section, project objectives range from near-term to long-term. The SCAQMD 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 the Program's projects is described below, from near-term to longer-term.

- *Deployment* or technology commercialization efforts focus on increasing the utilization of clean technologies in conventional applications, promising immediate and growing emissions reduction benefits. It is often difficult to transition users to a non-traditional technology or fuel due to higher costs or required changes to user behaviors, even if such a technology or fuel offers significant societal benefits. As a result, in addition to government's role to reduce risk by funding technology development and testing, one of government's roles is to support and offset any incremental cost through incentives to help accelerate the transition and use of the cleaner technology. The increased use and proliferation of these cleaner technologies often depends on this initial support and funding as well as efforts intended to increase confidence of stakeholders that these technologies are real, cost-effective in the long term and will remain applicable.
- Technologies ready to begin field *demonstration* in 2019 are expected to result in a commercial product in the 2022-2024 timeframe, and technologies being field demonstrated generally are in the process of being certified. The field demonstrations provide a controlled environment for manufacturers to gain real-world experience and address any end-user issues that may arise prior to the commercial introduction of the technology. Field demonstrations provide real-world evidence of a technology's performance to help allay any concerns by potential early adopters.
- Finally, successful technology *development* projects are expected to begin during 2019 with durations of at least two or more years. Additionally, field demonstrations to gain longer-term verification of performance may also be needed prior to commercialization. Certification and ultimate commercialization would be expected to follow. Thus, development projects identified in this plan may result in technologies ready for commercial introduction as soon as 2023-2025. Projects are also proposed that may involve the development of emerging technologies that are considered longer term and, perhaps higher risk, but with significant emission reduction 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 emissions reductions needed to achieve NAAQS and thus form the core of the Program.

The goal is to fund viable projects in all categories. However, not all project categories will be funded in 2019 due to funding limitations, and 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 SCAQMD to leverage its funds with other funding agencies to expedite the demonstration and eventual implementation of cleaner alternative technologies in the Basin. A concerted effort is continually made to form public private partnerships to leverage Clean Fuels funds. Two prime examples of this effort in 2018 are projects with Daimler and Volvo. The first is a $31.3 million project with Daimler, with SCAQMD providing 28 percent of the cost-share, to develop 20 heavy-duty electric trucks with EV infrastructure that includes energy storage systems to demonstrate the trucks in real-world commercial fleet operations in and around environmental justice communities. The second is a $44.8 million award from CARB's Greenhouse Gas Reduction Fund (GGRF) Program to conduct a wide-scale Volvo battery electric truck and off-road vehicle and infrastructure demonstration; SCAQMD has committed $4 million in cost-share for this nearly $90 million project from the Clean Fuels Program.

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. Priorities may also shift to address specific technology issues which affect residents within the SCAQMD's jurisdiction. AB 617, signed by the Governor in mid-2017, will require planning initially focused on three disadvantaged communities in our region, and additional flexibility will be needed to develop new strategies and technologies. Changes in priority may also occur to leverage opportunities such as cost-sharing by the state government, the federal government or other entities.

The following nine core technology areas are listed by current SCAQMD priorities based on the goals for 2019.

Hydrogen/Fuel Cell Technologies and Infrastructure

The SCAQMD 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-duty fuel cell vehicles (FCVs) by supporting the required fueling infrastructure.

Calendar Years 2015-2019 have been 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 Fuel Cell. Hyundai announced plans for a new 2019 model, Nexo, available for lease or purchase at three dealerships in California. Mercedes-Benz's announcement of the EQC platform GLC F-cell plug-in hybrid fuel cell have similarly disclosed plans to introduce FCVs in 2019. Since hydrogen fueling stations need 18-36 month lead times for permitting, construction and commissioning, plans for stations need to be implemented now. While coordination efforts 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 to

general consumers are still needed. In addition, SCAQMD continues to review the market to understand new business models and new sources of funding besides grants for construction necessary to enable the station operations to remain solvent during the early years until vehicle numbers ramp up. Lastly, a deliberate and coordinated effort is necessary to ensure that the retail hydrogen stations are developed with design flexibility to address specific location limitations, robust hydrogen supply, and with refueling reliability matching those of existing gasoline and diesel fueling stations.

In January 2018, 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. This is double the current target in Assembly Bill 8 (Perea), chaptered in September 2013, but set its target goal for only two years earlier (end of 2023). 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; FCEVs are expected to comprise a significant portion of this future ZEV fleet.

Fuel cells can also play a role in medium- and heavy-duty applications where battery recharging time is insufficient to meet operational requirements. The California Fuel Cell Partnership's (CaFCP) 2030 Vision[6] 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 establishes metrics for measuring progress. Toyota Motors has displayed a second Class 8 fuel cell truck prototype with planned demonstrations at Port of Long Beach, fueling at a new 1,000 kg/day truck fueling station with Equilon, cofunded by CEC and SCAQMD, using hydrogen produced by a new tri-generation system under development. Also, SCAQMD is cofunding GGRF projects with the San Pedro Bay Ports, including one project with POLA and Kenworth for fuel cell powered trucks and hydrogen infrastructure. Kenworth will continue development on a vehicle it demonstrated in SCAQMD's ZECT 2 project. Toyota will integrate its fuel cells into ten Kenworth trucks and the project will build hydrogen fueling stations to support the demonstration and future heavy-duty hydrogen powered trucks.

The 2019 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, including energy stations with electricity and hydrogen co-production and higher pressure (10,000 psi) hydrogen dispensing and scalable/higher throughput;
- 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 marine 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; and
- coordination with fuel cell vehicle OEMs to develop an understanding of their progress in overcoming the barriers to economically competitive fuel cell vehicles and develop realistic scenarios for their large scale introduction.

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

- 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.

Electric/Hybrid Technologies and Infrastructure

In an effort to meet the 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. With that in mind, the SCAQMD supports projects to address the main concerns regarding cost, battery lifetime, travel range, charging infrastructure and OEM commitment. Integrated transportation systems can encourage further reduction of emissions by matching the features of electric vehicles (zero emissions, zero start-up emissions, all electric range) to typical consumer demands for mobility by linking them to transit. Additionally, the impact of fast charging on battery life and infrastructure costs needs to be better understood. This is especially important today when every month roughly 36,000[7] new plug-in vehicles are sold or leased in the U.S. This number will increase significantly with the introduction of vehicles with 200-plus mile ranges, such as the Chevy Bolt, launched in December 2016, the Tesla Model 3 which came out in mid-2017, and Hyundai Kona, Nissan Leaf and more to come in 2019-20.

The development and deployment of zero emission goods movement systems remains one of the top priorities for the SCAQMD to support a balanced and sustainable growth in the port complex. The SCAQMD continues to work with our regional partners, in particular the Ports of Los Angeles and Long Beach, the Southern California Association of Governments (SCAG) and Los Angeles County Metropolitan Transportation Authority (Metro) to identify technologies that could be beneficial to all stakeholders. Specific technologies include zero emissions trucks (using batteries and/or fuel cells), or plug-in hybrid powertrains, locomotives with near-zero emissions (e.g., 90% below Tier 4), electric locomotives using battery tender cars and catenary, 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 more economical one than it is today, including a call for a zero and near-zero emissions vehicle pilot project in Southern California. The Port of Los Angeles's Sustainable City Plan corroborates this effort, setting a goal of 15 percent of zero emission goods movement trips by 2025 and 35 percent by 2035. More recently, the Clean Air Action Plan 2017 Update adopted by Ports of Los Angeles and Long Beach call for zero emissions cargo handling equipment by 2030 and zero emissions drayage trucks by 2035. SCAQMD is cost-sharing a project with the Port of Long Beach (the START Project) to develop and demonstrate 102 near-zero and zero emissions vehicles, vessels and cargo handling equipment including charging infrastructure, across an intermodal freight network spanning three California seaports and three California air districts.

There are now over 17 light-duty PHEVs certified to California's cleanest ATPZEV or TZEV standards and 16 pure battery electric vehicles (BEVs) commercially available in California. All of these vehicles offer the benefits of higher fuel economy and range, as well as lower emissions. Continued technology advancements in the light-duty infrastructure, particularly in the arena of codes and standards, have helped facilitate the development of corresponding codes and standards for medium- and heavy-duty vehicle infrastructure. Additional traction may be gained in this area as a result of the Transportation Electrification Partnership release in September 2018 of their Zero Emissions 2028 Roadmap, which sets a goal to move toward an additional 25 percent reduction in GHGs and air pollution beyond current commitments through accelerating transportation electrification. Additionally, SCE's Charge Ready Program will include funds for medium- and heavy-duty vehicles and EVSE.

[7] https://insideevs.com/december-2018-u-s-ev-sales-recap/?utm_source=feedburner&utm_medium=email&utm_campaign=Feed%3A+InsideEvs+%28InsideEVs%29

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

- demonstration of electric and fuel cell electric technologies for cargo container transport operations, e.g., heavy-duty battery electric or plug-in electric drayage trucks with all electric range;
- demonstration of medium-duty electric and fuel cell electric vehicles in package delivery operations, e.g., electric walk-in vans with fuel cell or CNG range extender;
- development and demonstration of CNG hybrid vehicle technology;
- development of hybrid vehicles and systems for ocean-going vessels and other off-road vehicles;
- 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 electric vehicles and mass transit, and rideshare services that cater to multiple users;
- development of eco-friendly intelligent transportation system (ITS) strategies, demonstrations that encourage electric drive vehicle deployment in autonomous applications, optimized load-balancing strategies 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 currently on the roads or soon entering the market, and to reduce cost, improve convenience 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);
- repurpose of EV batteries for other or second energy storage uses, as well as reusing battery packs and approaches to recycle lithium, cobalt and other metals;
- development of a methodology to increase understanding of the capability to accept fast-charging and the resultant life cycle and demonstration of the 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, and open standards and demand response protocols for EV chargers to communicate across charging networks.

Engine Systems/Technologies

In order to achieve the emissions reductions required for the South Coast Air Basin, the internal combustion engines (ICEs) used in the heavy-duty sector will require emissions that are 90% lower than the 2010 standards. In 2016, commercialization of the Cummins 8.9 liter (8.9L) natural gas engine achieving 90% 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 SCAQMD 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. For smaller and long-haul trucks that cannot utilize the 8.9L and 12L near-zero engines, the 2019 Plan Update includes potential projects to develop, demonstrate and certify engines in the 6-7L and larger 13-15L displacement. The Plan Update continues to incorporate pursuit of cleaner engines for the heavy-duty sector. Future projects will support the development, demonstration and certification of engines that can achieve these massive emissions reductions using an optimized systems approach. In December 2018, SCAQMD 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 2019 Plan includes potential projects

that the SCAQMD 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 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

The EPA's recent initiation to create a rule for a national low NOx standard for all on highway heavy duty engines will further motivate manufacturers to develop lower-NOx emitting technologies.

Fueling Infrastructure and Deployment (NG/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 South Coast Air 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.

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 the potential health risks). In fact, studies indicate that smoggy areas 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.

Over the past few years, the SCAQMD has funded emission studies to evaluate the impact of tailpipe emissions of biodiesel and ethanol fueled vehicles mainly focusing on criteria pollutants and greenhouse gas (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. 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. SCAQMD funded studies in 2015 to further investigate the toxicological potential of emissions, such as ultrafine particles and vapor phase substances, and to determine whether or not other 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% of all vehicle sales in the U.S. in 2009 to an estimated 60% by 2016, it is important to understand the impact on air quality from these vehicles. As such, SCAQMD 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, SCAQMD initiated an in-use real-world emissions study, including fuel usage profile characterization as well as an assessment of the impact of current technology and alternative fuels on fuel consumption.

In recent years, there has also been an increased interest both at the state and national level on the use of alternative fuels including biofuels 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, based on higher average summer temperatures noted over the past few years, there is interest on how the higher temperatures are impacting ozone formation. These types of studies may be beneficial to support the Clean Air Protection Program being developed under AB 617.

Some areas of focus include:

- demonstration of remote sensing technologies to target different high emission applications and sources;
- studies to identify the health risks associated with ultrafine and ambient particulate matter including their composition to characterize their 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 the impact of new technologies, in particular PEVs on local air quality as well as the benefit of telematics on emissions reduction strategies;
- lifecycle energy and emissions analyses to evaluate conventional and alternative fuels;
- analysis of fleet composition and its associated impacts on criteria pollutants; and
- evaluation of the impact of higher ambient temperatures on emissions of primary and secondary air pollutants.

Stationary Clean Fuel Technologies

Although stationary source NOx emissions are small compared to mobile sources in the South Coast Air 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 SCAQMD 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 could be applied to not only improve air quality, but enhance power quality and reduce electricity distribution congestion.

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. The University of California Riverside's (UCR's) Sustainable Integrated Grid Initiative and University of California Irvine's (UCI's) Advanced Energy and Power Program, funded in part by the SCAQMD, 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; and
- vehicle-to-grid or vehicle-to-building, or other stationary energy demonstration projects to develop sustainable, low emission energy storage alternatives.

Emissions Control Technologies

Although engine technology and engine systems research is required to reduce the emissions at the combustion source, dual fuel technologies and post-combustion cleanup methods are also needed to address the current installed base of 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 catalysts, 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. 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 diesel particulate traps and selective catalytic reduction catalysts) as well as non-thermal regen technology; and
- development and demonstration of low-VOC and PM lubricants for diesel and natural gas engines.

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 as needed, efforts to expedite the implementation of low emissions and clean fuels technologies, coordination of these activities with other organizations and information dissemination to educate the end user. Technology transfer efforts include support for various clean fuel vehicle incentive programs as well cosponsorship of technology-related conferences, workshops and other events.

Target Allocations to Core Technology Areas

The figure below presents the potential allocation of available funding, based on SCAQMD projected program costs of $16.7 million for all potential projects. The expected actual project expenditures for 2019 will be less than the total SCAQMD projected program cost since not all projects will materialize. The 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 SCAQMD funding. Specific contract awards throughout 2019 will be based on this proposed allocation, the quality of proposals received and evaluation of projects against standardized criteria and ultimately SCAQMD Board approval.

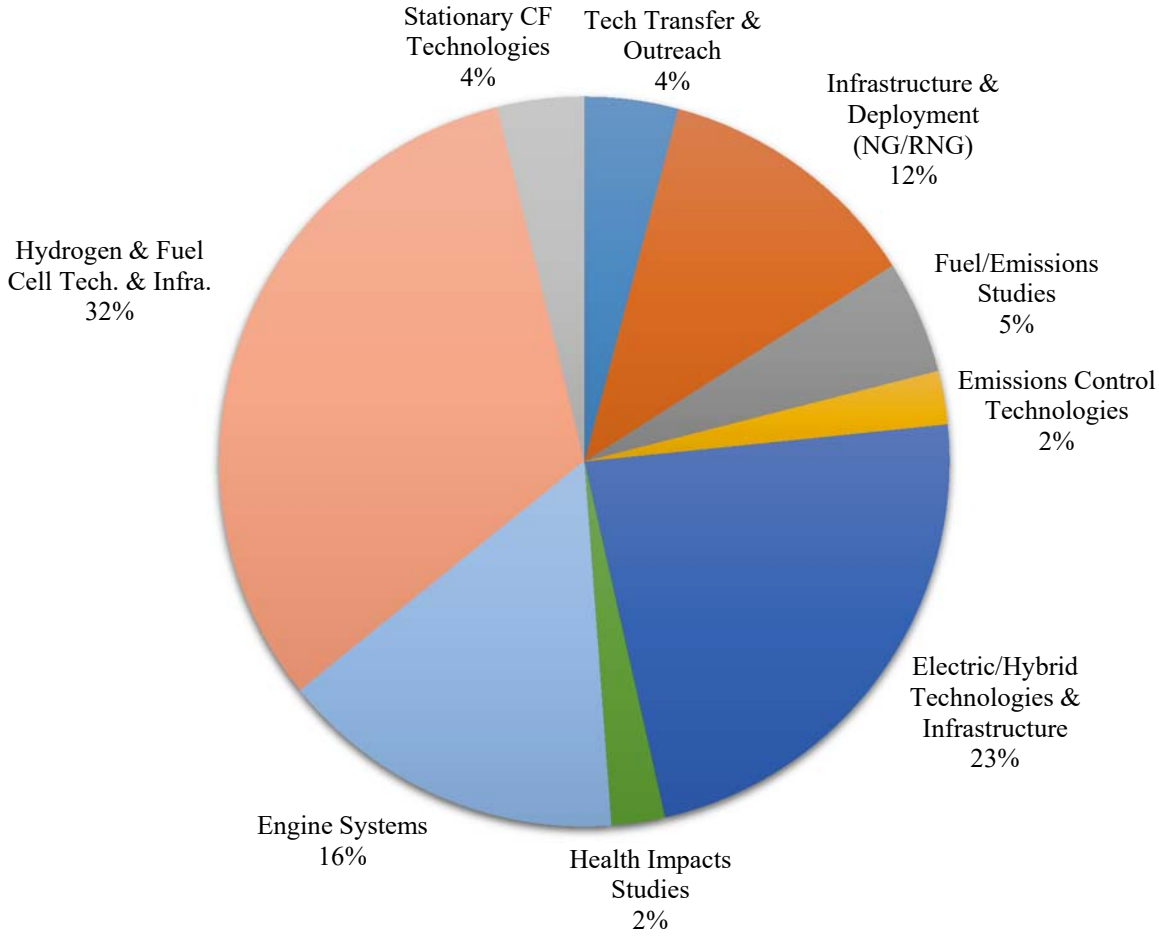


Figure 23: Projected Cost Distribution for Potential SCAQMD Projects in 2019 ($16.9M)

CLEAN FUELS PROGRAM
Program Plan Update for 2019

This section presents the Clean Fuels Program Plan Update for 2019. The proposed projects are organized by program areas and described in further detail, consistent with the SCAQMD budget, priorities and the best available information on the state-of-the-technology. Although not required, this Plan also includes proposed projects that may be funded by revenue sources other than the Clean Fuels Program, specifically related to VOC and incentive projects.

Table 6 (page 71) summarizes potential projects for 2019 as well as the distribution of SCAQMD costs in some areas as compared to 2018. The funding allocation continues the focus on development and demonstration of zero and near-zero emission technologies including the infrastructure for such technologies. For the 2019 Draft Plan, there is a small increase for hydrogen and fuel cell technologies to incentivize large-scale hydrogen infrastructure projects at the Ports and in the Inland Empire and in light of current and projected roll out of fuel cell vehicles in 2016-2019. The SCAQMD shifted some resources to electric and hybrid-electric technologies in light of two large projects and grant awards the SCAQMD received in mid-July 2018 for a Daimler project and in September 2018 for Volvo's project which includes $44.8 million from the GGRF Program to demonstrate vehicles in this technology area. Small funding shift to Engine Systems and Fueling Infrastructure and Deployment (natural gas and renewable fuels) is also recommended in light of large projects last year and for biogas production, respectively. The other areas will continue with similar allocations for 2019. As in prior years, the funding allocations again align well with the SCAQMD's FY 2018-19 Goals and Priority Objectives. Overall, the Program is designed to ensure a broad portfolio of technologies and leverage 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 SCAQMD Governing Board for approval prior to contract initiation. This Plan Update reflects the maturity of the proposed technology and identifies contractors to perform the projects, participating host sites, and securing sufficient cost-sharing needed to complete the project and other necessary factors. Recommendations to the SCAQMD Governing Board will include descriptions of the technology to be demonstrated and in what application, the proposed scope of work of the project and the capabilities of the selected contractor and project team, in addition to the expected costs and expected 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 (page 71).

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

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

Expected Total Cost: The estimated total project cost including the SCAQMD 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 SCAQMD 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 2019

Proposed Project	Expected SCAQMD Cost $	Expected Total Cost $
Hydrogen/Fuel Cell Technologies and Infrastructure		
Develop and Demonstrate Operation and Maintenance Business Case Strategies for Hydrogen Stations	300,000	3,500,000
Develop and Demonstrate Hydrogen Production and Fueling Stations	2,000,000	6,000,000
Develop and Demonstrate Medium- and Heavy-Duty Fuel Cell Vehicles	3,000,000	12,000,000
Demonstrate Light-Duty Fuel Cell Vehicles	100,000	100,000
Subtotal	$5,400,000	$21,600,000
Electric/Hybrid Technologies and Infrastructure		
Develop and Demonstrate Electric and Hybrid Vehicles	2,000,000	8,000,000
Develop and Demonstrate Electric Charging Infrastructure	500,000	3,000,000
Demonstrate Alternative Energy Storage	200,000	1,500,000
Develop and Demonstrate Electric Container Transport Technologies	1,200,000	4,000,000
Subtotal	$3,900,000	$16,500,000
Engine Systems/Technologies		
Develop and Demonstrate Advanced Gaseous- and Liquid-Fueled Medium- and Heavy-Duty Engines & Vehicle Technologies to Achieve Ultra-Low Emissions	2,000,000	8,000,000
Develop and Demonstrate Alternative Fuel and Clean Conventional Fueled Light-Duty Vehicles	200,000	1,000,000
Develop and Demonstrate Low Load and Cold-Start Technologies	200,000	1,000,000
Develop and Demonstrate Low Emissions Locomotive Technologies	200,000	1,000,000
Subtotal	$2,600,000	$11,000,000
Fueling Infrastructure and Deployment (NG/Renewable Fuels)		
Deploy Natural Gas Vehicles in Various Applications	500,000	2,000,000
Develop, Maintain & Expand Natural Gas Infrastructure	500,000	2,000,000
Demonstrate Natural Gas Manufacturing and Distribution Technologies Including Renewables	1,000,000	10,000,000
Subtotal	$2,000,000	$14,000,000
Fuel/Emissions Studies		
Conduct In-Use Emissions Studies for Advanced Technology Vehicle Demonstrations	300,000	800,000
Conduct Emissions Studies on Biofuels, Alternative Fuels and Other Related Environmental Impacts	300,000	1,000,000
Identify and Demonstrate In-Use Fleet Emissions Reduction Technologies & Opportunities	250,000	1,000,000
Subtotal	$850,000	$2,800,000

Table 6: Summary of Potential Projects for 2019 (cont'd)

Proposed Project	Expected SCAQMD Cost $	Expected Total Cost $
Stationary Clean Fuel Technologies		
Develop and Demonstrate Reliable, Advanced Emission Control Technologies, and Low Emission Monitoring Systems and Test Methods	100,000	250,000
Develop and Demonstrate Clean Stationary Technologies	250,000	750,000
Develop and Demonstrate Renewables-Based Energy Generation Alternatives	300,000	1,000,000
Subtotal	$650,000	$2,000,000
Emissions Control Technologies		
Develop and Demonstrate Advanced Aftertreatment Technologies	200,000	2,000,000
Demonstrate On-Road Technologies in Off-Road and Retrofit Applications	200,000	800,000
Subtotal	$400,000	$2,800,000
Health Impacts Studies		
Evaluate Ultrafine Particle Health Effects	100,000	1,000,000
Conduct Monitoring to Assess Environmental Impacts	150,000	500,000
Assess Sources and Health Impacts of Particulate Matter	150,000	300,000
Subtotal	$400,000	$1,800,000
Technology Assessment and Transfer/Outreach		
Assess and Support Advanced Technologies and Disseminate Information	400,000	800,000
Support Implementation of Various Clean Fuels Vehicle Incentive Programs	300,000	400,000
Subtotal	$700,000	$1,200,000
TOTALS FOR POTENTIAL PROJECTS	**$16,900,000**	**$73,700,000**

Technical Summaries of Potential Projects

Hydrogen/Fuel Cell Technologies and Infrastructure

Proposed Project: Develop and Demonstrate Operation and Maintenance Business Case Strategies for Hydrogen Stations

Expected SCAQMD Cost: $300,000

Expected Total Cost: $3,500,000

Description of Technology and Application:

California regulations require automakers to place increasing numbers of zero emission vehicles into service every year. By 2050, CARB projects that 87% of light-duty vehicles on the road will be zero emission battery and fuel cell vehicles with fuel cell electric becoming the dominant powertrain.

In 2013, cash-flow analysis resulting in a Hydrogen Network Investment Plan and fuel cell vehicle development partnership announcements by major automakers enabled the passage of AB 8 which provides $20 million per year for hydrogen infrastructure cofunding through the CEC. This resulted in fuel cell vehicle production announcements by Hyundai, Toyota and Honda in 2014-2015.

In October 2016, the CaFCP released its Medium- and Heavy-Duty Fuel Cell Electric Truck Action Plan focusing on Class 4 parcel delivery trucks and Class 8 drayage trucks with infrastructure development and establishing metrics for measuring progress. More recently, in July 2018, the CaFCP released a Vision 2030 document establishing a roadmap for future fuel cell vehicle and hydrogen refueling stations, including barriers that need to be overcome.

In 2015, Hyundai and Toyota introduced fuel cell vehicles, with Honda initiating delivery in 2016 and others following in 2017 or soon thereafter. Government actions over the last couple of years, coupled with early adopter response, is helping to establish demand and thus a business case model for hydrogen stations.

Additional work in this project category includes (1) developing a plan to secure long-term funding to complete the hydrogen fueling network build-out; (2) providing details how funding can be invested; (3) assessing alternative revenue streams such as renewable incentives; (4) proposing alternative financing structures to leverage/extend CEC funding; and (5) supporting station operation during the transition to commercial viability, including optimizing designs with flexibility to address individual site characteristics, as well as ensuring higher levels of dispensing availability and reliability.

Furthermore, in the next couple of years an evaluation of actual market penetration of FCVs should be conducted to guide and protect local and state investments in the hydrogen market.

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 Fuel Cell vehicles (FCEVs) 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 FCEVs are available now. The deployment of large numbers of FCEVs, which is one strategy to attain air quality goals, requires a well-planned and robust hydrogen fueling infrastructure. This SCAQMD project, with significant additional funding from other governmental and private entities, will provide the hydrogen fueling infrastructure that is necessary in the South Coast Air Basin. The deployment of FCEVs and the development of the necessary fueling infrastructure

Proposed Project: Develop and Demonstrate Distributed Hydrogen Production and Fueling Stations

Expected SCAQMD Cost: $2,000,000

Expected Total Cost: $6,000,000

Description of Technology and Application:

Alternative fuels, such as hydrogen and the use of advanced technologies, such as fuel cell vehicles, 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 fuel cell vehicles 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 and dispensing pressure of up to 10,000 psi and compatibility with existing CNG stations may be considered.

Energy Stations: Multiple-use energy stations that can produce hydrogen for fuel cell vehicles 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 determine the viability of this strategy for hydrogen fueling infrastructure deployment and as a means to produce power and hydrogen from renewable feedstocks (e.g., biomass, digester gas).

Innovative Refueling Appliances: Home or small scale refueling/recharging is an attractive advancement for alternative clean fuels due to the limited conventional refueling infrastructure. 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 FCEV counts now exceed 23,000 in 2021 and 47,000 in 2024 in California and the majority of these do not include medium- and heavy-duty vehicles that may be deployed in the South Coast Air Basin. To provide fuel for these vehicles, the hydrogen fueling infrastructure needs to be significantly increased and become more reliable in terms of availability. SCAQMD 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.

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 SCAQMD 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. Fuel cell vehicles constitute some of the cleanest alternative-fuel vehicles today. Since hydrogen is a key fuel for fuel cell vehicles, 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 SCAQMD Cost: $3,000,000

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 fuel cell vehicles.

The California ZEV Action Plan specifies actions to help deploy an increasing number of zero emission vehicles, including medium- and heavy-duty ZEVs. CARB recently adopted Innovative Clean Transit Bus Regulation as another driver. 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 fuel cell vehicles 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 SCAQMD funds to demonstrate Zero Emission Container Transport (ZECT) technologies. In 2015, the DOE awarded SCAQMD 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	Vehicle Auxiliary Power Units
Shuttle Buses	Construction Equipment
Medium- & Heavy-Duty Trucks	Lawn and Garden Equipment
	Cargo Handling Equipment

Potential Air Quality Benefits:

The 2016 AQMP identifies the need to implement zero emission vehicles. SCAQMD 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 fuel cell vehicles. 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 zero emission fuel cell vehicles 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 emissions reductions.

Proposed Project: Demonstrate Light-Duty Fuel Cell Vehicles

Expected SCAQMD 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 fuel cell passenger vehicles using gaseous hydrogen with proton exchange membrane (PEM) fuel cell technology, mainly through showcasing this technology. Recent designs of light-duty fuel cell vehicles 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 fuel cell limited-production vehicles are planned for retail deployment in early commercial markets near hydrogen stations by several automakers. 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. SCAQMD has included fuel cell vehicles as part of its demonstration fleet since our first hydrogen station began operation in 2005; strengthening support, education, and outreach regarding fuel cell vehicle technology on an on-going 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 fuel cell vehicles in California, but the first commercial FCV leases are ending, and solo carpool lane access extends only for MY 2017 and later, encouraging new replacements. Mercedes-Benz announced its pre-production of GLC F-Cell plug-in fuel cell model to be introduced at the end of 2019. Hyundai also has announced its Nexo, their next-Generation Fuel Cell SUV, which was delivered to the first customer in California before the end of 2018. Innovative strategies and demonstration of dual fuel, zero emission vehicles could expand the acceptance of battery electric vehicles and accelerate the introduction of fuel cells in vehicle propulsion.

Potential Air Quality Benefits:

The 2016 AQMP identifies the need to implement zero emission vehicles. SCAQMD 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 fuel cell vehicles. Expected immediate benefits include the deployment of zero-emission vehicles in SCAQMD's demonstration fleet. Over the longer term, the proposed projects could help foster wide-scale implementation of zero emission fuel cell vehicles 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.

Electric/Hybrid Technologies and Infrastructure

Proposed Project: Develop and Demonstrate Electric and Hybrid Vehicles

Expected SCAQMD Cost: $2,000,000

Expected Total Cost: $8,000,000

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 the United States, the EPA estimated that in 2016, transportation was responsible for about 28% of the nation's carbon emissions, while electricity sector emissions declined from 31% to 28%.

The global light-duty vehicle market is changing rapidly in response to government-led initiatives to improve fuel economy and market demand for alternative transportation options. These changes are being driven primarily by the adoption of vehicles with various levels of drivetrain electrification. The SCAQMD has long supported the concept of using increased battery power to allow a portion of the driving cycle to occur in all-electric mode for true zero emission miles. This battery dominant strategy is accomplished by incorporating an advanced battery pack initially recharged from the household grid or EV chargers. This "plug-in" hybrid EV strategy allows reduced emissions and improved fuel economy. Most automobile manufacturers have announced production plans for a range of electrified vehicle powertrains, including "blended" plug-in hybrid electric, extended-range electric vehicles (E-rEV), or battery electric vehicles (BEVs). Electric utilities refer to PHEVs, E-rEVs and BEVs as plug-in electric drive vehicles (PEVs) and are working with automakers to support PEVs. Long-range BEVs are now becoming price competitive after subsidies and affordable 200+ mile BEVs should have a big impact on the vehicle market. Plug-in hybrids (PHEVs) are also making incremental advances. Competition between automakers should also help improve technology and bring down costs. Recently, for example, Volkswagen teamed up with Ford to develop an EV to compete against Telsa's significant market share. Continued market expansion is likely to result as OEMs have announced significant investment in PEVs together with a shift in their product mix from sedans to the larger vehicles consumers are demanding, including crossovers, SUVs, and light-duty trucks.

The SCAQMD has long been a leader in promoting early demonstrations of next generation light-duty vehicle propulsion technologies (and fuels). However, given the current and planned market offerings in this category, priorities have shifted. Nevertheless, the SCAQMD will continue to evaluate market offerings and proposed technologies in light-duty vehicles to determine if any future support is required.

Medium- and heavy-trucks make up 4.3% of vehicles in the United States and drive 9.3% of all miles driven each year, yet are responsible for more than 25% of all the fuel burned annually. Hybrid technologies have gained momentum in the light-duty sector with commercial offerings by most of the automobile manufacturers. Unfortunately, the medium- and heavy-duty platforms require the greatest emissions reductions, especially for the fleets due to low turnover.

CARB's Low Carbon Transportation programs, local support and federal funds have collectively accelerated the development and demonstration of medium-duty plug-in hybrid electric truck platforms. Analysis of project data and use profiles will help optimize drive systems, target applications for early commercialization and fill gaps in product offerings.

The SCAQMD has investigated the use of hybrid technologies to achieve similar performance as the conventional-fueled counterparts while achieving both reduced emissions and improved fuel economy. Development and validation of emission test procedures is needed, but is complicated due to the low volume and variety of medium- and heavy-duty vehicles.

Platforms to be considered include utility trucks, delivery vans, shuttle buses, transit buses, waste

haulers, construction equipment, cranes and other off-road vehicles. Innovations that may be considered for demonstration include: advancements in the auxiliary power unit, either ICE or other heat engine; battery-dominant hybrid systems utilizing off-peak re-charging, with advanced battery technologies. 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 emissions benefits can be demonstrated as equivalent or superior to alternative fuels. Both new designs and retrofit technologies and related charging infrastructure will be considered.

This project category will develop and demonstrate:

- various PEV architectures;
- anticipated costs for such architectures;
- customer interest and preferences for each alternative;
- integration of the technologies into prototype vehicles and fleets;
- evaluation of any new promising light-duty vehicle propulsion technologies or fuels; and
- electric and hybrid-electric medium- and heavy-duty vehicles (e.g., utility trucks, delivery vans, shuttle buses, transit buses, waste haulers, construction equipment, cranes and other off-road vehicles)

Potential Air Quality Benefits:

The 2016 AQMP identifies zero or near-zero emitting vehicles as a key attainment strategy. Plug-in HEV technologies have the potential to achieve near-zero emissions while retaining the range capabilities of a conventionally gasoline-fueled combustion engine vehicle, a key factor expected to enhance broad consumer acceptance. Given the variety of PEV systems under development, it is critical to determine the true emissions and performance utility compared to conventional vehicles. Successful demonstration of optimized prototypes would promise to enhance the deployment of near-ZEV and ZEV technologies.

Expected benefits include the establishment of criteria for emissions 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 emitting vehicles in the South Coast Basin, which is a high priority of the AQMP.

Proposed Project: Develop and Demonstrate Electric Charging Infrastructure

Expected SCAQMD Cost: $500,000

Expected Total Cost: $3,000,000

Description of Technology and Application:

There is a critical need to address gaps in EV charging infrastructure availability. Almost half (48%) of the 1,064,346 EVs sold in the U.S. since 2011 were in California, and of those sales in California, it is estimated that almost half (43%) of CVRP rebates issued to date were issued in SCAQMD. In addition, the California ZEV Action Plan, which was updated in 2018, calls for 5 million ZEVs and supporting infrastructure by 2030.

The recent adoption of revised recommended practice SAE J1772 enables passenger vehicles to charge from 240V AC (Level 2) and 480V DC charging using a common conductive connector in 30 minutes for 90 miles of range (50 kW fast charger) or 40 minutes for 200 miles of range (135 kW Tesla fast charger). Together with the growing adoption of long range EVs above 200 mile electric range, the technology and infrastructure of three fast charging systems (CCS, CHAdeMO and Tesla) are developing as well, although China recently adopted a standard based on CHAdeMO. Technological developments improving the driving range of EVs, as well as increasing availability and speed of charging infrastructure, could change the need for charging infrastructure in the future. However, a study of fast-charging impact on battery life and degradation is very limited. The research and demonstration to increase understanding of the degradation effects of fast-charging will have implications on what types of charging EV owners will leverage and what EVSE stakeholders will bring to market. SCAQMD is committed to continuing to support the successful deployment of EV charging infrastructure as well as demonstration of fast-charging effect on battery life, leveraging funds from the state and the Volkswagen settlement.

The SCAQMD is actively pursuing development of intelligent transportation systems to improve traffic efficiency of battery electric and fuel cell electric cargo container trucks. This system provides truck drivers real-time vehicle operation advice based on changing traffic and road conditions where trucks can dynamically change their speed to better flow through intersections. A truck eco-routing system can provide the most eco-friendly 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.

This project category is one of SCAQMD's continued efforts to:

- deploy a network of DC fast charging infrastructure (up to 350kW) and rapidly expand the existing network of public plug-in EV charging stations including energy storage systems;
- 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 emissions 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 petroleum-fueled vehicles to battery and fuel cell electric vehicles. In addition, this project will assist in achieving improved fuel economy and lower tailpipe emissions, further helping the region to achieve federal ambient air quality

standards and protect public health. Expected benefits include the establishment of criteria for emissions evaluations, performance requirements and customer acceptability of the technology. This will help both regulatory agencies and OEMs to expedite introduction of zero emissions vehicles in the South Coast Basin, which is a high priority of the AQMP.

Proposed Project: Demonstrate Alternative Energy Storage

Expected SCAQMD Cost: $200,000

Expected Total Cost: $1,500,000

Description of Technology and Application:

The SCAQMD 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 vehicles. This effort will support several projects for development and demonstration of different types of low emission hybrid 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 repurposing 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 low emission 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 and other applications. Benefits will include proof of concept for the new technologies, diversification of transportation fuels and lower emissions of criteria, toxic pollutants and greenhouse gases.

Proposed Project: Develop and Demonstrate Electric Container Transport Technologies

Expected SCAQMD Cost: $1,200,000

Expected Total Cost: $4,000,000

Description of Technology and Application:

Advanced transportation systems can be used to transfer cargo containers from ports to both local and "distant" intermodal facilities, thereby significantly reducing emissions from on-road trucks and locomotives and also reducing traffic congestion in local transportation corridors. Some solutions involve using wayside power such as fixed dedicated guideways to move containers powered by magnetic levitation or catenary electric lines. While these types of solutions are elegant and futuristic, they are expensive and difficult to implement in industrial urban environments where they are needed. Previous efforts, including one project with Siemens eHighway catenary hybrid truck system has highlighted complications of building a new infrastructure within an existing infrastructure. Wayside power systems are not excluded in the solutions for addressing the air quality issues we face, though until cost and implementation challenges are addressed, there are more viable technologies that exist and are being pursued.

There are other options for electric container applications such as dual-mode locomotives, hybrid electric technologies with battery storage, a battery tender car and fuel cell propulsion systems. This technical review will evaluate all available technology options to determine whether their systems can be successfully developed and deployed, financially viable, and reliably operated on a long-term basis.

Potential Air Quality Benefits:

On-road heavy-duty diesel truck travel is an integral part of operations at the ports moving cargo containers into the Basin and beyond. The 2016 AQMP proposes to reduce emissions from this activity by modernizing the fleet and retrofitting NOx and PM emission controls on older trucks. To modernize the fleet, SCAQMD's approach is to engage OEMs to develop advanced heavy-duty trucks with battery electric, fuel cell electric and hybrid electric propulsion for transporting containers on roadways. The emissions benefits have not yet been estimated because the fate of the displaced trucks has not been determined.

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 SCAQMD Cost: $2,000,000

Expected Total Cost: $8,000,000

Description of Technology and Application:

The objective of this proposed project would be to support development and certification of near commercial prototype low-emission medium- and heavy-duty gaseous- and liquid-fueled engine technologies, as well as and integration and demonstration of these technologies in on-road vehicles. The NOx emissions target for this project area is 0.02 g/bhp-hr and lower and the PM emissions target is below 0.01 g/bhp-hr. To achieve these targets, an effective emission control strategy must employ advanced fuel system and engine design features, aggressive engine calibration and improved thermal management, improved exhaust gas recirculation 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 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. 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.

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 horsepower engines. Higher horsepower 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 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.

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 emission reduction benefit 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 and 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. 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 SCAQMD fleet regulations and towards implementation of the 2016 AQMP control measures.

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

Expected SCAQMD Cost: $200,000

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 bio-diesel 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 SCAQMD 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 SCAQMD Cost: $200,000

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. The thermal efficiency of the internal combustion engine is significantly lower at cold-starts and lower loads. Exhaust aftertreatment systems require a temperature of 250 degrees Celsius or higher to operate at the highest level of emissions reduction efficiency. 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 hybrid engines are experiencing similar warm-up issues due to the on-off drive cycles. 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 deactiviation, EGR fraction, turbo control, lubrication warming, 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.

- design and prove cylinder activation technology;
- develop control algorithms to ensure the catalyst maintains temperature throughout the duty cycle.

The project would be implemented, and fleet tested, and recorded over a minimum twelve month period. Further projects can develop from this technology and should be tested in regards 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'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 SCAQMD Cost: $200,000

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.

Fueling Infrastructure and Deployment (NG/Renewable Fuels)

Proposed Project: Deploy Natural Gas Vehicles in Various Applications

Expected SCAQMD Cost: **$**500,000

Expected Total Cost: $2,000,000

Description of Technology and Application:

Natural gas vehicles (NGVs) have been very successful in reducing emissions in the South Coast Air Basin due to the deployment of fleets and heavy-duty vehicles utilizing this clean fuel. In order to maintain the throughput, utility and commercial potential of the natural gas infrastructure and the corresponding clean air benefits, deploying additional models of NGVs in existing applications are needed. This technology category seeks to support the implementation of early-commercial vehicles in a wide variety of applications, such as taxis, law enforcement vehicles, shuttle buses, delivery vans, transit buses, waste haulers, Class 8 tractors and off-road equipment such as construction vehicles and yard hostlers. It also seeks to deploy low-emission natural gas vehicles using renewable fuels to achieve further emission reductions.

Potential Air Quality Benefits:

Natural gas vehicles have inherently lower engine criteria pollutant emissions than conventional vehicles, especially in the heavy-duty applications where older diesel engines are being replaced. Incentivizing these vehicles in city fleets, goods movement applications and transit bus routes help to reduce the local emissions and exposure to nearby residents. Natural gas vehicles also can have lower greenhouse gas emissions and increase energy diversity depending on the feedstock and vehicle class. Deployment of additional NGVs is consistent with SCAQMD's AQMP as well as the state's Alternative Fuels Plan as part of AB 1007 (Pavley).

Proposed Project: Develop, Maintain & Expand Natural Gas Infrastructure

Expected SCAQMD Cost: $500,000

Expected Total Cost: $2,000,000

Description of Technology and Application:

This project supports the development, maintenance and expansion of natural gas fueling station technologies to increase the overall number of such fueling stations in strategic locations throughout the Basin including the Ports. The intent is to develop and demonstrate advanced technologies to reduce the cost of natural gas equipment, develop and demonstrate closed loop systems for dispensing and storage, standardize fueling station design and construction and help with the implementation of SCAQMD's fleet rules. 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. NGVs have significantly lower emissions than gasoline vehicles 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, besides improving the refueling time. While new or improved NGV stations have an indirect emissions reduction benefit, they help facilitate the introduction of low emission, NGVs in private and public fleets in the area, which have a direct emissions reduction benefit. 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 Natural Gas Manufacturing and Distribution Technologies Including Renewables

Expected SCAQMD Cost: $1,000,000

Expected Total Cost: $10,000,000

Description of Technology and Application:

Lack of sufficient statewide LNG production results in increased fuel costs and supply constraints. The cost of transporting LNG from out-of-state production facilities increases the fuel cost from 15 to 20 cents per gallon of LNG and subjects users to the reliability of a single supply source. High capital costs prevent construction of local, large-scale liquefaction facilities. Small-scale, distributed LNG liquefaction systems may provide 25 percent lower capital costs than conventional technology per gallon of LNG produced. Because these smaller plants can be sited near fleet customers, costs for transporting the LNG to end-users are much lower than those for remote larger plants. Beyond these cost reductions, the smaller plants offer key benefits of much smaller initial capital investment and wider network of supply than the larger plant model.

The project category will also consider the development and demonstration of technologies for the production of Renewable Natural Gas (RNG) from various feed stocks including landfill gas, green waste, and anaerobic digester gases.

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

- commercially viable methods for converting renewable feed stocks into CNG or LNG (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 LNG and L/CNG refueling facilities; and
- strategic placement of LNG storage capacity sufficient to provide supply to users in the event of a production outage.

Potential Air Quality Benefits:

The SCAQMD relies on a significant increase in the penetration of zero- and low-emission vehicles in the South Coast Basin to attain federal clean air standards by 2023 and 2032. This project would help develop a number of small-scale liquefaction technologies that can reduce LNG costs to be competitive with diesel fuel. Such advances are expected to lead to greater infrastructure development. Additionally, this project could support the state's goal of redirecting landfill waste for local fuel production.

Fuel/Emissions Studies

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

Expected SCAQMD Cost: $300,000

Expected Total Cost: $800,000

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.

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 SCAQMD's air quality goals.

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

Expected SCAQMD Cost: $300,000

Expected Total Cost: $1,000,000

Description of Technology and Application:

The use of biofuels can be an important strategy to reduce petroleum dependency, air pollution and greenhouse gas emissions. 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 on 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.

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.

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.

Lastly, in an effort to evaluate the contribution of meteorological factors to high ozone and PM2.5 episodes occurring in the South Coast air 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 SCAQMD 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 SCAQMD Cost: $250,000

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, marine vessels 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.

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.

Stationary Clean Fuel Technologies

Proposed Project: Develop and Demonstrate Reliable, Advanced Emission Control Technologies, and Low-Emission Monitoring Systems and Test Methods

Expected SCAQMD Cost: $100,000

Expected Total Cost: $250,000

Description of Technology and Application:

Currently, the inability of air/fuel ratio control (AFRC) systems to keep rich-burn engines in compliance contributes significantly to air pollution in the basin. Reliable, low-cost emission monitoring systems are needed for small-to-intermediate size combustion devices, including stationary engines, boilers, heaters, furnaces and ovens that are not large enough to justify a continuous emission monitoring system (CEMS). This class of combustion device is often permitted on the basis of a single demonstration or periodic demonstrations of NOx and CO emissions meeting SCAQMD rule requirements or a RECLAIM concentration limit. However, SCAQMD-unannounced tests on engines and boilers have found that in many cases NOx and/or CO levels have increased significantly above levels that have been initially or periodically demonstrated due to equipment malfunction and/or inadequate operator attention. It is suspected that the same may be true of heaters, furnaces and ovens.

A demonstration project funded in part by the SCAQMD consisted of retrofitting a biogas engine with a digester gas clean up system and catalytic oxidizer at the exhaust followed by SCR which resulted in significant reductions of NO_x, VOC and CO. Based on the successful deployment of this project, further emission reductions may be achieved by other biogas combustion sources such as gas turbines and boilers by the continued development of specialized low cost biogas clean up systems that will allow for the use of catalytic after control systems.

Demonstrations of newer technologies in recent years could result in a commercially viable alternative to CEMS that is both reliable and feasible in terms of lower costs. For example, manufacturers of flue gas analyzers have, in recent years, developed low-cost multi-gas analyzers suitable for portable or stack-mounted use. Some preliminary testing of a new type of AFRC, which uses a different type of O2 sensor known as a wide-band O2 sensor, is another alternative that can be analyzed. Another technical approach might be to deploy technology utilizing the O2 signature of a post-catalyst O2 sensor and additional control concepts being developed by manufacturers. Since an underlying problem has been that engine, catalyst and AFRC manufacturers have developed systems independently, a system being co-developed to perform continuous diagnostics to assist operators in keeping rich-burn engines in compliance is possibly another alternative for demonstration.

Potential Air Quality Benefits:

Stationary engines, boilers, heaters, furnaces and ovens account for approximately 11 percent of total NO_x emissions and about 6 percent of total CO emissions. There has been a long-standing compliance problem with rich-burn IC engines in the basin and evidence indicates that many of these devices are operating with NOx and/or CO emissions above levels required in their permits. 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 SCAQMD's ability to enforce full-time compliance.

Proposed Project: Develop and Demonstrate Clean Stationary Technologies

Expected SCAQMD Cost: $250,000

Expected Total Cost: $750,000

Description of Technology and Application:

Stationary sources, including VOC sources such as large printing facilities and furniture manufacturers, have become cleaner and cleaner due to the regulatory requirements for low emissions and the advancements in technology to meet those requirements. Best Available Control Technology (BACT) regulations, however, are only required for new, modified, or relocated sources that may result in an emissions increase of a non-attainment air contaminant, any ozone depleting compound or ammonia. This project category is to develop and demonstrate new technologies that can provide emissions reductions in new installations or as retrofit modifications. Possible technology examples include:

- low NOx technologies (burners, thermal and ICEs);
- low-Btu gas technologies (e.g., digester, landfill, or diary gases);
- alternative fuels and hydrogen blends;
- alternative diesel fuels (emulsified, gas-to-liquids, biodiesel with aftertreatment);
- low emission refinery flares;
- catalytic combustion;
- cost-effective fuel cell and fuel cell hybrid distributed generation;
- fumes-to-fuel technology to replace thermal oxidizers and capture VOC emissions for electricity generation while ensuring no emission of air toxics; and
- boiler optimization design and strategies to improve efficiencies.

Depending on the technology, a proof-of-concept project, demonstration, or pre-commercial deployment would be considered to garner further information on the technology. Issues to investigate include viability (reliability, maintainability and durability) of the technology, cost-effectiveness and operator ease-of-use in order to assess commercialization.

Potential Air Quality Benefits:

The SCAQMD has a substantial number of older, small, stationary source technologies within its jurisdiction. Since these devices are not subject to continuous emissions monitoring system requirements, evidence suggests that these devices may not be operating at their permitted NOx, CO, hydrocarbon and PM emissions levels. Replacing these devices with cleaner and more reliable technologies or technology/fuel combinations can have dramatic reductions in all of these criteria pollutants. VOC emission reductions may also be achieved at larger stationary VOC sources to achieve the new federal ozone and PM2.5 standards.

Proposed Project: Develop and Demonstrate Renewables-Based Energy Generation Alternatives

Expected SCAQMD Cost: $300,000

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.

Emissions Control Technologies

Proposed Project: Develop and Demonstrate Advanced Aftertreatment Technologies

Expected SCAQMD Cost: $200,000

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 diesel particulate filters (DPFs), oxidation catalysts, selective catalytic reduction (SCR) systems and NOx adsorbers. 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 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, marine vessels, 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 SCR and NOx adsorbers, could also have NOx reductions of up to 90%.

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

Expected SCAQMD Cost: $200,000

Expected Total Cost: $800,000

Description of Technology and Application:

Heavy-duty on-road 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, marine vessels 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 non-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 SCAQMD Cost: $100,000

Expected Total Cost: $1,000,000

Description of Technology and Application:

Reducing diesel exhaust from vehicles has become a high priority in the South Coast Air Basin since CARB identified the particulate phase of diesel exhaust as a surrogate for all of the toxic air contaminant emitted from diesel exhaust. Additionally, health studies indicate that the ultrafine portion of particulate matter 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 ultrafine particles 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 the new technologies and the health effects of these emissions, an evaluation and comparison of ultrafine particulate matter and the potential impacts on community exposures are necessary.

In this project, measurements and chemical composition of ultrafine particulates will be done, as well as studies conducted to characterize their toxicity. The composition of the particulates 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 ultrafine particulate matter, 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 and new engines 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 this 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 South Coast Basin relies on significant penetration of low emission vehicles to attain federal clean air standards. Reduction of particulate 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 amount of ultrafine particulates generated by different types of fuels and advanced control technologies as well as provide information on potential health effects of ultrafine particles. 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 SCAQMD Cost: $150,000

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, distribution centers and freeways is important to identify the emissions exposure to the surrounding communities and provide the data to then conduct the health impacts due to these sources. This project category would identify areas of interest and conduct ambient air monitoring, conduct emissions monitoring, analyze the data and assess the potential health impacts from mobile sources. The projects would need to be at least one year in duration in order to properly assess the air quality impacts in the area.

Potential Air Quality Benefits:

The proposed project will assist in the 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; 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 SCAQMD Cost: $150,000

Expected Total Cost: $300,000

Description of Technology and Application:

Previous studies of ambient levels of toxic air contaminants, such as the MATES series of studies, have found that diesel exhaust is the major contributor to health risk from air toxics. Analyses of diesel particulate matter in ambient samples have been based on measurements of elemental carbon. While the bulk of particulate elemental carbon in the South Coast Air 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 South Coast Air Basin. Analysis of particulate bound organic compounds was utilized as tracers to estimate levels of ambient diesel particulate matter as well as estimate levels of particulate matter 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, an updated emissions inventory of toxic air contaminants and a to air toxics, MATES IV also measured ultrafine particle concentrations and black carbon at the monitoring sites as well as near sources such as airports, freeways, rail yards, busy intersections and 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 ultrafine particle concentrations typically emitted or converted from vehicle exhaust. Based on preliminary results of MATES V, further assessment may need to be performed to assess secondary organic aerosols; including installation of sensors and additional monitoring acivities.

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 the health effects and potential community exposures. 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 diesel particulate matter as well as levels of particulate matter from other significant combustion sources, including gasoline and diesel generated VOCs. This will allow a better estimation of potential exposures to and health effects from toxic air contaminants from diesel exhaust in the South Coast Air Basin. This information in turn can be used to determine the health benefits of promoting clean fuel technologies.

Technology Assessment and Transfer/Outreach

Proposed Project: Assess and Support Advanced Technologies and Disseminate Information

Expected SCAQMD Cost: $400,000

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 SCAQMD's outreach efforts to expedite the implementation of low emission and clean fuels technologies and to coordinate these activities with other organizations.

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;
- emissions studies and assessments of zero emission alternatives;
- preparation of reports, presentations at conferences, improved public relations and public communications of successful demonstrations of clean technologies;
- participation in and coordination of workshops and various meetings;
- support for training programs related to fleet operation, maintenance and refueling of alternative fuel vehicles;
- publication of technical papers, reports and bulletins; and
- production and dissemination of information, including web sites.

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 and associated infrastructure.

Potential Air Quality Benefits:

SCAQMD adopted fleet regulations requiring public and private fleets within the Basin to acquire alternatively fueled vehicles when making new purchases. Expected benefits of highlighting success stories in the use of advanced alternatively fueled vehicles could potentially expedite the acceptance and commercialization of advanced technologies by operators seeking to comply with the provisions of the recently adopted SCAQMD fleet rules. The resulting future emissions benefits will contribute to the goals of the AQMP.

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

Expected SCAQMD Cost: $300,000

Expected Total Cost: $400,000

Description of Project:

This project supports the implementation of zero emission vehicle incentive programs, the Carl Moyer incentives program and the school bus incentives program. Implementation support includes application approval, grant allocation, documentation to the CARB, verification of vehicle registration and other support as needed. Information dissemination is critical to successful implementation of a coordinated and comprehensive package of incentives. Outreach will be directed to vehicle dealers, individuals and fleets.

Potential Air Quality Benefits:

As described earlier, the SCAQMD will provide matching funds to implement several key incentives programs to reduce diesel emissions in the Basin. Furthermore, the SCAQMD recently adopted fleet regulations requiring public and private fleets within the Basin to acquire alternatively fueled vehicles when making new purchases. Expected benefits of highlighting zero emission vehicle incentives could potentially expedite the acceptance and commercialization of advanced technologies by operators seeking to comply with the provisions of the recently adopted SCAQMD fleet rules. The resulting future emissions benefits will contribute to the goals of the AQMP. The school bus program and the Carl Moyer incentives program will also reduce large amounts of NOx and PM emissions in the basin in addition to reducing toxic air contaminants.

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Appendix A

SCAQMD Advisory Groups

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Technology Advancement Advisory Group

Dr. Matt Miyasato, Chair	SCAQMD
Don Anair	Union of Concerned Scientists
*Chris Cannon	Port of Los Angeles
*Steve Cliff	California Air Resources Board
Dr. John Froines	Professor Emeritus University of California, Los Angeles
*Yuri Freedman	Southern California Gas Company
*Jodean Giese	Los Angeles Department of Water and Power
*Phil Heirigs	Western States Petroleum Association
Randall Lewis	Lewis Group of Companies
Tim Olson	California Energy Commission
David Pettit	Natural Resources Defense Council
Dr. Sunita Satyapal	Department of Energy
*Heather Tomley	Port of Long Beach
Dawn Wilson	Southern California Edison

*Newly appointed members

SB 98 Clean Fuels Advisory Group

Dr. Matt Miyasato, Chair	SCAQMD
Robert Bienenfeld	American Honda Motor Company Inc.
*Dr. John Budroe	California Environmental Protection Agency, Office of Environmental Health Hazard Assessment
Dr. Stephen Charlton	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
Vacant	Academic Community
Dr. Scott Samuelsen	University of California, Irvine, Combustion Laboratory/National Fuel Cell Research Center
Dr. Robert Sawyer	Sawyer Associates
Andreas Truckenbrodt	Independent Consultant in Fuel Cell Technologies
Kevin Walkowicz	National Renewable Energy Laboratory
Michael Walsh	Independent Consultant in Motor Vehicle Pollution Control

*Newly appointed members

Appendix B

Open Clean Fuels Contracts as of January 1, 2019

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Contract	Contractor	Project Title	Start Term	End Term	SCAQMD $	Project Total $
Hydrogen and Mobile Fuel Cell Technologies and Infrastructure						
11555	University of California Los Angeles	Construct Hydrogen Fueling Infrastructure	12/07/12	12/31/19	400,000	2,589,990
15150	Air Products and Chemicals Inc.	Install and Upgrade Eight Hydrogen Fueling Stations Throughout SCAB (including SCAQMD's Diamond Bar Hydrogen Station)	10/10/14	04/09/19	1,000,000	17,335,439
15366	EPC LLC	Operate and Maintain Publicly Accessible Hydrogen Fueling Station at SCAQMD's Headquarters	10/10/14	04/09/19	0	0
15609	ITM Power, Inc.	Installation of Riverside Renewable Hydrogen Fueling Station	10/06/15	10/05/19	200,000	2,325,000
15611	Ontario CNG Station, Inc.	Installation of Ontario Renewable Hydrogen Fueling Station	07/10/15	07/09/20	200,000	2,325,000
15618	FirstElement Fuel, Inc.	Installation of Eight Hydrogen Stations in Various Cities (two renewable, six delivered)	02/05/16	02/04/21	1,000,000	16,442,000
15619	H2 Frontier Inc.	Installation of Chino Renewable Hydrogen Station	12/04/15	12/03/20	200,000	4,558,274
15635	Center for Transportation and Environment	ZECT II: Develop and Demonstrate One Class 8 Fuel Cell Range-Extended Electric Drayage Truck	04/27/16	10/26/20	821,198	7,109,384
16025	Center for Transportation and Environment	Develop and Demonstrate Fuel Cell Hybrid Electric Medium-Duty Trucks	02/05/16	08/04/20	980,000	7,014,000
16251	H2 Frontier, Inc.	Develop and 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	05/31/19	589,750	1,574,250
17312	Hydrogenics USA Inc.	ZECT II: Develop Fuel Cell Range-Extended Drayage Truck	11/20/17	05/19/21	125,995	2,433,553
17316	Center for Transportation and the Environment	Develop and Demonstrate Ten Zero Emission Fuel Cell Electric Buses	06/09/17	04/30/20	1,000,000	45,328,859
17317	American Honda Motor Company, Inc.	Three Year Lease of One Honda 2017 Clarity Fuel Cell Vehicle for TAO's Fleet Demonstration Program	03/22/17	03/21/20	17,304	17,304
17343	American Honda Motor Company, Inc.	Three Year Lease of One Honda 2017 Clarity Fuel Cell Vehicle for TAO's Fleet Demonstration Program	02/21/17	02/20/20	17,328	17,328
17385	American Honda Motor Company, Inc.	Three Year Lease of One Honda 2017 Clarity Fuel Cell Vehicle for TAO's Fleet Demonstration Program	05/17/17	05/16/20	17,304	17,304
18150	California Department of Food and Agriculture, Division of Measurement Standards	Conduct Hydrogen Station Site Evaluations for Hydrogen Station Equipment Performance (HyStEP) Project	06/28/18	02/27/20	100,000	805,000

Contract	Contractor	Project Title	Start Term	End Term	SCAQMD $	Project Total $
Hydrogen and Mobile Fuel Cell Technologies and Infrastructure (cont'd)						
18158	Alliance for Sustainable Energy, LLC (on behalf of National Renewable Energy Laboratory)	California Hydrogen Infrastructure Research Consortium H2 @ Scale Initiative	08/31/18	03/30/20	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
19213	Frontier Energy Inc.	Participate in California Fuel Cell Partnership for CY 2018 and Provide Support for Regional Coordinator	01/01/18	07/01/19	245,000	1,253,491
Electric/Hybrid Technologies and Infrastructure						
08063	Quantum Fuel Systems LLC	Develop & Demonstrate 20 Plug-In Hybrid Electric Vehicles	01/22/08	01/31/19	2,165,613	2,899,057
13058	Capstone Turbine Corporation	Develop Microturbine Series Hybrid System for Class 7 Heavy-Duty Vehicle Applications	08/12/13	12/31/19	360,000	1,210,000
13433	U.S. Hybrid Corporation	Develop and Demonstrate Two Class 8 Zero-Emission Electric Trucks	06/26/13	12/31/19	75,000	150,000
14052	Altec Capital Services, LLC	Lease of Two Plug-In Hybrid Electric Vehicles	01/02/15	01/01/20	61,302	61,302
14184	Clean Fuel Connection Inc.	DC Fast Charging Network Provider	04/04/14	06/30/20	920,000	1,220,000
14222	Odyne Systems,LLC	Develop and Demonstrate Plug-In Hybrid Electric Retrofit System for Class 6 to 78 Trucks	04/24/14	03/31/19	389,000	2,226,571
14256	National Strategies LLC	Develop and Demonstrate Vehicle-2-Grid Technology	09/05/14	01/31/19	250,000	3,377,689
16022	Gas Technology Institute	ZECT II: Develop and Demonstrate One Class 8 CNG Hybrid Electric Drayage Truck	12/04/15	06/30/20	1,578,802	5,627,319
16046	Transportation Power, Inc.	ZECT: Develop and Demonstrate Two Class 8 CNG Plug-In Hybrid Electric Drayage Trucks	12/04/15	12/31/19	195,326	2,103,446
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	367,425
16200	California State University Los Angeles	Cost-Share Regional Universities for U.S. DOE EcoCAR 3 Competition	04/14/16	04/15/20	100,000	300,000
16227	Selman Chevrolet Company	Lease One 2016 Chevrolet Volt Extended-Range Electric Vehicle for Three Years	02/01/16	01/31/19	15,677	15,677
17029	University of California Irvine	Demonstrate and Evaluate Plug-In Smart Charging at Multiple Electric Grid Scales	06/29/17	06/28/20	250,000	750,000
17065	Clean Fuel Connection, Inc.	EV Infrastructure Installer	12/02/16	12/31/21	805,219	805,219
17105	BYD Motors Inc.	Develop and Demonstrate Up to 25 Class 8 Battery Electric Drayage Trucks	04/14/17	10/13/23	794,436	8,942,400

Contract	Contractor	Project Title	Start Term	End Term	SCAQMD $	Project Total $
Electric/Hybrid Technologies and Infrastructure (cont'd)						
17207	Peterbilt Motors	Develop and Demonstrate Up to 12 Class 8 Battery Electric Drayage Trucks	04/07/17	10/06/23	642,436	11,006,340
17225	Volvo Technology of America LLC	Develop and Demonstrate Up to Two Class 8 Battery Electric Drayage Trucks	06/09/17	06/08/20	1,741,184	9,458,446
17244	Kenworth Truck Company	Develop and Demonstrate Up to Two Class 8 Battery Electric Drayage Trucks	09/08/17	01/08/20	2,823,475	9,743,739
17353	Odyne Systems, LLC	Develop and Demonstrate Medium-Heavy-Duty (Class 5-7) Plug-In Hybrid Electric Vehicles for Work Truck Applications	06/09/17	09/08/20	900,000	6,955,281
18072	Electric Power Research Institute	Study Electrification Options of Energy Services for EJ Communities and Non-Attainment Areas	06/08/18	06/07/19	150,000	1,558,657
18075	Selman Chevrolet Company	Lease Two 2017 Chevrolet Bolt All-Electric Vehicles for Three Years for TAO's Fleet Demonstration Program	08/18/17	08/17/20	26,824	26,824
18129	Electric Power Research Institute	Versatile Plug-In Auxiliary Power System Demonstration	06/28/18	06/27/20	125,000	273,000
18151	Rail Propulsion System	Develop and Demonstrate Battery Electric Switcher Locomotive	04/05/18	12/30/19	210,000	925,000
18232	Hyster-Yale Group Inc.	Electric Top-Pick Development, Integration and Demonstration	09/14/18	09/13/21	2,931,805	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	3,568,300	4,198,000
18280	Honda of Pasadena	Three-Year Lease of One Honda 2018 Clarity Plug-In Vehicle	02/07/18	02/06/21	18,359	18,359
18287	EVgo Services LLC	Charging Station and Premises Agreement for Installation of One DC Fast Charger at SCAQMD Headquarters	06/27/18	06/26/28	0	0
19190	Daimler Trucks North America	Zero Emissions Trucks and EV Infrastructure Project	12/18/18	06/20/22	8,230,072	31,340,144
Engine Systems and Technologies						
17197	VeRail Technologies Inc.	Develop and Demonstrate Ultra-Low Emission Natural Gas Switcher Locomotive	03/03/17	09/02/19	1,000,000	5,100,000
17393	Southwest Research Institute	Develop Ultra-Low Emissions Diesel Engine for On-Road Heavy-Duty Vehicles	05/30/18	07/31/19	575,000	1,325,000
18018	North American Repower LLC	Develop High Efficiency Near-Zero Emission Natural Gas Engines for Heavy-Duty Vehicles	12/14/17	12/12/19	200,000	1,958,096
18194	CALSTART Inc.	Develop and Demonstrate Near-Zero Emissions Opposed Piston Engine	05/30/18	07/31/20	1,000,000	15,500,000

Contract	Contractor	Project Title	Start Term	End Term	SCAQMD $	Project Total $
Engine Systems and Technologies (cont'd)						
18122	Clean Energy	Southern California Trucking Demonstration of Near-Zero ISX12N Beta Engines	01/05/18	01/04/20	3,495,000	5,995,000
18211	West Virginia University Innovation Corporation	Develop Thermal Management Strategy Using Cylinder Deactivation for Heavy-Duty Diesel Engines	06/08/18	06/07/20	250,000	700,000
Fueling Infrastructure and Deployment (NG/RNG)						
12667	West Covina Unified School District	Upgrade CNG Fueling Facility	10/12/12	03/01/20	60,000	60,000
14219	City of West Covina	Upgrade CNG Station at City Yard	05/15/14	08/01/19	200,000	618,429
15541	Foundation for California Community Colleges	Implement Enhanced Fleet Modernization Program	05/07/15	01/30/19	21,270	30,000
16075	City of Desert Hot Springs	Purchase One Heavy-Duty CNG-Powered Truck	03/11/16	03/10/20	38,000	63,000
16076	Coachella Valley Association of Governments	Purchase and Deploy One Heavy-Duty CNG Paratransit Vehicle	12/01/15	11/20/19	140,000	140,000
16244	CR&R, Inc.	Renewable Natural Gas Production and Vehicle Demonstration Project	09/03/16	03/02/20	900,000	55,000,000
16333	Ontario CNG Station, Inc.	Implement Alternative Fuel Station Expansion	05/13/16	11/12/19	200,000	798,535
17092	Kore Infrastructure, LLC	Construct RNG Production Facility and Demonstrate RNG with Next Generation Natural Gas Engine	10/14/16	10/13/21	2,500,000	25,500,000
17349	University of California Riverside/CE-CERT	Establish Renewable Natural Gas Center	08/03/17	02/02/19	100,000	261,110
18336	ABC Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/05/18	11/30/34	117,900	162,900
18337	Alta Loma School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/05/18	11/30/34	78,600	108,600
18344	Bellflower Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	09/07/18	11/30/34	39,300	54,300
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	325,800
18348	Cypress School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	09/07/18	11/30/34	39,300	54,300
18349	Downey Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	09/14/18	11/30/34	157,200	217,200
18350	Fountain Valley School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	09/07/18	11/30/34	39,300	54,300
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	217,200
18354	Hemet Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/05/18	11/30/34	196,500	271,500
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	814,500

Contract	Contractor	Project Title	Start Term	End Term	SCAQMD $	Project Total $
Fueling Infrastructure and Deployment (NG/RNG) (cont'd)						
18363	Orange Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	09/14/18	11/30/34	39,300	54,300
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	325,800
18365	Pupil Transportation Cooperative	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/05/18	11/30/34	235,800	325,800
18367	Rialto Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/05/18	11/30/34	510,900	705,700
18368	Rim of the World Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/05/18	11/30/34	117,900	162,900
18369	Rowland Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	11/02/18	11/30/34	117,900	162,900
18370	San Jacinto Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	09/14/18	11/30/34	78,600	108,600
18374	Upland Unified School District	Replace Diesel School Buses with Near-Zero Emissions CNG Buses	10/12/18	11/30/34	157,200	217,200
Fuel/Emissions Studies						
15607	University of California Riverside/CE-CERT	Innovative Transportation System Solutions for NOx Reductions in Heavy-Duty Fleets	12/19/15	01/31/19	79,980	139,980
15636	University of California Riverside/CE-CERT	Evaluate PEV Utilization Through Advanced Charging Strategies in a Smart Grid System	12/15/15	12/31/19	170,000	270,000
15680	National Renewable Energy Laboratory	ComZEV: Develop Detailed Technology and Economics-Based Assessment for Heavy-Duty Advanced Technology Development	08/25/15	06/30/19	520,000	540,000
17245	West Virginia University Research Corporation	Conduct In-Use Emissions Testing and Fuel Usage Profile on On-Road Heavy-Duty Vehicles	06/09/17	06/08/21	1,625,000	1,625,000
17276	University of California Riverside/CE-CERT	Develop ECO-ITS Strategies for Cargo Containers	08/03/17	08/02/20	543,000	2,190,233
17277	University of Southern California	Conduct Market Analysis for Zero Emission Heavy-Duty Trucks in Goods Movement	11/03/17	11/02/19	350,000	524,000
17278	University of Southern California	Develop Freight Loading Strategies for Zero Emissions Heavy-Duty Trucks in Goods Movement	11/03/17	11/02/19	200,000	1,001,000
17286	University of California Riverside/CE-CERT	Conduct In-Use Emissions Testing and Fuel Usage Profile on On-Road Heavy-Duty Vehicles	06/09/17	06/08/21	1,625,000	1,625,000
17331	University of California Riverside/CE-CERT	Conduct In-Use PM Emissions Study for Gasoline Direct Injection Vehicles	07/14/17	01/31/19	222,000	273,000

Contract	Contractor	Project Title	Start Term	End Term	SCAQMD $	Project Total $
Fuel/Emissions Studies (cont'd)						
17352	California State University Maritime Academy	Develop and Demonstrate Vessel Performance Management Software and Vehicles	06/09/17	06/08/21	50,086	195,195
18090	University of California Riverside/CE-CERT	Study Secondary Organic Aerosol Formation from Heavy-Duty Diesel and Natural Gas Vehicles	12/05/17	06/30/20	85,000	85,000
18206	University of California Irvine	Assess Air Quality and Greenhouse Gas Impacts of a Microgrid-Based Electricity System	04/06/18	04/05/20	660,000	1,300,000
Stationary Clean Fuels Technology						
13045	ClearEdge (novated from UTC Power Corp.)	Energy Supply and Services Agreement to Install One 400 kW Phosphoric Acid Fuel Cell at SCAQMD Headquarters	09/28/12	09/27/22	450,000	4,252,680
Emissions Control Technologies						
17367	Southwest Research Institute	Develop and Evaluate Aftertreatment Systems for Large Displacement Diesel Engines	02/28/18	6/30/19	400,000	480,000
Technology Assessment and Transfer/Outreach						
08210	Sawyer Associates	Technical Assistance on Mobile Source Control Measures and Future Consultation on TAO Activities	02/22/08	02/28/20	10,000	10,000
09252	JWM Consulting Services	Technical Assistance with Review and Assessment of Advanced Technologies, Heavy-Duty Engines, and Conventional and Alternative Fuels	12/20/08	06/30/20	30,000	30,000
12376	University of California Riverside	Technical Assistance with Alternative Fuels, Biofuels, Emissions Testing and Zero-Emission Transportation Technology	06/13/14	05/31/20	75,000	75,000
12453	Tech Compass	Technical Assistance with Alternative Fuels, Fuel Cells, Emissions Analysis and Aftertreatment Technologies	06/21/12	05/31/20	75,000	75,000
15380	ICF Resources LLC	Technical Assistance with Goods Movement, Alternative Fuels and Zero Emissions Transportation Technologies	12/12/14	12/11/20	30,000	30,000
16262	University of California Davis-Institute of Transportation Studies	Support Sustainable Transportation Energy Pathways (STEPs)	01/05/18	01/04/22	240,000	5,520,000
17097	Gladstein, Neandross & Associates, LLC	Technical Assistance with Alternative Fuels and Fueling Infrastructure, Emissions Analysis and On-Road Sources	11/04/16	06/30/19	200,000	200,000
17358	AEE Solutions, LLC	Technical Assistance with Heavy-Duty Vehicle Emissions Testing, Analysis and Engine Development	06/09/17	09/08/19	100,000	100,000

Contract	Contractor	Project Title	Start Term	End Term	SCAQMD $	Project Total $
Technology Assessment and Transfer/Outreach (cont'd)						
18019	Ricardo Inc.	Technical Assistance with Heavy-duty Vehicle Emissions Testing, Analysis, and Engine Development and Applications	09/01/17	08/31/19	50,000	50,000
18253	Three Squares Inc.	Identify and Secure a "Futurist" Clean Transportation or Goods Movement Technologies Expert	04/05/18	05/31/18	11,845	11,845
19078	Clean Fuel Connection Inc.	Technical Assistance with Alternative Fuels, EVs, Charging and Infrastructure, and Renewable Energy	09/07/18	09/06/20	100,000	100,000
19160	Coordinating Research Council	Cosponsor 2019 Mobile Source Air Toxics Workshop on 2/4-6/19	11/07/18	02/28/19	5,000	75,000

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Appendix C

Final Reports for 2018

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SCAQMD Contract #12057 **October 2018**

Expand Hydrogen Fueling Infrastructure

Contractor
Linde LLC

Cosponsors
California Energy Commission
SCAQMD

Project Officer
Joseph Impullitti

Background

Hydrogen fuel cell electric drive technology offers tremendous potential for the light-duty passenger vehicle market and medium- and heavy-duty truck and bus markets. Fuel Cell Electric Vehicles (FCEV) can drive more than 300 miles on a tank of hydrogen and be refueled in 3 to 5 minutes. FCEVs have zero tailpipe emissions and the carbon footprint of these vehicles using hydrogen from reformed natural gas is similar to plug-in electric vehicles. A benefit of hydrogen technology is its ability to be scaled up to handle larger numbers and sizes of vehicles without requiring vast electric grid upgrades. FCEVs require a new network of refueling stations which this project supports. This project also validated liquid hydrogen storage at a typical 7-11 gas station. An advantage of using liquid hydrogen is that a greater amount can be stored at the station as opposed to the more common high pressure hydrogen gas storage method. Liquid hydrogen also offers the benefit of being able to use the stored cold temperatures to increase station throughput and reduce station refrigeration needs to perform -40C fast cold fills as required by the fueling protocol J2601.

Project Objective

The objective of this project was to develop a public retail hydrogen fuel station (HFS) capable of filling hydrogen vehicles, according to fueling protocol J2601 (2010 version), using most major credit cards by means of liquid hydrogen storage and ionic compression.

Technology Description

In this HFS, liquid hydrogen is delivered to the station and stored in a Linde cryogenic liquid hydrogen tank. Hydrogen is drawn from the tank and compressed by the Linde IC90, ionic compressor, and stored at high pressure to be readily supplied to a car. A temperature control unit is held at -40 C to cool the high pressure hydrogen as it enters the car tank. This is required to meet the J2601 (2010 version) fuel protocol which stipulates that the fill can be done in about three minutes without overheating the car hydrogen tank. The process Linde uses has the unique advantage that the cold hydrogen from the liquid hydrogen tank is cooled by the thermal storage temperature control unit (TCU) during each compression cycle, which reduces the electrical energy from refrigeration to maintain the TCU at -40 C.

Status

The San Juan Capistrano hydrogen fuel station is open to the public, having been commissioned in October 2015. The station is certified by the California Division of Measurement Standards to sell hydrogen by the kilogram and has multiple FCV OEM letters of support assuring the station meets all the J2601 fuel protocol requirements. The completed HFS is shown below. This station has been operated and maintained by Linde for the past three years and is currently in the process of being sold to a third party. This station will continue to operate and service FCVs in the area under the new ownership. Linde will work with the prospective buyers for a smooth transition.

Figure 1: External View of Equipment Yard

Results

The following reflects results for the San Juan Capistrano Linde H2 Fuel Station from 10/1/15 through 9/30/18:

Description	Value
Total kg of Hydrogen Dispensed, kg	30,312
Average kg/day	80.1
Approximate % of H70	94
Approximate % of H35	6
Total Sales, $	501,361
Number of Days Vehicles Filled	1096
# of Transactions (~Vehicles Filled)	10,520
Average fill (kg)	3.1
Average Transactions per day	28
Total Gallons of Gasoline Equivalent displaced, GGE (1 gal = 0.997 kg)	30,403

Benefits

From station commissioning to the end of September 2018, 30,312 kg of hydrogen was dispensed. Assuming a FCEV delivers 60 miles/kg of hydrogen, there was a GHG emissions reduction of 436 metric tons. This assumes the difference in emissions between gasoline and hydrogen is 240 gCO2e/mi, as taken from the CaFCP report based on the Argonne National Lab GREET V1_2013 model. This station, and others like it, will lead the transition of personal transportation energy from gasoline to hydrogen, ultimately leading to a renewable transportation energy system and cleaner air for all of California.

Project Costs

Originally the proposed location for this station was in Orange County within the city of Laguna Niguel because it would extend the Irvine cluster to the south into neighborhoods that are a target market of the OEMs. Unfortunately, the original site could not be completed and a new site in the city of San Juan Capistrano was chosen because it offered similar attributes to the original site. Consequently, costs for Task 3-Site Installation were higher than planned. The City of San Juan Capistrano required the design of the HFS to match that of the existing site. The additional scope encompassed the installation of stonework and various other architectural elements to enhance the site appearance. They also required the addition of louvers to screen equipment. Bringing in 480V electrical service required additional equipment and re-design to accommodate the needs of the site. The actual cost for the Task 3-Site Installation project was $330,000 higher than originally budgeted. SCAQMD's original co-funding was $250,000 but they provided another $80,000 to cover the site location change cost increases.

Funding Source	Amount
CEC Funding	$2,056,029
SCAQMD Funding	$ 330,000
Linde Match Funding	$ 425,108
Total Project Cost	**$2,811,137**

Commercialization and Applications

Linde is now operating two, high-capacity, liquid hydrogen based fueling stations to supply light-duty vehicles in California, in addition to the bus and light-duty vehicle fueling stations at AC Transit in Emeryville and Oakland. This is a great step forward for California, and Linde, in leading the nation with hydrogen zero emissions vehicle infrastructure and technology deployment. This project has contributed to the commercialization of the IC90 ionic compressor, which is becoming the industry standard for station developers. It has also facilitated real-world verification of liquid hydrogen supply storage and 350 bar and 700 bar gaseous dispensing as a valid hydrogen pathway for this market. This project has made possible the real application of liquid hydrogen supply and storage for retail stations, which is fundamental to understanding how most effectively to scale the hydrogen economy. The data from this entire effort will be significant in shaping the future hydrogen economy. Based on lessons learned the Linde liquid hydrogen storage and IC90 compressor are ready for widespread commercial adoption. It was determined that the hydrogen dispenser should be improved to reduce operations and maintenance costs and increase station reliability. Linde has developed a new hydrogen dispenser for future applications that has been determined to be a significant improvement over the current generation of dispensers used for this HFS. Linde plans to continue its internal efforts to design and implement a cost-effective and reliable hydrogen production, transportation, storage and dispensing solution to enable market growth, increase gasoline replacement and facilitate the integration of renewable energy.

SCAQMD Contract #14684 **February 2018**

Conduct Hydrogen Station Site Evaluations for Site Certifications for Commercial Sale of Hydrogen

Contractor

California Department of Food and Agriculture, Department of Measurement Standards

Cosponsors

California Fuel Cell Partnership
California Air Resources Board
California Energy Commission
SCAQMD

Project Officer

Lisa Mirisola

Background

Hydrogen fueling station (HFS) operators need to be able to sell hydrogen fuel by the kilogram, and consumers need to be able to accurately purchase the fuel. In order to enable such commercial sales, California regulations need to be established that allow appropriate dispenser accuracy tolerances.

The specifications and tolerances for hydrogen dispensers are designated in the National Institute of Standards and Technology (NIST) Handbook 44 (HB 44) Section 3.39. Hydrogen Gas-Measuring Devices – Tentative Code. Industry representatives have expressed concern that the HB 44 Acceptance Tolerance of 1.5% and Maintenance Tolerance of 2.0% are too restrictive for the current state of hydrogen measuring and dispensing technology. As such, and prior to the Department's work through interagency funding agreements, no entity has submitted their hydrogen dispenser for the full testing and approval process required for type evaluation and approval of a commercial hydrogen gas weighing and measuring device. To help encourage an earlier transition to commercialization of this zero-emission fuel dispensing technology, the requirements specified in NIST HB 44 have been adopted with modifications in the California Code of Regulations (CCR) Title 4, Division 9, § 4002.9. Hydrogen Gas-Measuring Devices (3.39).

Project Objective

California Department of Food and Agriculture, Department of Measurement Standards (DMS), in cooperation with California Air Resources Board (CARB), proposed a project to collect accuracy data from hydrogen-gas dispensers to determine current dispenser capabilities and provide certification for retail sale of hydrogen fuel. DMS signed an agreement with the National Renewable Energy Laboratory (NREL) to develop a reference standard device for the measurement of compressed gaseous hydrogen in California. The device developed was used to collect data at a number of existing hydrogen fueling stations and allow them to be certified for commercial sale.

Technology Description

The Gas Technology Institute (GTI) in Des Plains, Illinois began work on the evaluation of hydrogen dispenser accuracy in 2007 and developed a standard testing device for hydrogen dispensers. In 2010, the CEC funded research and development by DMS to develop a transportable field standard for testing and validating hydrogen dispenser performance at retail stations. Three metrological methods (gravimetric, pressure-volume-temperature (pvt), and master meter) were evaluated. DMS defined the general requirements and specifications for a field standard, and contracted with NREL for its development and construction, leading to the current HFS.

Figure 1: DMS staff testing a hydrogen dispenser

Status

Selected stations utilized variations of both pressure-volume-temperature (PVT) and Coriolis measurement technology and incorporated variations in technology from different dispenser manufacturers. Following testing, owner-operators of the hydrogen dispensers were provided with the raw test data for their specific device, an accuracy assessment, and a Report of Test letter that summarized their device's conformance to established specifications. Follow-up consultation was provided to each station operator and device manufacturer to determine, if needed, any corrective actions necessary to support retesting and eventual type approval for the commercial use of their dispenser.

Results

The HFS incorporates into a single test standard all three proposed metrological methods (gravimetric, pressure-volume-temperature (pvt), and master meter). The HFS was subject to a validation period at NREL. The gravimetric method was the only procedure that could be directly traced to the kilogram reference standard. To meet the fundamental considerations for a reference standard, the expanded uncertainty must be less than 10 grams (0.5% of tolerance). The gravimetric procedure is less than one third or less than 10 grams for the acceptance tolerance of the device under test, while the PVT and master meter failed this criterion. As a result, the HFS gravimetric standard has become the material and method in use for verification that hydrogen dispensers conform to established tolerance requirements.

Of the eight dispensers that qualified for temporary use permits, six manufacturers applied for formal type evaluation; five of these dispenser design types successfully passed permanence testing and were, or are currently being issued a California Type Evaluation Program Certificate of Approval for weighing and measuring devices. Certificates of Approval allow the specific dispenser design type and model to be placed in service at multiple hydrogen stations throughout the state as an approved device. To date, the issued type-approval certificates have facilitated the growth of retail hydrogen fueling stations from zero in 2014 to 31 as of March 31, 2018. The Division also has one additional type evaluation ongoing through second quarter 2018.

Figure 2: Examples of Type Approved hydrogen dispensers

Benefits

SCAQMD's Clean Fuels Program has been active in funding the development and demonstration of low- and zero-emission technologies. Hydrogen fueling stations are necessary to facilitate the introduction and deployment of zero-emission fuel cell vehicles, and this effort will help the SCAQMD to meet its clean air goals, and also better align with CARB's Zero Emission Vehicle and Zero Emission Bus regulations.

Project Costs

Agreements	Cash Budget
CARB (plus in-kind)	$100,000.00
California Energy Commission (CEC)	$100,000.00
California Fuel Cell Partnership (CaFCP)	$150,000.00
SCAQMD	$100,000.00
TOTAL	$450,000.00

Commercialization and Applications

The CEC continues to co-fund the installation of a network of hydrogen fueling stations in the state. Continuing collaboration with public and private stakeholders will be required to facilitate Division testing and type evaluation of these newer dispenser designs as they become available for use. The National Conference on Weights and Measures has adopted a single accuracy class for hydrogen gas measuring devices. This single class with increased acceptance tolerance of 5.0% and increased maintenance tolerance of 7.0% supports the early adoption of expanding accuracy classes by California. With the new tolerances published in the National Institute of Standards and Technology Handbook 44, California can now align its specifications with this new national model standard and facilitate marketplace consistency across the country.

SCAQMD Contract #17394 **March 2018**

Provide Analysis of Renewable Hydrogen Pathways, Economics and Incentives

Contractor
Energy Independence Now

Cosponsors
California Hydrogen Business Council
Fuel Cell Energy
Honda Motor Company
Hydrogenics Corporation
ITM Power
Leonardo DiCaprio Foundation
The Linde Group
Nel Hydrogen
Pacific Gas & Electric Company
Proton OnSite
SCAQMD
Southern California Gas Company
Toyota Motor Corporation

Project Officer
Lisa Mirisola

Background
Energy Independence Now (EIN) developed the Renewable Hydrogen Roadmap which explores decarbonized or carbon-free hydrogen production, primarily through the lens of California's zero emissions transportation goals and its Renewables Portfolio Standard (RFS). This Renewable Hydrogen Roadmap explores the most cost-effective and scalable production technologies and feedstocks, such as renewable electricity or biogas, to present viable pathways for industry, government and consumers.

Project Objective
EIN studied renewable hydrogen pathways, economics initiatives and policy that is conducive for renewable hydrogen. With the findings, EIN produced a white paper and a presentation to engage the broader stakeholder community to support renewable hydrogen education and outreach. It lays out policy and action recommendations to help California achieve its ambitious energy, climate and air quality goals by dramatically reducing pollution and GHG emissions from the energy generation and transportation sectors.

Technology Description
Hydrogen is produced primarily from two technologies: steam methane reforming and electrolysis. A third technology, called Tri-generation, uses natural gas or biogas as a feedstock to produce electricity, heat and hydrogen. Hydrogen can also be produced using direct solar water-splitting and biological processes; however, these processes are in early stages of research or commercialization.

Status
The final version of Renewable Hydrogen Roadmap was completed in May 2018 and subsequently made publicly available on EIN's website and distributed as a resource for multiple state agencies.

Results
The Renewable Hydrogen Roadmap identifies the opportunities and challenges for renewable hydrogen to provide zero emissions or even carbon-negative transportation fuel as well as critical energy storage for renewable electricity. It considers the many aspects of the current hydrogen ecosystem and identifies the steps and policy decisions that are necessary to stimulate growth in the renewable hydrogen marketplace.

Renewable hydrogen presents a near best-case scenario for clean energy storage and zero emissions transportation. Today, in California and across the world, hydrogen is already produced at scale for industrial processes, such as oil refining and ammonia production. Industrial hydrogen is commonly produced through the reformation of natural gas, but there are many ways to produce hydrogen renewably. This roadmap explores those that are currently most cost-effective and scalable, including production technologies and feedstocks, and lays out the following series of eight high priority policy and stakeholder recommendations for California:

1. Begin the journey to 100 percent renewable hydrogen now;
2. Fund scalable projects for 100 percent renewable hydrogen production;

3. Improve low carbon fuel standard (LCFS) incentives;
4. Promote tools to lower the cost of electricity for renewable hydrogen producers;
5. Address hydrogen distribution and storage challenges;
6. Expand US EPA's RFS Program;
7. Incentivize consumers and stakeholders; and
8. Broaden the hydrogen community through education and outreach.

While the roadmap illustrates the case for renewable hydrogen through the lens of transportation, it truly transcends the entire energy sector, enveloping agriculture, waste management and urban planning. Even with the projected number of FCEVs in California surpassing 40,000 by 2022, hydrogen demand by the transportation sector will still only amount to roughly one percent of California's overall need for this vital energy carrier. If all the hydrogen in California (approximately 550 million kg annually at this time) were produced renewably, it would have a truly massive economic and environmental impact.

Benefits

This zero emissions approach puts California on track to achieve its GHG goals and significantly reduce pollution levels. Californians will benefit from cleaner air and reductions in pollution-related health issues while combatting climate change, catalyzing innovation and creating new economic opportunities.

A roughly $120 million investment would be necessary to fully meet FCEV fuel demand in this short time frame. Without including compression storage distribution and feedstock development, this investment would create approximately 1,725 jobs in the next five years using the American Recovery and Reinvestment Act methodology, or approximately 1,620 jobs using the methodology of the Bay Area Council Economic Institute.

Project Costs

The Renewable Hydrogen Roadmap required extensive research and field interviews with industry, policymakers and energy stakeholders as well as graphic design and copy editing. It cost approximately $182,500 to produce, with the majority of the funding and support coming from automobile industry, hydrogen sector, and utility companies. SCAQMD funding of $25,000 was also provided.

Commercialization and Applications

As of late 2017, there were approximately 3,500 light-duty FCEVs in California and 31 publicly accessible hydrogen fueling stations, compared to approximately 25 million total registered automobiles and about 10,000 gas stations. The market for FCEVs and hydrogen fuel are in their infancy and near-term consumer demand for renewable hydrogen likely will not be enough to make an economic case for developers to invest in renewable production infrastructure. Currently, the SB 1505 33.3 percent renewable requirement, coupled with LCFS credits and emerging consumer demand for hydrogen fuel are the only revenue drivers for renewable hydrogen in the transportation market.

As California continues the rollout of hydrogen stations and infrastructure development to support FCEVs, demand for hydrogen by the transportation sector will increase. CARB estimates that by 2019 there will be 13,500 FCEVs on the road, and by 2022, there may be as many as 43,600 FCEVs. Using a "business-as-usual" scenario, CARB projects that by 2022 the capacity of the statewide hydrogen station network will be 16,580 kg/day (assuming only 180 kg/day station capacity for new stations). However, CARB created an "expected" scenario that assumes lower station costs, higher station capacity and private investment not assumed in the "business-as-usual" scenario. The expected scenario splits stations into two groups: those receiving state funding to meet the AB 8 goal of 100 stations; and additional stations funded privately or funded by a new state program. For the first expected scenario, the capacity of stations needed to meet demand would increase to 18,473 kg/day, a nearly 2,000 kg/day increase. For the second expected scenario, the station capacity would need to increase to 46,550kg/day.

Using the "business-as-usual" scenario, the most conservative of CARB's projections, California FCEV drivers will consume over 6 million kilograms of hydrogen annually, and of that figure, over 2 million kilograms will need to be produced renewably in order to meet the SB 1505 requirement. While this is only a fraction of California's current overall hydrogen production, the state currently produces very little renewable hydrogen without the use of offsetting renewable energy certificates to provide a renewable designation.

SCAQMD Contract #13426 **July 2018**

Develop and Demonstrate Catenary Class 8 Trucks (1 Electric and 1 CNG Platform)

Contractor
Transportation Power, Inc.

Cosponsors
SCAQMD

Project Officer
Joe Impullitti

Background
SCAQMD has identified the development and deployment of zero emissions goods movement transportation systems as one of the agency's top priorities in order to attain federal air quality standards. This project, *Development of Electric and CNG Hybrid Trucks for the Zero Emission Truck & Electric Catenary Highway (ECT-ZETECH),* initiated the development and demonstration of a catenary, zero emissions goods movement corridor that includes one mile of catenary system and catenary accessible trucks. The primary goal of this project was to promote the implementation of zero emission goods movement technologies, and the secondary goal was to demonstrate the most viable technology to be adopted for a future, regional zero-emissions corridor. Although this project was for a one-mile demonstration, the potential next phase is to build out the remaining route from the ports to the near-dock rail yard which is approximately 5 miles.

Project Objective
The primary objective of this project was to demonstrate the feasibility of using overhead catenary power lines to extend the range of a variety of zero and near zero emission trucks. Transportation Power, Inc. ("TransPower") proposed to deliver two trucks with catenary accessibility. The project approach was to build on the battery-electric drive technology TransPower had been developing for the previous two years, first by converting an existing truck that utilizes a TransPower drive system into a version that can be operated on the catenary, and then by developing a CNG hybrid truck that incorporates components into a new series-hybrid architecture that uses energy generated by a CNG engine and generator to augment both stored battery energy and energy obtained from the catenary. The battery-electric truck would have an operating range of about 30-40 miles on battery power only, but with a catenary power line, the truck would need battery power only to get to and from the roadway(s) equipped with catenary power. The CNG hybrid truck (pictured below) would have similar battery-electric range, but would also be capable of driving for 100 miles or more using power produced by an onboard natural gas generator, enabling it to operate away from catenary power lines for much longer distances.

Figure 1: TransPower Electric Truck

Technology Description
The core TransPower ElecTruck™ drive system used in both trucks employs a unique combination of two 150 kW permanent magnet motors that were originally developed for the Fisker Karma hybrid passenger car. The demonstration vehicles were equipped with Inverter-Charger Units (ICUs) that combine the functions of the vehicle inverter and battery charger. An Automated Manual Transmission uses proprietary software to control a transmission shift mechanism, enabling operation in multiple gears to maximize vehicle efficiency. The battery modules installed on both

trucks used lithium iron phosphate cells. A proprietary vehicle control system optimizes vehicle efficiency, maximizes battery life, and protects key components such as batteries and power electronics from excessive temperatures, voltage spikes, or current surges.

This core ElecTruck™ system was augmented with large pantograph power pick-up devices built by Siemens and installed onto the trucks by TransPower. This device can be seen in the preceding photo extending over the truck cab to make contact with the overhead catenary line. TransPower also installed DC-to-DC converters on both trucks to convert the higher voltage of the catenary system (up to 750 volts DC) to the 400 volts used by the ElecTruck™ system, along with special electronics to assure safe interaction between the catenary system and the truck's onboard drive system.

Status

The project was completed at the end of 2017. By that time, the battery-electric test truck had been tested intermittently for more than two years and the CNG hybrid truck had undergone more than a year of testing. Testing of the trucks on catenary power was initiated near the end of 2015 on a short catenary test segment in Carson that was a few hundred feet long. Catenary testing was limited to this site until 2017 due to delays in building a longer 1-mile catenary segment along Alameda Avenue. Testing on the 1-mile segment was finally initiated in mid-2017, using the two trucks built under this project and a third hybrid truck built by Volvo under a separate contract. The majority of catenary and off-catenary testing was achieved with TransPower's two trucks, which were completed earlier than the Volvo truck and which performed very reliably. In fact, TransPower's CNG hybrid truck made several trips on its own power from TransPower's headquarters in San Diego County to the Carson test sites, accumulating nearly 1,500 miles of operation over the course of the project. The battery-electric truck accumulated approximately 750 miles of total operation, on top of more than 4,000 miles accumulated prior to its conversion to a catenary-compatible truck.

Results

The project successfully demonstrated the proof of concept of using overhead catenary power to move large Class 8 trucks. A number of new technologies and components were developed to support this end goal, including the DC-to-DC converter and a new, customized battery management system (BMS) capable of operating at higher voltages than previously available BMS products. In addition, the CNG hybrid truck developed for this project was one of the first Class 8 CNG hybrid trucks with sufficient operating range to make intercity trips. Of the mileage figures cited above, the battery-electric truck was driven for a total of 610 miles on the main catenary test segment, achieving a maximum of 65 miles of testing in a single day, and the CNG hybrid truck was driven for 912 miles on this segment, achieving a daily maximum of 80 miles.

Benefits

TransPower believes that catenary technology can further the adoption of electric trucks by increasing vehicle range without adding more battery energy storage capacity. Based on the test results of this project, TransPower has calculated that each minute of operation on a catenary power line can extend the operating range of a Class 8 truck by 2 miles and displace approximately 5 kilowatt-hours (kWh) of onboard battery capacity. With integrated battery systems likely to cost at least $300/kWh for the foreseeable future, the availability of catenary power can potentially reduce onboard battery costs by thousands of dollars. However, this benefit must be compared against the incremental cost of the pantograph power pickup system and other truck additions required for catenary operation, along with the cost of the catenary infrastructure itself.

Project Costs

The total cost of the TransPower catenary project was just under $3.2 million, with a SCAQMD funding contribution of just over $2.1 million, EPA funding of $500,000 and TransPower contribution of almost $600,000. The project was completed within budget.

Commercialization and Applications

The potential size of the U.S. electric Class 8 truck market is in the tens of thousands of trucks per year, signifying great market potential for catenary powered trucks, if net benefits can be proven.

SCAQMD Contract #14062 **December 2018**

Develop and Demonstrate Catenary Zero Emissions Goods Movement System and Develop and Demonstrate Diesel Catenary Hybrid Electric Trucks

Contractor

Siemens Industry Inc.

Cosponsors

China Shipping Fund
California Energy Commission
SCAQMD
Port of Long Beach
L.A. Metro
Siemens Industry Inc.

Project Officer

Joseph Impulitti

Background

While innovations for transitioning combustion trucks to lower emissions are progressing, the increasing road traffic volume is currently over-riding those improvements.

There is the need of a rapid and practicable solution to freeze and sustainably lower all emissions including locally harmful exhausts and greenhous gases. Taking the increasing demand for renewable electrical energy in all sectors into account, it will be essential to apply solutions with maximum efficiency. At the same time the technical and operational limitations of energy storage systems such as batteries must be taken into consideration. For heavy-duty trucks a high degree of efficiency can best be achieved by a conductive supply of electrical energy by means of an electric road system (ERS).

Project Objective

Heavy-duty trucks are the number one source of smog-forming emissions in Southern California. Developing a zero- or near-zero emission goods transport system at the ports will reduce smog-forming, toxic and greenhouse gas emissions in communities around the ports, which are heavily impacted by air pollution.

The primary goal of this project was to promote the implementation of zero emission goods movement technologies, and the secondary goal was to demonstrate the most viable ERS technology to be adopted for a future, regional zero emissions corridor. This was accomplished through the installation and testing of a one mile overhead contact line based electric road system with trucks from different original equipment manufacturers (OEM) utilizing three different drive technologies.

Technology Description

Catenary ERS comprise four subsystems.

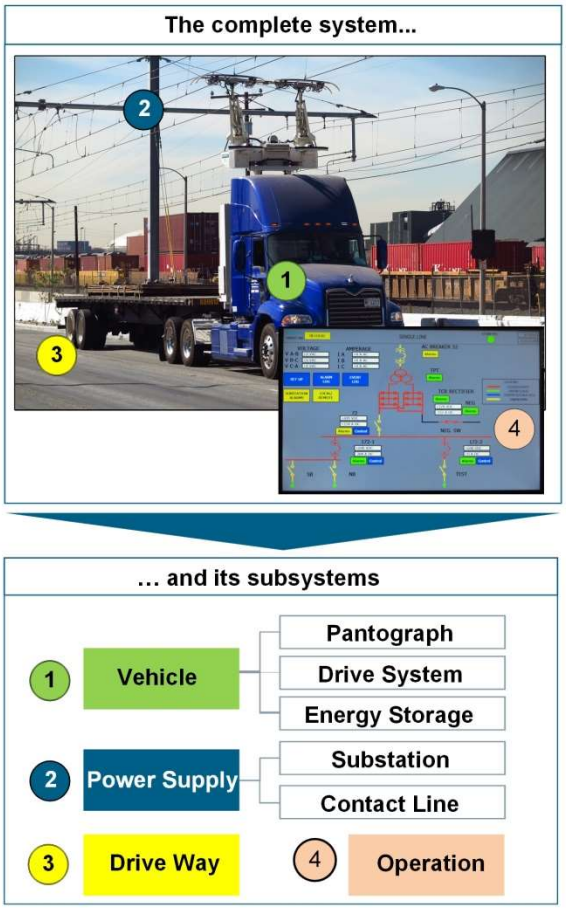


Figure 1: Siemens eHighway System

The core of the system is an active controlled pantograph installed on a hybridized tractor truck. The electrical energy is supplied via an overhead caternary system running over the electrified lanes of the chosen corridor.

The road testing of the catenary based zero emission technology required two inter-related work strings. First, all planning, design and implementation works of the subsystems including their technical interfaces and adaption to the local specifics had to be carried out. Second, the external stakeholders and technical interfaces, e. g. to energy suppliers and road administration, required intense collaboration.

Status

Four active pantographs were produced of which three were integrated into hybridized tractor trucks. The whole system was successfully planed, installed, commissioned and tested. In the course of the project the design of the infrastructure had to be adapted to unforeseen ground conditions. To achieve the initial goal of the project the decision was made to go for a solution which included compromises in the design to increase the speed of realization. Consequently the resulting infrastructure included aspects which are of a rather temporary nature (e.g. type of footings, location of substation).

Testing ended by December 31, 2017 and decommissioning started as foreseen in the scope of work. A full project report on all tasks and test items was provided by February 28, 2018.

Results

During the system testing phase from June 30 to December 31, 2017 the trucks accumulated the following test days and mileages.

Truck	**Testing days**	**Total mileage****	**Catenary mileage*****
ECAT*	60	980 km	230 km
CCAT*	45	1,460 km	200 km
MACK	50	1,260 km	370 km
	~ 150	**~ 3,700 km** *(2,300 miles)*	***~ 800 km*** *(500 miles)*

* catenary trucks by Transpower (ECAT full electric with battery; CCAT with CNG range extender)
** including turnarounds, battery/CNG/Diesel drives
*** with PAN connected, traction power transfer active

After commissioning, the system ran stable and all required test items were successfully accomplished and demonstrated. During the testing phase the pantographs accumulated 2,380 connect and disconnect cycles. As a key result the expected average power consumption of a loaded truck-trailer combination in electric mode of 2.5 kWh per mile (at 45 mph and 66,000 lbs. combined vehicle weight) can be confirmed.

Benefits

Based on the demonstration results the eHighway system supplying hybrid trucks via an overhead catenary system can be considered as a valid option for zero emission road freight transports. Additional key benefits include:

- Considerable reduction of emissions in comparison with combustion engines
- High efficacy of locally limited infrastructure measure compared to other ZE technologies
- Increased lifequality of residents at truck routes in conurbations
- Overhead catenary can be installed and integrated without pavement interference
- Successful proof of concept in a representative application environment.
- Ready for next ramp-up steps towards industrialization.

Project Costs

The original project budget was $14,780,000 including $1,280,000 of Siemens in-kind contributions. Unplanned additional costs for crash protection on the median increased overall project costs to $15,210,000.

Funding Source	Amount
China Shipping Fund	$4,000,000
CEC	$3,000,000
SCAQMD	$2,930,000
Metro	$2,000,000
POLB	$2,000,000
Siemens (in-kind)	$1,280,000
Total Project Costs	$15,210,000

Commercialization and Applications

In order to support commercialization, two business cases for different scales of applications were analyzed and presented.

For the I-710 corridor, the economic savings could exceed $660 million and would yield reductions in criteria pollutants worth $450 million. Such potential gains should motivate increased action in exploring catenary systems further. An accelerated implementation plan in the South Coast air basin could start with smaller shuttle applications, that prove the business models.

SCAQMD Contract #15382 **January 2018**

Install Electric Charging Infrastructure

Contractor
ChargePoint

Cosponsors
SCAQMD

Project Officer
Patricia Kwon

Background
There are approximately 1,800 PEV chargers in need of being upgraded in the South Coast Air Basin. These sites are ideal locations for upgrading EV infrastructure to Level 2 charging stations and can be done at a lower cost than installing new site locations. Leveraging the DOE and/or CEC funding received by two major Electric Vehicle Support Equipment (EVSE) manufacturers—Chargepoint and ECOtality—SCAQMD executed contracts with these manufacturers to install new or upgraded Level 2 EVSE at high usage site locations. These site locations were identified by SCAQMD and the manufacturers. Chargepoint received a combination of DOE and CEC funding to pay for hardware and partial installation costs for Level 2 infrastructure at 70 site locations. SCAQMD is providing co-funding of $1,000 per charger to offset installation costs at these locations. Data will be collected from these chargers and provided to SCAQMD to assist in SCAQMD's PEV infrastructure planning process for the DOE and CEC PEV infrastructure grants covering the South Coast region.

Project Objective
The objective of this project was to install 155 Level 2 charging ports in the South Coast Air Basin. The charging stations had to be public access and located in high utilization areas. Examples of site hosts are amusement parks, community colleges, shopping centers, and municipalities.

Technology Description
ChargePoint's CT4000, a Level 2 charging station capable of charging vehicles at 7.2kW, was the EVSE installed at all sites. This station comes in a single-port or dual-port configuration, and can be wall or pedestal mounted. This station complies with SAE J1772 standard and is UL certified and ENERGY STAR certified. Stations utilize the ChargePoint network, allowing station owners to set pricing, access controls, and obtain utilization data.

Status
This project has been successfully completed with all 155 Level 2 charging ports installed at various sites throughout the South Coast Air Basin. The last stations were installed in December 2017.

The project began in December 2014 and was completed in January 2018. Customer recruitment proved to be more difficult than anticipated due to the requirement for stations to be publicly accessible, and the prevailing wage requirement for site hosts and their installation contractor. In addition, the $1,000 per port rebate only covered a small portion of the equipment, networking, and installation costs.

Figure 1: EV Charging Stations: Westfield Santa Anita Mall, Arcadia

Results
From January 2015 to December 2017, 155 charging stations dispensed 1,012,318 kWh of electricity.

As a result of increased utilization each year in addition to more charging stations coming online, consumption (kWh) steadily increased, with over 500,000 kWh dispensed in 2017. The chart below shows annual kWh consumption for the three years of this project.

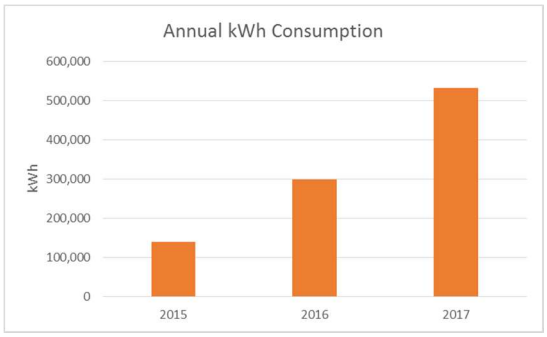


Figure 2: Annual kWh consumption between 2015 and 2017

With the rise in EV adoption rates and all electric range of vehicles, utilization of the charging stations and associated environmental benefits is anticipated to increase.

Benefits

Electric vehicles play an increasingly important role in reducing emissions and greenhouse gases. Transportation is the largest source of greenhouse gases in California, accounting for roughly 40% of the total, with most of that coming from light duty passenger vehicles and SUVs. EV charging stations are going to play a critical role in EV adoption, providing EV drivers with charging and thereby reducing range anxiety.

This project installed 155 publicly accessible charging ports, which over a three year period saved approximately 425 tons of CO2 and avoided the use of roughly 127,046 gallons of gasoline.

Project Costs

A fixed $1,000 per port rebate was provided to sites that installed EVSE. The grant was provided to sites after station installation and activation was successfully completed. Sites were responsible for selecting their own installation contactor. Depending on the contractor and the complexity of the installation, such as the need for trenching or electrical infrastructure upgrades, costs varied greatly. Average hardware costs were approximately $7,000 per dual charger and installation costs varied from $500 per charging port if no electrical infrastructure upgrades or trenching was required to $10,000 - $20,000 per charging port if electrical infrastructure upgrades and/or trenching was required.

Total funding in the amount of $162,000 was provided by SCAQMD to ChargePoint. Costs under this project were as follows: $1,000 x 155 publicly accessible charging ports = $155,000 plus $7,000 for installation reports.

Commercialization and Applications

ChargePoint's CT4000 Level 2 station and networking software are commercially available and best suited for public charging where vehicle dwell time is at least one hour and charging rates can offset the cost of electricity, network and payment processing fees, as well as operation and maintenance costs.

Demand for EV charging stations has significantly increased across the South Coast Air Basin and California as EV adoption increases. EV use is expected to continue to increase and public charging will play a vital supporting role in encouraging EV use.

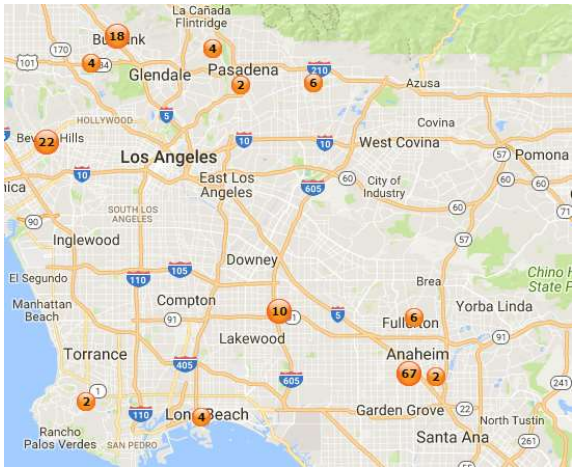


Figure 3: 155 ChargePoint Level 2 Charging Locations in Los Angeles and Orange Counties

SCAQMD Contract #15650 **January 2018**

Develop and Demonstrate Solar Forecasting for Larger Solar Arrays with Storage and EV Charging

Contractor

University of California, San Diego

Cosponsors

California Energy Commission
U.S. Environmental Protection Agency
California Public Utilities Commission
SCAQMD

Project Officer

Scott Epstein and Aaron Katzenstein

Background

Solar photovoltaic (PV) is an increasingly significant energy resource in California providing zero emissions energy to the electric grid. However, solar PV variability and uncertainty limits solar penetration into the electric power system and increases run-time of peaker plants. Solar forecasting and controllable loads help to reduce the uncertainty of solar PV. Business cases for solar PV operation in conjunction with solar forecasting and controllable electric vehicle (EV) charging are considered.

Project Objective

The objective of the contract was to demonstrate how warehouse rooftops in the Los Angeles Basin can host substantial amounts of zero-emission solar generation and how smart charging of Electric Vehicles (EVs) can mitigate the variability in solar power production.

Technology Description

Decarbonization and criteria pollutant reductions in the electric power sector cannot be achieved by reducing system demand alone. Electricity consumed at different times of the day and year has different underlying emissions impacts. Energy storage and flexible loads combined with solar forecasting into a Virtual Power Plant (VPP) can play an important role in reducing emissions by offering operational flexibility in the power system while providing reserve capacity to markets.

Smart EV charging can provide benefits both system-wide to the electric grid as well as to the utility customer. Detailed methodologies to evaluate business cases were developed for wholesale market sales, demand charge management, energy arbitrage, and generation capacity savings/deferral.

To generate solar forecasts, nine hemispheric sky imaging cameras were deployed in the Los Angeles Basin. This globally unique network of cameras provide wide-area coverage with a specific focus on warehouse rooftop areas. Simulations show how more accurate forecasts enable better dispatch of workplace EV loads with long layover periods during which they are connected to the grid. PV forecasts are leveraged to shape an aggregated EV load profile that 'fills the valley' in feeder net load resulting from PV generation. Different fleets of EVs that range up to the medium and heavy-duty (school busses) were considered. Control actions are updated in real time given the present and forecast net load as well as the currently connected Plug-in Electric Vehicles (PEVs) and their departure times.

Status

The project was completed on schedule in January 2018. University of California, San Diego (UCSD) in conjunction with University of California, Los Angeles and Strategen Consulting, Inc. were not successful at finding demonstration sites for the EV charging algorithms. It was too difficult to find all the required hardware (solar, EV, flex charging) in one place and get the owner and occupant to agree to the fairly extensive installation of monitoring and control equipment. Simulations were based on real load data, real PV production data, and real EV data sets and can be considered representative of actual conditions.

Results

The algorithm was successful in flattening the net load. Economics of the selected use cases are analyzed over a year in Figure 1. Forecasting-aware

scheduling benefits the customer primarily through reduction of demand charges. Conversely, wholesale market sales of PV energy directly to the California Independent System Operator (CAISO) day-ahead market were found to be economically infeasible. The ratepayer benefit of focusing on capacity deferment only was found to be small compared to the microgrid cost savings due to high reliability of the CAISO system. However, ratepayer benefits accrue also indirectly when optimizing around the retail energy costs. Appropriately designed time-of-use tariffs drive scheduling decisions that benefit both the customer and all ratepayers.

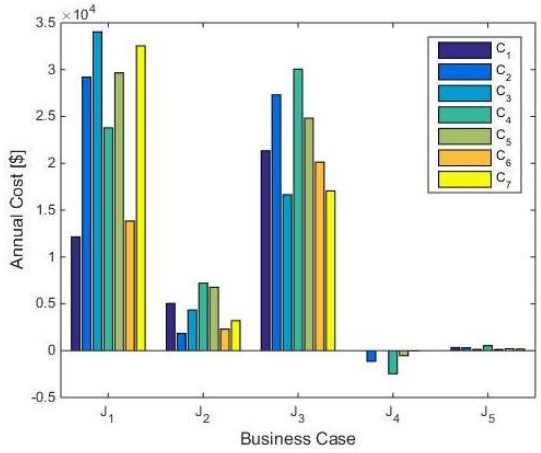


Figure 1: Distribution of annual costs when optimizing for different business cases: C_1: Non coincidental demand charge only; C_1: Peak demand charge only; C_3: Energy arbitrage only; C_4: Wholesale market sales only; C_5: Capacity deferment only; C_6: All objectives; C_7: non-optimized charging. The costs for each business case are split by category: J_1: Non coincidental demand charge; J_2: Peak demand charge; J_3: Energy arbitrage; J_4: Wholesale market sales;J_5: Capacity deferment

Benefits

The project showed that utility customers who implement solar forecasting and smart EV charging could achieve a 67% reduction in energy costs over the year. Monthly peak demand is reduced by 63% on average.

Flexible EV charging at the workplace also reduces criteria pollutant emission through two pathways:

1) EV consumption of excess solar electricity during midday reduces curtailment of solar power. Thus carbon-free energy that would otherwise be wasted is utilized and displaces carbon-intensive electricity that would otherwise be consumed at night when commuters plug in at home.

2) EV Charging is scheduled to lower peak load on the grid which reduces the runtime or even allows mothballing of inefficient peaker plants.

Project Costs

The total project costs consisted of $98,908 from SCAQMD; $396,700 from U.S. Environmental Protection Agency (EPA); $156,386 from the California Public Utilities Commission (CPUC) and $999,984 from California Energy Commission.

Funding Source	Amount
CEC	$999,984
EPA	$396,700
CPUC	$156,386
SCAQMD	$98,908
Total Project Cost	$1,651,978

Commercialization and Applications

Recommendations are provided in the final report to increase the availability of daytime EV charging that support the concepts developed in this contract. UCSD is currently working with Nuvve Corporation to implement solar forecasting and smart EV charging algorithms into EV fleets. These demonstrations commenced in the spring of 2018 and may pave the way for widespread commercialization of smart EV charging. The project parties expect substantial emissions and economic benefits from the technology developed under the SCAQMD award.

SCAQMD Contract #16047 **September 2018**

ZECT I: Develop and Demonstrate Three Class 8 LNG Plug-In Hybrid Electric Drayage Trucks

Contractor

US Hybrid Corporation

Cosponsors

US Hybrid Corporation
U.S. Department of Energy
SCAQMD
University of California, Riverside
National Renewable Energy Laboratory

Project Officer

Phil Barroca

Background

Thousands of older model year diesel-powered heavy-duty vehicles are used in Goods Movement activities in Southern California and, as a result, significantly contribute to NOx emissions and to this region's non-attainment with NAAQS for ozone pollution. This project was developed and supported through DOE's Zero Emission Cargo Transportation Program to demonstrate zero emissions heavy-duty vehicle technology useable in freight transportation. This project developed and demonstrated three Class 8 plug-in hybrid electric trucks (PHETs), two of which were demonstrated in drayage operations by fleet operator TTSI which serves the San Pedro Bay Ports area, railyard and regional freight transportation operations. The third PHET was used as a demonstration vehicle for interested parties and events, for continued product development, and conducting emissions testing at the University of California Riverside (UCR) in order to quantify emissions reduction benefits of the hybrid electric system.

Project Objective

The objective of the project was to develop and demonstrate heavy-duty hybrid electric technology that is useable in drayage operations. Operational data collected from the two demonstration vehicles helped quantify fuel economy and other metrics including total cost of ownership. Project goals included:

1) Reducing emissions by utilizing zero and near-zero powertrain technologies and alternative, low-carbon fuels;
2) Validating the technical and market feasibility of the pre-commercial technologies in preparation for a full-scale, commercial vehicle production launch;
3) Generating operational and performance data for the new, PHET vehicle to facilitate commercialization and broad deployment, thereby increasing the environmental and fuel efficiency benefits; and
4) Creating a positive economic impact for California through job creation and cost reduction of drayage truck operations.

Technology Description

The primary technology utilized in this project included the Cummins ISL-G 8.9-liter LNG-powered spark-ignited engine and a 222 kW interior permanent magnet motor in a parallel electric hybrid configuration, 80 kWh of lithium-ion battery storage, and 72 DGE of LNG fuel storage.

Figure 1: PHETs

PHET integration includes electric motor/generator in-line between the engine and transmission with auto clutch and, all electric air, hydraulic and HVAC system with 12V and 24V batteries, DC-DC converter powering the auxiliary systems, and a high voltage lithium-ion batteries. The electronically controlled pneumatic driven clutch allows the electric motor to be decoupled from the engine and permits electric only operation seamlessly and fully transparent to the driver. The electric auxiliary systems (i.e., power steering, air compressor and air conditioning) are installed in parallel with the engine driven systems to give full functionality in EV-only mode. Transitioning between all-electric mode and hybrid-electric mode is an automated transparent

function that is controlled by the vehicle control unit and requires no input from the driver. The vehicle is equipped with an onboard charger that allows it to be plugged in when not in service, providing a full battery state-of-charge at the beginning of every shift.

The PHET's parallel hybrid configuration results in greater horsepower and torque than larger displacement diesel engines while providing zero emissions operation in near-dock operations, near-zero emissions operation in most other regional applications and a 250-mile total operating range utilizing existing LNG fueling infrastructure with no evaporative emissions. By optimizing the overall control architecture, the Class-8 PHET has significantly higher fuel economy than a comparably powered conventional engine powertrain while providing the power and torque necessary for drayage operations including accelerating over port bridges and steep highway passes.

Status

The PHET project was completed in September 2018. PHET #1 and #2 were completed and delivered to TTSI on February 27, 2017, and March 29, 2017, respectively. Truck #3 was completed and delivered to UCR for dyno testing in Q3-2017. A no-cost time extension was executed to allow additional time to optimize the hybrid systems to improve fuel efficiency and performance and complete the project.

Results

TTSI demonstrated the PHET vehicles from March 2017 through October 2018. Data from each vehicle was collected, compiled and analyzed by NREL. NREL's analysis of these vehicles showed an average efficiency of 3.82 kWh/mi or a 62.5 percent improvement relative to the baseline diesel vehicle tested under this project. The PHETs developed under this project produced higher power (Figure 2) and torque (Figure 3) than the baseline 8.9-liter ISL-G and the 12-liter diesel powered Cummins ISX12 rated at 400 h.p. and 1650 lb-ft. (2237 N-m) torque, significantly improved energy efficiency, and 80 percent less NOx. The trucks performance with both LNG and battery had a range of 250 miles, with exclusive "all-electric" battery range of about 30 miles.

The PHETs demonstrated in this project exceeded operator's expectations for handling all cargo loads and duty cycles expected of drayage vehicles

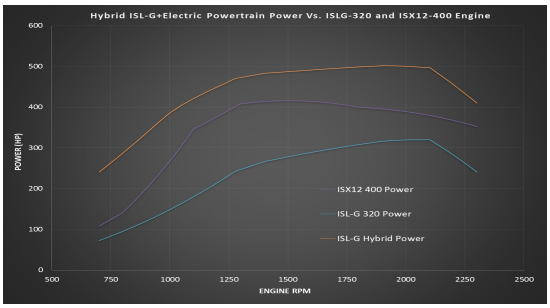


Figure 2: Power Curves

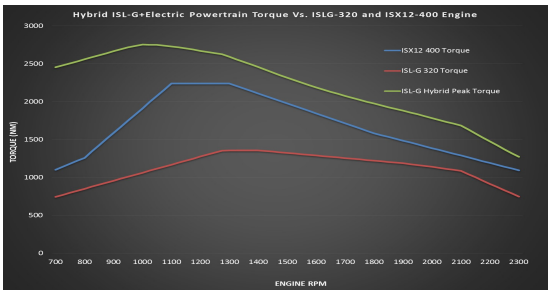


Figure 3: Torque Curves

while meeting zero emissions and near-zero-emissions operations for NOx and lowering GHG emissions using: (1) plug-in battery electric operation for the first 30 miles, (2) hybrid-electric operation during on-road operation, and (3) renewable low carbon intensity LNG alternative fuel. The hybrid configuration provided better fuel and energy economy and hence lower operating costs than a comparably powered non-hybrid heavy-duty vehicles. Additionally, the all-electric operation applied in queuing operations at the port significantly reduced NOx emissions attributable to idling and lower exhaust temperature events.

Project Costs

Total project costs were $1,996,675 with $925,000 from DOE, $22,896 from SCAQMD and $1,048,779 from US Hybrid.

Commercialization and Applications

US Hybrid believes drayage truck operators can benefit the most from this technology and can realize immediate return on investments from outstanding engine performance, improved energy efficiency, and reduced emissions from near dock and other operations associated with drayage operations.

SCAQMD Contract #15632 **June 2018**

Develop Ultra Low-Emission Natural Gas Engine for On-Road Medium-Duty Vehicles

Contractor
Gas Technology Institute

Cosponsors
SCAQMD
Ricardo
Southern California Gas Company
Power Solutions International

Project Officer
Joseph Lopat

Background

Medium- and heavy-duty on-road diesel vehicles are currently amongst the top ten sources of NO_x emissions in the South Coast Air Basin. These source categories are still projected to be one of the largest contributors to the NO_x emissions inventory, even as the legacy fleet of older and higher polluting vehicles are retired from operation and replaced with vehicles meeting the most stringent 2010 emission standards. The development of ultra-low emission natural gas engines would significantly reduce emissions from this on-road source category and assist the region in meeting federal ambient air quality standards in the coming years. Additionally, the ability to develop an internal combustion engine that emits 90% lower NO_x emissions, relative to current standards for heavy-duty vehicles would begin to address the issues associated with the NOx emissions produced in the operation of heavy- duty vehicles when also factoring in emissions associated with electricity production.

Project Objective

The objective of this project is to develop an ultra-low NO_x natural gas engine suitable for on-road applications in the Class 4 to Class 7 vehicle weight rating range. This vehicle segment includes delivery, emergency, transit and other small heavy-duty applications.

In addition the engine system must be commercially viable and capable of:

- Achieving emissions targets of 0.02 g/bhp-hr NOx, 0.01 g/bhp-hr PM, 0.14 g/bhp-hr NMHC, and 15.5 g/bhp-hr CO, as determined by the heavy duty engine FTP
- Keeping exhaust NH_3 emissions as low as achievable while targeting 10 ppm,
- Achieving minimal fuel economy penalties relative to 2010 U.S. EPA and CARB certified diesel engines on similar duty cycles, and
- Being certified by the U.S. EPA and CARB.

Technology Description

Utilizing Ricardo's vast experience in research and development, a naturally aspirated 8.8 liter engine was chosen. The existing stoichiometric cooled exhaust gas recirculation (EGR) spark ignited combustion was selected as the platform. Ricardo began modeling and developing the required exhaust gas recirculation and turbo charger configurations that would best suit the 0.02g/bhp-hr requirement. Power Solutions International (PSI) is an engine builder of natural gas powered engines. The collaboration between PSI and Ricardo was determined to be a positive pathway for development.

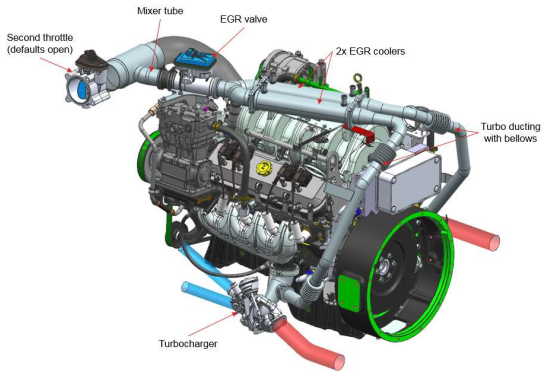


Figure 1: Engine Concept

Status

Many design ideas such as the configuration of EGR and Turbo charger were developed. The control software also had begun to be developed.

Results

The project was mutually terminated among all parties and the funds repurposed for other projects.

Benefits

The 8.8 –liter engine would have been a favorable alternative for class 4-7 vehicles. The availability of an engine with ultra-low emission, specifically one that reduces NOx by over 90% from the current federal standard would enable air quality districts in California as well as other areas of North America to carry out their emissions reduction plans and move closer to meeting their ambient air quality goals. Specifically targeting the NOx emissions attributed to commercial on-road vehicles would be an additional benefit.

Project Costs

This project was originally funded by SCAQMD, Ricardo, SCG and PSI in an amount totaling $1.8 million. The chart below reflects actual expenditures before the project was ended.

Project Partners	Funding Amount
SCG	$55,000
SCAQMD	$250,000
Total	$305,000

Commercialization and Applications

This project was ended before completion. The original design had packaging concerns with integration into the vehicle. After several months of design technical readiness level two discussions, PSI decided to pursue different alternatives in other markets. PSI determined there would not be a significant market to ensure payback on development of the technology.

SCAQMD Contract #16205 **June 2018**

Develop, Integrate and Demonstrate Near-Zero Emissions 12-Liter Natural Gas Engine for On-Road Heavy-Duty Vehicles

Contractor

Cummins Westport Inc.

Cosponsors

California Energy Commission
Clean Energy Fuels
SCAQMD
Southern California Gas Company

Project Officer

Joseph Lopat

Background

Heavy-duty on-road diesel vehicles are currently among the top ten sources of NOx in the South Coast Air Basin (Basin). This source category is still projected to be one of the largest contributors to NOx, even as the legacy fleet of older and higher polluting vehicles are retired from operation and replaced by the cleanest vehicles meeting the most stringent emissions levels. Development of near-zero emissions natural gas engines would significantly reduce emissions from this source category and assist the region in meeting federal ambient air quality standards.

Project Objective

The objectives of this project were for Cummins Westport Inc. (CWI) to develop and demonstrate a 12-liter natural gas engine and associated aftertreatment technologies suitable for on-road heavy-heavy-duty vehicle applications, such as Class 8 trucks and buses. In addition, the engine system had to be commercially viable and capable of:

- Achieving emissions targets of 0.02 g/bhp-hr NOx, 0.01 g/bhp-hr PM, 0.14 g/bhp-hr NMHC and 15.5 g/bhp-hr CO, as determined by heavy-duty engine Federal Test Procedures (FTP);
- Keeping exhaust NH3 emissions as low as achievable while targeting 10 ppm;
- Achieving minimal fuel economy penalties relative to 2010 U.S. EPA and CARB-certified diesel engines on similar duty cycles, and
- Being certified by U.S. EPA and CARB.

Technology Description

An extensive process was undertaken to design and develop a 12-liter engine and aftertreatment to meet the 0.02 gram NOx level. Utilizing learnings from previous technology development, the existing stoichiometric-cooled exhaust gas recirculation (EGR) spark-ignited combustion was selected as the platform to complement with the following additions/changes:

- Implementation of a closed crankcase ventilation (CCV) system with additional pressure sensor;
- Aftertreatment size increased, improved formulation, and O2 sensor location changed;
- Redesigned fuel system for improved fuel delivery accuracy and responsiveness; and
- Improved software with various emissions optimizing control strategies and addition of an HD-OBD.

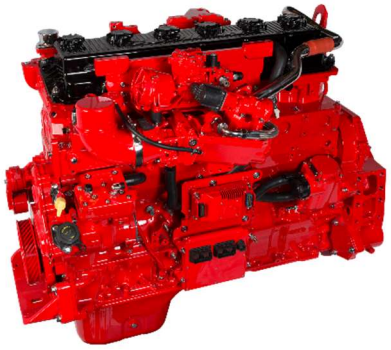


Figure 1: 12-Liter NG Engine

The closed crankcase ventilation system consists of an electrically driven coalescence filter and hose assembly. Crankcase emissions are routed to the filter where oil is separated through high speed rotation of the filter. The vapor is introduced into air intake at the turbo compressor inlet so that it can enter the combustion process. Separated oil is returned to the engine sump. An additional CCV pressure sensor allows the control system to monitor pressure in the CCV system and alert the operator to issues as part of system diagnostic.

The combination of increased aftertreatement size and improved formulation increases the overall conversion efficiency of the catalyst and thereby

reduces emissions. A key part in the optimized control of the aftertreatment is the relocation of the O2 sensor from the outlet to the mid-bed location.

A redesigned fuel system achieved the goal of increasing the accuracy and responsiveness of the fuel delivered to the combustion chamber, enabling the control software improvements.

The optimized control software targets high NOx forming portions of the duty cycle and utilizes the above-mentioned hardware changes to reduce tailpipe emissions.

Status

The project was successfully completed with the ISX12N receiving U.S. EPA and CARB certification (to the optional low NOx 0.02 g/bhp-hr level) in December 2017. The engine went into commercial production at the Cummins Jamestown, NY, engine plant February 2018. The final report is on file with technical details of the project.

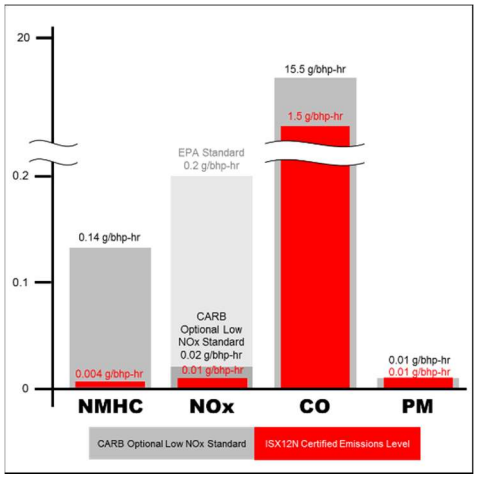
The standard Cummins engine development process was followed, which included analysis and testing at a component level thru to the system level. Multiple prototype engine builds were completed prior to production and tested in test cell dynamometers and in test vehicles.

Fifteen pre-production engines were installed in 14 tractor style trucks and in one refuse truck. Thirteen of these vehicles were owned by fleets and placed back into commercial service. Two of the vehicles were "rapid" test vehicles operated by Cummins and intended to accumulate mileage quickly. The field test vehicles successfully accumulated 1.25 million miles.

The University of California, Riverside (UCR) conducted a third-party chassis dynamometer testing of one field test vehicle, which showed that the ISX12N 400 natural gas engine met and exceeded the target NOx emissions of 0.02 g/bhp-hr and maintained those emissions during in-use duty cycles found in the Basin. Other gaseous and particulate matter emissions were below the standards and/or similar to previous levels. Particle number, ammonia emissions and methane emissions were higher than current 2010 certified diesel engines on similar drive cycles.

Results

The objectives of this project were achieved. U.S. EPA and CARB certification were received, with results shown in the following graphic.



While the stretch NH3 target of 10 ppm was not achieved, NH3 emissions were reduced by over 50 percent with a value of 40 ppm demonstrated.

Fuel economy analysis based on CO2 emissions from the FTP cycle suggest the ISX12N is approximately 15 percent more fuel efficient than a similar 2010 ISX12 diesel engine. Also based on CO2 emissions, UCR testing found the fuel economy also appeared to be similar to previous versions where the urban dynamometer driving schedule showed the lowest CO2 emissions and were below the current FTP standard of 555 g/bhp-hr for both the cold start and hot start tests during in-use chassis testing.

Benefits

The availability of a 12-liter near-zero emissions engine, specifically one that reduces NOx by over 90 percent from the current federal standard enables air quality districts in California (and other states who wish to adopt more stringent standards) to carry out their emissions reduction plans in order to meet ambient air quality goals, specifically targeting NOx attributed to heavy-duty on-road vehicles.

Project Costs

Total project costs were $5.25 million with cost-share funding as follows: Clean Energy-$500,000 (10%); CEC-$1,000,000 (19%); SCG-$1,000,000 (19%); CWI-$1,000,000 (19%); and SCAQMD-$1,750,000 (33%).

Commercialization and Applications

This engine is now available to a wide range of original equipment manufacturers of heavy-heavy-duty vehicles for duty cycles used in regional haul and refuse trucks and coach buses. It is also available for incentive funding programs.

SCAQMD Contract #12851 **December 2018**

Install, Operate and Maintain Three Natural Gas Fueling Stations

Contractor
Clean Energy

Cosponsor
California Energy Commission
SCAQMD

Project Officer
Phil Barroca/Drue Hargis

Background
The South Coast Air Basin (Basin), which encompasses all of Orange County and the non-desert portions of Los Angeles, Riverside and San Bernardino counties, is in non-attainment with state and federal standards for ozone and PM emissions. Ozone and PM emissions affect human health contributing to respiratory disease, lung damage, cancer, birth defects and premature death. Air pollution also negatively impacts the environment and sensitive ecosystems. Alternative fueled vehicles help to reduce NOx and PM emissions and meet federally mandated air quality standards. The SCAQMD has a long history of supporting development and commercialization of alternative fueled vehicles and the infrastructure to support them.

Project Objective
Clean Energy has been operating natural gas fueling facilities in the Basin for many years. The SCAQMD, through a CEC grant (#PON-09-006), provided Clean Energy funding to offset the cost to install, operate and maintain three public access, liquefied natural gas (LNG) fueling stations. The three stations would be located at the following sites: 14226 Valley Blvd., Fontana (92335) at an existing truck stop located less than one-half mile from Interstate 10; 45-601 Dillon Road, Coachella (92336), at an existing travel stop less than one-tenth mile from Interstate 10; and 23261 Cajalco Expressway, Perris (92571) at an existing travel zone center less than one-half mile from Interstate 215. Clean Energy was responsible for designing, constructing, installing and commissioning the three LNG fueling stations.

Technology Description
These stations were designed to support heavy duty trucks and included the following equipment: LNG storage tank, LNG pump skid, offload skid, two LNG dispensers, vaporizer skid, switchgear, and card reader as well as site improvements including, but not limited to, utility service lines, block wall, asphalt, concrete and landscaping.

Furthermore, Clean Energy's LNG is significantly derived from renewable low carbon intensity sources to help reduce greenhouse gas emissions.

Status
All three public access station projects were successfully implemented and are currently open and operating.

The Coachella station opened to the public in May 2013 and the Fontana station in November 2013.

Figure 1: Coachella LNG Station

Figure 2: Fontana LNG Station

The Perris station opened in July 2015, following difficulties establishing permanent power for the station. It was a catch-22 situation. The county would not provide a meter release because the station lacked power on final inspection but Clean Energy couldn't get one without the other. Their lead engineer had to work closely with the county and SCE to get the count inspector to finally grant a meter release. A lessons learned here is to allow more time for this process and the need to continue educating county inspectors.

Figure 3: Perris LNG Station

In addition, the Perris station closed temporarily in December 2017 because it was dispensing very low volume due to a number of factors from anticipated customers deciding to install private, mobile fuelers to the variable seasonable demand from local hay farmers coupled with lower diesel costs slowing natural gas truck procurements. Clean Energy made the decision to temporarily close the LNG station to save operational costs while working to identify new fleet customers. The station was re-opened in May 2018. A longer final report is on file.

Results

Natural gas for transportation typically costs less than gasoline or diesel, saving money daily for vehicle and fleet owners who use these stations. Specifically, these three LNG fueling stations helped promote transition to cleaner burning fuels, encouraging current natural gas fleets to expand use of natural gas and new fleets to switch to natural gas. Furthermore, these three LNG stations are reducing significant amounts of air pollutants through the displacement of heavy-duty diesel trucks.

Although the original estimated throughput for each station was higher than the first full calendar year of actual fuel dispensed, the stations brought real, quantifiable emissions reductions based on the volume of diesel displaced. California is accelerating fleet turnover to transition to cleaner burning fuels, and since these stations are at convenience fueling sites near major interstates, throughput should increase steadily.

ANNUAL THROUGHPUT IN DGE		
	2016	2017
COACHELLA	110,100	181,529
FONTANA	439,461	608,370

Benefits

Based on the stations' volume over the past three years, the stations have directly reduced 1,378,883 pounds of criteria pollutants and greenhouse gas emissions.

Emission Reductions (Pounds)					
Emissions Reduced:	Carbon Monoxide (CO)	Volatile Organic Compound (VOC)	Nitrogen Oxide (NOx)	Fine Particulate Matter (PM2.5)	Greenhouse (GHG)

This project has displaced 825,145 gallons of diesel, a large contributor of air pollution linked to lung disease, asthma, cancers and other respiratory and critical illnesses.

Project Costs

SCAQMD using CEC funding provided Clean Energy $1.4 million to offset the costs to construct all three LNG stations. Clean Energy provided the remaining cost-share. Projected costs varied from actual costs due to the cost of construction and delay in permitting. The engineering timelines were longer than the development timeline which caused costs to be higher than anticipated. Projected vs actual costs are illustrated below.

	Coachella	Fontana	Perris
Projected Costs	$1,319,356	$1,394,317	$1,287,323
Total Cost	$1,526,496	$1,361,684	$1,425,921
Grant	$500,000	$500,000	$400,000
Cost-Share	$1,026,496	$861,685	$1,025,921

Commercialization and Applications

Clean Energy successfully established three new public access LNG stations in the Basin. These stations are operating on 24-hour per day, 7-days per week basis.

SCAQMD Contract #12852 **January 2018**

Upgrade Existing CNG Fueling Station at City Corporate Yard

Contractor
City of Corona

Cosponsors
City of Corona
MSRC/AB 2766 Discretionary Fund
SCAQMD

Project Officer
Phil Barroca/Drue Hargis

Background
In 2003, the City of Corona constructed a CNG station at 430 N. Cota Street, Corona, near the I-15 and SR-91. The station was originally constructed with two Greenfield C3U gas compressors delivering a maximum throughput of 764 cubic feet (CF) per minute, with a storage capacity of 36,000 CF, with a single dual-hose, fast-fill dispenser. Since it was the only CNG fueling station within a 12-mile radius, the station storage capacity and single dispenser became insufficient to serve the residents, commuter traffic and several corporate fleets in the area. When the SCAQMD through a CEC grant (#ARV-10-054) offered funding for new and upgraded natural gas stations, the City of Corona applied for and was awarded funding to upgrade its station.

Project Objective
The objective of this project was to increase the CNG fueling capacity and provide the public with faster fueling service. The City's goal was to add an additional 36,000 CF of CNG storage and an additional dual-hose fast-fill dispenser. This would double the throughput capacity, reduce the dispensing time and greatly enhance the local CNG infrastructure for the public's utilization. Under direction by the City of Corona, Fuel Solution Inc. developed design plans for the station upgrades, and the City contracted with Go Natural Gas Inc. to construct the station.

Technology Description
The City installed three storage vessels, a dual-hose fast-fill dispenser, card reader and priority valve panel. By doubling the existing storage capacity from 36,000 CF to 72,000 CF of CNG, it allowed for the installation of the additional dual-hose fast-fill dispenser, which is an ANGI Series II dispenser with an advanced LCD display and electronics, integrated micro-processor mass flow, sequential and display electronics eliminating remote components, weights and measures certified, three-bank sequencing, temperature compensation, and OPW P36 fill nozzles.

Status
The project was completed and the upgraded station opened to the public in September 2014. During the design phase of the project, there were some delays due to sub-consultants not performing per schedule and to the amount of time the different parties required for the plan review. During the construction everything ran smoothly; the concrete pad was built for the storage vessels; vessels were installed; lights were relocated; the fast-fill dispenser and card reader were installed; and other required civil improvements were constructed. A more detailed Final Report is on file.

Figure 1: New Dual-Hose Fast-Fill Dispenser

Figure 2: CNG Storage Vessels

Results

Expansion of the existing Cota St. public access CNG fueling station was essential to accommodate increasing users and the subsequent demand for CNG utilization. According to EIA's Alternative Fuel Vehicle Data, CNG demand has increased steadily since 1995. This is beneficial to the environment since natural gas emits approximately 6-11 percent lower levels of GHGs compared to gasoline throughout fuel life cycle, according to the Argonne National Laboratory. Another study shows that there is more than a 90 percent reduction in petroleum use for CNG compared to gasoline. The U.S. DOE mentions that another positive thing is that U.S. natural gas reserve is abundant compared to petroleum, of which 33 percent is imported from politically volatile countries.

Table 1: Throughput in Gasoline Gallon Equivalents (GGE) Consumed

Period	GGE	Fueling Transactions
9/1/14 to 8/30/15	490,795	54,835
9/1/15 to 8/30/16	454,913	49,720
9/1/16 to 8/30/17	425,952	45,813
9/1/17 to 8/30/18	373,523	44,349

Benefits

The construction of the project increased the CNG fueling services provided by the City of Corona. The storage capacity was increased by approximately 36,000 CF and the fueling wait time was decreased by the installation of the additional dual-hose dispenser. CNG burns cleaner than gasoline or diesel and produces fewer emissions of hydrocarbons, NOx, CO and CO2. CNG is also less expensive than gasoline or diesel, resulting in cost savings for the City and the users of its CNG fueling station.

Figure 3: Station after Upgrade

Project Costs

The costs for the project included design, equipment procurement, geotechnical construction services and construction. The original estimate was $450,000, and while there were no major change orders during the design or construction of the project, some costs were underestimated. Funding for the project was as follows:

Table 2: Funding Partners

Cosponsor	Cost-Share
MSRC/AB 2766 Discretionary Funds	$225,000
SCAQMD (through CEC AB 118 grant)	$200,000
City of Corona General Fund	$57,812
Total	$482,812

Commercialization and Applications

The use of CNG vehicles benefits the environment and public health. The City will install additional storage capacity in the future if needed.

SCAQMD Contract #12853 **December 2018**

Upgrade CNG Fueling Station

Contractor
Rainbow Disposal Company, Inc.

Cosponsors
California Energy Commission
SCAQMD

Project Officer
Phil Barroca/Drue Hargis

Background
In 2010, the SCAQMD amended Rule 1193. The revised rule required solid waste collection vehicles providing waste collection services to public agencies to be powered by alternative fuels by January 1, 2020.

Rainbow Disposal Company, Inc. (RDC), has operated a CNG fuel station in the northwest quadrant of Orange County since 2007. The access to alternative fuels for communities is limited by geographic convenience, fueling capacity, physical barriers to quantity, and the amount of compatible vehicles. The existing public fuel station at RDC has 24-hour accessibility with ingress and egress access for buses, heavy equipment, and multi-passenger vehicles to fuel simultaneously. Additionally, RDC originally installed 50 CNG "time-fill" dispensers which served three quarters of its collection vehicle fleet.

Project Objective
The objectives of this project were three-fold: 1) Comply with Rule 1193 by increasing the quantity of CNG powered vehicles from 50 to 72; 2) Increase CNG fueling capacity by increasing the quantity of time-fill CNG dispensers to accommodate 22 additional CNG-powered collection vehicles and increase the volume of reserve CNG capacity at the public "fast fill" station; and 3) Reduce CNG electrical costs by increasing the volume of CNG storage reserves. This last objective would be achieved by increasing the amount of CNG that can be compressed overnight during lower electric rate periods, reducing the number of CNG compressor start-ups and shut-downs, and cost effectively utilize stored CNG during higher electric rate periods. These efforts would results in lower operating costs through reduced compressor usage during higher electric rate periods. Data collected by RDC shows these station improvements reduced the amount of kilowatts (kW) consumed by nearly eight percent.

Figure 1: CNG "Cascading" Storage Tanks

Figure 2: Public CNG Station

Figure 3: CNG Time-Fill Dispenser

Technology Description

The technology used in this project includes one ASME three-pak of CNG storage vessels rated at 12,207 scf at 5,000 psig and eight time-fill dual-hose dispensers with three bank sequencing for each hose.

Status

RDC completed the installation of the additional CNG storage vessels and the 22 vehicle dispensers in January 2015. The existing intercompany and public fueling stations remained operational during the project.

Results

Rule 1193 Compliance/Increased CNG Dispenser Capacity – The addition of the 22 fueling dispensers allowed RDC to replace its remaining fleet of diesel trash collection vehicles with CNG trucks. A total of 20 diesel collection trucks and 3 diesel transfer trucks were replaced with CNG trucks between 2015 and 2018. Using an energy density ratio of 86.55 percent CNG:diesel, **Figure 4** shows the amount of diesel gallons reduced by increasing the facility's CNG capacity. **Figure 5** depicts the total amount of CNG gallons used in the last five years.

Year	Rainbow CNG Usage	Increased CNG Gallons (Since 2014)	Reduced Diesel Gallons
2014	437,262	-	-
2015	482,201	44,939	38,894
2016	522,998	85,736	74,205
2017	547,751	110,489	95,628
2018	599,141	161,880	140,107
Totals	**2,152,091**	**403,044**	**348,834**

Figure 4: Diesel Usage Reductions

Year	Public	Rainbow	Total
2014	99,446	437,262	533,708
2015	94,867	482,201	577,068
2016	64,067	522,998	587,065
2017	64,052	547,751	611,803
2018	73,269	599,141	672,411

Figure 5: Total CNG Gallons Used

Increased CNG Fueling Capacity – In addition to the 22 CNG fuel dispensers, 3 "cascading" CNG storage tanks that were added to reduce kWs used to start and stop the CNG pumps. As shown in **Figure 6**, the facility achieved a sustained 7.8 percent kW consumption reduction following the installation of the additional CNG storage tanks in 2015.

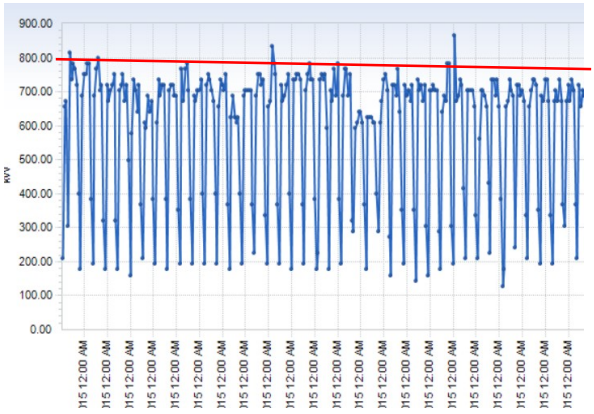


Figure 6: kW Consumption Reductions in 2015

Benefits

Following the completion of the CNG upgrade project, RDC has displaced approximately 348,834 gallons of diesel. Using the EPA/DOT standard of 22.38 pounds of CO2 emissions per gallon for diesel consumed and 14.22 pounds of CO2 per gallon for CNG consumed, this project has resulted in a reduction of approximately 2,075,619 pounds in CO2 emissions since it was completed in 2015.

Project Costs

Costs for the station upgrades paid by Rainbow Disposal and SCAQMD with funding from a pass-through grant from the CEC.

Funding Source	Cost-Share
RDC	$240,891
SCAQMD (through CEC pass-through revenue grant #ARV-10-054)	$200,000
Total Cost	**$440,891**

Commercialization

The technology employed in this project, cascade sequential CNG storage and dispensing with time-fill, is commercially proven and provides lower costs of operation for anchored fleets that can fuel overnight.

SCAQMD Contract #12854 **December 2018**

Upgrade LNG Fueling Station at Baldwin Park Facility

Contractor
Waste Management

Cosponsors
SCAQMD
Waste Management

Project Officer
Phil Barroca/Drue Hargis

Background
Waste Management (WM) owns and maintains a fueling facility for refuse collection vehicles at 13940 Live Oak Ave., Baldwin Park. WM has operated a limited public-access liquefied natural gas (LNG) refueling station since 2003. Committed to reducing emissions and implementing cleaner solutions, WM has increased their fleet from 53 heavy-duty natural gas solid waste collection trucks to 75 with the purchase of additional LNG and compressed natural gas (CNG) heavy-duty vehicles to operate at the Baldwin Park facility. To fuel this natural gas fleet, WM planned for the expansion of their fueling station. This included the installation of an additional LNG storage vessel, compressors, pumps, dispensers and a vaporizer to create CNG. WM applied for and received cofunding from the SCAQMD as cost-share for the installation of the storage vessel as well as related work for site improvements.

Project Objective
The objective of this project was to add approximately 16,000 gallons of additional LNG storage capacity to an existing 16,000 gallons for a total capacity of approximately 32,000 gallons at its existing publicly accessible LNG fueling station in Baldwin Park. In addition, WM would expand the use of their fueling station by adopting advance technologies to vaporize LNG to CNG to support local fleets, both public and private. Other related work would include site improvements and upgrade of controls related to the added storage capacity and technology.

The purpose of this project was to reduce emissions from heavy-duty refuse collection vehicles by installing the necessary infrastructure to fuel extremely low emissions natural gas vehicles. WM will operate the LNG/LCNG fueling station at its facility in Baldwin Park.

Figure 1: LNG Tank Installation

Technology Description
This project involved the installation of one additional above-ground storage tank with a capacity of approximately 16,000 gallons, four CNG storage spheres, two LCNG pumps, one fan assisted LCNG vaporizer, one odorant injection system, and an upgrade to an existing PLC control system to allow the interface of the new equipment.

All equipment meets AGA, ANSI, API, ASME, ASTM, NEC, NFPA, OSHA, and SAE requirements.

Status
WM completed installation of the LNG tank, and the station has been operational since May 2012**.** No significant problems were encountered during the construction of the project. The final report is on file with complete technical details of the project. In accordance with Contract #12854, Waste Management will operate the station for at least five years and continue reporting to the SCAQMD during that period.

Results

Now that the additional LNG storage installation and related work is complete, the station can adequately provide fuel for their growing natural gas fleet. The expansion of the station will result in fuel cost-savings due to the lower cost of natural gas, increase energy security and lower emissions, all air quality benefits achieved by displacing diesel fuel.

Annual Fuel Throughput

Throughput data from the upgraded LNG-CNG station since it was completed in May 2012:

Period	LNG Gallons	CNG (DGE)
May2012-Apr2013	282,224	344,728
May2013-Apr2014	246,883	325,706
May2014-Apr2015	333,998	397,241
May2015-Apr2016	251,166	495,065
May2016-Apr2017	154,393	505,121
May2017-Apr2018	136,666	541,758

The first two-year period is data from WM vehicles only, while the throughput listed fro subsequent years includes WM vehicles and third-party users accessing the fueling station.

Benefits

WM is familiar with the many benefits of natural gas, operating one of the largest fleet of heavy-duty natural gas trucks in North America. Benefits identified include fuel cost-savings, energy security, and lower emissions.

Additionally, natural gas fuel contains less carbon than any other fossil fuel and thus produces lower carbon dioxide (CO2) and greenhouse gas (GHG) emissions per year. In fact, natural gas vehicles produce 20-30 percent less greenhouse gas emissions than comparable diesel vehicles. Therefore, the successful installation of this additional storage tank will lower the tail-pipe emissions of WM's natural gas fleet and other public and private fleets operating within the South Coast Air Basin.

Based on the average throughput of 310,149 gallons of LNG per year and 292,572 DGE of CNG per year, WM estimates that the Baldwin Park station achieves a reduction of approximately 36 tons of NOx and 0.73 tons of PM per year[1].

Project Costs

The total cost of the new LNG storage tank and related site improvements was $1,719,189. WM paid $1,419,189 and was awarded $300,000 cost-share from the SCAQMD as pass-through funding from the CEC AB 118 Program (Agreement #ARV-10-054) for the upgraded natural gas fueling station.

Commercialization and Applications

This project will provide the additional necessary infrastructure needed in order to make alternative fuels like natural gas a commercially available and preferable fueling option. Commercial fleet drivers and owners of CNG –equipped vehicles can now fuel at WM's newly upgraded Baldwin Park station.

Additionally, the Baldwin Park LNG/LCNG Infrastructure Expansion Project will provide solutions to the development and widespread use of natural gas as a transportation fuel. Public and private fleets will be encouraged to switch to natural gas as additional infrastructure is available due to both the environmental and cost-saving benefits. This project is also beneficial to those vehicles subject to Rule 1193, which requires public and private solid waste collection fleets having exclusive contracts with public entities and greater than 15 trucks to purchase or replace existing vehicles with alternative fuel vehicles.

WM is committed to reducing emissions and implementing cleaner solutions, such as the construction/expansion of alternative fuel infrastructure and natural gas vehicle deployment throughout the South Coast Air Basin.

[1] Estimated using Carl Moyer Program Guidelines (Adopted April 2011) methodology for calculating criteria pollutant emission reductions and using a baseline model year 2006 diesel refuse collection vehicle

SCAQMD Contract #15438 **June 2018**

Refurbish Ontario LCNG Fueling Facility

Contractor
United Parcel Service

Cosponsors
California Energy Commission
Department of Energy
SCAQMD

Project Officer
Phil Barroca

Background
An important aspect of natural gas vehicle deployment in California is the supporting infrastructure. The UPS Ontario LNG/CNG (LCNG) station is a public/private access LNG and CNG refueling facility located at 3140 E. Jurupa Ave. Ontario, CA 91761. The facility is adjacent to the Ontario International Airport in a predominantly industrial and commercial zone of the Inland Empire region of Southern California, one of many regions that comprise the South Coast Air Basin (Basin), a region which continues to be non-attainment with state and federal ozone and PM air quality standards.

The United Parcel Service (UPS) LCNG facility has provided natural gas fueling since 1997. The station received funding support from the CEC and DOE to refurbish storage and dispensing equipment and other associated systems to permit the station to operate reliably and continue providing natural gas fueling to UPS and other natural gas vehicle operators in the area. The UPS LCNG refurbishment was a replacement project to the original CEC award under #ARV-10-035; the original CNG infrastructure project, also located in Ontario, was abandoned due to irreconcilable differences between the station owner and its partner.

Project Objective
The goal of this project was to continue reliable LNG fueling for UPS and other LNG-powered vehicles. UPS' original proposal was based on unreliable LNG fuel supply in combination with expected increases in fleet size, vehicle miles traveled (VMT) and fuel demand. Subsequent to grant award and contract execution, UPS realized a significant improvement in the reliability of LNG fuel delivery, reducing the immediate need for more onsite LNG storage capacity. In recognition of improved fuel delivery and to reduce project costs, UPS and SCAQMD submitted a request to revise the project scope to a station refurbishment, eliminating the costs associated with the purchase and installation of a new 18,000 gallon LNG tank. The project scope was further revised when it was determined that a proposed new LNG dispenser would not be able to communicate with the rest of the LNG system because UPS was unable to gain legal access to proprietary software access codes.

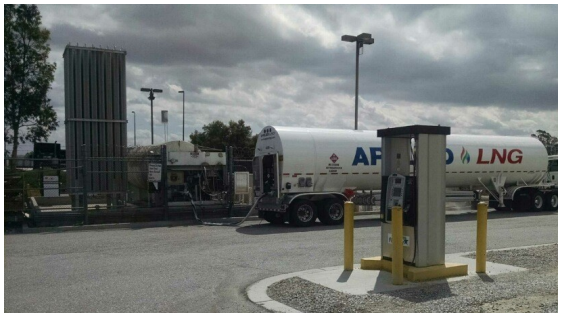


Figure 1: LNG Fuel Delivery to Station

Technology Description
UPS performed the following upgrades and refurbishments to the LNG/LCNG refueling station:

- Removal and replacement of LNG submersible pump;
- Rebuilt old LNG pump for back-up;
- Removed and replaced LCNG pump cold ends and rebuilt old cold ends for back-up;
- Removed and replaced CNG dispensers with new dual-hose 3,600 psi dispensers;
- Removed and replaced odorant injection system;
- Performed corrosion control on CNG storage vessels and repainted CNG vessels;
- Identified leaks on LNG storage vessel and repaired as necessary;
- Tested LNG tank and vacuum jacketed piping for proper vacuum and re-pulled vacuum on LNG tank and lines following repairs;

- Serviced the air system and changed air compressor oil and replaced air filters;
- Changed system desiccant dryer material and leak tested all connection points and repaired leaks, as necessary.

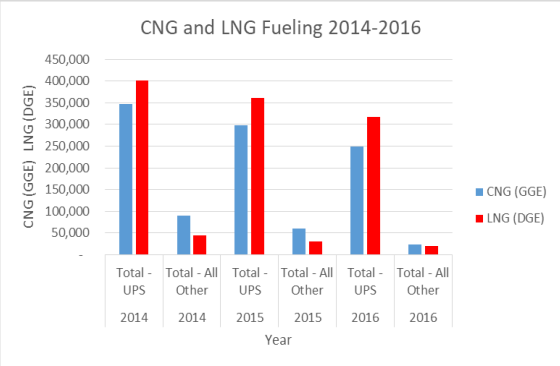
Status

UPS met the goals of this reduced-scope project, successfully restoring and upgrading an established public access LNG/LCNG fueling station in the Inland Empire area near the well-travelled 10 and 60 Interstate freeways. The completion of these upgrades restores the reliability and fueling capacity of the original LCNG station and provides increased incentive for goods movement operators, municipal fleets, school districts and water agencies to adopt or expand the use of natural gas vehicles. UPS continues to use this station to fuel heavy-duty vehicles operating between Southern California and Las Vegas as well as heavy-duty goods movement activities within the Basin.

Results

The refurbishment of this station restored the station to its original capacity, maintaining its current refueling capabilities and upgrading all private CNG dispensers, hoses and nozzles to 3,600 psig. Below is a graph of the throughputs reported for LNG and CNG from this facility between 2014 and 2016. UPS is the major consumer of the fuel dispensed at this station. UPS has expanded its fleet of heavy-duty LNG powered vehicles from 11 to 44 since 2010.

Table 1 Throughput for CYs 2014-2016



Between UPS's 38 heavy-duty CNG vehicles and its heavy-duty LNG fleet, it is displacing more than 600,000 gallons of petroleum fuel annually, with public fleets displacing another 100,000 gallons annually.

Benefits

UPS' fleet of Class 8 LNG-powered and Class 7 CNG-powered heavy-duty vehicles are the largest and most consistent fuel consumers at this refueling facility. A baseline emissions reduction assessment for this facility can be performed using the Carl Moyer Program Guidelines (July 2014)[1] methodology for calculating criteria pollutant emission reductions. If it is assumed that a comparable fleet of heavy-duty diesel-powered vehicles, subject to the 1.2g NOx per bhp-hr standard, used an equivalent amount of diesel fuel as shown in Table 2 (converting CNG to diesel gallon equivalents), the reduction in NOx from the heavy-duty natural gas-powered vehicles would be approximately 13 tons per year.

Project Costs

The UPS Ontario refurbishment project received $55,792 from the CEC and $223,168 from the U.S. DOE, which were received as pass-through funds to SCAQMD who administered the project. Total project expenses were $278,960, with in-kind contributions provided by UPS.

Commercialization and Applications

This project will provide the continued and necessary infrastructure needed to make natural gas a commercially available and preferable fueling option. UPS remains committed to reducing emissions and creating cleaner solutions, such as the construction of alternative fuel natural gas refueling stations for its fleet and others within the neighborhoods that UPS employees work and live. This refurbishment project helps to illustrate how the lifespan of a natural gas refueling station can be extended and in turn increase the investment potential and economic attractiveness of natural gas as an alternative fuel.

[1] California Environmental Protection Agency, Air Resources Board, "Carl Moyer Program Guidelines" July 2014 Appendix D – Tables for Emission Reduction and Cost Effectiveness Calculations

SCAQMD Contracts #15625 **June 2018**

Evaluate SOA Formation Potential from Light-Duty GDI Vehicles

Contractor
University of California Riverside/CE-CERT

Cosponsors
California Air Resources Board
ICM Inc.
Manufacturers of Emission Controls Association
SCAQMD

Project Officer
Wei Li

Background
Gasoline direct injection (GDI) vehicles are known for higher fuel efficiency and power output but the particulate matter (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 forming potential from these vehicles as it could lead to further impact on the ambient PM concentration in the South Coast Air Basin (Basin).

Project Objective
The University of California, Riverside (UCR)/CE-CERT evaluated the primary emissions and SOA production from eight current technology GDI vehicles over the LA92 test cycle. This program had three distinct goals (or separate exercises): 1) evaluate primary emissions and SOA formation from conventional GDI vehicles; 2) evaluate particulate emissions, toxic pollutants and SOA formation from GDI vehicles with and without gasoline particle filters (GPFs); and 3) examine the impact of fuel composition on the tailpipe emissions and SOA formation from GDI flexible fuel vehicles (FFVs).

Technology Description
A 30m^3 mobile environmental chamber, which is the largest known reactor currently available, was designed and constructed for this program. The large volume (surface area to volume ratio of ~2.2:1) and non-reactive chamber material was selected to help minimize wall loss of aerosols and semi-volatile precursors.

Emissions tests were conducted in CE-CERT's light-duty chassis dynamometer over the LA92 test cycle. Primary emissions were measured during the tests. Emissions were also collected using the mobile environmental chamber during emissions tests then the chamber was transferred to the atmospheric processes laboratory for aging until air mass was depleted. Secondary emissions measurements were made during the reaction process.

Figure 1: A vehicle is being tested on the chassis dynamometer with the mobile environmental chamber collecting primary emissions.

Status
The scope of this study was expanded with additional funding and in-kind contribution from ICM, MECA and CARB to include hot-start test cycle, additional and more detailed emissions characterization and toxicity analysis. Emissions tests were successfully completed in November 2017. Comprehensive data analysis for the primary and secondary emissions was completed in August 2018. CE-CERT is producing journal papers describing the results of this project with four journal papers having been submitted to date. Two additional journal papers are in preparation for submittal.

Results
For the first exercise, four 2015 to 2016 model year GDI vehicles were tested. Results showed that PM, black carbon (BC) and particle number (PN) emissions increased markedly during accelerations and the cold-start phase, indicating severe wall

wetting that led to slower fuel evaporation and pool burning. PN and BC emissions showed large reductions during the urban and hot-start phases. Aged exhaust emissions resulted in distinct secondary aerosol emissions that varied significantly in physical and chemical structure. Two of the four vehicles produced considerable amounts of inorganic aerosol, thereby modifying secondary aerosol volatility and hygroscopicity. Primary PM emissions from all vehicles in this study met their certification requirements for their respective model years; however, all vehicles exhibited potential to form a considerable amount of secondary aerosol with different composition.

For the second exercise, two 2016 model year GDI vehicles were evaluated for the effects of catalyzed GPF addition to GDI vehicles. The use of catalyzed GPFs greatly reduced the toxic polycyclic aromatic hydrocarbons (PAHs) and their nitrated derivatives (nitro-PAHs), as well as dramatically reduced PM, PN and BC emissions. Gaseous emissions of NOx, total hydrocarbons (THC) and non-methane hydrocarbons (NMHC) were also reduced. Production of SOA was reduced with GPF addition, but was also dependent on engine design which determined the amount of SOA precursors at the tailpipe. This study indicates that SOA production from GDI vehicles will be significantly reduced with the application of catalyzed GPFs through the mitigation of reactive hydrocarbon precursors.

For the third exercise, two GDI FFVs were tested with four fuels of different ethanol blend levels: E10 with high aromatics, E10 with low aromatics, intermediate E30 and high E78 blend. Vehicles fueled with E30 and E78 exhibited reductions in THC, NMHC, CO and NOx emissions compared to the high aromatics E10. Particulate emissions from vehicles fueled with E30 and E78 showed large reductions compared to both E10 fuels. Acetaldehyde formation was favored by the higher ethanol content in the fuel, whereas benzene, toluene, ethylbenzene and xylene (BTEX) emissions increased with the high aromatics E10 and reduced with E30 and E78 fuels. As the ethanol content increased, the secondary aerosol formation potential decreased in both FFVs, due to reduction in SOA precursors (i.e., NMHC). In general, this study found that high ethanol content is not only effective in the reduction of tailpipe PM, but also has the potential to greatly decrease SOA formation potential of the emitted exhaust.

As shown in the Figure 2, results from this study were compared to earlier peer-reviewed studies exploring SOA formation from gasoline vehicles. The comparison showed that SOA formation dropped as the emissions certification standards became more stringent.

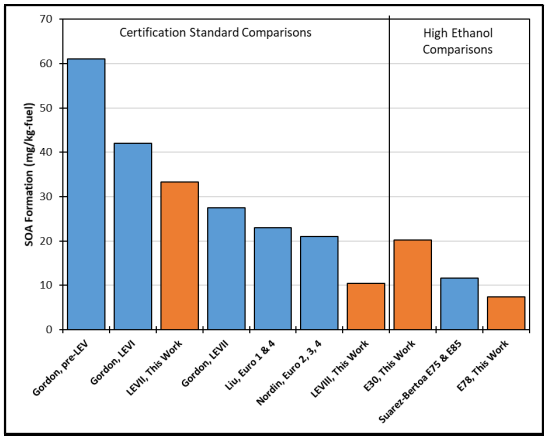


Figure 2: Comparison of SOA formation from GDI vehicles in this study and from gasoline vehicles in earlier peer-reviewed studies

In summary, this study showed that higher aromatics will increase SOA, while higher ethanol blends will reduce SOA formation. The results also showed that SOA formation increased with increasing NMHC emissions, suggesting that further reductions in NMHC emissions are necessary from current technology GDI vehicles. Catalyzed GPFs may help to reduce SOA productions from GDI vehicles.

Benefits

This study will enhance our ability to model the formation of SOA from GDI vehicles, helping to close the gap between atmospheric measurements and model predictions of PM concentrations. Models equipped with these SOA formation processes could then be used to help formulate science-based policy for the reduction of ambient PM concentrations.

Project Costs

SCAQMD	ICM Inc.	MECA	CARB	Total
$174,972*	$126,000	$50,000	In-kind analysis	$350,972

*The initial funding from SCAQMD under this contract was $149,972. An additional $25,000 was subsequently funded under another SCAQMD contract (#12376) for technical assistance and analysis through a task order issued to UCR/CE-CERT.

Commercialization and Applications

The mobile environmental chamber developed in this project could be further utilized for examining SOA formation from mobile sources, assessing air quality and the overall environmental impacts of mobile sources.

SCAQMD Contract #14185 / #17336 **June 2018**

Conduct Education Outreach for the Basin DC Fast Charging Network Project

Contractor
Three Squares Inc.

Cosponsors
California Energy Commission
EVgo
Clean Fuel Connection

Project Officer
Patricia Kwon

Background
Involving local stakeholders in Plug-in Electric Vehicle (PEV) readiness is crucial to the successful deployment of Direct Connection Fast Chargers (DCFC) charging stations. Drivers and charging site hosts need help understanding the benefits of driving PEVs and having public fast charging in their communities. They also need help in understanding the economic value proposition that PEV driving and/or charging holds for them, and the correct procedures for using DCFC charging stations.

Project Objective
The objective of this project was to develop and conduct a community outreach and education campaign to facilitate PEV readiness in electric vehicle fast charging station communities. This objective was launched by engaging stakeholder groups, including the following:

- Site hosts (owners/employees/students);
- Local businesses (owners/employees);
- Local homeowners and commuters;
- Local governments, associations, and media; and,
- PEV advocacy groups;
- SoCal Fast

Technology Description
Three Squares Inc. (TSI) served as the Project Community Outreach and Education Lead. In this role, they designed a comprehensive outreach strategy to raise awareness about the new DCFC stations throughout their surrounding communities. TSI developed a series of DCFC station launch events, ranging from traditional press events to awareness events held in conjunction with other scheduled events or site host promotional opportunities. TSI also partnered with community organizations and Electric Vehicle (EV) advocacy groups to spread the word about DCFC stations to their networks through social media, online calendars, and e-newsletter promotions.

Status
This project was completed in June 2018. Through this project, DCFC station launch events were held for the following locations: Calabasas City Hall, Palm Desert City Hall, Palm Springs Visitors Center, Mel's Drive-In on Sunset, City of Los Angeles Department of Transportation (LADOT), Westwood, LADOT Hollywood and Highland, La Kretz Innovation Center, and LADOT Little Tokyo.

Figure 1: Outreach Event-Hollywood Farmers Market

A range of outreach collateral was prepared as part of this campaign, including creation of a website, www.SoCalFast.com to provide a guide for the public to Southern California's electric vehicle fast charge network as well as pull-ups and postcards promoting SoCalFast and their network of stations.

Growing the attendance of launch events presented an unanticipated challenge during this project. After analyzing the problem, the team determined that the following factors limited the events' growth:

- When stations are located in smaller parking lots of commercial businesses, events must be held in off-hours so not to disrupt normal business operations. However, holding events in these hours also decreases the potential audience size for the launches.
- DCFC stations are only able to charge one car every 30 minutes. Therefore, a five-hour event is only able to accommodate a maximum of 10 cars.
- Currently, DCFC stations are only able to charge a select lineup of PEVs. Because of this, the majority of EV drivers are unable to participate in the launches.

To address these challenges, TSI amended the education and outreach strategy to prioritize hosting launch events in conjunction with other community events, such as farmers' markets. Applying this strategy, TSI was able to expand the outreach audience to include attendees of the other community events.

Results

DCFC station launch events were held to promote the grand opening of eight stations. Additionally, TSI executed digital outreach campaigns to promote the opening of those stations. TSI partnered with community organizations and EV advocacy groups to spread the word about DCFC stations to their networks through social media, online calendars, and e-newsletter promotions. These outreach campaigns were successful in getting information about DCFC stations and the SoCalFast network to millions of people.

The following table illustrates the digital reach of each campaign:

Station/Campaign	Digital Reach
Palm Desert City Hall & Palm Springs Visitors Center	137,500 people
Mel's Drive-In on Sunset	489,900 people
LADOT Westwood	803,700 people
LADOT Hollywood & Highland	704,600 people
La Kretz Innovation Center & LADOT Little Tokyo	821,900 people
Total	**2,957,600 people**

Given that the stated purpose of this project was to disseminate information about SoCalFast DCFC stations, this project can be considered successful. Information about these stations was distributed to nearly 3 million people who live in and around the communities in which the stations are located.

Benefits

Through the outreach and education campaign, PEV educational information was distributed to members of the communities where SoCalFast DCFC stations are located. Educational materials included information about the benefits of driving PEVs and having public fast charging, the economic value proposition that PEV driving and/or charging holds, and the correct procedures for using DCFC charging stations.

Project Costs

This project was completed for a total of $63,411.28, funded by SCAQMD. The project was executed for less than the original anticipated cost of $89,183.

Commercialization and Applications

N/A

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 a simplified 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 below take into account 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 "Consumer Reports" type approach:

● 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
BET—battery electric truck
BEV—battery electric vehicle
BSNOx—brake specific NOx
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
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
CVAG—Coachella Valley Association of Governments
CWI—Cummins Westport, Inc.
CY—calendar year
DC—direct connection
DCFC—direct connection fast charger
DCM—dichloromethane
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
FCV—fuel cell vehicle
FTA—Federal Transit Administration
FTP—federal test procedures
g/bhp-hr—grams per brake horsepower per hour
GC/MS—gas chromatography/mass spectrometry
GCW—gross combination weight
GCVW—gross container vehicle weight
GDI—gasoline direct injection
GGE—gasoline gallon equivalents
GGRF—Greenhouse Gas Reduction Relief Fund
GHG—Greenhouse Gas
GNA—Gladstein, Neandross & Associates, LLC
GTL—gas to liquid
GVWR—gross vehicle weight rating
H&SC—California Health and Safety Code

LIST OF ACRONYMS (cont'd)

HCCI—Homogeneous Charge Combustion Ignition
HCNG—hydrogen-compressed natural gas (blend)
HDDT—highway dynamometer driving schedule
HD-FTP—Heavy-Duty Federal Test Procedure
HD-OBD—heavy-duty on-board diagnostics
HPLC—high-performance liquid chromatography
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
LCFS—Low Carbon Fuel Standard
Li—lithium ion
LIMS—Laboratory Information Management System
LLNL—Lawrence Livermore National Laboratory
LNG—liquefied natural gas
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
MECA—Manufacturers of Emission Controls Association
MOA—Memorandum of Agreement
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
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
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

LIST OF ACRONYMS (cont'd)

RI—reactive intermediates
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—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
SOAs—secondary organic aerosols
SoCalGas—Southern California Gas Company (A Sempra Energy Utility)
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
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
WVU—West Virginia University
ZECT—Zero Emission Cargo Transport
ZEV—zero emissions vehicle