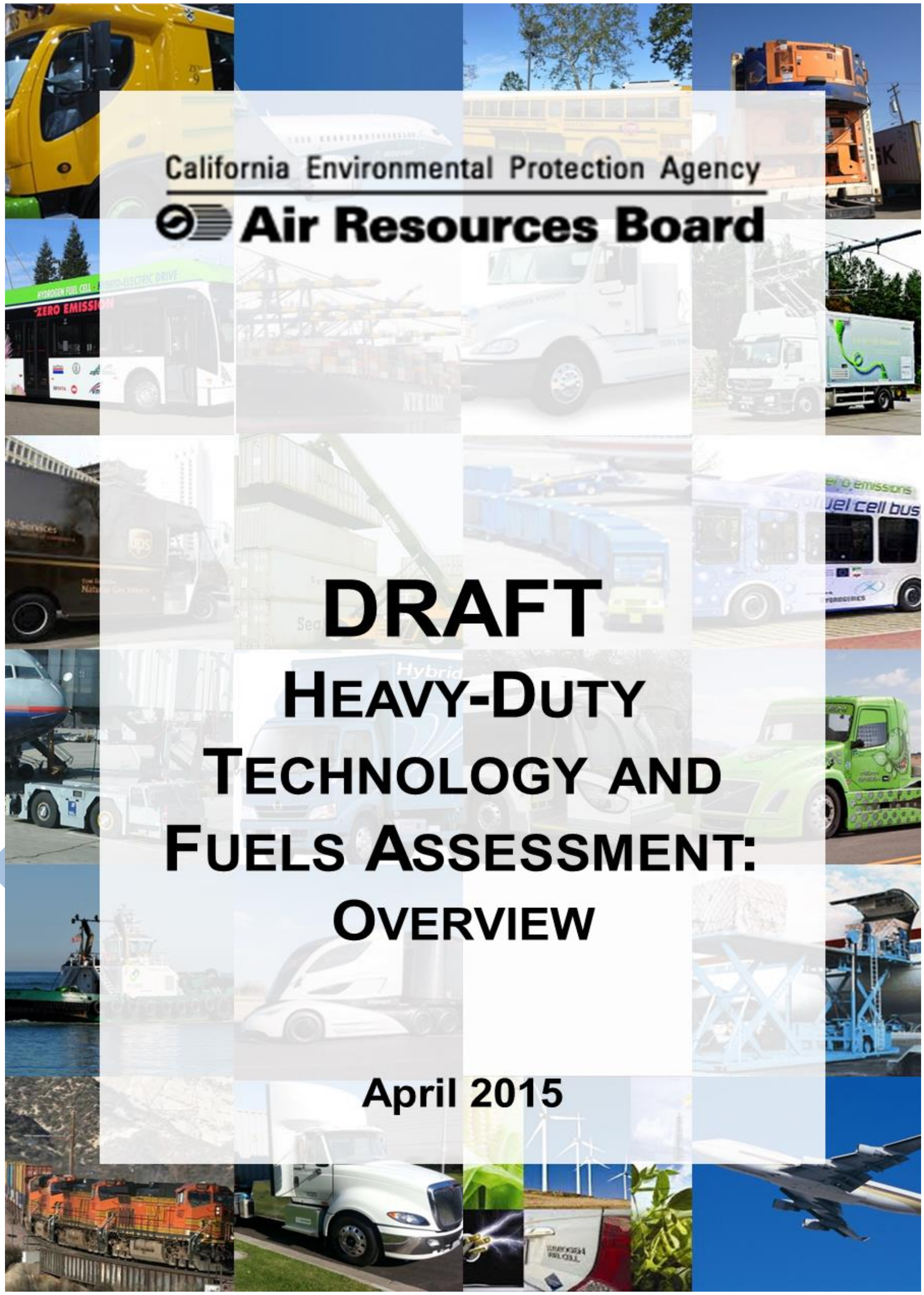


California Environmental Protection Agency

Air Resources Board

DRAFT

HEAVY-DUTY TECHNOLOGY AND FUELS ASSESSMENT: OVERVIEW

April 2015

State of California
AIR RESOURCES BOARD

EXECUTIVE SUMMARY

California has made substantial progress in reducing emissions from all mobile sources, with many vehicles sold today being over 90 percent cleaner than those sold just a decade ago. However, despite this progress, these vehicles and equipment remain major contributors to statewide emissions of oxides of nitrogen (NOx), greenhouse gases (GHG), and diesel particulate matter (diesel PM). Compared to today's levels, a 90 percent reduction in NOx emissions by 2031 will be necessary to achieve compliance with the current federal ozone standards, and an 80 percent reduction in GHG emissions below 1990 levels by 2050 will be necessary to meet California climate targets. Significant improvements in efficiency and the use of renewable fuels are also needed to meet the Governor's 50 percent petroleum reduction target by 2030. Finally, continued reductions in diesel PM and air toxics are necessary to reduce localized health risks and protect public health. Achieving each of these goals will require a transition to zero and near-zero emission technologies in all mobile sources.
The Air Resources Board (ARB) is in the process of developing proposals for new approaches and strategies to achieve this transition in mobile sources. Understanding technology options and pathways is fundamental to the developments necessary to achieve air quality and climate goals, and so in early 2014 staff initiated this heavy duty technology assessment that focuses on trucks, locomotives, off-road equipment, ships, commercial harborcraft, aircraft, and transportation fuels.

This document provides an overview and status update of the heavy duty technology assessment, and describes key observations to date that are helping to define the findings from the assessment. This document is intended to provide information to support the development and/or updates to the:

- Governor's Zero Emission Vehicle(ZEV) Action Plan
- California's Sustainable Freight Strategy
- State Implementation Plan
- Assembly Bill 32 Scoping Plan
- Short-Lived Climate Pollutant Plan
- Freight plans and funding initiatives at other public agencies

This technology assessment is on-going and focuses not only on zero and near-zero emission technologies that will ultimately be necessary to meet long-term air quality and climate goals, but also on improvements to conventional technologies and gains in vehicle and freight system operational efficiency that could provide substantial near-term emissions reductions and help facilitate the transition to zero and near-zero emission technologies. The technology assessment consists of a series of reports covering the transportation sectors identified above that will evaluate how each technology works, the fuels necessary to power each technology, as well as its state of market readiness, costs, environmental benefits, technology performance, and current deployment challenges. Draft sector-specific reports will be released for public comment and review as they are completed in 2015. As part of this work, staff is also assessing fleet age and vehicle/equipment use characteristics, regulatory climate, and other relevant factors to consider when developing emissions reduction strategies, incentive program guidance, and technology deployment approaches. Because regional differences across the state influence vehicle and equipment mix, age, and operation, the technology assessment covers a broad spectrum of available technologies for the State and local air districts to consider in assessing potential paths to air quality compliance.

This document addresses comments received through a series of workshops held in September 2014, as well as comments received at the December 18, 2014 Board hearing, where the status of the technology and fuels assessments was presented as an informational item. Many of the comments we received are specific to the detail presented in individual sector reports, and will be addressed in those documents when they are released. Staff's goal is to ensure the results of the technology assessment are robust, reflecting the current state of technology as accurately as possible. A partnership with industry stakeholders, non-governmental organizations, air districts, and other local, state, and federal governmental agencies is critical to meet this goal.

The heavy duty sector is diverse, and there are many different technologies and approaches that can achieve substantial emissions reductions. Over the past decade, heavy duty fleets have made substantial investments to adopt modern, lower-emitting vehicles and equipment. Building on this success to further reduce combustion emissions from engines and vehicles, near-zero emission technologies that provide ultra-low NOx emissions and operate on renewable fuels are under development. Substantial emissions reductions can be achieved through improvements to conventional technologies such as advanced combustion, aerodynamics, hybridization, and connected vehicle technologies. Renewable fuels can provide deep GHG and petroleum use reductions. Development and use of these technologies and fuels should be further encouraged to provide nearer term emission reductions.

In support of longer term emission reductions, the development of heavy duty zero emission technologies is also well underway. Today, zero emission vehicles are commercially available in battery and fuel cell forklifts, certain types of cargo handling equipment, and airport ground support equipment. Battery electric and fuel cell buses are in the early commercialization phase, with many transit agencies deploying growing numbers of vehicles. Demonstrations are underway across the State in a wide array of heavy-duty applications including drayage trucks, delivery trucks, school buses, and some types of off-road equipment. State incentives are in place that are encouraging the development and adoption of these technologies, increasing production volumes, fostering innovation, and reducing costs.

Early investments and incentives that accelerate deployment of zero and near-zero technologies in the heavy duty sector are critical. The vehicles and equipment in heavy duty sectors have long lifetimes -- many of the engines sold today may still be operating in 2030. So investments that bring the cleanest technologies to market as quickly as possible are essential for achieving near-term criteria pollutant reductions to meet ambient ozone air quality standards in 2023 and 2031, as well as PM2.5 standards. Incentive funding must be prioritized and coordinated in ways that can meet air quality, climate, and risk reduction goals.

In developing and deploying these technologies in the heavy-duty sector, the need for an integrated approach – focusing on vehicles; cleaner, renewable fuel production and storage; and fueling infrastructure and the electrical grid - is clear. Zero and near-zero emission technologies require coordinated deployment with different types of fueling infrastructure that those vehicles and equipment will require to operate. In addition, vehicle grid integration and power to gas technologies suggest a potentially synergistic relationship between renewable electricity on the grid, electricity supply / demand management, and zero and near-zero emission technologies in the heavy duty sector.

Achieving the successful transition to zero and near-zero emission technologies will be challenging and will take time and money to realize. Successful approaches and strategies must acknowledge economic realities and begin to build an environmental and business case that encourages and supports adoption of zero and near-zero emission technologies. Significant public and private investment will be critical. By providing a comprehensive assessment of emerging technologies and cleaner fuels, this heavy duty technology and fuels assessment will provide a strong technical foundation for future planning efforts including state implementation plans, scoping plan, and sustainable freight strategy, as well as regulatory, and incentive funding policy development.

This document is being released for public comment. Comments may be submitted to http://www.arb.ca.gov/msprog/tech/techreport/comments.htm

Heavy Duty Technology and Fuels Assessment
Overview and Status Update

Table of Contents

1. INTRODUCTION AND PURPOSE OF ASSESSMENT

California has made substantial progress in reducing emissions from mobile sources. Today's on-road heavy duty engines, for example, emit oxides of nitrogen (NOx) and particulate matter (PM) at levels that are 96 percent or more below those of pre-1990 engines. But further reductions are needed to meet California's air quality and climate goals, as described in ARB's 2012 Vision for Clean Air[1], and to improve public health by minimizing exposure to diesel particulate matter (diesel PM)[2]. California's air quality and climate goals include:

- Meeting ambient ozone air quality standards in 2023 and 2031, as well as PM2.5 air quality standards. Staff estimates meeting the ozone standard by 2031 will require a 90 percent reduction in NOx emissions below 2010 levels;
- Achieving an 80 percent reduction in greenhouse gas (GHG) emissions from 1990 levels by 2050;
- Up to a 50 percent reduction in petroleum use by 2030,
- At least 50 percent of electricity from renewable sources by 2030, and
- Reducing emissions of PM2.5, and minimizing near-source exposures to diesel PM and associated health risks near distribution centers, rail yards, and ports, many of which impact disadvantaged communities.

A transition to zero and near-zero emission technologies in heavy duty vehicles and equipment will be necessary to achieve these goals. Achieving this transition will require an integrated planning effort that focuses on criteria pollutants, toxic air contaminants, and GHG together. To support these planning efforts, staff is developing an assessment of technologies that may be used to power heavy-duty vehicles and equipment, and provide large emissions reductions in the heavy-duty sector. The results from this technology assessment will be used to inform ARB's Climate Change Scoping Plan, Statewide Implementation Plans, California's Sustainable Freight Strategy, the Governor's ZEV Action Plan and other climate initiatives; and will be used to help guide the deployment of incentive funding in the heavy duty sector.

This report provides an overview and status update of ARB's Heavy Duty Technology and Fuels Assessment. The report describes how the assessment is being conducted, the process for completing the assessment, and preliminary observations from staff's work to date. The report is organized by technology, and discusses prospects for each technology across different types of vehicles and equipment.

[1] Air Resources Board, *Vision for Clean Air: A Framework for Air Quality and Climate Planning,* June 27, 2012. Available at: http://www.arb.ca.gov/planning/vision/vision.htm

[2] Air Resources Board, *Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fueled Engines and Vehicles*, October 2000. Available at: http://www.arb.ca.gov/diesel/documents/rrpapp.htm

2. TECHNOLOGY ASSESSMENT APPROACH

The heavy duty technology and fuels assessment covers the following sectors:

- medium and heavy-duty trucks and buses;
- transport refrigeration units (TRUs);
- locomotives;
- ocean-going vessels;
- commercial harbor craft;
- cargo handling equipment;
- other heavy-duty off-road equipment;
- aviation sources including aircraft, ground support equipment, and shuttles; and
- conventional fuels, alternative fuels, and bio / renewable fuels.

Sector specific reports will be released for public comment in 2015 as they are completed. The individual sector reports will provide a thorough analysis of:

- the vehicles, vessels, equipment, and / or engines in each sector;
- the technologies to reduce emissions;
- the fuels that power these vehicles and equipment;
- the physical and fueling infrastructure necessary to support them; and
- well to wheels greenhouse gas emission factor analysis.

The technology assessment focuses on conventional and advanced technologies applicable to each sector including incremental improvements to conventional engines, advanced engine combustion technologies, alternative fuels, vehicle efficiency improvements, hybridization, and electrification using batteries or fuel cells. Staff conducted a literature search for each prospective technology and met with industry, interviewing people with knowledge and expertise including national laboratories, university researchers, technology experts, engine manufacturers, original equipment manufacturers, dealers, fuel suppliers, retrofit companies, electric power companies, and engineering consultants. There are seven elements to the technology assessment approach used for each sector-specific report:

1. ***Sector Description*** – A description of the sector including equipment used, rate of turnover, and air quality regulatory environment in which the equipment is operated;
2. ***Technology Description*** – A description of the technology and how it works including but not limited to fueling needs, fuel storage, and operating range;
3. ***Technology Readiness*** – An assessment of the stage of development for each technology including a description of completed or planned demonstration projects, scope of commercial introduction (number in use), and scope of current deployments (where, what types of fleets/applications);
4. ***Cost*** – An evaluation of cost at current production levels, anticipated costs at widespread development (if known), a comparison to conventional technology costs, both at current production levels and potentially widespread deployment levels, and potential returns on investment or payback period, if known;

5. ***Emissions Reductions*** – A description of per-unit emissions levels for GHG and criteria pollutants that can be achieved from the technology, including well-to-tank, tank-to-wheels, and combined well-to-wheels emissions estimates;

6. ***Technology Advantages*** – A description of the strengths of the technology; and

7. ***Key Performance Issues and Deployment Challenges*** – A discussion of technical issues that might make the technology less attractive for use and of deployment challenges that may impede deployment or become a barrier to commercialization.

Staff held three workshops in September 2014. Workshop topics are shown below.

September 2, 2014 Workshop - Trucks and Buses

- Truck & Bus Sector Description
- Engine/Powerplant Optimization & Vehicle/Trailer Efficiency
- Truck In-Use
- Lower-Emission Diesel Engines
- Lower-Emission Natural Gas and Other Alternative Fuels
- Hybrid Trucks
- Battery Electric Trucks
- Fuel Cell Trucks
- Truck Summary

September 3, 2014 Workshop - TRU, Rail, & Fuels

- Transport Refrigeration Units (TRU)
- Rail
- Fuels

September 9, 2014 Workshop - OGV, CHC, CHE, Aviation,& Summary

- Ocean Going Vessels (OGV)
- Commercial Harbor Craft (CHC)
- Cargo Handling Equipment (CHE)
- Aviation
- Technology & Fuels Assessment Summary

The heavy duty technology and fuels assessment is being conducted through a public process. Staff solicited comments after the workshops in September, as well as at the December 18, 2014 board hearing, where the technology and fuels assessment status was presented as an informational item. More than 20 letters, as well as oral and written comments were submitted from various organizations including technology providers, non-governmental organizations, and industry organizations. These comments are being carefully considered by staff, have been reflected as appropriate in this overview and status update, and will be reflected in the upcoming sector reports. The technology and fuels assessment is also being conducted with the active participation of technical staff at the South Coast Air Quality Management District (SCAQMD), and with review from the Bay Area Air Quality Management District (BAAQMD), and the San Joaquin Valley Air Pollution Control District (SJVAPCD), and other State agencies. Our goal is to ensure the results of the technology assessment are robust, reflecting the current state of technology as accurately as possible. Input from industry stakeholders, non-governmental organizations, air districts, and other State government agencies is critical to meet this goal.

3. OVERVIEW OF DIESEL ENGINES

Heavy-duty engines, which today are primarily powered by diesel fuel, are integral to the California economy. Transportation, trade, manufacturing, construction and agriculture all rely on diesel engines. These industries rely on diesel engines because they are powerful, durable, have a long range, and are easily fueled. Diesel engines last a long time, often operating for decades after they are purchased. Many of the engines do not operate exclusively in California – trucks and locomotives operate in other states, ocean going vessels and aircraft operate internationally. The California heavy-duty new engine market share as a percent of the nation is relatively small, as vehicles/equipment originally purchased outside of California are often operated, domiciled, and retired in California.

Statewide NOx emissions are shown in Figure 1. The heavy-duty mobile source categories included in this technology assessment are shown in shades of blue or white. Heavy-duty vehicles and equipment contribute a significant portion of the criteria pollutant inventories, and are responsible for about 70 percent of Statewide NOx emitted from all anthropogenic sources. Figure 2 shows California GHG emissions with added emissions associated with fuel sold in California that is burned outside of California. The GHG emissions shown in Figure 2 differ from those in the California Greenhouse Gas Emissions Inventory[3], which does not include GHG emissions generated outside of California. Staff chose the broader inclusion of GHG emissions for purposes of this technology assessment for consistency with fuel demand and well- to-wheel analyses that occur later in this document. HD vehicles and equipment are responsible for more than 15 percent of GHG emissions when fuel purchased in California and burned outside of California is considered.

[3] California Air Resources Board (2014). California Greenhouse Gas Emissions Inventory: 2000-2012. Available at http://www.arb.ca.gov/cc/inventory/pubs/reports/ghg_inventory_00-12_report.pdf. Assembly Bill 32, the California Global Warming Solutions Act of 2006, provides direction on what is included in the inventory.

Figure 1: 2012 Statewide NOx Emissions

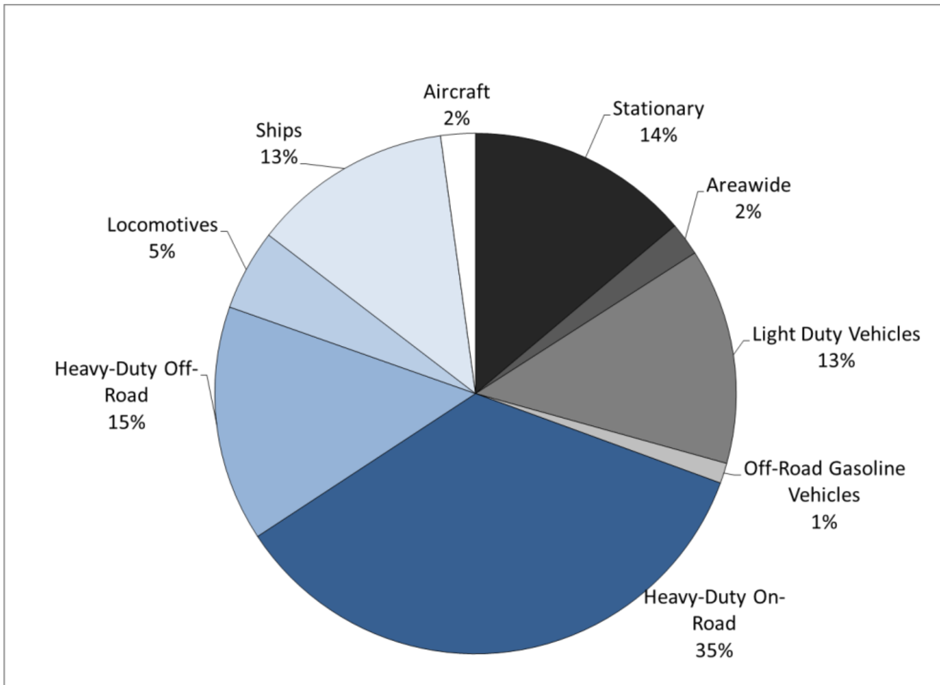
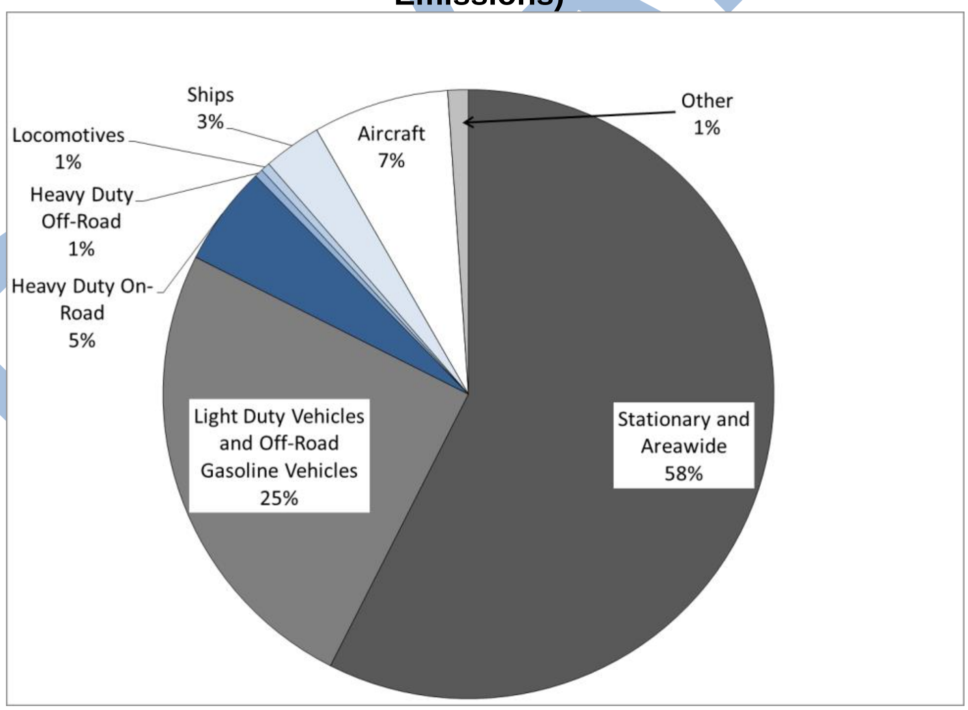


Figure 2: 2012 California Fuel Sales GHG Emissions (Included and Excluded Emissions)[4]



[4] The GHG emissions shown in Figure 2 differ from those in the California Greenhouse Gas Emissions Inventory, which does not include GHG emissions generated outside of California. This chart includes emissions associated with fuel purchased in California but burned outside of California for consistency with fuel demand and well- to- wheel analyses that occur later in this document.

The Air Resources Board (ARB) and the United States Environmental Protection Agency (U.S.EPA) regulate emissions from diesel engines. The 2010 on-road diesel engine standards provide significant (more than 90 percent) reductions in NOx and PM emissions compared to on-road engines manufactured just 10 years ago. Tier 4 standards for off-road equipment generally provide a similar magnitude of reductions. ARB also regulates transportation fuel specifications, including fuel for on-road vehicles, off-road equipment, locomotives, and marine vessels, which, for example, has enabled the use of exhaust after-treatment so engines could meet the 2010 on-road and Tier 4 off-road standards. While these standards and specifications provide major emissions reductions over time, those reductions can be slow to materialize due to slow vehicle turnover in fleets operating in California. As a result, for the past 15 years ARB has implemented in-use rules to accelerate deployment of cleaner engines.

In-use rules require diesel engines operating in California to meet performance standards through the use of alternative fuels, after-treatment retrofits, or replacement with newer vehicles and engines manufactured to modern emissions standards. ARB adopted rules applying to public fleets, solid waste collection vehicles, cargo handling equipment, commercial harbor craft, ocean-going vessels, in-use off-road diesel equipment, large spark ignited equipment, transport refrigeration units, and heavy-duty trucks. Some of these rules are fully implemented, while others like the Truck and Bus regulation continue to require emissions reductions between today and 2023. These regulations provide substantial public health improvement, reducing diesel PM along roadways, near ports and across California, and are key elements of the State's efforts to achieve ambient air quality standards statewide.

The emissions reductions provided by lower emissions standards and in-use rules are critically important and are improving air quality. However, they are not sufficient to meet air quality standards and climate goals in California, where a 90 percent reduction in NOx emissions is needed by 2031, and an additional 80 percent reduction in GHG emissions is needed by 2050. Achieving this level of additional reductions will require advanced technology in combination with renewable low carbon fuels in each sector, and accelerating deployment of zero-emission technologies is critical. Future policies that may be developed to implement the use of these technologies and fuels should carefully consider the regulatory and economic environment specific to each sector.

4. KEY PRELIMINARY OBSERVATIONS

In conducting the technology assessments and after considering comments received after the September workshops, staff has developed several observations that are guiding the development of findings in each sector and will be reflected in the sector-specific reports released later this year.

Zero Emission Vehicles / Equipment and Hybrids

- Zero emission vehicles and equipment are commercially available or in early commercialization in some heavy-duty applications
- Additional promising new zero emission heavy-duty vehicle and equipment platforms are in the concept and demonstration phase in many heavy-duty applications across multiple sectors
- Series hybrid heavy-duty applications could help to commercialize zero emission technologies, provide zero emission miles or activity in many applications, and serve as a pathway to help zero emission technologies mature in the heavy-duty sector
- Hybrid technologies can be used to reduce emissions by increasing fuel economy, and by electrifying vehicle accessories and/or operations during idle or at berth

Renewable Fuels

- Renewable fuels will be necessary to meet GHG and petroleum reduction goals and will be a critical part of an integrated solution to achieve a sustainable and renewable electrical grid and transportation system

Vehicle/Vessel/Equipment Efficiencies

- Incremental efficiency improvements to heavy-duty engines and vehicles/equipment can provide substantial GHG reductions, on the order of 40 percent or more in some sectors

Conventional Combustion Technologies

- Criteria pollutant emissions from existing and future heavy-duty engines operated in California can be reduced through improved durability, warranty, and certification requirements as well as enhanced inspection programs and improved maintenance practices designed to ensure emissions remain low in-use.
- Near-zero emission technologies are nearing commercialization, and when paired with renewable fuels could provide substantial emissions reductions

Sector and Systems Efficiencies

- Significant efficiencies can be gained by improving information sharing, automating material handling processes, and connecting vehicles to make optimum use of transportation infrastructure

Need for Coordinated Planning for Technology and Fueling Infrastructure Deployment

- Zero and near-zero emission vehicles and equipment are likely to compete for incentive funding in many sectors so refined prioritization criteria are needed
- An integrated planning approach is needed to help ensure deployment of zero and near-zero emission technologies by ensuring proper fueling infrastructure development and unlocking the potential for vehicle grid integration and power to gas technologies to support a high renewable portfolio electrical grid

- Government incentives and regulations have and are expected to continue to play a major role in accelerating technology development and commercialization
- There is a need for integrated planning for technology and fuel deployment

Each of these observations is discussed below.

a. Zero Emission Vehicles/Equipment and Hybrids

Zero emission vehicles and equipment are commercially available or in early commercialization in some heavy-duty applications

Technologies are considered commercially available when they are produced and distributed for sale. They are considered in early commercialization when the technology is commercially available, but because sales volumes are low capital costs are higher than similar conventional technologies. Technologies in the demonstration phase are being developed and tested in very small quantities. Pilot deployments represent larger scale demonstrations of more developed technologies nearing early commercialization.

Zero emission vehicles (ZEV) emit no criteria pollutant, toxic or GHG emissions at the tailpipe because they are powered by electric motors and fueled by electricity or hydrogen fuel cells. Zero emission technologies are clean, quiet, and in many cases preferred for their driving experience. In a few cases, while upfront costs are higher than similar conventional equipment, total cost of ownership has been shown to be lower due to lower operations and maintenance costs. California's light duty ZEV requirements continue to foster technology improvements in fuel cell-electric and battery electric vehicles in the light-duty sector. The light duty ZEV requirements have led directly to improvements in battery and fuel cell technology and reductions in costs that are benefitting the heavy-duty sector. Demonstrations conducted in urban transit bus fleets, for example, confirmed the viability of both battery and fuel cell electric buses in public transit and related applications like shuttles to the point that such technologies are in commercial revenue service today. These technologies benefitted from battery and fuel cell improvements driven by the light duty ZEV requirements.

Zero emission technologies are available for sale today in several applications including transit buses (both battery electric and fuel cell electric), electric aircraft ground support equipment, both battery and fuel cell electric forklifts, and some cargo handling equipment types. Examples of these vehicles are provided below. This document provides examples of different types of vehicles powered by different types of technologies, and is not designed to comprehensively identify every vehicle or equipment technology that was included in staff's assessment. In many cases there are other manufacturers, in addition to those shown, of these types vehicles, equipment, and vessels. The selected examples are for illustrative purposes only. Inclusion in this document does not constitute endorsement by ARB.

Figure 3 to the right shows a fuel cell electric bus operated by Sunline Transit. Current incremental cost for fuel cell buses over diesel is about $700,000 to $1 million; staff expects that to come down to $500,000 incremental cost at pilot scale production of 30-40 buses per year. The majority of the cost of transit buses is funded through federal subsidies. Fuel cell buses have a range of about 300 miles; fueling times are comparable to diesel.

Figure 3:
Fuel Cell Electric Transit Bus
Manufacturers: ElDorado National, Ballard, BAE Systems
Deployment Status: Early commercialization

Figures 4 and 5 below, respectively, show the Proterra and BYD battery electric buses. Current incremental capital cost over a diesel transit bus is about $400,000. Federal subsidies cover the majority of the cost for these buses. The Proterra bus has a smaller battery pack which recharges quickly but requires charging more frequently, its range is 30 miles per charge but its deployment is integrated with inductive charging systems installed on each deployed route. The BYD bus is heavier with a bigger battery pack; charging infrastructure is deployed at the bus yard for over-night charging. Its range is 150 miles per charge.

Figure 4:
Battery Electric Transit Bus
Manufacturer: Proterra
Deployment status: Early commercialization

Figure 5:
Battery Electric Transit Bus
Manufacturer: BYD Motors
Deployment Status: Early commercialization

Most of the larger airports in the state have electric ground support equipment (GSE), and several types of GSE are commercially available, including the belt loader shown in Figure 6. Electric and conventional fueled belt loaders are readily available from companies such as Tug Technologies Corporation, TLD, and Charlatte America. Figure 6 shows an electric belt loader manufactured by Tug Technologies Corporation. A typical price for this loader is about $57,000, which around $5,000 more than a conventional internal combustion belt loader.

Figure 6:
Electric Belt Loader
Manufacturer: TUG
Deployment status: Commercially Available

Figure 7:
Electric Baggage Tug
Manufacturer: TUG
Deployment Status: Commercially Available

Figure 7 shows a commercial electric baggage tug by Tug Technologies Corporation. Manufacturers of electric baggage tugs include Eagle Tugs, Tronair, Charlatte America and Tug Technologies Corporation. A typical price for an electric baggage tug is about $42,000, which is approximately $9,000 more than a conventional internal combustion baggage tug.

Figure 8:
Fuel Cell Forklift, Pallet Jack, and Stand-Up Reach Truck
Multiple manufacturers
Status: Early commercialization

Figure 8 shows fuel cell forklifts. There are about 8,000 hydrogen fuel cell electric forklifts operating in the U.S. at manufacturing facilities and warehouses distribution centers, with approximately 800 deployed in California, primarily at distribution centers. Manufacturers include Crown, Raymond, Hyster, Caterpillar, and others, with Plug Power doing the fuel cell integration. Operational advantages of fuel cell electric equipment include longer operating times than batteries, quick refueling time, longer lifetime, and improved facility space utilization. While the hydrogen fueling infrastructure cost and fuel cost are significantly higher than conventional battery operated forklifts, fuel cells can be the more cost effective option for high volume multi-shift warehouse distribution center operations where the fuel cell electric equipment offers savings in labor costs (quicker refueling versus more labor –intensive battery exchange) and facility costs (reduced facility space requirements with no need to store extra batteries as they recharge, and no loss of lifting capacity over a full shift.)

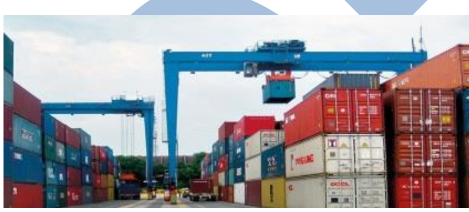


Figure 9:
Rubber Tired Gantry Crane
Multiple manufacturers
Status: Commercially Available

Figure 9 shows a grid connected rubber tired gantry crane (RTG). Electric cable reel or busbar RTGs and rail mounted gantry cranes (RMG) are a mature technology used at the automated foreign ports with the first delivered in 2002. Capital equipment costs for grid connected RTGs and RMGs are marginally higher than diesel models, on the order of 10 percent. These may equalize as the technology becomes more widely used. Retrofit of a diesel RTG to electric costs approximately $250,000.

While the upfront cost for electric and fuel cell vehicles is higher than conventional technologies, in many applications the total cost of ownership can be lower than conventional technologies because of reduced maintenance, lower fuel costs, and other operational advantages.

Additional promising new zero emission heavy-duty vehicle and equipment platforms are in the concept and demonstration phase in many heavy-duty applications across multiple sectors

Staff is assessing additional zero emission vehicle and equipment platforms in the concept, demonstration, or pilot scale deployment stage in the heavy duty sector. Examples include drayage trucks, delivery trucks, and selected types of cargo handling equipment (CHE) such as yard trucks. These technologies are limited today by cost and in some cases performance. As these technologies mature, moving from demonstrations to pilots and early commercialization, costs will decrease and performance will improve. Government policies and incentives can help accelerate technology improvement and market penetration in California heavy-duty fleets.

Figure 10:
Battery Electric Drayage Truck
Manufacturer: TransPower
Deployment Status: Demonstration

Figure 10 to the left shows TransPower's all-electric drayage truck. The current incremental cost when compared to diesel is not known since this truck is a prototype. This truck is entirely zero-emission and is currently beginning its field demonstration at the Port of Los Angeles and Long Beach. The ports are demonstrating zero emission yard trucks as well. The Ports of Los Angeles and Long Beach have been funding zero emission truck demonstration projects since 2007 and the projects have provided valuable information about how to improve technology and move toward the goal of zero emission drayage trucks that can perform in regular drayage service.

Battery electric delivery and shuttle vehicles are also commercially available, with over 100 vehicles deployed. These vehicles are well suited to regional applications, which are within their range and allow return-to-base refueling. ARB believes there are opportunities in regional applications to deploy larger numbers of zero and near-zero emission vehicles near-term.

Figure 11 to the right shows the all-electric EVI UPS delivery truck. The current incremental cost for this truck is $80-$90,000 when compared to its diesel counterpart. This commercially available truck is fully zero-emission with a range up to 90 miles on a single charge.

Figure 11:
Battery Electric Delivery Truck
Manufacturer: Electric Vehicle International (EVI)
Deployment Status: Commercially Available

Figure 12:
Electric Shuttle Bus
Technology: Electric shuttle bus
Manufacturer: Phoenix Motorcars

Figure 12 shows an electric zero-emission shuttle bus by Phoenix Motorcars. The bus is full electric drive, with a capability of driving up to 100 miles per charge. The incremental cost of this technology, as compared to a similar diesel model, is $100,000. The technology appears suitable for application in bus operations that have fixed shorter routes coupled with stop-and-go operation and more opportunity for charging.

Series hybrid heavy-duty applications could help to commercialize zero emission technologies, provide zero emission miles or activity in many applications, and serve as a pathway to help zero emission technologies mature in the heavy-duty sector

Another approach to achieving zero emissions in heavy-duty applications is the concept of zero emission miles. This can be accomplished through the use of series-hybrid vehicles with some all-electric range. A series hybrid is a vehicle or piece of equipment with an electric drive system that is powered by an on-board generator. This generator could be a diesel engine, a natural gas engine, or a turbine engine and is often referred to as a range extender. If the vehicle is equipped with batteries, the vehicle should be capable of achieving an all-electric range.

Staff's assessment shows that series hybrid applications could provide emissions benefits, support battery innovation in higher power demand heavy-duty applications and help build supply chains for zero emissions components like controllers, motors, and electricity converters. Because the vehicles are electric drive, they could help foster consumer and fleet acceptance of zero emission technologies and drivetrains. These hybrids are currently more expensive than conventional vehicles because both electrical components and engines are included in the vehicle; however, hybrids provide fuel savings which payback and could be commercialized relatively quickly. Fuel economy savings are on the order of 10 to 20 percent for mild hybrids, and from 20 to 70 percent for full hybrids. Payback periods vary significantly – from less than 5 years in some applications to more than twice as long for more expensive systems.

Figure 13:
Refuse Truck
Manufacturers: Capstone/Wrightspeed
Deployment status: Demonstration

Figure 13 to the left shows a Capstone / Wrightspeed Route truck with the powertrain incorporated into a refuse application, without the collection box. This system is a series hybrid that was retrofitted with a microturbine-electric powertrain for medium-duty fleet trucks. This project is in demonstration phase and projected costs have not been determined.

Figure 14:
Locomotive Battery Tender
Manufacturer: Proposed by Transpower
Deployment status: Concept

The locomotive battery or fuel cell tender concept could be applied to locomotives to provide zero emission track miles as shown in Figure 14 to the left. Current locomotives are powered by diesel-electric engines; the diesel engine generates electrical power that is transferred to electric motors that drive the locomotive. Current technology locomotives do not capture braking energy, and do not include batteries so they do not provide any all-electric range. A battery or fuel cell tender might be directly connected to a current technology locomotive to provide an all-electric range and to help capture energy from dynamic braking. The battery or fuel cell tender would eliminate tailpipe emissions while in use. One manufacturer suggested an all-electric range potential of up to 150 miles which could provide substantial emissions reductions. Staff sees the battery or fuel cell tender concept as an important technology to demonstrate.

Figure 15:
Electrified Catenary System, Hybrid Trucks with Pantographs
Manufacturer: Siemens
Deployment Status: Demonstration

A catenary system could also provide zero emission miles for truck or rail. Figure 15 shows Siemens catenary hybrid trucks. Catenary hybrids can operate with unlimited all-electric range when connected to the overhead catenary wires but can also operate outside of the catenary system as a fuel efficient hybrid electric vehicle when further range is needed, as in long haul trucking applications. The South Coast Air Quality Management District, along with other partners, has funded a catenary demonstration project in southern California. There should be results from this project in the 2016 timeframe. The technology readiness of the catenary hybrids is at the pilot/demonstration phase and projected costs have not been determined.

Figure 16 shows a hybrid-electric van from Via Motors. This system has pure electric range of up to 40 miles. Projected cost is currently estimated to be about $79,000, which would decrease with higher production volume. The incremental cost currently is estimated to be about $40,000 over a baseline conventional vehicle.

Figure 16:
Hybrid Electric Van with Pure Electric Range
Manufacturer: Via Motors
Deployment Status: Pilot scale deployment

Figure 17 to the right shows a plug-in hybrid truck manufactured by Odyne. The Odyne system uses a plug-in hybrid design for medium and heavy duty trucks that allows for an electric power take-off (ePTO) and has the capability to export up to 18 kW of power. This system has pure electric range of up to 40 miles. Odyne offers plug-in hybrid trucks for a variety of applications including but not limited to utility, crane, refuse, digger derrick, dump truck, and septic truck.

Figure 17:
Plug-In Hybrid Truck
Manufacturer: Odyne -
Deployment Status:
Demonstration

Figure 18:
Diesel Electric Hybrid Tugboat
Manufacturers: Foss Maritime and Aspin, Kemp and Associates Consulting
Deployment Status: Demonstration

Figure 18 to the left shows the diesel-electric hybrid tugboat, *Carolyn Dorothy,* one of three hybrid tugboats operated by Foss Maritime. The cost for the hybrid system retrofit is around $2 million. This vessel was designed to provide a zero-emission operation capability when on-board batteries are installed. The smaller auxiliary engines can also power the vessel under low load conditions, which reduces NOx compared to running the main propulsion engines.

Hybrid technologies can be used to reduce emissions by increasing fuel efficiency, and by electrifying vehicle accessories and/or operations during idle or at berth

In most vehicle and equipment applications, the propulsion engines are also used to provide climate control, power and light, or to support other auxiliary equipment even when a vehicle or equipment is not moving. Zero emission technology can be used to power these support services, and to capture waste energy from braking and equipment operation. Shore power technologies required at ports can reduce emissions from ocean-going vessels and commercial harborcraft when berthed.

Plug-in technologies can be used to provide auxiliary power for trucks or transport refrigeration units at truck stops or distribution centers. Mild hybrid systems can provide fuel economy benefits and in some cases are already commercially available in the heavy-duty sector. Alternative aircraft taxiing technologies, such as wheel tugs and taxi bots can help reduce emissions from aircraft when taxiing and could be powered with hybrid or zero emission technologies. Fuel cell auxiliary power units show promise to power auxiliary operations on aircraft. Examples of these hybrid technologies follow.

Figure 19:
Ship Shore power
Manufacturer: Multiple
Deployment Status: Early Commercialization

Figure 19 shows a container vessel that uses shore power for electricity instead of the vessel's diesel auxiliary engine. Typically, vessels use auxiliary engines to operate electric lighting, ventilation, cooling, pumps, communication, and other hoteling loads while at-berth. When connected to shore power, the auxiliary engines are shut down and the hoteling load is provided by the local electricity grid. The use of shore power results in significant reductions of harmful air contaminants, and is required in many cases by ARB regulation.

Figure 20:
Hybrid Electric TRU with All Electric Operation
All-electric plug-in battery transport refrigeration unit.
Manufacturer: Aura Systems Inc
Deployment Status: Early Commercialization

Figure 20 to the right shows an all-electric plug-in / battery Auragen transport refrigerator on a mid-sized truck. A high-efficiency alternator mounted on the truck engine charges the battery system while on the road. The system plugs into the electric grid while stationary at the distribution center. The incremental cost relative to a standard TRU is $22,500 installed, including the on-board electric power management system. While these costs are higher than a diesel-powered mechanical refrigeration system, the savings realized in fuel costs, maintenance costs, and reduced down time gives a typical payback period of two years. Range (number of hours between plug-in recharge) depends on what is being hauled (cargo space temperature set point), ambient temperatures, number of door openings, etc.; but is typically between 8 and 12 hours.

Figure 21 shows an aircraft taxiing assisted by "WheelTug". The WheelTug is installed in the nose landing gear of the aircraft to assist the pilot in moving the aircraft from the gate to the runway without the use of the aircraft's main engine(s), or tugs. The system is powered by the APU and is estimated to result in a more than 70 percent reduction in total on-ground fuel consumption, and a 75 percent reduction in NOx emissions compared to conventional taxiing. It is currently developed for narrow-body aircrafts such as the Boeing 737 and Airbus A320. The manufacturer expects to complete FAA certification around 2016. Similar technologies to reduce aircraft taxiing emissions are also being developed, such at the TaxiBot and EGTS. EGTS is installed on the main landing gear which is used to propel the aircraft during

Figure 21:
Aircraft Taxiing System
Taxi assist system, powers nose wheel off aircraft APU (jet fueled)
Manufacturer: Wheel Tug
Deployment Status: Expected 2016, awaiting FAA approval

taxiing. TaxiBot is on-ground equipment, controlled by the pilot and ground staff. It is powered by two 350 horsepower diesel engines and eight water-cooled electric motors in each wheel.

b. Renewable Fuels

Renewable fuels will be necessary to meet GHG and petroleum reduction goals and will be a critical part of an integrated solution to achieve a sustainable and renewable electrical grid and transportation system

i. Biofuel Supply Versus Demand in 2030

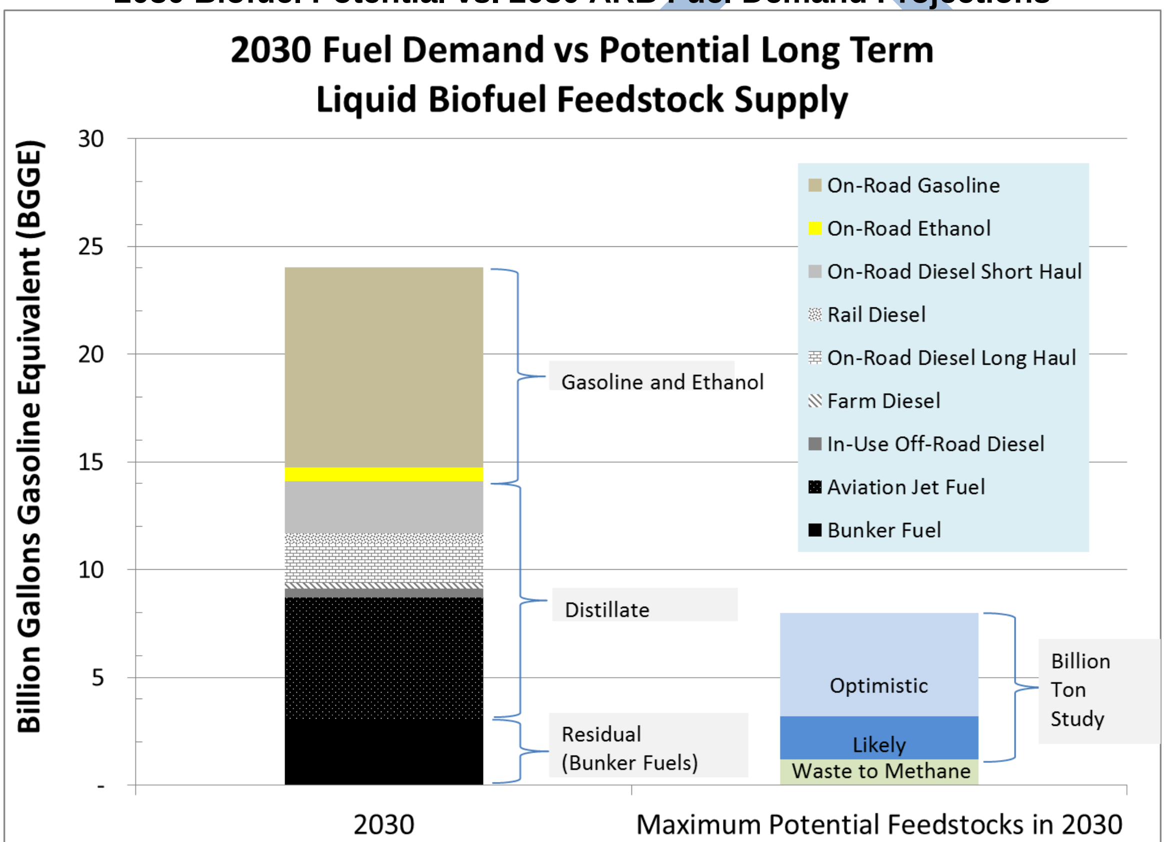
The ARB Low Carbon Fuel Standard (LCFS) is designed to foster innovation in fuels markets to develop the next generation of low carbon fuels used in California. ARB approved the LCFS regulation in 2009 to reduce GHG emissions by achieving a ten percent reduction in the carbon intensity of transportation fuels used in California by 2020. To address a lawsuit and subsequent court ruling, ARB staff brought a proposal for a new LCFS regulation to the Board for initial consideration in February 2015. The proposed LCFS regulation will contain revisions to the 2010 LCFS as well as new provisions designed to foster investments in the production of the low-CI fuels, offer additional flexibility to regulated parties, update critical technical information, simplify and streamline program operations, and enhance enforcement.

ARB is currently considering the proposed LCFS regulation and evaluating the low carbon intensity fuels that will be necessary to meet California's GHG emissions reduction targets. The technology assessment work conducted to date, as well as staff's air quality planning work confirm that renewable fuels, including renewable natural gas, renewable diesel, renewable electricity and renewable hydrogen, will be a critical part of the portfolio of technologies and fuels that will be used to meet California's GHG emission and petroleum reduction goals.

For example, three alternative drop-in jet fuels are already approved for use, and others are on the horizon, in aircraft applications. Aviation fueling standards now allow for up to a 50 percent blend of renewable jet fuel with conventional jet fuel. In another example, one of the comments we received from stakeholders during the technology assessment workshops was on the role that natural gas and other alternative-fueled vehicles and equipment could play in reducing emissions both today and in the future. Central to this discussion is the idea that renewable natural gas is an important ultra-low carbon intensity fuel that can be used in a wide variety of applications. Stakeholders have provided examples of renewable natural gas projects that can address waste disposal issues and provide renewable natural gas to power vehicles and generate electricity.

The technology assessment also found that projected biofuel supplies may not be able to supply the projected fuel demand, as shown in Figure 22. Figure 22 shows projected transportation fuel demand in California in 2030 in a business-as-usual case from ARB's emissions inventories reflecting currently adopted rules, and compares that to potential liquid biofuel supplies projected in the U.S. Department of Energy's Billion Ton Study Update[5] (with fuel apportionment to California). Because the Billion Ton Study Update does not include the biogas potential from waste diversions like municipal solid wastes and animal manure, an estimate for the bio-methane contribution from these sources is included in the Figure from a recent University of California (UC) Davis study[6]. There are significant GHG benefits from capturing and utilizing these waste methane streams, so although the volumes are not large, these projects are important.

Figure 22:
2030 Biofuel Potential vs. 2030 ARB Fuel Demand Projections



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[5] U.S. Department of Energy. 2011. *U.S. Billion-Ton Update*: *Biomass Supply for a Bioenergy and Bioproducts Industry*. R.D. Perlack and B.J. Stokes (Leads), ORNL/TM-2011/224. Oak Ridge National Laboratory, Oak Ridge, TN. 227p

[6] U.C. Davis, 2013. *Overview of Biomass.* University of California Davis, Policy Institute for Energy, Environment, and the Economy, webinar May 17, 2013. Stephen Kaffka and Colin Murphy. Available at: http://policyinstitute.ucdavis.edu/informing-policy-3/webinars/bioenergy-webinar/session-one/

Based on prior Vision modeling work and this technology assessment work, staff believes that low carbon fuels, vehicle and engine efficiency improvements, and zero emission vehicles will all be necessary to achieve California's GHG goals and the Governor's petroleum reduction goals. Low carbon fuels alone will most likely not be available in supplies large enough to service demand without major improvements in vehicle and engine efficiencies in all heavy-duty categories.

ii. Well-to-Wheels Analysis

ARB is developing Well-to-Wheel (WTW) emission factors for key sectors. WTW emission factors include not only the energy combusted to run the vehicle or equipment, but also the upstream energy used in the extraction, production, processing, and distribution of the fuel. In the case of biofuels, upstream emissions include the energy used to till, fertilize, and harvest the biomass, and to refine it into biofuel. It is useful to consider upstream emissions for GHGs, which are a global pollutant, even if they are generated outside of California and are not included in the California GHG inventory. A comparison of WTW emission factors can help identify technologies capable of achieving an 80 percent reduction in GHG emissions on a full fuel-cycle basis. It is important to note that zero emission vehicles do have a WTW emission factor, because of the upstream emissions associated with the production and distribution of electricity or hydrogen that is used to power the vehicle.

WTW emission factors are specific to each technology and fuel combination in each sector. There are many inputs to calculate WTW emission factors including but not limited to engine efficiency, vehicle efficiency, fuel type, source of fuel, and fuel distribution. Fuel-related inputs are often referred to as fuel carbon intensity. Because of variations in these factors and availability of technologies and fuels in each sector, a technology may look more favorable in one sector than another. Staff is developing WTW emission factors for important heavy duty sectors, like trucks and ocean-going vessels where these differences are important to understand and consider.

Staff analysis to date suggests substantial reductions in WTW emission factors are possible using advanced diesel and natural gas engines and vehicles, and that ZEVs where feasible can provide even greater reductions than advanced conventional technologies. However the greatest reduction in WTW emission factors can be achieved through the use of zero emission technologies operated on renewable electricity or hydrogen, and through the use of near-zero emission technologies operated on renewable fuels such as renewable natural gas or renewable diesel.

One issue that affects the WTW assessment has been the rate of methane leakage for natural gas fuels. Methane leakage is the loss, upstream of the vehicle, from the natural gas system – from production through distribution. Methane is a potent greenhouse gas. Studies indicate uncertainty in methane leakage estimates, with current estimates reducing natural gas WTW GHG emissions benefits relative to diesel. The methane leak rate currently being used is 1.08 percent of throughput, which is the default methane leak rate for North American natural gas in the Argonne GREET 2014 model. This methane leak rate reflects production, processing, transmission and storage, and distribution of natural gas. The leak rate estimate affects upstream emission calculations not only for natural gas vehicles, but also for electric vehicles (since natural gas is used to generate electricity), and fuel cell vehicles (since natural gas is a feedstock for hydrogen). Similarly, diesel vehicle analysis incorporates methane leaks at crude oil production.

More studies are underway to evaluate methane leak estimates for production, distribution, transmission, and many of these studies will be completed by the middle of 2015. Staff will review and if appropriate incorporate these studies into on-going analyses. The fuels sector report when it is released will cover the range of uncertainty and the methane leakage issue in detail.

iii. Renewable Power Generation and Storage

California's Renewable Portfolio Standard (RPS) was first adopted in 2002; subsequent amendments have established a target of achieving 33 percent renewable energy retail sales by 2020. Renewable energy sources (that are not carbon feedstock based) include solar, wind, geothermal, ocean waves / tides, and other thermal energy sources. Some of these sources provide more constant energy, like geothermal sources, while other sources, especially solar and wind (both of which are growing rapidly), provide energy periodically. This can create a mismatch between electricity supply and demand on the electrical grid as the renewable portfolio increases, and this mismatch must be managed. Zero emission technologies in the mobile source sector also represent a growing electricity demand on the grid. Some of this demand will occur during the day and some at night, depending on when vehicles are charged.

Heavy duty zero and near-zero emission technologies could play a significant role in helping to manage electricity on the grid and match supply and demand. Several technologies may be used to accomplish this goal. One technology is vehicle-grid integration. The goal of vehicle-grid integration is to create a mutually beneficial relationship between battery powered vehicles and the electrical grid by providing a two way power flow that allows vehicles to both accept a charge from the grid, and supply a charge to the grid when necessary to maintain balance between electricity supply and demand. This integration can be accomplished through market mechanisms that allow groups of aggregated vehicles to provide grid energy storage services on demand. These approaches are being tested in school buses, and in a demonstration funded by the Department of Defense at the Los Angeles Air Force Base. These mechanisms can also potentially provide a revenue stream that could offset increased capital costs of battery electric technologies. Earlier this year, the California Independent System Operator (Cal-ISO) released a vehicle-grid integration roadmap to help facilitate adoption of creative vehicle-grid integration approaches.[7]

[7] California Independent Systems Operator (CAISO), California Energy Commission, California Public Utilities Commission Joint report, December 27, 2013: *Vehicle - Grid Integration, A Vision for Zero-Emission Transportation Interconnected throughout California's Electricity System,* December 27, 2013. Available at: http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M080/K775/80775679.pdf

SB1505, adopted in 2006, requires one-third of hydrogen to be produced from renewable sources for state-funded stations now, and eventually for all stations once the annual mass of hydrogen dispensed for transportation exceeds 3,500 metric tons. Renewable hydrogen can be generated using renewable electricity to electrolyze water. This process is called power to gas, and result in the generation of renewable hydrogen without using carbon feedstocks. This hydrogen can be stored, in the natural gas pipeline or in storage vessels for later use, and can be used to fuel hydrogen fuel cell vehicles. Where carbon dioxide sources are available, hydrogen gas can be reacted to form methane. This methane can be injected into the pipeline for storage, and can also be burned in natural gas engines. Because hydrogen and methane can be stored, power to gas technologies provide a mechanism to absorb power when electricity generation is high, generating fuel for zero and near-zero heavy duty vehicles and equipment, and providing a powerful tool for managing electricity demand and supply on the electrical grid which will become much more important as use of renewable electricity expands.

iv. The Role of Renewable Fuels

Staff's analysis suggests that in order to meet climate and air quality goals, and to reduce public exposure to diesel particulate matter, zero emission equipment operating on renewable fuels (including renewable electricity and renewable hydrogen) will be needed wherever feasible. In addition, near-zero emission vehicles, equipment, and vessels operating on renewable fuels will be needed where zero emission technology is not yet feasible. Achieving deep GHG emissions reductions from these technologies will require low or no-carbon fuels including electricity, hydrogen, methane, and liquid fuels. The continued development of no-carbon fuels through power to gas technologies will be critical, as will the continued de-carbonization of the electrical grid, because carbon-based biofuels may not be available in sufficient quantities to supply the entire heavy-duty sector. Low carbon fuel use is being encouraged through the Low Carbon Fuel Standard, and developments such as recent demonstrations of alternative low carbon fuels in the aviation sector can be encouraged and built upon. Power to gas and vehicle-grid integration strategies can be part of an integrated solution to achieve a sustainable and renewable electrical grid, transportation and freight system.

c. Vehicle/Equipment/Vessel Efficiencies

Incremental efficiency improvements to heavy-duty engines and vehicles/equipment can provide substantial GHG reductions, on the order of 40 percent or more in some sectors

One of the common themes emerging from ARB's assessment of each sector is that incremental improvements to engines and vehicles are possible, which individually provide a small GHG emissions benefit, but collectively could provide substantial emissions benefits, potentially on the order of at least 40 percent GHG emissions reductions from today's levels. These benefits are generated in two areas: engines and vehicles; and apply to all vehicle and equipment types from trucks and locomotives, to ships and off-road equipment.

There are a number of engine technologies that can improve efficiency and reduce emissions. These include advanced combustion techniques, stop-start technologies, advanced transmissions, engine down-speeding, innovative fuel injection techniques, air handling improvements, waste heat recovery, cylinder deactivation, and other technologies. Hybridization can provide substantial benefits in certain applications, where the duty cycle maximizes the benefits of the hybrid's regenerative braking. Vehicle improvements such as light-weighting, aerodynamics, low-rolling resistance tires, automatic tire inflation systems, speed limiters, axle efficiency improvements, idle reduction and more efficient accessories all provide GHG emissions reductions. Most importantly, the combination of these technologies can provide a virtuous cycle, where vehicle efficiency improvements and advanced transmissions that provide substantial reductions on their own allow for engine downsizing that further reduces emissions. A brief discussion of heavy-duty trucks, ocean-going vessels, and aircraft is provided below to illustrate the potential of these improvements.

i. Heavy-Duty Truck Efficiency Improvements

ARB has developed a program for addressing heavy-duty truck GHG emissions, consisting of emissions standards and in-use programs. The program started in 2008 as an AB 32 early action when ARB adopted a new in-use regulation to reduce GHG emissions by improving the fuel efficiency of heavy-duty tractors that pull 53-foot or longer box-type trailers.

In 2011, U.S.EPA and the U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA) jointly adopted national GHG emission standards and fuel economy standards for medium- and heavy-duty engines and vehicles, informally known as the federal Phase 1 program. ARB aligned our GHG rules with the Phase 1 program in 2013, creating harmonized GHG truck standards in the United States. Once fully implemented in 2018, the Phase 1 standards will require a greater than 15 percent reduction in the CO2 emission rates for Class 8 sleeper cab trucks compared to trucks that meet 2010 emissions standards.

ARB, NHTSA, and U.S.EPA are currently working on the next phase of GHG heavy-duty truck emissions standards, called Phase 2. The Phase 2 standards are expected to take effect around 2020, to increase in stringency in the mid-2020s, and to provide substantial emissions reductions as compliant trucks are integrated into California's fleets. Sizeable further GHG reductions, on the order of an additional 13 to 25 percent relative to Phase 1, are possible.[8,9]

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[8] NHTSA, *Medium- and Heavy-Duty Fuel Efficiency Improvement Program – Final Environmental Impact Statement*, Table 3.2.3-1, June 2011.

[9] American Council for an Energy-Efficient Economy (ACEEE), "Further Fuel Efficiency Gains for Heavy-Duty Vehicles", September 25, 2013. Available at http://aceee.org/fact-sheet/heavy-duty-fuel-efficiency

To drive development of more efficient Class 8 trucks, the Department of Energy (DOE) has awarded $115 million to four teams participating in the SuperTruck Program. The DOE SuperTruck program has a goal of achieving a 50 percent improvement in freight efficiency from Class 8 long-haul tractor-trailer trucks, and as of 2013 this goal was achieved and/or exceeded by three of the four participants, as shown in Figure 23. Efficiency gains were achieved from improvements in aerodynamics, vehicle weight, rolling resistance, transmission and engine efficiencies. More recently, the Cummins team demonstrated further improvements, beyond those shown in Figure 23, on a newer Peterbilt – with a 76 percent improvement in freight efficiency (gallons/ton-mile) and a fuel economy of 10.7 mpg. These improvements were based on chassis related changes to reduce weight and reduce parasitic losses, as well engine efficiency improvements[10].

Figure 23:
Comparison of U.S. SuperTruck Targets and 2013 Status for Tractor-Trailer Freight Efficiency
(Percent increase in Freight Efficiency, miles/ton-gallon)

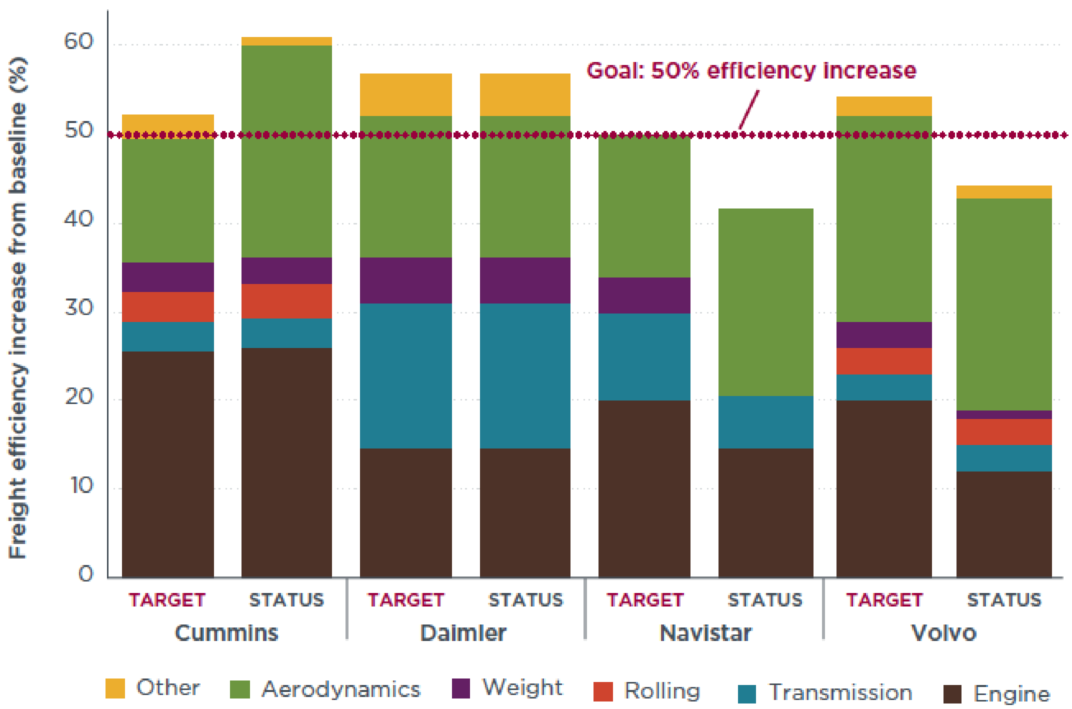

Figure 23: Note vehicle efficiencies are based on each manufacturers individual baseline and thus are not directly comparable. Taken from ICCT White Paper *"The U.S. Supertruck Program: Expediting the Development of Advanced Heavy-Duty Vehicle Efficiency Technologies"* by Oscar Delgado and Nic Lutsey. Available at: http://www.theicct.org/us-supertruck-program-expediting-development-advanced-hdv-efficiency-technologies

In addition to reducing fuel consumption, there are opportunities to lessen heavy-duty trucks' impact on climate change by using lower global warming potential (GWP)

[10] Cummins, email from David Koeberlein of Cummins Inc. to Alex Santos of ARB, January 28, 2015.

refrigerants. There may be opportunities in the Phase 2 program to incentivize use of low GWP refrigerants, which are currently available for light-duty sector.

Upon finalization of the federal Phase 2 program, ARB staff plans to bring a proposed California Phase 2 program before the Board in mid-2016. Depending on the stringency and scope of the federal Phase 2 program, there may be a need to pursue emissions reductions beyond the federal program for California to achieve its goals.

ii. Ocean-Going Vessel Efficiency Improvements

There are numerous technologies and efficiency improvements available that can reduce emissions from ocean-going vessels (OGV). These include systems for recycling heat energy, advanced designs for hull, propellers and rudders, optimization of the draft and speed for a given route and arrival time, and monitoring the fouling of hulls and propellers. Engine technologies are also an essential factor for achieving the potential benefits, and could include electronic controls that improve fuel efficiency, LNG engines, or diesel engines with SCR after-treatment.

Collaborative efforts are underway to better understand the opportunities these technologies could potentially provide. The two major OGV engine manufacturers, MAN Diesel & Turbo and Wärtsilä, have worked together since 2002 to develop new technologies for marine engines that will increase engine efficiency and reduce fuel consumption and CO2 emissions, reduce gaseous and particulate matter emissions, and increase engine reliability. This work was expected to reach completion by 2015. Another effort, the "Green Ship of the Future," is a joint effort to reduce CO2 by 30 percent, sulfur oxides (SOx) by 90 percent, and NOx by 90 percent with the focus on ship design, machinery, propulsion, operation and logistics. Today, this open private-public partnership has about 40 companies working together to identify innovative technologies and operational strategies to meet the Green Ship of the Future emission reduction targets. These efforts are being driven in part by GHG and NOx emissions requirements developed by the International Maritime Organization, but no completion date has been established to implement these voluntary efforts on a wider scale.

Finally, a more recent effort by the European Research Association, "Vessels for the Future," is focusing on ambitious emissions reduction goals for 2050. Specifically, the initiative is hoping to reduce vessel CO2 emissions by 80 percent, and NOx and SOx emissions by nearly 100 percent. This effort would be a public-private partnership composed of private companies, research institutes, academic organizations and other interested associations. The group is planning to target research in several maritime technologies: new materials and processes, fuels and propulsion systems, information and communication technology, hull water interaction, energy management and novel vessel design concepts.

iii. Aircraft Efficiency Improvements

There are aircraft, engine, and assist technologies that can reduce emissions from aircraft operations. Advanced wing and aircraft designs reduce aerodynamic drag and provide more efficient lift. Advanced airplane materials reduce weight, thereby reducing emissions and improving fuel economy. Some winglet technologies – special wing tips that reduce drag - have been applied as retrofits on the existing aircraft fleet. Several engine technologies, such as improved turbofans, open rotor engines, and advanced combustor designs all show promise for reducing emissions. Programs at U.S.EPA, Federal Aviation Administration, National Aeronautics and Space Administration, and in Europe all aim to foster reductions in noise, NOx emissions, and GHG emissions from aircraft operations. ARB and other stakeholders such as local air districts and airport authorities could work with these groups nationally and internationally on their programs, which are evaluating technology concepts that in the long-term could potentially achieve NOx emissions reductions on the order of 60-80 percent, and GHG reductions on the order of 25-50 percent, with a plan to evaluate interim progress by 2025.

d. Improved Combustion Technologies

Criteria pollutant emissions from existing and future heavy-duty engines operated in California can be reduced through improved durability, warranty, and certification requirements as well as enhanced inspection programs and improved maintenance practices designed to ensure emissions remain low in-use.

i. On-Road In-Use Emissions and Performance

Extensive certification and in-use testing demonstrates that today's diesel and natural gas engines in heavy-duty applications are the cleanest ever built. On-road trucks emit at levels that are more than 90 percent lower for PM and NOx than trucks built just ten years ago, through the use of after-treatment devices like diesel PM filters, selective catalytic reduction (SCR) devices for diesel NOx control and three-way catalysts (TWC) for natural gas NOx control. These after-treatment controls are installed worldwide on millions of vehicles on the road and equipment in-use.

Staff is evaluating in-use vehicle and emissions performance for on-road heavy heavy-duty trucks. To conduct this evaluation staff interviewed fleets, retrofit installers, equipment dealers and truckers; and is evaluating compliance data and emissions testing reports. This analysis is revealing several concerns that have implications for future planning as well as strategy and rule development in the on- and off-road sector. These results will be explained in the in-use portion of the truck sector technology assessment, and in staff's forthcoming report on diesel PM filter and engine performance.

Staff's analysis shows that not all on-road heavy-duty engine components are as durable as once thought. Warranty compliance reporting data shows that for the past ten years heavy-duty diesel and natural gas engines have experienced a high frequency of warranty claims. Interviews with fleets, retrofit installers and equipment dealers confirm these findings and suggest that excessive warranty claims represent engine component malfunctions. These malfunctions identified during the warranty period are not being fixed permanently and as a result, some fleets are experiencing significant downtime with their vehicles.

These engine component malfunctions appear to be having a secondary impact on diesel PM filter performance. When an engine component like a turbocharger or exhaust gas recirculation cooler fails, the engine can emit excess PM. This can cause a filter to regenerate more frequently and to require more frequent cleaning. Under extreme cases, the filter can be damaged and this damage can result in excess PM emissions. Recent studies conducted by ARB and ARB contractors (including NREL, UC Berkeley and the University of Denver) suggest this may be occurring. Studies suggest around eight percent of filters measured on the road may be cracked and releasing excess emissions. These studies suggest that more than 70 percent of all emissions from PM filter equipped trucks are generated by this small subset of damaged filters. Repairing these PM filters would provide substantial benefits. ARB staff is finalizing a report on engine and PM filter in-use performance that will be released in 2015, and will be identifying maintenance best practices that should serve to reduce the incidence of engine component malfunctions impact diesel PM filters. The report will propose recommendations for improving ARB's warranty reporting and certification requirements.

On-road diesel engines appear to be generating higher than expected in-use NOx emissions during low temperature, low load operations that characterize some vocational driving cycles. Many local delivery trucks, buses, and work trucks operate in these types of driving cycles. Emissions testing performed by ARB, SCAQMD and others suggests that, under these conditions, the SCR does not function effectively and does not achieve high NOx control efficiencies. Improved thermal management and NOx controls are needed to achieve further in-use emissions reductions, especially in low temperature, low load vocational driving cycles. The lack of effective NOx control at low temperatures is a limitation of current diesel SCR technologies, and the impact of engine component malfunctions on long-term in-use SCR control effectiveness is not well understood. ARB has initiated research to better understand these issues.

Natural gas engines have inherently low PM emissions and, by definition, do not emit diesel PM. Most natural gas engines certified to the 2010 standard utilize three way catalyst (TWC) technologies. Unlike similarly certified diesel engines, these current technology natural gas engines with properly operating TWC do not appear to generate higher in-use NOx. There is too little data available to make any conclusions regarding differences between identically certified natural gas and diesel engines at higher speeds that constitute the majority of Class 8 truck operations. More research is needed to evaluate natural gas and diesel engine emissions in real-world operation.

ii. Role of Near-Zero Emission Technologies

Near-zero emission technologies are nearing commercialization, and when paired with renewable fuels could provide substantial emissions reductions

Near-zero emission vehicles can play an important role in achieving emissions reductions in the coming decade. This was a major comment from multiple stakeholders during the workshop process; as a result ARB staff met with these stakeholders to obtain their perspective on this issue, and conducted additional research. For trucks, for example, on-going analysis suggest that vehicles equipped with engines that achieve a 90 percent reduction in NOx from today's levels, and powered by renewable natural gas or liquid fuels, can play an important role in reducing emissions of both criteria pollutants and GHG.

Proper engineering systems integration and the use of advanced after-treatment is the key to achieving much deeper criteria pollutant and GHG emissions control along with improved durability. Neither today's diesel nor natural gas heavy-duty engines emit at levels that are sufficiently low enough for California to meet ozone and PM2.5 air quality standards over the next fifteen years. Significantly lower heavy-duty NOx engine standards are needed for both on-road and off-road engines, in addition to the efficiency gains captured by Phase 2 (once finalized) and other off-road equipment/vessel efficiency gains.

ARB and SCAQMD have initiated programs with manufacturers and researchers to demonstrate low-emission diesel and natural gas on-road engines. Staff has identified both engine and after-treatment improvements that could be used in diesel or natural gas engines to achieve a 90 percent reduction in NOx emissions from currently certified levels. Ultimately, staff believes improvement in catalysts and other technologies will allow a 90 percent lower NOx standard to be met in both diesel and natural gas applications without impacting an engine's ability to achieve concurrent GHG emission reductions and fuel efficiency gains.

iii. On-Road Truck Optional Lower NOx Standards

Lower NOx natural gas engines, when paired with the use of renewable natural gas, could provide near-zero emissions of both criteria and greenhouse gases. Staff believes that low-NOx natural gas engines in some engine sizes, certified to an optional 0.02 g/bhp-hr standard, could be available within the next year, and low-NOx engines certified to the optional standard 0.05-0.1 g/bhp-hr range could be available as soon as 2015. Near-zero natural gas engines are likely to become available more quickly than diesel engines which may not be available for at least five years.

Some fleets are currently using conventional natural gas vehicles today. Renewable natural gas, which is also available today, is used in transportation projects in California because of the value of both California LCFS and federal Renewable Identification Number (RIN) credits under the federal Renewable Fuels Standard program. Considering these, renewable natural gas often has the added benefit of currently being cheaper for customers than pipeline natural gas for LCFS transportation uses like trucking and intrastate rail.

Despite the lower fuel cost, uptake of natural gas vehicles is slow, often due to their significant incremental capital cost. Early low-NOx engines may have a higher incremental cost than today's natural gas engines. Therefore, to expand the deployment of such cleaner vehicles, early low-NOx engines, certified to an optional standard and utilizing renewable fuel could be made eligible for larger incentive funding.

iv. On-Road Truck Required Lower NOx Standards

Optional standards may help achieve early reductions, but achieving larger reductions requires a mandatory standard for new engines. Staff believes regulatory work on a lower on-road NOx standard can begin at a national level in 2016, once the Phase 2 requirements are finalized. Staff believes that in addition to a more stringent emission standard, the standard can be enhanced to ensure adequate in-use emission performance by modifying and improving not-to-exceed requirements, providing greater authority for in-use compliance programs to recall engines based on excessive warranty claims, improving durability testing procedures for increased program effectiveness, expanding the warranty period for new engines, and continuing to improve on-board diagnostic requirements. Staff also anticipates development of enhanced inspection programs and improved maintenance practices applicable to HD on-road vehicles.

v. Off-Road In-Use Criteria Pollutant Reductions

Because some off-road duty cycles are similar to on-road duty cycles, and in many cases off-road engines are equipped with SCR and/or PM filters, we expect the observations described above would also apply to those off-road engines.

vi. Off-Road Equipment Potential Reductions

The path to near-zero is not as clear in the off-road sector. Some off-road vehicles and equipment are being certified to Tier 4 regulated levels without the use of SCR or a PM filter. This is occurring because off-road emissions standards are not uniform between horsepower categories and are not as stringent as on-road emissions standards. (The numerical limits are higher, though the test cycles are different so it is not an exact comparison). As a result, some off-road engines certified to Tier 4 levels will use only advanced EGR or SCR technologies without a PM filter. This is also the case with locomotives, which will meet locomotive Tier 4 standards that are unique to such engines without the use of SCR or PM filters.

For most off-road engines, as the engine ages, engine malfunctions are expected to eventually result in unacceptably high PM emissions. Without a PM filter it is unclear if engines that are not originally equipped with PM filters will provide a high level of PM control over their in-use lifetime and over real-world duty cycles. Today, the PM filter is the best available technology for maximum emission control. Therefore, off-road engines operating without a PM filter, albeit meeting all applicable standards, do not represent the cleanest, best available technology. The combination of SCR and PM filters provide an ability to achieve high engine efficiency and both low NOx and PM, solving the NOx-PM and NOx-GHG tradeoffs that are inherent in engines that are not after-treatment controlled. These engines also appear to be more durable than EGR and EGR-PM filter equipped engines, based on warranty claims data available in the heavy-duty on-road sector.

Staff believes there are substantial additional opportunities to realize NOx reductions, in-use PM reductions, and fuel efficiency benefits through the use of best available control technologies in the off-road sector, but capitalizing on those opportunities will require significant regulatory action at the state, federal, and even international level.

vii. Potential Reductions from Locomotives

Locomotives are a good example of an off-road technology where additional reductions are possible. Locomotives are projected to meet Tier 4 standards without the use of a PM filter or SCR technologies. The use of these aftertreatment technologies is possible but is not required under current federal regulation. Natural gas is seen as a potential alternative to diesel when diesel prices are high, but without lower emissions standards natural gas is unlikely to provide a substantial criteria pollutant or GHG benefit. Emissions benefits would depend on the criteria pollutant certification level of the engine, the efficiency of the engine, and upstream emissions associated with natural gas, including leakage. Other technologies such as battery tender or fuel cells in a tender or in a locomotive may be possible, but have not yet been demonstrated. Some technologies can capture emissions at rail yards from idling locomotives, providing emissions reductions in disadvantaged communities.

viii. Potential Reductions from Ocean-Going Vessels

Ocean-going vessels are another example. Aftertreatment is not currently used in slow speed ocean-going vessel engines because engines can meet current standards without them. Use of liquefied natural gas (LNG) in the marine sector may increase when diesel prices are high, and many manufacturers offer LNG as an option in dual fuel applications, and even as a retrofit option for existing engines. Use of LNG in dual fuel applications can reduce PM, NOx, and SOx in ECA areas, and might reduceCO_2. Further analysis is currently being conducted to determine if use of LNG in ocean-going vessel applications may provide a GHG benefit using a fuel life-cycle analysis relative to traditionally fueled ships. In LNG applications, fuel storage, delivery, and on-board tanks are issues that would need to be addressed, and lower emissions standards would be necessary to ensure NOx benefits. GHG benefits will depend on the source of methane and upstream emissions associated with production and distribution of that fuel internationally where the fuel is supplied. Other technologies such as shore power or capturing and treating emissions while at berth can reduce emissions in port communities, and in some cases these technologies are already required. Overall a mix of technologies will most likely be necessary to achieve near-zero emissions levels.

ix. National and International Standards Harmonization

As a leader in air quality, California has a long history of engaging in scientific, technical, and policy discussions with other states and countries. Our pioneering programs to reduce emissions of toxics and criteria pollutants have informed similar programs in other jurisdictions. California is continuing to work with international partners, such as China and Mexico, to encourage the adoption of the most stringent international standards, to share information on advanced technologies, and to stay abreast of technology breakthroughs worldwide. Expanding global action to fight air pollution and climate change also expands markets for clean technology – which may bolster business for those companies in California developing clean energy products. And, it helps to bring down the cost of those products globally and in California.

ARB works with U.S.EPA and with sister agencies worldwide to harmonize emissions standards for all the technology sectors, and maximize market share of vehicles/equipment/vessels sold with the cleanest technology. However, while the benefits of harmonization are important and well recognized, California must ensure it meets its legal obligations to reduce emissions to the fullest extent possible to achieve its criteria pollutant, GHG, and toxics obligations and goals. As such, it may be necessary to set California specific standards if federal or international agencies do not establish standards at a level that is sufficient for the State to meet its goals and obligations.

e. Automation, Connected Vehicles, and Intelligent Transportation Systems

Significant efficiencies can be gained by improving information sharing, automating material handling processes, and connecting vehicles to make optimum use of transportation infrastructure

Efficiencies can be achieved at three levels: the vehicle / vessel / equipment level, the sector level, and the systems level. Section 4c discussed vehicle level efficiencies. This section discusses technology-based efficiencies that may be achieved at the sector level, for example improving trips and vehicle routing. Systems level efficiencies will be further explored as part of California's Sustainable Freight Strategy development.

Sector level efficiencies can be gained through improvements in communication and in automation. Low technology approaches can generate efficiencies simply through information sharing and the development of partnerships across industry, and high technology approaches can generate efficiencies through vehicle communications and geographic positioning systems (GPS).

i. Cargo Handling Automation

Terminal automation at ports, warehouses, and distribution centers could provide improved efficiency. Terminal automation replaces manually-operated diesel-fueled CHE with automatically controlled electric or diesel-electric hybrid CHE using sophisticated software designed to more efficiently move goods from ship-to-drayage truck. Terminal automation was first introduced in 1993 at the Port of Rotterdam, which utilized automatic guided vehicles (AGV) and automated stacking cranes (ASC) together for the first time. There are now five semi-automated or fully automated terminals in Europe, six semi-automated or fully automated terminals in Asia and Australia, and two semi-automated terminals in the United States (both on the Eastern seaboard.) Two southern California port terminals are in the process of implementing automation. The Long Beach Container Terminal Inc. is in the process of becoming a fully automated terminal using all-electric CHE from ship-to-drayage. TraPac, at the Port of Los Angeles, is in the process of becoming a semi-automated terminal using a mix of electric and diesel-electric hybrid CHE. As automation is increasingly occurring at seaports, warehouses, and distribution centers ARB would like to see those applications help build a market for zero emission technologies. As existing facilities consider expansion or automation, there is potential to incorporate zero emission equipment and technologies. If automation continues to increase, there is also a need to include robust preparations for workforce training to ensure that California residents are ready to meet the more complex computer and engineering demands of the associated jobs.

ii. Truck Platooning

Platooning is one example of a technology reaching commercialization that can provide significant sector level efficiencies. Platooning is a type of cruise control technology that allows vehicles to travel closely together in formation to reduce the effects of aerodynamic drag resistance. Platooning vehicles benefit from reduced fuel consumption; overall benefits are estimated between 10 and 21 percent and differ for each truck depending on its position in the platoon. Costs associated with additional safety features and sensors are on the order of several thousand dollars. Demonstration projects on public roads are possible by 2015 with goals of full implementation within the next decade.

iii. Automated and Connected Vehicles and Intelligent Transportation Systems

In the future, vehicles are likely to communicate with each other and with roadway infrastructure. Initially this could improve safety (better collision avoidance), and lead to smoother traffic flows that increase average speeds and decrease GHG emissions on existing infrastructure. This would effectively increase the capacity of existing roadway systems. Eventually, with better vehicle/infrastructure coordination, manufacturers could take advantage of related efficiency improvements. In the off-road sector, autonomous technologies could allow more efficient operations, accomplishing more work in less time and with fewer emissions than today's operations.

California is helping to lead development and implementation of these technologies. The California Department of Transportation (Caltrans) is working with the United States Department of Transportation (U.S. DOT) and NHTSA and other members of the American Association of State Highway and Transportation Officials (AASHTO) to recommend standards, evaluate technology, and move towards infrastructure deployment. In 2014, NHTSA announced their decision consider mandating vehicle to vehicle (V2V) communications to be installed on new light duty vehicles. They are currently considering a similar decision for heavy-duty vehicles. Caltrans and the auto industry have been testing connected vehicle technologies in real world traffic on a stretch of El Camino Real (State Route 82) in Palo Alto since 2005. They are also researching truck platooning technology, which builds on prior truck development work from 2003 and 2009 projects, and intend to test it on the I-710 in Southern California or another suitable freeway corridor.

California Senate Bill 1298, adopted in 2012, required the Department of Motor Vehicles to adopt regulations for manufacturer's testing of autonomous vehicles on public roadways, and regulations for the public's operation of autonomous vehicles on public roadways. The testing regulations were adopted in September 2014. Within two months, seven manufacturers had applied for and received permits for autonomous vehicle testing in California, including Volkswagen, Mercedes Benz, Google, Delphi Automotive, Tesla, Bosch, and Nissan. These testing programs build on more than a decade of research supported by the National Highway Traffic Safety Administration, and a policy framework adopted by that agency in 2013 that provides recommendations to states like California about how to ensure safe operations as technology testing expands. The Department of Motor Vehicles is currently developing the regulations to allow the public operation of autonomous vehicles. The development of vehicle and infrastructure communication systems is going to emerge in the light duty sector before expanding into the heavy duty sector. ARB and other agencies can help to ensure that as autonomous vehicle technologies expand they focus on safety, efficiency and environmental benefits together, linking advanced zero and near-zero emission technologies with efficiencies and safety improvements that automation can bring.

f. Need for Continued Integrated Planning for Technology and Fuel Deployment

Zero and near-zero emission vehicles and equipment are likely to compete for incentive funding in many sectors so prioritization criteria are needed

Battery electric, plug-in electric hybrids, natural gas and fuel cell electric trucks are currently best suited for vocational applications in captive delivery and other types of truck fleets, because of limited fueling availability, duty cycle, and/or range of trip operational characteristics. Each of these technologies requires infrastructure, in the form of electricity, hydrogen, or natural gas, which is either not currently in place or sufficient to meet vocational needs, and will require both coordination and funding, by both public and private entities, to achieve. Incentive funding, coupled with regulatory drivers, may be necessary to send a market signal to engine manufacturers to invest in technology to achieve low-NOx emission levels. There is a natural tension between the desire for a portfolio based approach where all technologies are encouraged to compete to meet air quality and climate goals in the most economical fashion, and the limited nature of incentive funding. Prioritization is needed to help focus incentives in areas that can lead to the most efficient development and deployment of technologies in the heavy duty sector to achieve air quality and climate goals.

An integrated approach is needed to help ensure deployment of zero and near zero technologies by ensuring proper fueling infrastructure development and unlocking the potential for vehicle grid integration and power to gas technologies to support a high renewable portfolio electrical grid

In recognition of the need to balance electricity supply and demand on the electrical grid as renewable energy supplies increase, the California Public Utilities Commission in 2014 adopted a requirement for Pacific Gas and Electric, Southern California Energy, and San Diego Gas and Electric plan to procure 1.3 gigawatts of energy storage by 2020.[11] Vehicle-grid integration and power to gas technologies could help provide this storage. Under vehicle grid integration, vehicles would charge when there is excess electricity, and their batteries could feed energy back to the grid to help supply peak demand. Power to gas technologies use excess renewable electricity to generate hydrogen or methane, which could then be used in a vehicle for propulsion, or used later to generate electricity on demand. Using excess renewable energy to produce hydrogen is also referred to as "hydrogen energy storage." The expansion of storage requirements represents a start towards better coordination between the electrical grid and zero and near-zero emission vehicles. Meeting climate goals will require use of zero emission technologies coupled with renewable electricity and hydrogen. An

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[11] California Public Utilities Commission, *Decision Adopting Energy Storage Procurement Framework and Design Program*, Decision 13-10-040 October 17, 2013, Available at: http://www.cpuc.ca.gov/PUC/energy/electric/storage.htm

integrated approach that considers vehicle and grid issues together can achieve greater success than could be achieved by only focusing on fuels or vehicles individually.

Vehicle-grid integration and power to gas technologies show much promise for establishing synergies between achieving climate targets in the electricity and transportation sectors. In developing this technology assessment, the need for an integrated approach – focusing on vehicles, renewable fuels, fueling infrastructure, the electrical grid, and gas pipeline systems together is very clear. Vehicles and equipment, fuels, infrastructure, and energy are all inter-related, and likely to become much more interconnected in the future. Many independent studies conducted by non-governmental organizations have reached similar conclusions.[12,13,14] Over the past decade planning and collaborative efforts have focused on individual technologies, for example the California Fuel Cell Partnership, the California Electric Transportation Coalition, and the Natural Gas Vehicle Collaborative. Each of these groups has made important strides to develop technology and infrastructure, in both the light-duty and heavy-duty sectors. These efforts should continue, and can be coordinated across vehicle, infrastructure, and fuels technologies.

> ***Government incentives and regulations have and are expected to continue to play a major role in accelerating technology development and commercialization***

i. Regulations

Regulations play an important role in sending clear market signals and accelerating technology and fuels commercialization. For example, in 2000 ARB adopted its Transit Fleet Rule, which required large transit agencies to purchase and demonstrate zero emission buses. This program led to several effective demonstration projects that advanced zero emission buses to early commercialization. Another significant example is the light-duty ZEV requirements. This technology forcing regulation singularly led to the development of battery and fuel cell technologies around the world that are now being considered in challenging heavy-duty applications. A third example is regulations focused on achieving greater engine and vehicle efficiencies in heavy-duty trucks. Current regulations, coupled with the on-going development of new regulatory proposals, are spurring innovation that was not occurring in the absence of regulatory efforts.

Regulations on fuels also spur innovation. Federal and state fuels specifications have eliminated lead from gasoline, reduced sulfur levels in both gasoline and diesel enabling

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[12] California Independent Systems Operation (CaISO), *California Vehicle-Grid Integration (VGI) Roadmap: Enabling vehicle-based grid services,* February, 2014.
[13] National Renewable Energy Laboratory, *Energy Systems Integration Facility Report,* NREL/BR-5C00-63540, January 2015.
[14] M.J. Bradley and Associates LLC, *Electric Vehicle Grid Integration in the U.S., Europe, and China Challenges and Choices for Electricity and Transportation Policy,* report commissioned by The Regulatory Assistance Project (RAP) and the International Council on Clean Transportation (ICCT), July 2013.

advanced engine after-treatment. Similar requirements for low sulfur fuels for marine applications are helping to enable more stringent international engine emissions standards. ARB's LCFS requirement, currently under consideration for re-adoption, and the federal Renewable Fuels Standard have fostered the development of reduced carbon biofuels. California's Renewable Portfolio Standard requirements are increasing the amount of renewable electricity, and Senate Bill 1505 requires renewable hydrogen for vehicle use.

Moving forward government could play a major role in helping develop technologies and markets for zero and near-zero emissions vehicles and equipment as well as renewable fuels. Regulatory concepts include reducing certification barriers to innovative technologies, and requiring the use or purchase of zero emission technologies. These regulatory concepts, in addition to fostering technology development, would also increase the use of renewable electricity and hydrogen.

ii. Incentives

Incentives will play an important role in supporting the demonstration and commercialization of emerging zero and near-zero emission freight, rail, and other heavy-duty technologies as well as associated infrastructure and clean, renewable transportation fuels. Demonstration funding supports technology transfer from light-duty vehicles to more challenging heavy-duty applications, while attracting private capital investments in California. As technologies advance from the demonstration phase to pilot scale deployment to early commercialization, incentives help to reduce the higher initial cost that can be a barrier to market success. State incentives for hybrid and zero emission trucks and buses have resulted in deployment in California in far greater numbers than the rest of the nation. Continued incentives will increase the use of zero emission technologies and help California meet air quality and climate change goals.

The State has a number of different, but complementary, incentive programs aimed at developing and deploying advanced technologies, fuels, and infrastructure for the transportation sector. The State also provides related investments in workforce training to help ensure that California has a skilled work force necessary to support these technology advances. These programs provide a mechanism for funding the further development and deployment of the promising technologies identified in this technology assessment. As incentive funding continues to evolve the State can help focus and prioritize spending to encourage development and demonstration of innovative technologies in new applications, support pilot programs to further advance promising applications, and incent early commercialization of advanced technologies that have a remaining incremental cost that the market will not directly bear.

State and other incentive funding programs include:

- **ARB's Air Quality Improvement Program (AQIP)**, created by Assembly Bill (AB)118 (Núñez, Chapter 750, Statutes of 2007) and reauthorized by AB 8 (Perea, Chapter 401, Statutes of 2013), is an incentive program with an annual budget of $25-30 million to fund clean vehicle and equipment projects that reduce criteria pollutant and air toxic emissions, often with concurrent climate change benefits. ARB has focused AQIP investments in technology advancing projects such as that also provide immediate emission reductions, including initial deployment of hybrid and zero-emission trucks, zero-emission and plug-in hybrid passenger cars, and other advanced technology demonstrations critical to meeting California's long-term air quality and climate change goals.

- **California Energy Commission's Alternative and Renewable Fuel and Vehicle Technology Program**, also created by AB 118 (2007) and reauthorized by AB 8 (2013), provides about $100 million annually through 2024 to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. To date, the Energy Commission has awarded over $500 million for biofuel production, alternative fueling infrastructure, advanced vehicle demonstration and deployment, vehicle and component manufacturing, and workforce training.

- **Cap-and-Trade Auction Proceeds Low Carbon Transportation Investments:** The State's share of the auction proceeds generated through ARB's Cap-and-Trade Program provide a new funding source for projects that support efforts to reduce greenhouse gas emissions and accelerate the transition to low carbon freight and passenger transportation, with a priority for disadvantaged communities. The fiscal 2014-15 State budget appropriated $200 million in auction proceeds to ARB for Low Carbon Transportation projects to expand existing zero-emission car and hybrid and zero-emission truck and bus incentive programs, as well as provide incentives for the pre-commercial demonstration of advanced freight technology to move cargo in California, which will benefit communities near freight hubs.

  In 2014, the Governor signed Senate Bill (SB) 1204 (Lara, Chapter 524) which creates the California Clean Truck, Bus, and Off-Road Vehicle and Equipment Technology Program to be funded with auction proceeds appropriated by the Legislature. The goals of this program are to fund the development, demonstration, pre-commercial pilot, and early commercial deployment of zero- and near-zero emission truck, bus, and off-road equipment with priority given to projects that benefit disadvantaged communities. With its focus on moving technologies through the commercialization process, this program can help accelerate the development of promising technologies identified in this technology assessment.

- **Other ARB Incentive Programs:** Other ARB incentive programs such as the Carl Moyer Memorial Air Quality Standards Attainment Program and the Proposition 1B Goods Movement Emission Reduction Program have generally focused funds on turning over the State's legacy fleet to cleaner, commercially available technologies ahead of compliance deadlines. Additionally, each of these programs have technology advancement elements. For example, the Carl Moyer Program funds electrification of agricultural pumps and the Goods

Movement Emission Reduction Program provides funds for the electrification of cargo handling equipment, hybrid commercial harbor craft, shore power infrastructure, and electric trucks. In 2013, Assembly Bill (AB) 8, in addition to extending funding for a number of the incentive programs, directed ARB to evaluate the policies and goals of the Carl Moyer Program. In partnership with CAPCOA, it was recommended that statutory changes to the Carl Moyer Program should be developed to better increase deployment of zero emission and near-zero technologies and to realize co-benefit greenhouse gas project reductions, as well as continue to provide criteria emission reductions. Staff reported to the Board in December 2014 on the progress of these efforts and the steps needed to support recommended changes.

- **Air District Technology Advancement Programs:** In addition to these State level programs, a number of local air districts have technology advancement programs to fund the development, demonstration, and deployment of cleaner transportation technologies.

  For example, the SCAQMD has been a leader in fostering demonstration and pilot programs to introduce zero emission technologies in new applications, such as drayage trucks. SCAQMD and Department of Energy in 2012 started a joint project totaling over $9 million dollars to demonstrate zero emission trucks by Balqon, Transpower, US Hybrid, and Vision Industries Corporation. SCAQMD recently added additional funding for Transpower to demonstrate additional trucks. SCAQMD has also funded a project which will demonstrate a one-mile catenary system in the City of Carson, designed by Siemens, which will be used by series trucks with pantographs and a natural gas range extender. SCAQMD also recently announced funding for a demonstration of five fuel cell range extender drayage trucks, with varying fuel cell and battery sizes to assess different technology approaches as part of a federal Department of Energy Program.

  The San Joaquin Valley Air Pollution Control District (SVJAPCD) has funded a Class 7 electric traction with CNG microturbine over the road delivery vehicle, as well as demonstration of an all-electric TransPower yard hostler at the IKEA distribution center in Lebec. SJVAPCD has also recently announced funding for durability testing of a 0.02 g/bhp-hr NOx CNG truck engine by Cummins Westport, a fuel cell range-extended Class 8 electric over the road truck to be used in in daily service by Harris Ranch, and for a PHEV/CNG Class 4 delivery vehicle to be used by Trinity Packing in Reedley, CA.

  The Bay Area Air Quality Management District (BAAQMD) has led numerous projects to develop, demonstrate, and deploy clean transportation technologies. Among these projects is a statewide effort funded by the U.S. Department of Energy, California Fleets and Workplace Alternative Fuels Project, to identify barriers to the introduction of alternative fuels and vehicles and identify mitigation measures. BAAQMD has led the deployment of a Tier 4 switcher locomotive, demonstration of a DPF filter on a Tier 2 locomotive, and the demonstration of a wind-assisted marine vessel using carbon fiber sail technology to reduce fuel consumption and emissions. Recently, BAAQMD has been working with airlines and major Bay Area airports to replace diesel-powered ground support equipment with electric equipment. The BAAQMD continues to seek opportunities and partners to develop, demonstrate and deploy advanced technologies in the Bay Area.

- **Ports of Los Angeles and Long Beach Technology Advancement Program:** The Ports of Los Angeles and Long Beach Technology Advancement Program annually funds the demonstration of cleaner port-related technology. Past projects have included zero or near-zero emission drayage trucks, yard hostlers, cargo handling equipment, ship aftertreatment systems, and commercial harborcraft repowers.

- **Federal Funding:** There is also considerable investment in advanced transportation at the federal level. For example, the federal Department of Energy has funded the Super Truck program ($115 million)[15], and there are federal programs to spur biofuel ($181 million in 2013 from USDA)[16] and zero emission technology development ($45 million in 2013)[17].

There is a need for integrated planning for technology and fuel deployment

Deployment of zero and near-zero emission heavy-duty technology, fueling infrastructure, and renewable fuels are all inter-related and important goals. An integrated and multi-fuel planning approach is needed to ensure infrastructure is available to support newly deployed technologies, to capitalize on the benefits of vehicle-grid integration and power to gas technologies, and to assure incentive dollars are invested to provide emissions reductions consistent with the State's long term vision to achieve climate, air quality, petroleum reduction and public health goals. Developing such roadmaps on a regional basis may be beneficial, to account for inter-regional differences in how vehicles and equipment are used. These studies could help identify how to prioritize funding, and what policy levers might be used to help achieve technology and market development for zero and near-zero technologies in the heavy duty sector both statewide and on a regional-specific basis.

[15] http://www.truckinginfo.com/channel/fuel-smarts/article/story/2010/01/us-doe-shells-out-115-million-to-build-super-truck.aspx
[16] United States Department of Agriculture new release No. 0195.13, October 21, 2013, Available at: http://www.usda.gov/wps/portal/usda/usdahome?contentid=2013/10/0195.xml
[17] http://www.greencarcongress.com/2013/09/20130904-doe.html

5. PUBLIC COMMENTS

In September 2014 staff presented a status update on the technology assessments and provided an opportunity for stakeholders to comment. Staff received about 20 written comments from various organizations in response to the September workshops, and has attempted to address those comments both in this document and in the individual sector reports where applicable. This document also includes consideration of comments received at the December 18, 2014 board hearing, where the technology and fuels assessment status was presented as an informational item. Many of the comments we received are specific to the detail presented in individual sector reports, and will be addressed in those documents. Draft sector-specific reports will be released for public comment and review in 2015.

This document is being released for public comment. Comments may be submitted to: http://www.arb.ca.gov/msprog/techreport/comments.htm

6. NEXT STEPS

These technology assessments are part of a longer process to reduce criteria pollutant and GHG emissions to meet California's air quality and climate goals. Because technologies are evolving rapidly, these documents will represent a snapshot of results that will need to be periodically updated as the science changes, as new technologies are developed, and as current technologies progress. Staff will be releasing individual sector-specific reports for public comment over the next several months.

Internal combustion engines will continue to be the primary power source for the foreseeable future in heavy-duty applications. There are a myriad of engine and vehicle technologies that can reduce criteria pollutant and GHG emissions simultaneously from conventional combustion technologies. These technologies include advanced combustion, aerodynamics, hybridization, and connected vehicle technologies. These technologies should be encouraged, and where demonstrated to be effective and cost effective, could be required. Partnerships, demonstrations, incentives, and regulatory approaches can all be used to encourage the use of lower emission and more efficient technologies.

Low or no-carbon renewable fuels can provide deep GHG reductions, and their development and use should be encouraged. Renewable fuels can be used in both conventional combustion engines as well as advanced technology applications and provide immediate GHG benefits.

From ARB's air quality modeling work, staff knows that California needs more than improvements to conventional combustion technologies. California needs zero emission tailpipe vehicles and equipment. Fortunately, innovation in zero and near-zero-emission technologies is well underway. Zero emission battery electric vehicles are commercially available in airport ground support equipment, and are in early commercialization in cars, some light-heavy truck applications, and buses. Fuel cells are in the early commercialization stage for forklifts, cars, and buses. All of these applications should be encouraged. Today costs are high relative to currently commercially available technologies, but with economies of scale and continued innovation, these costs will come down. In many cases these vehicles require less maintenance, are cheaper to operate, and are more pleasant to operate than traditional heavy-duty vehicles. We are seeking policies that accelerate technology development and deployment so that costs for zero and near-zero technologies are reduced, and performance reaches parity with conventional technologies sooner than the normal cycle of technology evolution.

By providing a comprehensive assessment of currently emerging technologies and cleaner fuels, this technology and fuels assessment (overview and sector reports) provides a strong technical foundation for the development of new approaches and strategies to meet air quality and climate goals.