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Vision for Clean Air: A Framework for Air Quality and Climate Planning

Appendix:
Actions for Development, Demonstration, and Deployment of Needed Advanced Technologies

This document has been prepared by the staffs of the California Air Resources Board, the South Coast Air Quality Management District and the San Joaquin Valley Unified Air Pollution Control District. Publication does not signify that the contents reflect the views and policies of the Air Resources Board, the South Coast Air Quality Management District or the San Joaquin Valley Unified Air Pollution Control District. This document will be presented as an informational item at a noticed public meeting scheduled for June 28, 2012.

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Developing and Deploying Advanced Technologies

Vision for Clean Air has illustrated the possible types of technology and fuel transformation needed to meet both air quality standards and climate goals. The next step is developing the actions and timeframes needed to facilitate that transformation through SIP and other public planning efforts. SIP development is underway now in the South Coast and San Joaquin Valley for federal particulate matter standards. The SCAQMD is working to include early actions for accelerating penetration of advanced mobile technologies in its particulate matter SIP that would achieve remaining needed emissions reductions for ozone attainment.[1] The SCAQMD has traditionally approached its SIP planning efforts from this multi-pollutant perspective. The San Joaquin Valley is not intending to address ozone as a part of its particulate matter SIP, however a major focus of that plan is how to achieve NOx emissions reductions, which contribute to ozone reductions as well. SJVAPCD will also consider advanced technology measures in its SIP due in 2015 for the 0.075 ppm ozone standard.

The update to the California's Scoping Plan for meeting greenhouse gas reductions targets is due in 2013. For successful coordination of planning for greenhouse gases and conventional air pollutants, air agencies will need to assess the benefits of advanced technologies from both perspectives. The *Vision* scenarios illustrate that developing and deploying advanced technologies will be needed to meet both sets of goals. This appendix provides a framework for the technology assessments and decision-making that will be necessary to move quickly towards the development and deployment of cleaner technologies.

This appendix describes various advanced technologies that have the potential to be part of the transformation envisioned to meet the federal air quality standards and climate goals. All of them are in different stages of development and commercialization. Some are already on the market, while others are still maturing through demonstration programs and limited test markets. Just as the scenarios were not intended as a list of SIP-ready control measures, the technologies included here do not represent a policy choice that favors certain technologies over others. Instead they are included to provide a view of the types of technologies that could be successful in helping California meet its multi-pollutant goals. It is expected that there are technologies not included here that will ultimately be an important part of meeting the air quality standards and the State's climate goals.

[1] The approved ozone SIPs for the South Coast Air Basin and the San Joaquin Valley Air Basin include emissions reductions relying on advancement of technologies. These measures have come to be known as the "Black Box." Clean Air Act, Section 182(e)(5), authorizes regions classified as "extreme" nonattainment for the federal ozone air quality standard to rely on advancement of technologies to achieve emission reductions needed to meet federal air quality standards. However, enforceable contingency measures achieving the needed emission reductions must be submitted for inclusion in the SIP three years prior to implementation. *Id*.

The seven key concepts, described in *Vision for Clean Air,* together provide a foundation for coordinated solutions to California's air quality and climate goals. One of those concepts is that to meet federal deadlines, early actions are needed to identify candidate advanced technologies and accelerate their development and deployment. Some actions are already well underway. These include publicly funded programs to incentivize new passenger vehicle and truck purchases, demonstrate advanced technologies, and fund infrastructure investments, such as the Carl Moyer program administered by the air districts, the Clean Vehicle Rebate Project run by ARB, and the Alternative and Renewable Fuel and Vehicle Technology Program overseen by the California Energy Commission.

There are also opportunities to accelerate penetration of advanced technologies at the regional level into specific projects and uses by 2023. A basic process to evaluate, develop, demonstrate, fund, and deploy advanced technologies is outlined below. At the completion of each phase of the process is a decision point for continuing to the next phase or not with the candidate technologies.

The technology descriptions are arranged by major sector. The basic technology development and deployment process is then repeated for each sector, but revised in a way to reflect the specifics of the sector. A timeframe and actions are also included. Together, this information serves as a starting point for SIP development and other planning efforts.

While early actions to accelerate the use of advanced technologies are a critical strategy, *Vision for Clean Air* demonstrated it is only one of multiple strategies that are needed. Decisions on what advanced technologies to pursue, timeframes, and implementation mechanisms must be part of larger multi-strategy, planning efforts that consider cost, technical feasibility, trade-offs between near-term and longer-term emissions reduction potential, scalability from local and regional to statewide application, federal deadlines, and other factors. As such, the phases are for illustrative purposes and need to be tailored to individual circumstances and sectors. To do this, refinement of the actions through the SIP process and other planning efforts is the next step.

Scoping and Planning

This phase involves working with public and private stakeholders, securing funding, and scoping and planning for development of technology prototypes. There are, in general, multiple technologies that can be considered. During this step, technologies are initially analyzed to assess utility and practicality, costs, benefits, and reliability. Some technologies are more developed than others; some may have a quicker ramp-up to commercialization than others. It will be important at this point and in the subsequent phases to consider, near-term and longer-term emissions reduction potential, scalability, and developmental risk.

Prototype Development and Demonstration

This phase involves the development, design validation, and initial demonstration of prototype technologies. Important tasks involve development, design validation, and initial demonstration of advanced prototypes. The demonstrations would include technology optimization for prescribed equipment types and functions taking into consideration: 1) the compatibility of the technology options with the equipment design, activity, and duty cycle, 2) effect on operations, and 3) the costs associated with developing and implementing the technology.

Select Technologies and Conduct for Field Evaluation

Based on the outcomes of the prototype demonstrations, this phase involves deployment and assessment of performance of candidate technologies in larger-scale field tests. This provides the opportunity to compare technologies, engage in data collection and analysis, and improve design.

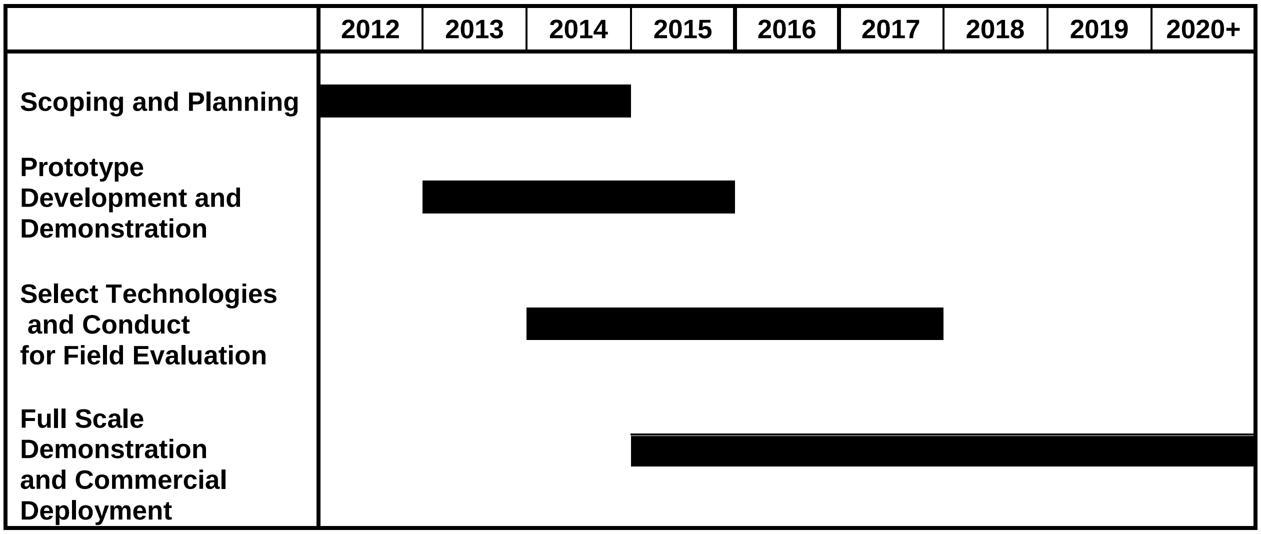
Full Scale Demonstration and Commercial Deployment

Based on the results of the prior phases, decisions would be made on what technologies are appropriate for full-scale demonstration. Once these decisions are made, the data gathered in the prior phases will also assist in commercialization, especially in designing the regulatory and market mechanisms needed to launch and expand commercialization. Such mechanisms may include incentive funding, lease agreements, environmental mitigation conditions, and regulatory SIP measures. An important part of this effort is developing needed infrastructure.

Implementing Agencies

To accomplish these steps will require the coordinated efforts of many stakeholders. The air districts provide regional goals, technical capability, planning, and incentive and regulatory actions. ARB provides unique technical expertise, regulatory authority, and a statewide planning perspective. Coordination with State energy agencies is key. Transportation planning agencies, port and airport authorities, and local governments have planning responsibilities, funding authority and resources, and can provide regional political leadership. In addition, U.S. EPA has resources and critical responsibility to set emissions standards for many types of equipment, particularly equipment involved in interstate and international commerce. Finally, the private sector, including vehicle and engine manufacturers, advanced mobile source technology developers, energy providers, and other stakeholders must be part of the process starting with initial planning. Public processes will be incorporated into these planning efforts and agency decision-making.

The timeframe for these steps will vary by source category, technology, and project. Some activities and action may be phased-in. Nevertheless, a general timeline for technology deployment in time to provide emission reductions by the 2023 federal ozone deadline would look as follows:



For some sectors where advanced technologies are closer to maturity, the timelines could be moved up. The timelines would be revised periodically depending on ongoing research and demonstrations. Regardless, scoping and planning and prototype development and demonstration must be conducted as early as possible. More specific timelines are provided for each of the sectors described below.

Passenger Vehicles

Introduction

Passenger vehicles, including cars and light duty trucks (e.g. SUVs, minivans, and pickup trucks) are the single largest source of GHG emissions in California and the second largest source of criteria emissions. Most passenger vehicles currently use traditional internal combustion engines (ICE) fueled by conventional gasoline. Nevertheless, the transition to zero and near-zero emission technologies is underway.

A critical step in that transition is the Advanced Clean Car program adopted by ARB in January 2012. Advanced Clean Cars combines the control of criteria pollutants and greenhouse gas emissions into a single coordinated package of requirements for model years 2015 through 2025. It will act as a focused technology-forcing program by requiring manufacturers to produce increasing numbers of pure ZEVs and plug-in hybrid electric vehicles in the 2018-2025 model years. In addition, the Advanced Clean Cars program includes amendments to the Clean Fuels Outlet regulation that will assure ultra-clean fuels such as hydrogen are available to meet vehicle demands brought on by these amendments to the ZEV program. Advanced Clean Cars builds on California's Low Emission Vehicle (LEV I and LEV II) program and ARB's Pavley regulations, the first regulations in the nation to require significant reductions of GHGs from motor vehicles.

Zero and Near-Zero Advanced Passenger Vehicle Technologies

Hydrogen fuel cell vehicles (FCV), battery-electric vehicles (BEV), and plug-in hybrid-electric vehicles (PHEV) with low carbon biofuels are the three most viable candidates for near-zero passenger vehicle transportation. All are included along with conventional technologies in the scenarios. The mix and amounts of the various technologies in the scenarios do not represent a specific proposed or required outcome. Rather this analysis shows all three vehicle technologies will be necessary in order to achieve the criteria emission and greenhouse gas targets, and to lessen the risk of technology or market failures. The specific mix will be a function of market forces and related technology and infrastructure development. ARB's Clean Vehicle Rebate Project – part of ARB's Air Quality Improvement Program – provides critical incentive funding for early deployment and consumer acceptance of plug-in hybrid and zero-emission passenger vehicles.

Battery electric vehicles (BEVs) run on electricity stored in batteries and have an electric motor rather than a gasoline engine. BEVs are zero emission cars because they have no internal combustion engine so they have no tailpipe exhaust and no evaporative emissions from the fuel system.

Over the years, manufacturers have developed different types of BEVs that include full function BEVs that can travel between 70 and 130 miles per full charge and neighborhood electric vehicles that can be used for short trips around town since they are speed limited to 25 miles per hour and can only go on roads with posted speed limits of 35 mph or less. Several automakers are marketing full function BEVs currently, with more expected over the next year.

Hydrogen fuel cell vehicles are zero emission vehicles that run on compressed hydrogen fed into a fuel cell "stack" that produces electricity to power the vehicle. A fuel cell is used in combination with an electric motor to drive a vehicle – quietly, powerfully, and cleanly. An individual fuel cell consists of two electrodes, one positively charged (cathode) and one negatively charged (anode), with a substance that conducts electricity (electrolyte) sandwiched between them. Oxygen from the air passes over the cathode and hydrogen over the anode, generating electricity and water.

The hydrogen fuel for a fuel cell electric vehicle can be supplied in several ways. Several automakers have demonstrated fuel cell vehicles in the last few years and two have begun to place fuel cell vehicles with customers. Automakers have announced plans to introduce commercial volumes of fuel cell vehicles around 2015. Customers had been fueling at private, fleet demonstration stations, but are now accessing retail fueling stations in growing networks located in Southern California and in the San Francisco Bay Area.

Hydrogen Internal Combustion Engine. Some vehicles with an internal combustion engine (ICE) are specially designed to run on hydrogen. While hydrogen infrastructure is still ramping up, current hydrogen ICE vehicles are designed to run on either gasoline or liquid hydrogen. Hydrogen ICE vehicles could provide a good transition to fuel cells and result in fewer smog and greenhouse gas emissions than their gasoline counterparts. Hydrogen ICE vehicles are significantly less efficient than hydrogen fuel cell vehicles. Although two automakers have demonstrated hydrogen ICE vehicles, neither has pursued bringing this technology to commercialization.

Hydrogen can be produced from many domestic feedstocks, such as natural gas (through a steam methane reformer) and renewable resources electricity electrolysis (electrolyzing water). California is working to increase use of renewable production sources.

Hybrid electric vehicles (hybrids or HEVs) combine an internal combustion engine with a battery and electric motor. This combination offers the range and refueling capabilities of a conventional vehicle, while providing improved fuel economy and lower emissions. Manufacturers continue to make more hybrid models each year.

Conventional hybrids (those that do not plug in) use battery power, an electric motor and an engine to drive the vehicle. Conventional hybrids are generally configured to make the most efficient use of the gasoline engine by boosting power with the battery and electric motor. Examples of how the electric motor is used include providing launch power from a stop allowing the gasoline engine to start up at a lower power, adding power when accelerating, and recovering energy from the system when slowing and braking. The use of the electric motor and battery improve efficiency of the vehicle. But while current generation hybrid vehicles provide potential greenhouse gas benefits, they may not necessarily result in criteria pollutant emission reductions.

Plug-in hybrids (PHEVs) are similar to conventional hybrids but they are equipped with sufficient battery energy to take the car some distance on electricity from the grid. This larger battery allows you to drive on a combination of electric and gasoline or other conventional fuel and alternative fuels. It is expected that PEHVs will offer 10 to 40 miles of all-electric range and will behave very much like battery electric vehicles until the battery is nearly depleted. Once a PHEV's battery is nearly depleted, the PHEV will behave much like a conventional hybrid with a combination of battery and gasoline engine power. Plug-in hybrids are available now with several new models coming very soon.

Two types of PHEVs will be coming to market. Both offer miles of electric driving with electric motors powered by large battery packs charged by plugging into a source of electricity. One PHEV type operates only on battery power until the engine is needed to provide energy to the batteries. The other PHEV type operates on a mix of battery and engine power. Both PHEVs provide all-electric range as well as improved fuel economy over conventional vehicles.

Ethanol flexible fuel vehicles (FFVs) are capable of operating on gasoline, E85 (85 percent ethanol, 15 percent gasoline), or a mixture of both. Ethanol is an alcohol made primarily from corn. Because ethanol is derived from feedstock that is grown, it is considered a renewable fuel. In addition, since the feedstock for ethanol can be domestically produced, it reduces the nation's dependence on foreign oil. There is a wide variety of FFV's available for consumers with more coming as the number of fueling stations begins to grow.

Transit and School Buses

Introduction

Transit Buses - The transit bus system represents approximately 8,700 miles of bus routes in the South Coast Air Basin. Approximately 4,900 transit buses serve the 8,700 miles of bus routes within the Basin. Transit buses are defined as a passenger-carrying vehicle with a gross vehicle weight of at least 33,000 pounds, with a load capacity of 15 or more passengers and intended primarily for intra-city operation, i.e., within the confines of a city or greater metropolitan area. Transit bus operation is characterized by short rides and frequent stops.

It is estimated that over 85 percent of the transit buses operating in the South Coast Air Basin are operated on dedicated compressed natural gas. The remaining transit buses have been identified to operate on either diesel or other advanced technologies such as gasoline-or diesel-hybrid electric, liquefied propane gas or fully electric. Over half of the total transit bus population is operated by the Los Angeles County Metropolitan Transportation Authority, the largest transit bus agency in the South California Air Basin. More than 10 percent of the buses are operated by the Orange County Transportation Authority, and over 5 percent are deployed by Foothill Transit which serves over twenty cities in the San Gabriel Valley. The remaining transit bus agencies and cities each account for less than 5 percent of the transit bus operations. The extensive use of compressed natural gas buses and other advanced technologies is largely due to applicable rules/ regulations requiring lower emission transit buses along with the availability of funding provided through the Federal Transit Administration as well as incentive funding provided by the state and other local funding sources.

School Buses - It is estimated that there are about 10,000 school buses operating in the South Coast Air Basin. Although there are significantly more school buses in operation than transit buses, the annual emissions from transit buses are greater than those from school buses largely due to a greater daily vehicle miles traveled accumulated on transit buses. School buses are used for the express purpose of transporting students through grade 12 from home to school and are capable of transporting 10 to 72 passengers. Most school buses within the basin are diesel-powered. However, over 1,400 school buses operate on clean natural gas (CNG) in the Basin with those being mostly the larger type of school buses, Types C and D. Approximately 500 of the smaller school buses (Type A) operate on gasoline and several hundred of the Type C buses operate on propane. Approximately half the school bus population is operated by public school districts and the remaining school buses are operated by private school bus service providers. First Student, a private school bus service provider, is the largest operator of school buses in the Basin, supplying about 40 percent of the school buses. The Los Angeles Unified School District operates the second-most number of buses in the basin, approximately 13 percent.

Using state, federal and its own matching funds, the South Coast Air Quality Management District has provided substantial incentives to public school districts to purchase new CNG buses and CNG refueling stations. In addition it has provided incentive funding for the legacy diesel school buses for purposes of add-on retrofit devices to reduce diesel particulate matter emissions.

Zero and Near-Zero Advanced Transit and School Bus Technologies

Hydrogen fuel cell, battery-electric, trolley/catenary electric and alternative fuel with low carbon biofuels are the most viable candidates for near-zero transit/school buses. The technologies are discussed further.

Battery-Electric Buses operate continuously in zero-emissions mode by using electricity from the grid stored on the vehicle in battery packs. In the South Coast region, Foothill Transit is currently operating several quick-charge electric transit buses equipped with lithium titanate batteries. These buses have a range of about 30 miles and can charge in less than ten minutes. The in-route fast charging capability enables these buses to remain in service throughout the day without having to leave the route to be charged before returning to service. Quick charging can be performed while passengers are entering and exiting the buses. In addition 27 battery-electric buses operating in Santa Barbara's Metropolitan Transit District have logged more than one million miles.

A production model Type C electric school bus manufactured by TransTech is also being operated by the Kings Canyon Unified School District in the Central Valley of California. The bus is designed to hold up to 52 passengers and has a range of 80-130 miles, and the lithium-ion batteries recharge in 6 to 8 hours. These parameters are well-suited for the demands of typical school bus routes. ARB's AQIP Advanced Technology Demonstration Program has funded two additional battery-electric TransTech eTrans school buses for use by Kings Canyon Unified School District. Most recently the company manufacturing these school buses applied to the Mobile Source Review Reduction Committee (MSRC) to be placed on the approved vendor list for eligible school buses to participate in the MSRC school bus program in the South Coast region. The AQIP Advanced Technology Demonstration Program is funding an additional battery-electric school bus demonstration focused on the manufacture and field demonstration of a large battery-electric Type-D school bus to be shared among participating San Diego County school districts.

Fuel Cell Battery-Electric Buses use an electrochemical reaction of hydrogen and oxygen in on-board fuel cell stacks to generate electricity onboard a vehicle to power electric motors. Fuel cells are commonly combined with battery packs and regenerative braking to extend the operating range of a battery-electric vehicle. These buses typically have a range of about 300 miles and hydrogen refueling is fast, taking only 5 to 10 minutes. In 2010, over 50 hydrogen fuel cell buses shuttled athletes and governmental officials during the Olympic Games in Guangzhou City, China. A 12-bus demonstration program is currently underway in the Bay Area for hydrogen fuel cell transit buses. In the South Coast region, Sunline Transit, which provides service in the Coachella Valley, is also operating three hydrogen fuel cell buses and having two additional buses built for Sunline Transit. A hydrogen fuel cell transit bus will also be deployed in the near future at the San Francisco International Airport. There are also hydrogen fuel cell transit buses operating in other states, Canada, Europe, Korea, and Australia. The expansion of hydrogen refueling stations is a critical component for extensive deployment of fuel cell battery-electric vehicles.

All-Electric Range Hybrid Electric Buses utilize a combination of conventional-fueled or alternative fueled internal combustion engine with an electric motor and are designed to operate exclusively in electric mode for certain distances. While not yet available for bus applications, all-electric range hybrid trucks are currently being demonstrated. For example, Meritor has developed a heavy-duty hybrid electric truck with all-electric range, which is being demonstrated by Walmart, Inc. in the Detroit area. This vehicle can operate at zero-emissions for 20 miles at speeds less than 48 mph, which presents a good fit for many bus applications. If such operation is coupled with quick-charge plug-in charging capability, it would open the potential for 24-hr zero emission operation, depending on the specific needs of the vehicle operation. More recently, the South Coast Air Quality Management District and the Southern California Gas Company are exploring potential compressed natural gas/hybrid systems for transit bus applications.

Trolley and Overhead Catenary Electric Buses have been in operation for many years, going back prior to World War II. These buses operate without a track and draw electric power from suspended electrical wires. Trolley buses use less wires than catenary buses and are typically best suited for lower speeds, such as those used in cities (i.e. San Francisco). The overhead electrical lines, whether in a trolley or catenary configuration allows curbside loading which is not possible for rail car whose tracks are laid in the center of the road. Technological advances provide variations to conventional trolley and catenary electric operation. Many cities currently operate “dual-mode” transit buses that can operate in electric mode using the overhead wires, but have the capability to disconnect from the overhead wires and operate as conventional buses. In Boston and other cities, such buses operate “off wire” through diesel engines. Rome is using a dual-mode electric and battery-electric transit bus with a detachable overhead wire connection. The batteries are charged as the bus operates on the wired roadway.

Lower NOx Buses - Presently, on-road heavy-duty engines (for both buses and trucks) are certified at NOx levels of less than 0.2 grams per brake horsepower-hour. Discussions are underway to develop heavy-duty truck engines certified at levels that are at least 80 percent lower than the current exhaust emissions standard. Such reductions could be achieved through further refinement of existing fuel management, in-cylinder, enhanced aftertreatment control, vehicle hybridization, and other technologies.

Actions

As mentioned above, there are on-going efforts to develop zero-emission transit buses as part of the statewide Transit Bus Regulation. Additional demonstration programs must be identified to field test these technologies.

On-Road Heavy-Duty Vehicles

Introduction

The State's current programs and regulations are designed to ensure that the overwhelming majority of trucks that will be operating in California's in 2023 will meet today's cleanest emissions standards. Nevertheless, based on the *Vision for Clean Air* scenario analyses, additional clean-up of conventional technology will be needed along with the use of advanced zero- and near-zero truck technologies. The approaching 2023 deadline means that development and deployment of some zero- and near-zero technologies must begin now in order to provide reduction by the deadline even as additional clean-up of conventional technology is being pursued.

Potential Zero-Emissions Technologies

Zero- and near-zero emission truck technologies include battery-electric trucks, fuel cell trucks, dual-mode (hybrid) electric trucks with all-electric range and, potentially, other technologies. Battery-electric trucks are established in smaller trucks and in a variety of different vocations. Fuel cell trucks – either with a small battery pack or with the fuel cell as a range extender with a larger battery pack -- have been demonstrated in other categories and are seeing significant progress in both light and heavy-duty applications. The Hybrid Truck and Bus Voucher Incentive Project provides funding for zero-emission trucks that typically operate in urban, stop-and-go duty cycles. These technologies provide a critical bridge for the more advanced technologies needed.

All-Electric Range Hybrid Electric Vehicles utilize a combination of conventional-fueled or alternative fueled internal combustion engine with an electric motor and are designed to operate exclusively in electric mode for certain distances. All-electric range hybrids are currently being demonstrated. For example, Meritor has developed a heavy-duty hybrid electric truck with all-electric range, which is being demonstrated by Walmart, Inc. in the Detroit area. This vehicle can operate at zero-emissions for 20 miles at speeds less than 48 mph. If such operation is coupled with quick-charge plug-in charging capability, it would open the potential for 24-hr zero emission operation, depending on the specific needs of the vehicle operation. Finally, if trucks with significantly lower NOx emissions than current technology (e.g., at least 80 percent lower) became available sooner than 2023, they could also be the focus of early actions to reduce NOx.

Dual-mode trucks could have sufficient battery power to operate in electric-only mode, but would also have a source of power (e.g., internal combustion engine running on diesel, natural gas, hydrogen, or other fuel) that provides flexibility for longer routes. The terminology of dual-mode is being used here to signify a truck with a distinct all-electric range as opposed to most current hybrids which use a battery and electric motor to augment an internal combustion engine.

Wayside power technologies include overhead catenary and in-road power such as third rail or linear synchronous motor (LSM). In addition, fast charging could be used to quickly charge batteries. All these technologies must be integrated closely with the zero emission trucks, and all have the potential to significantly increase the functionality and range of trucks utilizing batteries, including dual mode-hybrids. In overhead catenary systems, power is delivered from the electrical grid through the overhead wire to a pantograph on the vehicle. Catenary systems are well-established and efficient in light-rail applications, trolley cars and buses, and large mining trucks. Siemens is developing a prototype hybrid electric truck in Germany. The truck operates with zero emissions when operated with the overhead catenary. The truck automatically senses the wire which allows the driver to raise the pantograph connection while driving at highway speeds. The pantograph automatically retracts when the truck leaves the lane with catenary power. The powered lane can be shared by cars and traditional trucks.

For in-road power, the roadway itself provides power to the vehicles, which must be equipped with pick-up devices. In one technology, cables/wires embedded in the roadway carry electric power; in another technology, LSMs provide power by interacting with a permanent magnet on the vehicle. In-road power systems have advantages but the technology is currently less developed than catenary. Fast-charging is a high-power charging system used to quickly recharge the batteries in an electric vehicle at destination points, e.g., railyards or distribution centers. While technically not "wayside" power, fast charging is similarly grouped with other approaches that require infrastructure to be designed and built into or in close proximity to the freight facilities and corridors.

Zero-emission truck prototype testing is underway. For example, with support from the Port of Los Angeles and the South Coast District, a demonstration of the Balqon battery electric truck has been initiated, as has testing of a truck made for drayage by Vision Motor Corporation, using a combination of lithium-ion batteries and fuel cells.

Potential Projects in the South Coast

Southern California has long been a goods movement hub, and a significant amount of work has already been done to assess current and future goods movement volumes, to explore the range of technologies under consideration, to evaluate user needs and potential markets, to analyze current and projected transportation corridors and select the highest priority corridors, and to develop and test vehicle prototypes.

Over the last five years, studies have assessed the transportation corridors carrying high volumes of freight truck traffic and likely to be most impacted by traffic and pollution in the future. The I-710 corridor was selected as high priority for introduction of zero-emission technology. The 2012 Regional Transportation Plan also designates a route along State Route 60 as an east-west freight corridor.

In the near term, it is anticipated that several major regional infrastructure projects will be considered for approval. These include the I-710 freight corridor project, the BNSF

Southern California International Gateway railyard project, and the Union Pacific Intermodal Container Transfer Facility modernization and expansion project. These proposed projects will, if approved, comprise key portions of regional freight infrastructure for many decades to come. The action to approve such projects will be a key opportunity to establish appropriate operating and environmental requirements for the infrastructure. In some cases, the project approval action may be the only opportunity to establish requirements. It is therefore important that such project approvals be fashioned to assure that the projects participate in the technology development and demonstration activities for trucks described below, and that the project approvals ensure implementation of resulting technologies when determined to be feasible.

The case of container transport between the San Pedro Bay ports and near-dock railyard facilities is unique. Such transport presents fewer technical and other issues compared to regional transport due to the relatively short distances involved — about five miles. In addition, as described in the Roadmap for Moving Forward with Zero Emission Technologies at the Ports of Long Beach and Los Angeles, the ports have already done considerable work to evaluate and develop truck technologies for this service, and battery and fuel cell hybrid vehicles are now being demonstrated. This corridor would also be a good location to initially demonstrate wayside power technology that ultimately could be deployed for longer range regional transport. Finally, the total number of trucks needed for this service is limited compared to the thousands of vehicles needed for regional service.

Potential Projects in the San Joaquin Valley

Freight transport in the San Joaquin Valley is characterized by interregional movement along the twin Interstate 5 and State Route 99 corridors. Given the long distances trucks move along these two systems, it is more difficult to realize the types of early technology deployment than could be possible in the South Coast. In the longer-term, technology development in the context of the South Coast will provide information and experience for action in the San Joaquin Valley. Planning and technology efforts in the South Coast will need to consider potential for use outside the South Coast Air basin.

In the interim, the SJVAPCD has considered ways to increase system efficiency through mode shift such as short sea shipping/marine highways. The M-580 Marine Highway Project is already operational, shipping containers between the Port of Stockton and Port of Oakland. For the future, the SJVAPCD has considered the development of a Marine Highway along the West Coast. This would reduce truck traffic and their associated emissions from the major traffic corridors in the Valley.

Near-term actions to develop, demonstrate, and deploy needed technologies

The actions and timeline below describe a path to evaluate, develop, demonstrate, fund, and deploy technologies for on-road heavy-duty vehicles in the South Coast. They are generally consistent with the actions to develop a regional zero- and near-zero-emission freight system described in the 2012 update to the Regional Transportation Plan adopted by the Southern California Association of Governments. Multiple technologies would need to be considered, and each analyzed to assess utility and practicality, costs, benefits, and reliability. Some technologies are more developed than others; some may have a quicker ramp-up to commercialization than others.

Fundamental to the actions and timeline are evaluations and determinations regarding the infrastructure needed to support deployment of specific zero- and near-zero emission technologies. One key question is whether electric-trucks will be able to operate fully under their own power with zero-emissions, or whether they will require some form of “wayside” electric or magnetic power built into or near the roadway infrastructure to boost capability or range. This may include battery charging or, or transportation infrastructure such as dedicated truck lanes. Such lanes can provide opportunities to provide wayside electric power to trucks, much as power is now provided to electric transit buses in San Francisco and other cities. If battery, fuel cell, or other zero/near-zero emission technologies strategies are selected, the need for wayside power may be reduced or eliminated and other infrastructure requirements would need to be addressed.

Phase 1: Project Scoping and Existing Work

Continue to build on current regional research and technology testing efforts.

Phase 2: Evaluation, development, and prototype testing

Convene working groups and increase understanding of operational needs. Evaluate, develop, and test prototype trucks and infrastructure options such as wayside power. Work with public and private-sector partners to secure funding commitments for the development of new technology prototypes and demonstrations. Evaluation in this phase will address technology readiness, operational feasibility and funding availability.

As noted above, the case of container transport between the San Pedro Bay ports and near-dock railyard facilities is unique. Such transport presents fewer technical and other issues compared to regional transport due to the relatively short distances involved and other factors. The truck technologies being developed and demonstrated for container transport between the ports and near-dock railyards could form the basis of technologies used in the region as a whole. For example, development of trucks capable of operating on electric power, even for relatively short distances, could potentially be coupled with wayside power to extend zero-emission range farther through the region.

The current effort to develop and demonstrate zero-emission truck technologies for the port to near-dock railyard application thus should be viewed as an important initial part of the effort to develop regional zero-emission transport. For these reasons, the timeframes for action come earlier for technology implementation between the ports and near-dock railyards than for the region as a whole, soon as practicable but no later than 2020. The timeframes for regional zero-emission truck technology deployment in the South Coast extend from 2017 to beyond 2021, depending on infrastructure needs.

Phase 3: Initial deployment and operational demonstration

Port to Near Dock Railyards Demonstration: Develop and build trucks and infrastructure sufficient for demonstration within the transport corridor consisting of the Terminal Island Freeway and connecting routes to the Ports (or alternative routes serving the same locations); commence demonstration upon completion of trucks and infrastructure. The SCAQMD is currently leading an effort to secure $10 million from the U.S. Department of Energy to provide the bulk of the funding needed for this project.

Truck Fleet Evaluation Testing. Develop, deploy and assess, with local fleet users, multiple vehicles with on-going data collection, analysis and sharing for rapid iterative design improvement.

Phase 4: Full scale demonstrations, commercial deployment and infrastructure construction

Phases 1-3 are designed to bring potential truck technologies and needed infrastructure to the beginning of commercial deployment. Based on the outcomes of Phases 1-3 and related planning efforts, a selection of truck technologies and their needed infrastructure for Phase 4 deployment would be made. In addition, the results of the first three phases would be used to determine the concrete commercialization steps needed in Phase 4, including potential regulatory and market mechanisms needed to launch and expand commercialization. Finally, this phase would include expanding plans for any needed wayside power infrastructure to additional high priority corridors (e.g., priority East-West corridor route identified in the 2012 RTP). The timing for this would be highly dependent on the need for wayside power if needed and the infrastructure construction.

Initial Operational Deployment (2015): As described in the Goods Movement Appendix of the Southern California Association of Governments (SCAG) Regional Transportation Plan 2012-2035, build wayside power infrastructure sufficient for operation on the Terminal Island Freeway and connecting routes to the Ports (or alternative routes serving the same locations), and build maximum number of trucks for initial operational deployment allowed by available funding (with all feasible leveraging of private resources), unless a zero-emission technology not utilizing wayside power is determined to be superior and can be implemented in a similar or earlier timeframe. In the latter case, remaining funds allocated to this project will be applied to demonstration and deployment of zero-emission trucks not utilizing wayside power.

The following table illustrates implementation actions and timeframes that agencies including local air districts, ARB, and local metropolitan planning organizations, as well as private stakeholders, could pursue to deploy zero- and near-zero emission trucks. The timelines may change as research and demonstrations are conducted.

Year(s)	Timeline of Needed Actions
2012-2014	Continue to evaluate potential truck technologies and implementation and funding mechanisms. Begin initial deployment and field testing of potential technologies.
2015-2016	Evaluate technology performance based on field testing and determine need for power infrastructure for trucks on major freight movement corridors. Through public planning processes, including SIPs and fiscally-constrained RTPs, make and reflect decisions on what technology to develop further, funding, and implementation mechanisms, including: • Strategy description and timeframe for potential regulatory actions • Strategy description, potential funding sources and timeframe for needed incentives Begin initial deployment of zero- and near-zero emission trucks for regional service identified through public planning processes and decision-making.
2017+	• Begin implementation of multiple strategies (zero- and near-zero trucks, lower NOx, efficiencies, etc.) for substantially all regional transport. • 2020 – Target for full deployment of zero-emission trucks transporting containers between the ports and near-dock railyard facilities.

Freight and Passenger Locomotives

Introduction

While critical authority rests with the federal government to set standards for new locomotives, important steps can be taken by California to ensure a cleaner locomotive fleet operating in the State. In 1998, a MOU was developed with the railroad companies that has resulted in the use of cleaner locomotives in the South Coast Air Basin. The 2012 South Coast Air Quality Management Plan is expected to propose that at least 95 percent of locomotives operating in the South Coast be Tier 4, necessary for attainment of the ozone standard by 2023. Significant emissions from locomotives also occur in the San Joaquin Valley. As for trucks, the valley is characterized as a transport corridor and a transport hub like the South Coast Air basin. Consequently, the logistics for locomotive clean up in the Valley can be more challenging. Nevertheless, strategies pioneered in the South Coast can have potential application more broadly.

Potential Zero-Emissions Technologies

At this time, several broad technology categories have gained the most focus and could be applied toward freight and passenger locomotives to achieve zero-emission track miles: overhead catenary (with electric or dual-mode locomotives), battery-hybrid systems (either integrated into a new locomotive or as a tender car), and linear synchronous motor (LSM) technology. Another technology with potential for zero emissions is fuel cells. In addition, the use of alternative fuels such as liquefied natural gas (LNG) have a potential role in reducing emissions further prior to commercialization of zero-emission systems and as a primary fuel in conjunction with battery-hybrid technologies.

Of these technologies, catenary systems are the most extensively used today, although commonly in passenger train and light-rail applications. Electric freight locomotives are used in many countries around the world, but electric locomotives would need to be engineered for use with trains of the size and length operated in the United States. An issue that would have to be addressed with catenary systems is how the transition would be made to non-electrified portions of the interstate rail network (e.g., would electric locomotives have to be added to trains when entering the South Coast Air Basin). Dual mode (i.e., combined diesel-electric and electric capable) locomotives with wayside power have the potential for zero-emission range capability within catenary system areas, and have the ability to minimize operational changes, but have not been developed or demonstrated in a freight application due to insufficient market case or regulatory impetus. LSM systems are less developed, but have potential in terms of being able to use existing rail beds and conventional rail cars, with modifications.

General Electric (GE) has indicated that Tier 4 diesel-electric locomotives could be augmented with advanced battery technology to allow periodic zero-emission operation. GE indicated that the goal would be for the batteries to be able to provide full power for a line-haul locomotive for up to 30 miles with no emissions from the locomotive engine, operate in the Tier 4 diesel-electric mode for up to 70 miles while also recharging the battery bank, and then return back to the battery mode for the next 30 miles. The fuel savings would allow a one-third downsizing of the fuel storage tank to be able to provide additional space for battery storage within a conventional length locomotive. This approach would allow the battery mode to be engaged up to twice while operating within the South Coast Air Basin. Under this scenario, the GE hybrid locomotive could provide up to a 60 percent reduction beyond Tier 4 emissions levels within the Basin.

Another option is the use of battery tender cars connected to locomotives to provide power within urban areas. Such a system could provide zero-emission operation with either new or existing locomotives, and would reduce or eliminate the need for wayside power. Tender cars could also potentially be designed to connect existing locomotives to wayside power. The operational impacts of tender car augmentations, the duty cycle and power demands of line haul locomotives, and the power, weight, and costs of battery tender cars – while operating within the South Coast Air Basin – would need to be studied further. However, the potential benefits can be significant since the battery tender car could potentially be used in any urban area and recharged as the train transits from the South Coast Air Basin to its destination. In addition, the use of tender cars addresses the concerns regarding sufficient space for the batteries if they are installed inside the locomotive and capacity and number of batteries needed will not be limited to the dimensions of the locomotive, but to the capacity and dimension of the rail car.

All of these systems and approaches (with the exception of traditional catenary-electric locomotives) will need additional study, research, design, proof of concept testing, and both small and full scale demonstration programs to advance the technology for freight and passenger applications within Southern California. All will need additional examination of means to address operational impacts and costs.

Significant effort has gone into analyzing the options for a zero-emission rail system in the South Coast Air Basin. These include recent efforts by the Ports of Long Beach and Los Angeles in their *Roadmap* study[2] and by SCAG in the freight rail electrification report[3]. Each of these efforts highlights the technical opportunities and the need to pursue a zero-emission freight transport system for the future. However, they also highlight the difficult challenges associated with this sector, especially with regard to operational needs, integration of the technologies into the national rail system, federal safety requirements, and cost.

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[2] Port of Long Beach and Port of Los Angeles, Roadmap for Moving forward with Zero Emission Technologies at the Ports of Long Beach and Los Angeles, Technical Report, August 2011.

[3] Southern California Association of Governments. *Task 8.2 Analysis of Freight Rail Electrification in the SCAG Region*, Technical Memorandum. Draft Version, Prepared by Cambridge Systematics, August 26, 2011.

Near term actions to develop, demonstrate, and deploy needed technologies

The actions and timeline below describe a path to evaluate, develop, demonstrate, fund and deploy advanced technologies locomotive initially in the South Coast. They are generally consistent with the actions to develop a regional zero- and near-zero-emission freight system described in the 2012 Regional Transportation Plan adopted by the Southern California Association of Governments. Multiple technologies would need to be considered, and each analyzed to assess utility and practicality, costs, benefits, and reliability. Some technologies are more developed than others; some may have a quicker ramp-up to commercialization than others. As mentioned before the actions are illustrative only and would need to be defined in SIPs and other planning processes.

Phase 1: Project Scoping and Existing Work

Phase 2: Evaluation, development, and prototype testing

This phase could entail four overall elements:

> *Secure Funding.* Collaborate with public and private partners to secure funding commitments for the development of new technology locomotive prototypes and infrastructure demonstrations.
>
> *Evaluate Practicability of Applying Existing Electrified Rail Technologies to Region*. Conduct an evaluation of the practicability of applying existing electrified rail technologies to the region. Electrified rail technologies are currently used in many countries to move passenger and freight. This evaluation would comprehensively assess the practicability of utilizing such existing technologies for rail service in the South Coast Air Basin.
>
> *Develop Locomotive Prototypes and Wayside Power Infrastructure*. This phase would involve the development and design validation, and initial proof of concept and prototype testing of several types of zero-emission locomotive technologies and supporting infrastructure. This could include improvements to currently available technologies as well as new technologies that may have cost or operational advantages. Basic performance requirements at this stage needs to include, but are not limited to, sufficient tractive power to haul double-stacked railcars, adequate braking capability and other parameters to support safe operation, and the ability to operate in zero-emission mode. Potential technologies should include:
>
> - *Overhead catenary electric system*: Development of an overhead catenary demonstration, with either an all-electric or dual-mode locomotive. The goal would be a prototype locomotive providing comparable performance capabilities (e.g., tractive effort) as a U.S. diesel-electric freight locomotive. The prototype electric or dual mode electric locomotive would need to be tested with an existing electrical rail system

(e.g., Amtrak passenger electric rail system for the Acela on the east coast) – assuming the electric rail system has the proper voltage and electrical connections/hardware for the prototype locomotive.

- *Dual-mode with battery-hybrid system*: Development of battery-hybrid locomotives with zero-emission range that could achieve at least 60 percent lower than Tier 4 emissions when operating within the South Coast Air Basin.

- *Battery tender car*: A prototype designed for compatibility with existing U.S. diesel-electric or new Tier 4 locomotives. If the battery tender car is designed for use with catenary systems, similar to the electric or dual-mode locomotives, it would need to be tested within an existing electrical rail system.

- *LSM technology*: Test track and demonstrate proof of concept for an LSM system in a freight locomotive application.

- *Other technology options:* ARB and the District are currently funding a study by UC Irvine to develop a design for a Solid Oxide Fuel Cell to power a locomotive. A fuel cell needs to be able to generate comparable horsepower as a current U.S. diesel-electric freight line haul locomotive, or about 4,500 gross horsepower. Union Pacific Railroad has agreed to participate in the construction of a prototype fuel cell locomotive upon successful completion.

Select Locomotive Technologies for Phase 3 Demonstration. Assess the development of the locomotive technologies and infrastructure from Phase 2 programs and select appropriate technologies to proceed with prototype development and testing programs.

Phase 3: Initial deployment and operational demonstration

Conduct Advanced Technology Locomotive Demonstrations. Evaluate zero-emission line-haul rail technologies with any needed wayside power source on test or operations track with sufficient length, switches and grades to validate operational feasibility within the Basin. Move most promising technologies to initial demonstration in operational service, preferably within the South Coast Basin. For some potential technologies such as battery tender cars, initial demonstration may occur earlier than expected. However, other technologies where infrastructure is needed, demonstration may occur later.

Select Advanced Technology Locomotive Technologies for Phase 4 Deployment. Assess the development of the locomotive technologies and infrastructure from Phase 3 testing and demonstration programs, and select technologies and infrastructure to proceed to initial deployment.

Phase 4: Full scale demonstrations, commercial deployment and infrastructure construction (if wayside power is needed)

At this stage, it is expected that advanced rail technologies will require additional field demonstrations prior to full commercialization. Technology choices need to advance from small scale demonstration phase to full scale demonstration in operational service. New technology deployments must be coordinated with any needed infrastructure. The timing for this step is highly dependent on the need for wayside power (or not) and the construction of such infrastructure.

The actions needed to develop implementation mechanisms (e.g. funding and regulatory mechanisms) to deploy zero- and near-zero emission rail technologies as part of a long-term freight system are illustrated in the timeline below. The actions would be implemented by various agencies including local air districts, ARB, local metropolitan planning organizations, and stakeholders, and the timelines may change as demonstrations are conducted.

Year(s)	Timeline of Needed Action
2012-2013	Identify funding to support rail evaluation and demonstration efforts. Evaluate and determine practicability of applying existing electrified rail technologies to region. Evaluate potential funding and implementation mechanisms for zero- and near-zero emission locomotives, and wayside power including: private (railroads); federal, state, local government; public-private partnerships; electric utility.
2012-2014	Begin discussions on development and deployment of Tier 4 locomotives with footprint to hookup external power source Evaluate and determine practicability of external sources of power such as battery tender cars Initiate demonstration projects for identified technologies. If demonstrations of zero- and near-zero technologies are determined feasible, begin discussions to deploy such technologies on a phase-in basis.
2015-2016	Identify technologies, infrastructure, and implementation mechanisms and incorporate into the Regional Transportation Plan and next major SIP. If existing electrified rail technologies were determined to be practicable for the region, begin infrastructure planning, development and deployment of such technologies.
2018	If new rail technologies are needed to achieve zero- and near-zero emission in the region, determine need for wayside power for new rail technologies (based on expected range of technologies in zero-emission mode without wayside power in the 2020-2030 timeframe).

Year(s)	Timeline of Needed Action
	If wayside power is needed, incorporate "footprint" and planning for wayside power into rail lines into the constrained Regional Transportation Plan. Incorporate recommendations regarding type of funding and implementation mechanism into constrained RTO and next major SIP, including: • Strategy description and timeframe for potential regulatory actions or other enforceable mechanisms • Strategy description, potential funding sources and timeframe for incentives, if needed.
2018+	If battery tender car or other external sources of electrical power are demonstrated, begin deployment such technologies. Construct needed infrastructure for zero-emission technologies as needed.

Cargo Handling Equipment

Introduction

The actions to demonstrate and commercialize advanced zero-emission and near-zero emission technologies for cargo handling equipment operated at marine ports, intermodal freight facilities, and warehouse distribution centers that could be deployed in the 2020 to 2030 timeframe are discussed in this section. Such technologies include advanced engine controls to achieve at a minimum, 80 percent reduction in NOx exhaust emissions beyond the Tier 4 off-road exhaust emissions standards and zero-emission technologies such as electric, battery-electric, and fuel cells.

Potential Zero Emission Technologies

Zero-emission technologies include battery electric (BEV) and plug-in electric hybrid (PHEV) technologies. These technologies are based on automotive systems and are now being demonstrated in cargo handling equipment. Other potential technologies include fuel cell (FC) and fuel cell-battery hybrids (FCH) for mobile equipment, as well as container movement systems using wide-span grid-power based overhead cranes and container conveyer systems to replace cranes, forklifts, and yard trucks. In addition, hybrid systems have been developed and deployed on cranes used at marine ports and intermodal railyards. ARB has proposed in the fiscal year 2012/13 AQIP Funding Plan to devote $1 million toward the demonstration of zero-emission off-road equipment. Suitable technology demonstrators are eligible to apply for project funds in coordination with a suitable public agency. The following table summarizes potential zero-emission and hybrid systems to be evaluated over the next several years.

Technology	Application	Status/ Potential Emission Reduction
Electric	Wide Span Gantry Cranes	Available but not used in local ports, demonstrations under discussion/100 percent
Battery-Electric	Yard Tractor; Top-Pick/ Side-Pick; Forklifts	Yard tractor demonstrations underway, other CHE demonstrations planned/100 percent
Fuel Cell	Yard Tractor; Top-Pick/ Side-Pick; Forklifts	Demonstrations under discussion /100 percent
Plug-In Hybrid Electric	Yard Tractor; Top-Pick/ Side-Pick; Forklifts	Drayage truck demonstration underway, CHE Demonstrations under discussion /75 percent

Technology	Application	Status/ Potential Emission Reduction
Hybrid Systems	Gantry Cranes	Available but in limited use. Demonstration under discussion/50 percent
Battery-Electric	Gantry Cranes	Demonstration under discussion/100 percent
CNG/LNG	Yard Tractor; Top-Pick/Side-Pick; Forklifts, Gantry Cranes	Available for trucks and forklifts, demonstrations under discussion for CHE/ 50 percent

Battery-electric and fuel-cell equipment. Zero-emission yard truck prototype testing is underway with funding from the Port of Los Angeles, the Port of Long Beach, and the District. A demonstration of the Balqon lead-acid battery electric truck was initiated in 2007. The battery was upgraded to a lithium-ion battery, and testing of the upgraded system is underway. Additional testing is ongoing with units made specifically for drayage by Vision Motor Corporation, using a combination of lithium-ion batteries and fuel cells. Transfer of these technologies from on-road truck applications to off-road yard trucks will be straightforward and is currently in the planning stage at the Ports of Los Angeles. Transfer of the technology to cargo handling equipment such as top picks is in the discussion stage but has not been demonstrated.

Hybrid diesel-electric equipment. Class 6 hybrid and/or plug-in hybrid trucks offering reduced emissions are now becoming commercially available from a number of established manufacturers, e.g. Kenworth T370. These trucks could operate in drayage service and development is continuing on Class 7 and Class 8 trucks. Application of these technologies to yard trucks would be straight forward. The Ports are currently considering a demonstration of a hybrid yard truck. Applications of hybrid technologies to other cargo handling equipment including forklifts, top-picks/side-picks, and gantry cranes are in the research and development stage with demonstrations possible within two years. Ports are also evaluating alternative fueled drayage trucks and are planning to demonstrate CNG and LNG cargo handling equipment.

Grid electric. Wide span gantry cranes and automated guideways for moving and positioning cargo containers in the port are commercially feasible but have not been used in local port applications. The Ports have reviewed some proposals for demonstrations and are in continuing discussions with applicants.

Alternative Fuels. Natural gas fueled trucks and buses are commonly available. Gasoline and propane fueled off-road equipment is available and could be adapted to compressed or liquid natural gas.

Actions to develop, demonstrate, and deploy needed technologies

The actions and timeline below describe a path to evaluate, develop, demonstrate, fund and deploy zero- or near-zero-emission cargo handling equipment in the South Coast. Multiple technologies would need to be considered, and each analyzed to assess utility and practicality, costs, benefits, and reliability. Some technologies are more developed than others; some may have a quicker ramp-up to commercialization than others. As mentioned before the actions are illustrative only and would need to be defined in SIPs and other planning processes.

The actions described below are directed at developing and demonstrating technologies for.

Phase 1: Project Scoping and Existing Work

Zero-emission truck technologies are being assessed for the freight transport system. These technologies could be adapted to cargo handling equipment, particularly yard trucks which representing nearly 50% of port cargo handling equipment.

Zero-emission truck technology includes battery-electric trucks and fuel cell trucks. Battery-electric trucks are established in smaller trucks and in a variety of different vocations. Fuel cell trucks – either with a small battery pack or with the fuel cell as a range extender with a larger battery pack – have been demonstrated in other categories and are seeing significant progress in both light and heavy-duty applications. Zero-emission truck prototype testing is currently underway with funding from the Port of Los Angeles, the Port of Long Beach, and SCAQMD.

Phase 2: Evaluation, development, and prototype testing (2012-2015 timeframe)

Secure Funding. Collaborate with public and private partners to secure funding commitments for the development of vehicle prototypes and infrastructure demonstrations.

Develop and Demonstrate Equipment Prototypes. This phase involves the development, design validation, and initial demonstration of several types of advanced prototype vehicles. The demonstration would include technology optimization for prescribed equipment types and functions. This task would take into consideration: 1) the compatibility of the technology options with the equipment design, activity, and duty cycle, 2) effect on terminal and railyard operations, and 3) the costs associated with developing and implementing the technology. The following candidate technologies will be evaluated for development:

- *Battery-Electric and Fuel Cell Equipment* – Both zero-emission technologies are already being evaluated in drayage truck applications. Specifically, Balqon battery electric trucks and a Vision Motor battery/hydrogen fuel cell truck. Prototypes should be considered to assess designs for yard trucks, cargo handling equipment, loaders, and cranes.

- *Hybrids* – Although partial zero emission hybrids are becoming commonplace in other applications, no heavy-duty (Class 8) hybrids with zero-emission range are being demonstrated in local service yet. A number of promising different prototypes are available now or soon will be and should be evaluated. A partial list includes the Meritor dual-mode hybrid and the Artisan/Capstone/Parker turbine range-extender electric truck. Discussions are also underway with Volvo and Daimler Trucks to develop similar hybrid technologies with all electric range. The Quick charge capability, locations, charger hardware design and cost, should also be evaluated.

- *Grid Power* – Wide-span gantry cranes and guide way technologies have been proposed previously. The Ports, through the Technology Advancement Program, can determine the best potential demonstrator of these technologies.

- *Alternative Fuels* – Yard trucks are commercially available today with on-road natural gas engines. These engines could be applied to off-road equipment.

Select Technologies for Phase 3 Fleet Evaluation. Assess the development of cargo handling equipment technologies and select appropriate technologies and equipment categories to proceed with cargo handling equipment prototype deployment and small scale demonstrations.

Phase 3: Initial deployment and operational demonstration (2013-2020 timeframe)

Conduct Technology Demonstrations. Evaluate zero- and near-zero cargo handling equipment technologies during actual terminal and railyard operations. Move most promising technologies and application to initial demonstrations while continuing development of less ready technologies.

Select Equipment and Technologies for Phase 4 Deployment. Assess the development of technologies from Phase 3 testing and demonstration programs and select technologies to proceed to initial commercial deployment.

Phase 4: Full scale demonstrations, commercial deployment (2015 on)

Phases 1-3 are designed to bring zero emission technologies to the beginning of commercial deployment. Technology choices need to advance from small scale demonstration phase to full scale demonstration in operational service. New technology deployments must be coordinated with any needed infrastructure.

Actions

The actions needed to develop implementation mechanisms to deploy zero and near-zero emission cargo handling technologies are illustrated below for the South Coast Air Basin. The timeframes may change as advanced technologies are demonstrated.

- *San Pedro Bay Ports Technology Advancement Program (TAP) Working Group (2012-2014 timeframe)*
  The District, ARB, and U.S. EPA serve on the TAP Working Group to evaluate potential emission reduction projects. The TAP could serve as a forum to focus efforts specifically on zero-emission penetration into specific types of cargo handling equipment. The power storage, drive systems, and fast charging technologies are currently emerging technologies. Other technologies and/or combinations of technologies may emerge that could also play a role in the longer-term zero emission cargo handling system. The Working Group should coordinate with core end users to define their needs and key vehicle design parameters in 2012.

- *Secure Funding (2012-2014 timeframe)*
  Collaborate with public and private partners to secure funding commitments for the development of vehicle prototypes and infrastructure demonstrations.

- *Develop and Demonstrate Equipment Prototypes (2012-2015 timeframe)*
  This phase involves the development, design validation, and initial demonstration of several types of advanced prototype vehicles. The demonstration would include technology optimization for prescribed equipment types and functions. This task should seek to further evaluate, develop, and test prototypes.

- *Select Technologies for Field Evaluation (2012-2017 timeframe)*
  Select both the equipment types and drive technologies to test in small-scale demonstrations. Designate equipment test deployment, and develop a test and development plan for a limited number of equipment.

- *Equipment Evaluation Testing (2013-2020 timeframe)*
  Develop, deploy and assess, with operators, multiple equipment types with on-going data collection, analysis, and sharing for rapid iterative design improvement.

- *Deployment (2015+ timeframe)*
  Identify/develop mechanisms to deploy demonstrated technologies as early as possible. Such mechanisms may include lease agreements, environmental mitigation measures, funding incentives, and regulatory actions.

Commercial Harbor Craft

Introduction

The actions needed to commercialize advanced engine control technologies and hybrid systems on commercial harbor craft that could be deployed in the 2020 to 2030 timeframe are discussed in this section. Such technologies include advanced engine controls to achieve at least a 60 percent reduction in NOx exhaust emissions beyond the most stringent Category 1 and 2 marine engine exhaust emissions standards. There are approximately 750 commercial harbor craft operating within the South Coast Air Basin that are estimated to emit 17.7 tpd of NOx in 2023. Commercial harbor craft includes tug, ferry, crew and supply, excursion, commercial fishing, work, barge, dredge, and pilot vessels. Commercial harbor craft generally have multiple propulsion and auxiliary engines per vehicle with total power of between several hundred and several thousand horsepower. Essentially all are currently diesel powered. Work activity varies significantly with some vessels spending most time within the port harbor and adjacent waters while others leave the local port for adjacent ports, Catalina Island, or oil platforms.

Potential Zero and Near-Zero Emission Technologies

Zero-emission technologies include battery electric (BEV), fuel cell (FC), and fuel cell-battery hybrids (FCH). The following discussion and table summarizes potential zero-emission and hybrid systems to be evaluated over the next several years.

Technology	Application	Status/ Potential Emission Reduction
Battery-Electric	Vessels with high percentage of standby time or low load time while docked	Small excursion or pleasure craft are available, but not commercial harbor craft/100 percent
Fuel Cell	Vessels with high percentage of medium to high power that have access to fueling infrastructure	Demonstration units in development/100 percent
Diesel-Electric Hybrid Systems	Vessels with variable engine loads, limited standby time while docked and need for extended range some times.	Technology demonstrated on two tugboats/50 percent NOx, 70 percent PM compared to similar standard diesel engine
SCR/DPF Aftertreatment	Vessels with high usage and space available for installation of the systems.	Commercialized in Europe, local demonstration projects underway/80 percent from Tier 2

<u>Battery-electric.</u> Battery powered recreational boats have been available for many years. Advanced lithium battery technology can be applied to harbor craft.

<u>Fuel cells.</u> Fuel cell power systems are being demonstrated for on-road vehicles and have been used commercially for stationary power generation. Testing is ongoing with units made specifically for drayage by Vision Motor Corporation, using a combination of

lithium-ion batteries and fuel cells. Application of these technologies to harbor craft operating appears technically feasible and would provide extended range needed for many harbor craft.

Diesel-electric hybrid. Diesel-battery hybrid technology has been demonstrated on a two tugboats at the Ports of Los Angeles and Long Beach. The vessels are is equipped with batteries and an electric propulsion motor. This system allows the auxiliary engines to provide electrical propulsion power as well as supply electrical power to the vessel. With advanced software the power to propel the vessel can come from on-board batteries, one or both auxiliary engines and one or both of the main engines, or any combination of on-board power sources. In addition, when the vessel is docked, grid based power can be used to charge the batteries thereby displacing a portion of the use of the diesel engines for propulsion and electrical generation. Engine use is thus minimized and optimized and can result in significant emission reductions. The two hybrid tugs are in operation in the Ports of Los Angeles and Long Beach have shown emission reductions of 50 percent for NOx and 70 percent for diesel PM as well as fuel savings of over 25 percent. Several harbor craft operators have deployed hybrid vessels to improve fuel efficiency and reduce criteria and greenhouse has emissions.

SCR/DPF Aftertreatment. Diesel aftertreatment systems have been demonstrated on ferries in New York and California and will soon be demonstrated on tugs in the District. These systems include selective catalytic reduction (SCR) catalysts for control of NOx and diesel oxidation catalysts (DOC) or DOC plus diesel particulate filters (DPF) for control PM, VOC, and CO. SCR catalyst systems have been in operation in Europe for more than 10 years on over 200 vessels without any technical issues. These systems have achieved up to 80 percent control of emissions from commercial harbor craft engines. After-treatment systems are particularly appropriate for in-use vessels because of the long useful life of boats and marine engines but space constraints, urea tanks, and high heat from DPF systems are safety concerns. Currently, ARB in coordination with SCAQMD and Hug Filtersystems have begun a demonstration of an SCR/DPF aftertreatment device on a tug boat at the Ports of Los Angeles and Long Beach.

Actions to develop, demonstrate, and deploy needed technologies

The actions and timeline below describe a path to evaluate, develop, demonstrate, fund and deploy advanced technology comer harbor craft in the South Coast. Multiple technologies would need to be considered, and each analyzed to assess utility and practicality, costs, benefits, and reliability. Some technologies are more developed than others; some may have a quicker ramp-up to commercialization than others. As mentioned before the actions are illustrative only and would need to be defined in SIPs and other planning processes.

Phase 1: Project Scoping and Existing Work

Commercial harbor craft have propulsion engines from several hundred to several thousand horsepower. Essentially all are currently diesel powered. Work activity varies significantly with some vessels spending most time within the port harbor and adjacent waters while others leave the local port for adjacent ports, Catalina Island, or oil platforms. As a result, zero-emission drive systems are more difficult to deploy except in the smaller vessels that operate exclusively inside the harbor.

Another technology being demonstrated on larger commercial harbor craft (tugs) is a diesel-battery hybrid technology. The vessel is equipped with batteries and an electric propulsion motor. This system allows the auxiliary engines to provide electrical propulsion power as well as supply electrical power to the vessel. In addition, when the vessel is docked, grid based power can be used to charge the batteries thereby displacing a portion of the use of the diesel engines for propulsion and electrical generation. Engine use is thus minimized and optimized and can result in significant emission reductions. A hybrid tug in operation in the Ports of Los Angeles and Long Beach has shown emission reductions of 50% for NOx and similar reductions for other pollutants as well as fuel savings of over 25%.

Phase 2: Evaluation, development, and prototype testing (2012-2015 timeframe)

The following actions are directed at developing and demonstrating reduced emission technologies for commercial harbor craft.

Secure Funding. Collaborate with public and private partners to secure funding commitments for the development of prototypes and demonstrations.

Develop and Demonstrate Prototypes. This phase involves the development, design validation, and initial demonstration of reduced emission technologies on vessels. The demonstration would include technology optimization primarily for vessels identified in Task 1 as good candidates for early implementation. This task would seek to further evaluate, develop, and test prototypes for the following technologies (other technologies could be added to the list below):

- *Battery-Electric and Fuel Cell Systems* - Both of these zero-emission technologies are being evaluated in on-road vehicles. Specifically, Balqon battery electric trucks and a Vision Motor battery/hydrogen fuel cell truck are being developed and demonstrated in the South Coast Air Basin. Prototypes should be evaluated for harbor craft duty cycles and activity requirements.

- *Reduced Emission Hybrids* – Hybrid electric drives based on energy recovery are not feasible on vessels. However, fuel savings and emission reductions have been demonstrated from converting direct diesel drive to diesel-electric drive with battery storage. This is particularly true for commercial harbor craft that spend significant time idling or at part throttle. These vessels include tugs, work boats, barge tenders, and ferries. The San Pedro Ports Clean Air Action Plan reported on a demonstration of a diesel-electric tugboat that provided 50% NOx reduction.

- *Reduced Emission Diesel Engines* - More significant emission reductions (potentially, at least 60% below marine Tier 4 – 0.5 g/bhp-hr NOx) will require further advancements in engine technologies or adoption of aftertreatment technologies. These technologies currently exist, are used for stationary and mobile sources, and are being demonstrated as retrofit devices. These technologies are not likely to be used in marine engines without new technology forcing standards.

- *DPF/SCR After-treatment* – Aftertreatment systems are particularly useful for the legacy fleet of vessels. The current statewide Commercial Harbor Craft Regulation and San Pedro Bay Ports Clean Air Action Plan measure will leave the majority of commercial harbor craft with Tier 2 or at best Tier 3 engines. SCR aftertreatment systems have been demonstrated at >70% efficiency from Tier 2 baseline emissions and stand the best near-term technology. Demonstrations on different vessel types are needed.

Select Technologies for Phase 3 Fleet Evaluation. Assess the development of advanced technologies for harbor craft and select appropriate technologies and vessel categories to proceed with prototype deployment for small scale demonstrations.

Phase 3: Initial deployment and operational demonstration (2015-2017 timeframe)

Conduct Technology Demonstrations. Evaluate zero- and near-zero emission technologies during actual vessel operations. Move most promising technologies and applications to initial demonstrations while continuing development of less ready technologies.

Select Equipment and Technologies for Phase 4 Deployment. Assess the development of technologies from Phase 3 testing and demonstration programs and select technologies to proceed to initial commercial deployment.

Phase 4: Full scale demonstrations, commercial deployment (2015+ timeframe)

Phases 1-3 are designed to bring zero emission technologies to the beginning of commercial deployment. Technology choices need to advance from small scale demonstration phase to full scale demonstration in operational service. New technology deployments must be coordinated with any needed infrastructure.

Actions

The following actions and timeframes illustrate the development and demonstration needed for potential advanced control technologies for commercial harbor craft in the South Coast Air Basin. The timelines may change depending on the results of the research and demonstration efforts.

San Pedro Bay Ports Technology Advancement Program (TAP) Working Group (2012-2013 timeframe)
The SCAQMD, ARB , and U.S. EPA serve on the San Pedro Bay Ports Technology Advancement Program (TAP) advisory committee. The TAP could serve as a forum to focus efforts specifically for reduced emission technologies for commercial harbor craft.

Secure Funding (2012-2014 timeframe)
Collaborate with public and private partners to secure funding commitments for the development of technology prototypes and in-vessel demonstrations.

Develop and Demonstrate Prototypes (2012-2015 timeframe)
This phase involves the development, design validation, and initial demonstration of reduced emission technologies on vessels. The demonstration would include technology optimization primarily for vessels identified by the Working Group as potential candidates for early implementation.

Select Technologies for Field Evaluation (2012-2017 timeframe)
Identify potential vessels and low emission technologies to test in the small scale demonstrations in Phase 3. Designate vessel deployment and lay out a test and development plan for a limited number of vessels.

Technology Evaluation Testing (2013-2020 timeframe)
Develop, deploy, and assess, with vessel operators, multiple technology and vessel types with on-going data collection, analysis, and sharing for rapid iterative design improvement.

Deployment (2015+)
Identify/develop mechanisms to deploy demonstrated technologies as early as possible. Such mechanisms may include lease agreements, environmental mitigation, measures, and funding incentives.

Commercial Ships (Ocean Going Vessels)

Introduction

Commercial ships or ocean-going vessels, which primarily run on heavy fuel, contribute a significant portion of NO_x, PM, greenhouse gas, and toxic emissions particularly in coastal regions and in and around shipping ports. These emissions contribute to on-shore air quality problems. In order for progress to continue meeting clean air goals, emission reductions from ocean-going vessels are necessary.

Potential Reduced Emission Technologies

Currently, the San Pedro Bay Ports Technology Advancement Program (TAP) Advisory Group, comprised of the Ports, SCAQMD, ARB, and U.S. EPA, is exploring promising retrofit technologies to be used on ocean-going vessels. The TAP has sponsored several demonstration projects on various retrofit technologies. The primary objectives of the ocean-going vessel technology demonstration projects are to identify technologies that are capable of reducing NO_x, SOx, PM, and greenhouse gases, identify and demonstrate emission measurement systems capable of accurately measuring pollutant emissions in ship exhaust streams; and install the most promising technology on an in-use vessel for demonstration under real world conditions and establish the emission reduction potential in different modes of operation.

As part of the San Pedro Bay Ports Clean Air Action Plan 2010 update, the Ports have adopted a program to reduce diesel particulate matter (DPM) and NOx emissions from the existing fleet of vessels through the identification of new effective technologies. Numerous emission reduction technologies are being evaluated for integration into vessel new builds and use of these technologies as a retrofit for existing vessels will be explored. These would fall into several broad categories shown in the table below. Many of these technologies are currently available and demonstrated in Europe on smaller ocean-going vessels. The two major marine engine manufacturers, MAN Diesel and Wartsila, have been developing these technologies to meet current and future International Maritime Organization (IMO) standards.

Control	Control Details	Estimate Emission Reductions*	
		NOx	PM
Engine Technologies	Common Rail Fuel Injection, Slide Valves, Electronic Fuel Control, Electronically Controlled Lubrication Systems, and Automated Engine Monitoring/Control Systems	Up to 20 percent	Up to 40 percent
Engine Support Technologies	Water Injection, Exhaust Gas Recirculation, High Efficiency Turbo Charging, Scavenging Air Moistening/Humid Air Motor, Two Stage Turbo Charging	Up to 60 percent	Up to 20 percent
After-Treatment Technologies	Selective Catalytic Reduction (SCR), and Exhaust Gas Scrubbers (Wet – freshwater, saltwater, hybrid, and Dry)	Up to 90 percent	Up to 90 percent
Alternative Fuels	Liquefied Natural Gas	Up to 90 percent	Up to 99 percent
Alternative Supplemental Power Systems	Wind and Solar Power, Marine Fuel Cell, Marine Hybrid Systems, Waste Heat Recovery	Data Not Available	Data Not Available

*San Pedro Bay Ports Clean Air Action Plan – Guide to OGV Emission Control Strategies

New Slide Valve Designs **-** Replacement of existing valves on main and auxiliary engines with new “slide” valves could provide up to 30 percent reduction in NOx (depending on the design). In addition, installing slide valves reduces particulate emissions and leads to greater fuel efficiency. MAN Diesel (one of the two leading manufacturers of marine engines) currently has such slide values commercially available. Slide valves are in use on several marine vessels operating in Europe. Slide valves are being tested on container vessels operating in California.

Internal Engine Modifications - There are several modifications that could be made to the engine’s operation that would lead to reduced NOx emissions. Modifications include: delayed fuel injection and ignition, which reduces the in-cylinder duration of the combustion gases at high temperatures; lowering fuel injection pressure; raising the degree of premixing; advancing the closing time of the inlet valve to lower the final combustion temperature (“Miller valve timing”); reducing the temperature and pressure of the combustion air fed into the cylinders; optimizing the geometry of the combustion space and the compression ratio; and optimizing the fuel injection method. Such modifications could result in up to 30 percent reduction in NOx emissions.

Direct Water Injection (DWI) - Direct water injection is a form of diesel emulsification, where freshwater is injected into the combustion chamber. Injecting water lowers the combustion temperature leading to lower NOx emissions (on the order of 40 to 50 percent reduction). Typical water to fuel ratio is ranges between 40 to 70 percent. As of 2005, there are about 23 vessels operating in the Baltic Region, equipped with water injection, primarily on auxiliary engines.

Humid Air Motor (HAM) or Saturated Air Motor (SAM) - HAM is similar to the direct water injection application except that seawater is vaporized directly into the combustion chamber to lower the combustion temperature. The waste heat is recovered and used to vaporize the seawater. The salt content of the Baltic Sea water is not as high as in other parts of the ocean, which makes the HAM application more appealing since there is no need to store freshwater on board the vessel.

Selective Catalytic Reduction (SCR) - Similar application to stationary source boilers and engines. SCR technologies have been applies to ferries and roll-on/roll-off vessels in Europe. In addition, four steel carrier vessels operating between California and Korea have used SCR since the early 1990s. The two major Category 3 marine engine manufacturers have indicated that SCR technologies will most likely be Tier 3 solutions. Such technologies can achieve over 90 percent emission reduction in NOx from uncontrolled levels.

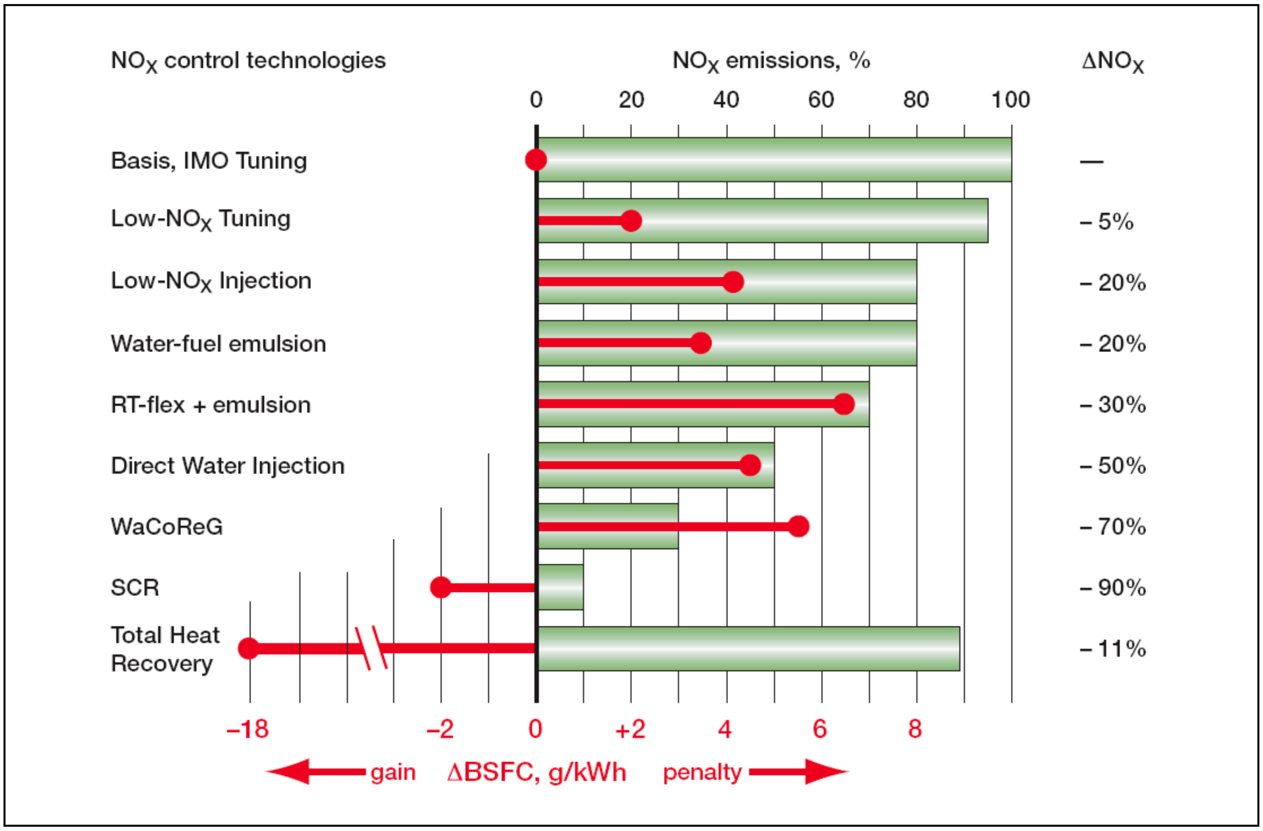
Exhaust Gas Recirculation (EGR) - EGR technologies are similar to that used on on-road engines. However, the units are much larger in size and have not been fully developed at this point. As with on-road engine applications, the expected NOx emission reduction is about 50 percent.

Sea Water Scrubbers - Sea water scrubber systems are developed primarily for the cleanup of sulfur oxides and particulates. Relative to NOx emissions reduction, the sea water scrubber has been estimated to have about a 5 percent benefit.

LNG Fueled Marine Engines - Currently there is limited use of liquid natural gas (LNG) to power propulsion engines on marine vessels. One of the major category 3 marine engine manufacturers recently announced plans to manufacture additional LNG-fueled ocean-going vessels. LNG could meet Tier 3 emissions levels and reduce greenhouse gas emissions.

Impact of Implementation of Marine Engine Control Technologies on Climate Change

The primary impact on climate change of implementing the various control technologies discussed above can be associated with fuel economy associated with the technologies. The following chart (prepared by Wartsila Corporation – one of the major Category 3 marine engine manufacturers) shows the estimated fuel consumption and the NOx emissions reduction associated with the various technologies. The green bars represent the percentage NOx emissions remaining with the use of the various control technologies and the red line (ending with a red dot) represents the fuel consumption. In addition to the technologies discussed above, the chart shows the emissions and fuel economy benefits of implementing heat recovery systems.



(Source: *Wärtsilä Corporation, April 2005)*

As seen in the above chart, implementation of SCR technologies results in fuel savings and climate change benefits. The other technologies have associated fuel consumption penalties that could be offset with implementation of heat recovery systems.

Actions to develop, demonstrate, and deploy needed technologies

The actions and timeline below describe a path to evaluate, develop, demonstrate, fund and deploy advanced technology in commercial shipping serving the South Coast. Multiple technologies would need to be considered, and each analyzed to assess utility and practicality, costs, benefits, and reliability. Some technologies are more developed than others; some may have a quicker ramp-up to commercialization than others. As mentioned before the actions are illustrative only and would need to be defined in SIPs and other planning processes.

Phase 1: Project Scoping and Existing Work (2012-2014 timeframe)

Ocean going vessels have multiple propulsion engines, each of several thousand horsepower. Essentially all use heavy fuel oil and require continuous duty for many consecutive days. As a result, pure zero-emission drive systems are unlikely to be used. A number of engine modification and aftertreatment demonstration projects are currently underway at the Ports of Los Angeles and Long Beach.

Phase 2: Evaluation, development, and prototype testing (2012-2017 timeframe)

The following actions are directed at developing and demonstrating reduced emission technologies for ocean-going vessels.

Secure Funding. Collaborate with public and private partners to secure funding commitments for the development of prototypes and demonstrations.

Develop and Demonstrate Prototypes. This phase involves the development, design validation, and initial demonstration of reduced emission technologies on vessels. The demonstration would include technologies for vessels identified as good candidates for early implementation. This task should seek to further evaluate, develop, and test prototypes for the following technologies, at a minimum:

- *Reduced Emission Engine kits* – Several companies have developed rebuild kits. These kits require demonstration and testing to verify their effectiveness.

- Engine Support Technologies – Various technologies have been proposed that modify or condition the fuel or inlet air prior to combustion to reduce emissions. These technologies are in early stages of evaluation and require demonstration and testing to verify their effectiveness.

- *DPF/SCR After-treatment* – Aftertreatment systems are being tested on harbor craft and can be expanded for ocean going vessels. These systems should be evaluated further as the sulfur content of fuels is reduced.

- *Alternative fuels* – LNG tankers normally operate main engines on natural gas. Use of these engines on new container and general cargo vessels may be practical and should be investigated.

Select Technologies for Phase 3 Fleet Evaluation. Assess the development of advanced technologies for ocean going vessels and select appropriate technologies and vessel categories to proceed with prototype deployment for small scale demonstrations.

Phase 3: Initial deployment and operational demonstration (2015-2020 timeframe)

Conduct Technology Demonstrations. Evaluate reduced emission technologies during actual vessel operations. Move most promising technologies and applications to initial demonstrations while continuing development of less ready technologies.

Select Equipment and Technologies for Phase 4 Deployment. Assess the development of technologies from Phase 3 testing and demonstration programs and select technologies to proceed to initial commercial deployment.

Phase 4: Full scale demonstrations, commercial deployment (2017 + timeframe)

Phases 1-3 are designed to bring reduced emission technologies to the beginning of commercial deployment. Technology choices need to advance from small scale demonstration phase to full scale demonstration in operational service. New technology deployments must be coordinated with any needed infrastructure.

Actions

The actions and timeframe to have cleaner ocean-going vessels in the South Coast Air Basin are illustrated below. The timeframes may change as demonstrations are conducted.

San Pedro Bay Ports OGV 5 and OGV 6 Task Force (2012-2014 timeframe)
The Ports along with the SCAQMD, ARB, and U.S. EPA have formed the OGV 6 and OGV 6 task force to work with stakeholders (including vessel operators, engine manufacturers, regulatory agencies) to identify and prioritize technology options as well as the most appropriate vessel types for early introduction of the technology using cost, feasibility, operational integration, and other parameters identified by the task force. Technology gaps will also be identified.

Identify and Secure Funding (2012-2014 timeframe)
Partnerships with public and private sector groups would be developed to secure funding commitments for the development of prototype demonstrations. Efforts to expand these partnerships for candidate funding sources such as other U.S. Ports, federal agencies (e.g., U.S. Maritime Administration), international organizations (e.g., IMO) and air districts should be considered. Interested technology developers and engine manufacturers are also candidates for in-kind contributions as well as vessel operators.

Develop and Demonstrate Prototypes (2012-2015 timeframe)
Conduct collaborative demonstration projects with stakeholders for the development, design validation, and initial demonstration of reduced emission retrofit technologies on vessels are performed. These demonstrations would include retrofit technology optimization primarily for vessels types and engines identified as good candidates for early implementation.

Select Technologies for Fleet Evaluation (2012-2017 timeframe)
Identify potential vessels and retrofit technologies to test in the small scale demonstrations. Develop a plan designating vessel test deployment, and lay out a test and development plan for a limited number of vessels.

Technology Evaluation Testing (2015-2020 timeframe)
Develop, deploy and assess with multiple vessels with on-going data collection, analysis and sharing for rapid iterative design improvement. Monitor and evaluate equipment performance and emission benefits of the demonstration projects.

Deployment (2017+ timeframe)
Identify and develop mechanism to deploy demonstrated technologies as early as possible. Such mechanism may include, but not limited to, lease agreements, environmental mitigation measures, and funding. The San Pedro Bay Ports have adopted programs to incentivize Tier 2 and Tier 3 vessel calls.

As part of this action, between 2012 to 2015, the South Coast Air Quality Management District, ARB, the San Pedro Bay Ports, and U.S. EPA will collaborate and develop potential additional mechanisms to incentivize or require Tier 3 vessel calls at the state and federal levels.

Commercial Ships (Ocean Going Vessels) at Berth

Introduction

Commercial ships or ocean-going vessels (OGV) visit the Ports of Los Angeles and Long Beach over 4,500 times per year and can remain at berth for up to 48 hours or more loading and unloading cargo. While at berth, marine vessels use auxiliary engines to provide electrical power and boilers to provide steam to operate on board equipment and for environmental control (cooling and heating). These auxiliary engines and boilers, which primarily run on diesel oil, contribute a significant portion of NO_x, PM, greenhouse gas, and toxic emissions particularly in coastal regions and in and around shipping ports. These emissions contribute to on-shore air quality problems. In order for progress to continue meeting clean air goals, emission reductions from marine vessels at berth are necessary.

Potential Emission Reduction Technologies

Electrical power for ship operations can be provided to a ship at berth via electrical cables using shore power allowing the vessel to shut down their auxiliary engines. Shore power can either be taken directly from the grid or be locally generated at the port. Shore power can be locally generated using clean technologies such as fuel cells, gas turbines, microturbines, and combined cycle units. These stationary power generating systems can use alternative fuels such as natural gas, reducing emissions to very low levels.

Alternative shorepower technologies are in various stages of development and include exhaust gas scrubbing technologies that would duct the auxiliary engine and boiler emissions as they exit the stack and treat the exhaust before it is released to the atmosphere, and shore side electrical pumps to assist in offloading product from tankers (typically steam turbine pumps are used for offloading). This exhaust cleaning equipment has been used on factories and other industrial sources for many years and can achieve reductions of emissions of over 90 to 95 percent. As an additional benefit, the boiler emissions are controlled as well as the auxiliary engines when using this type of technology.

To meet the goal of eliminating at berth ship emissions, continued work on alternative shorepower technology is needed to assist vessels and terminals where shorepower infrastructure is not feasible. Alternative shorepower technologies have been developed and are now being demonstrated and deployed. For example, through the San Pedro Bay Ports Technology Advancement Program (TAP) an exhaust treatment system known as the Advanced Maritime Emissions Control System (AMECS) has been demonstrated on two vessels, and will soon be ready for more extensive longer term testing after final modifications to the technology. A similar treatment system is also being developed by one of the port terminals as part of its lease obligations. Initial system designs and testing of the collection system has been completed. A prototype will be built and tested in the near future. There are also plans to deploy the system on a barge such that the unit can be moved to different berths and the unit can be attached directly to the vessel from the barge. In sum, alternative technologies are being demonstrated or will soon be demonstrated and if successful should soon become commercially available. Commercial deployment could begin as early as 2014.

Between now and the 2014 timeframe, there is a need to identify options to encourage additional deployment of shorepower infrastructure as well as alternative shorepower technologies. Work with stakeholders to identify and implement methods (e.g., incentives, regulations, lease agreements, etc.) to encourage or require deployment of additional shorepower or alternative shorepower beyond that needed to comply with the statewide Shorepower Regulation.

Construction and Other Heavy-Duty Equipment

Introduction

Construction and industrial equipment include engines from all horsepower categories and fuel types and can have substantially different work locations and duty cycles. Construction equipment range from small boom lifts to heavy off-road trucks and dual engine scrapers and are usually operated at field locations with limited grid power and limited access. As a result, zero emission drive systems are more difficult to deploy in construction equipment than other off-road mobile categories. Industrial equipment is usually operated at fixed sites with readily available grid power and with access to alternative fuel required for fuel cells. Industrial equipment therefore is a more likely candidate for early introduction of zero emission drive systems than off-road construction equipment.

Potential Zero-Emission Technologies

ARB has proposed in the fiscal year 2012/13 AQIP Funding Plan to devote $1 million toward the demonstration of zero-emission off-road equipment. Suitable technology demonstrations are eligible to apply for project funds in coordination with a suitable public agency.

The following summarizes potential zero-emission and near-zero emissions systems to be evaluated over the next several years.

Technology	Application	Status/Potential Emission Reduction
Battery-Electric	Equipment with high percentage of standby time or low load time and located at site with grid power	Industrial equipment commercialized, smaller construction equipment demonstration needed /100 percent
Fuel Cell	Equipment with access to fuel infrastructure – most likely equipment at fixed sites or returning to equipment yards at night.	Development of forklifts and other industrial equipment in process/100 percent
Plug-In Hybrid Electric	Equipment with energy recovery duty cycles or high percentage of idle/low power operation. Equipment can operate at remote sites with conventional fuel or grid power if available at job site. Hybrid technology may vary by equipment type.	On-road truck systems commercialized; industrial equipment in development, construction equipment depends on market interest/40 percent from Tier 4
CNG/LNG	Equipment at fixed sites or returning to equipment yards at night	Available for some forklifts; demonstrations underway for heavy construction equipment/60 percent from Tier 4

Technology	Application	Status/Potential Emission Reduction
Hybrid Systems	Equipment with energy recovery duty cycles or high percentage of idle/low power operation. Equipment can operate at remote sites with diesel fuel. Hybrid technology may vary by equipment type.	Entering commercialization in selected applications/ 25 percent from Tier 4
Cleaner engines	Heavy construction equipment >300 hp	Engine controls that are at least 60 percent from Tier 4 levels

<u>Battery-Electric Equipment</u> – Battery-electric equipment is already commercialized for many industrial equipment categories. However, this equipment has been developed with conventional automotive lead acid battery technology. Further demonstrations are needed in conjunction with the latest battery technologies.

<u>Fuel Cell Equipment</u> – This zero-emission technology is being demonstrated in light duty passenger cars, buses and trucks. Fuel cell technologies need additional development for off-road applications.

<u>Hybrids</u> – Hybrid electric drives are now being introduced into construction equipment (Caterpillar D7E bulldozer and Komatsu excavator). Other manufacturers including Volvo and John Deere are developing diesel hybrid equipment. For smaller equipment, plug-in hybrid systems are being adapted from light and medium duty on-road vehicles.

<u>Reduced Emission Diesel Engines</u> - More significant emission reductions (60 percent below Tier 4 – 0.12 g/bhp-hr) will require further advancements in engine and exhaust treatment technologies for diesel engines or use of alternative fuels such as natural gas. Many of these technologies currently exist and are used for passenger car and truck engines. However, these technologies are not likely to be used in off-road engines without new technology forcing exhaust emission standards.

Actions to develop, demonstrate, and deploy needed technologies

The actions and timeline below describe a path to evaluate, develop, demonstrate, fund and deploy technologies for construction and industrial equipment. Multiple technologies would need to be considered, and each analyzed to assess utility and practicality, costs, benefits, and reliability. Some technologies are more developed than others; some may have a quicker ramp-up to commercialization than others. As mentioned before the actions are illustrative only and would need to be defined in SIPs and other planning processes.

Phase 1: Project Scoping and Existing Work

Construction equipment is usually operated at field locations with limited grid power and limited access to alternative fuels. As a result, zero-emission drive systems are more difficult to deploy in construction equipment than other categories. Industrial equipment are usually operated at fixed sites with readily available grid power and with better access to alternative fuel required for fuel cells. Industrial equipment is therefore more likely candidate for early introduction of zero-emission drive systems than off-road construction equipment. Candidate drive systems include:

- Plug-in hybrid or hybrid engines that reduce NOx emissions 25-40 percent below Tier 4 standards.
- Reduced emission engines (may include hybridization) that reduce NOx emissions at least 60 percent below Tier 4 standards.
- Battery-electric systems that provide zero emissions.
- Fuel cell electric systems that provide zero emissions.

Phase 2: Evaluation, development, and prototype testing

The following illustrate the actions needed to develop and demonstrate zero- or near-zero emission technologies for construction and industrial equipment where feasible.

Secure Funding. Collaborate with public and private partners to secure funding commitments for the development of vehicle prototypes and infrastructure demonstrations.

Develop and Demonstrate Equipment Prototypes. This phase involves the development, design validation, and initial demonstration of selected types of advanced prototype vehicles. This task should take into consideration: 1) the compatibility of the technology options with the equipment design, activity, and duty cycle, 2) effect on construction and industrial operations, and 3) the costs associated with developing and implementing the technology. The following they types of potential candidate technologies would be evaluated for development:

- *Battery-Electric Equipment* – Battery-electric equipment is already commercialized for many industrial equipment categories. However, this equipment has been developed with conventional automotive lead acid battery technology. The objective in this task is to extend battery-electric applications to selected off-road construction equipment with the most favorable duty cycles and work locations. Development and demonstration goals include advanced solid state battery design, fast charging, and rugged design for off-road conditions with demonstration units.

- *Fuel Cell Equipment* – This zero-emission technology has been evaluated in light duty passenger cars (eg, GM, Honda, and Mercedes) and is being evaluated in buses and trucks (Vision Motor battery/hydrogen fuel cell). Prototypes should be considered (in conjunction with feedback from the Working Group) to assess designs for high volume construction and industrial equipment such as loaders, excavators, and forklifts. Fuel cell technologies need additional development for off-road applications.

Combined with batteries for immediate start, they are especially well suited for large equipment with relatively high power requirements such as trucks, dozers, graders, and loaders. The state of fuel cell system development will be assessed. Accelerated development of fuel cells systems for off-road equipment can be sponsored through demonstration projects. Field demonstrations to ensure that the systems are rugged enough for off-road equipment applications are needed prior to commercial deployment.

- *Reduced Emission Hybrids* – Because of the job-site locations, working environment, and duty cycles, zero-emission equipment is not expected to penetrate to a high level in construction equipment, particularly large – high power equipment. Hybrid electric drives are now being introduced into construction equipment (Caterpillar D7E bulldozer and Komatsu excavator). Other manufacturers including Volvo and John Deere are developing diesel hybrid equipment. For smaller equipment, plug-in hybrid systems could be adapted from light- and medium duty on-road vehicles. Plug-in hybrid systems can significantly reduce engine running time while still providing in-field operating capability. Implementation of hybrid technologies will be driven primarily by market demand due to improved fuel efficiency and reduced operating cost.

- *Reduced Emission Diesel Engines* - More significant emission reductions (60 percent below Tier 4 – 0.12 g/bhp-hr) will require further advancements in engine and exhaust treatment technologies. Many of these technologies currently exist and are used for passenger car diesel engines. However, these technologies are not likely to be used in off-road engines without new technology forcing exhaust emission standards.

Select Technologies for Phase 3 Fleet Evaluation. Assess the development of construction and industrial equipment technologies and select appropriate technologies and equipment categories to proceed with prototype deployment and small scale demonstrations.

Phase 3: Initial deployment and operational demonstration

Equipment Evaluation Testing. Evaluate zero and near-zero equipment technologies during actual in-field operation. Move most promising technologies and applications to initial demonstrations while continuing development of less ready technologies.

Select Equipment and Technologies for Phase 4 Deployment. Assess the development of technologies from Phase 3 testing and demonstration programs and select technologies to proceed to initial commercial deployment.

Phase 4: Full scale demonstrations, commercial deployment

Phases 1-3 are designed to bring near-zero and zero-emission technologies to the beginning of commercial deployment. The results of the first three phases will be used to determine the concrete commercialization steps needed in Phase 4.

Actions

The following illustrate the actions and timeframe for the development and demonstration of zero- or near-zero emission technologies for construction and industrial equipment where feasible. The timeframes may change depending on the results of the demonstrations.

Secure Funding (2012-2014 timeframe)
Collaborate with public and private partners to secure funding commitments for the development of equipment prototypes and infrastructure demonstrations similar to the Off-Road Showcase.

Develop and Demonstrate Equipment Prototypes (2012-2015 timeframe)
This phase involves the development, design validation, and initial demonstration of several types of advanced prototype equipment. The demonstration would include technology optimization for equipment types and applications most likely to be commercialized.

Select Technologies for Field Evaluation (2012-2017 timeframe)
Identify potential equipment types and technologies to test in the small scale demonstrations.

Equipment Evaluation Testing (2013-2020 timeframe)
Develop, deploy and assess, with equipment operators, multiple equipment types with on-going data collection, analysis and sharing for rapid iterative design improvement.

Deployment (2015+ timeframe)
Identify/develop mechanisms to deploy demonstrated technologies as early as possible. Such mechanisms may include provisions to use cleaner equipments as part of business contractual agreements, environmental mitigation measure, and funding incentives. In addition, promulgation of more stringent exhaust emissions standards could facilitate the development of cleaner engine technologies.

Cleaner Aircraft Engines

Introduction

Aircraft is a category where the State is highly dependent on federal action to achieve reduction to achieve both air quality standards and climate goals. There are advanced technologies and sustainable jet fuels that could become available to recue emissions substantially over the next 20 to 30. Because of the State's dependence on efforts at the federal level, the actions and timeframes below are representative of those that could provide emission reductions within the federal Clean Air Act deadlines as opposed to a specific plan of action that California can undertake.

Potential Emissions Reduction Technologies

At this time, several broad technology categories have gained the most focus and could be applied toward aircraft engines to achieve emissions targets proposed by the U.S. Federal Aviation Administration (FAA) under the Continuous Lower Energy, Emissions and Noise (CLEEN) Program. These technologies include advanced ultra-high geared turbo fan with reduced drag and weight, lean cool technology to reduce fuel burn, and advanced alternative fuels.

State and local aircraft emission regulation is preempted by the Clean Air Act which gives that responsibility to the U.S. EPA in consultation with the FAA. New engine aircraft standards were adopted in 2005 and 2012 by U.S. EPA. No regulations are planned for the in-use aircraft fleet. Thus at this time, emission reductions can only be achieved through additional fleet turnover or routing of the cleanest aircraft engines to the South Coast Air Basin. Fortunately, new aircraft offer lower fuel consumption as well as reduced emissions providing an economic incentive for airlines to accelerate replacement of their older aircraft.

In 2010, the U.S. Federal Aviation Administration initiated the CLEEN Program to reduce NOx emissions by 75 percent relative to the 2005 emission standards by 2025. Potential low emission aircraft technologies include alternative fuels, lean combustion burners, high rate turbo bypass, advanced turbo-compressor design, and engine weight reduction. This program provides a framework and goal to develop and demonstrate technologies for improved efficiency and reduced emissions on a continuous incremental basis.

Actions and timelines for the deployment of new and cleaner aircraft engines are illustrated below. The timelines are for illustrative purposes. More specific timelines will be developed as part of future SIPS involving discussion among the local air districts, ARB, U.S. EPA, FAA, and affected stakeholders.

Secure Funding (2012 – 2018 timeframe)
The FAA has provided limited funding for test and evaluation. Participating companies are also providing internal research, prototype preparation and

laboratory tests. Additional funding would be needed to further demonstrate identified technologies.

Develop and Demonstrate Equipment Prototypes (2012 – 2018 timeframe)
Prototype technologies for laboratory testing.

Develop Mechanisms to Accelerate or Incentivize Deployment of New Engines (2012 – 2015 timeframe)
This phase would be conducted in parallel with technology development to put into place programs that will accelerate the use of the cleanest aircraft engines in nonattainment areas. As part of this phase, the U.S. EPA, FAA, ARB, local air districts, and local airport authorities would evaluate potential mechanisms to deploy such engines.

Select Technologies for Fleet Evaluation (2015 – 2018 timeframe)
Select successful technology improvements from bench test data to test in flight operations. Identify target flight test partners and lay out a test and development plan for a limited number of vehicles.

Technology Evaluation Testing (2018 – 2020 timeframe)
Develop, deploy and assess the selected engine technologies on aircraft operated by participating airlines. Provide on-going data collection, analysis and sharing for rapid iterative design improvement and support for FAA and international flight certification.

Prepare and Submit FAA Certification and Application (2018 – 2020 timeframe)
Each engine manufacturer is responsible for obtaining certification of successfully demonstrated technology improvements.

Deployment (2020+ timeframe)
Mechanisms identified under Task 4 will be in place to deploy commercialized technologies as early as possible.

Agricultural Equipment

Introduction

The San Joaquin Valley is one of the most productive agricultural areas in the country. Over the past decade, under SJVAPCD regulations, the agriculture industry has made significant investments in new emission control programs and made considerable changes to their longstanding practices. Grant funding from SJVAPCD and the U.S. Department of Agriculture has encouraged the agricultural community replace thousands of units of agricultural equipment utilizing older high-emitting diesel engines.

There are special challenges in reducing emissions in agriculture, including remote locations, unique operating conditions, and specific operational needs. Efforts are underway now to clean up mobile agricultural equipment to the cleanest, currently available conventional technology and emission reductions from these efforts are important for reducing ozone levels. Given the special challenges of the sector, careful consideration of potential future technologies is required. That said, with the size of the agricultural community in the San Joaquin Valley and the SJVAPCD's and ARB's constructive working relationship with that community, the San Joaquin Valley is an ideal place to focus funds and new technologies for agriculture.

Potential Zero and Near Zero-Emissions Technologies

The agricultural equipment category includes a wide variety of types of equipment, operating in diverse duty cycles. Equipment ranges from agricultural tractors, to more specialized equipment such as harvesters which themselves can be divided into many unique equipment subtypes such as combine harvesters, almond harvesters, and grape harvesters among myriad others. Agricultural operations also utilize construction equipment such as wheel loaders, skid steers, and backhoes. Due to the wide variability and variety of agricultural equipment, the following table does not attempt to identify specific technologies for certain applications; rather, as these technologies are developed, their fit to the existing applications will become more defined.

Technology	Status/Potential Emission Reduction
Battery-Electric	Commercialized in Agricultural UTVs, under demonstration for self-propelled spray rigs/100%
Fuel Cell	Development of agricultural tractor in progress/100%
Plug-In Hybrid Electric	Demonstrations underway in wheel loader and utility truck equipment/40% from Tier 4
Hybrid Systems	Available commercially for bulldozer and excavator applications which may be utilized by land preparation operations/25% from Tier 4
Tier 4	Under development, there is a wide range of Tier 0 and Tier 1 equipment currently being operated in agriculture/98% from Tier 1 and 60% from Tier 4.

Battery-Electric Equipment – Utility Terrain Vehicles (UTV's) have led in the development of battery electric technology, with more than six companies producing dozens of models of zero-emission ATV's and UTV's suitable for agricultural operations. The Valley Air District is making progress in the demonstration of a prototype battery-electric self-propelled spray rig for use in row crops and orchards.

Fuel Cell – A prototype agricultural tractor utilizing hydrogen fuel cells is being produced by New Holland. Further development will be necessary in fuel cell technologies for agricultural sector.

Plug-In Hybrid Electric – The Valley Air District is in the process of demonstrating plug-in hybrid electric drivetrains in agricultural activities as both a wheel-loader and utility truck. This category includes potential of utilizing alternative fuels, with propane being demonstrated in one of these projects.

Hybrid Systems – Hybrid electric drives are now being introduced into construction equipment (for example, Komatsu excavator). Other manufacturers, including Volvo and John Deere, are developing diesel hybrid equipment for construction. In cases where the these pieces of construction equipment may be utilized in agricultural operations, additional incentives and successful technology demonstrations, with consideration for associated end-user benefits, will be necessary to enhance adoption in agriculture and to transfer the technologies into more agriculture-specific equipment.

Near term actions to develop, demonstrate, and deploy needed technologies

Adoption of zero- and near-zero emission technologies in agriculture will depend heavily on technology transfer from other equipment categories, such as off-road construction equipment. Continued development of battery and fuel cell technology in these categories will benefit the adoption of those technologies into agriculture specific equipment.

Agricultural operations have space for renewable zero-emission energy sources. The increasing utilization of photovoltaic and more recently demonstration of thermal solar for agricultural pumping is an example of the potential for on farm renewable energy. Further development to improve the capital costs of zero-emission technologies along with successful demonstrations of on farm renewable energy could lead to more widespread adoption of zero- and near-zero emission technologies in agriculture.

Collaboration with public and private partners to secure funding commitments to bring these demonstrations to agricultural operations should be prioritized. The agriculture industry has invested millions of dollars in emission reducing projects. Further reductions and adoption of zero- and near-zero emission technologies will necessitate further investments from agriculture industry and focus for these technologies should be in areas where there is a benefit to both emissions and the economics of agriculture.