Technology Assessments: Hybrid, Battery Electric, and Fuel Cell Electric Vehicles

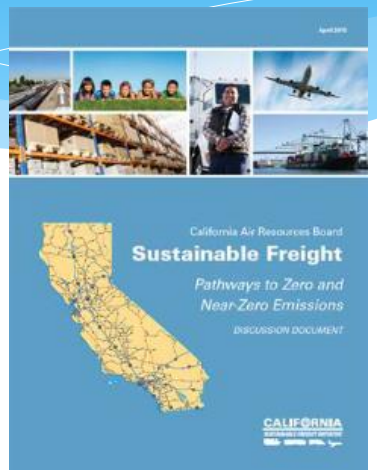
November 19, 2015

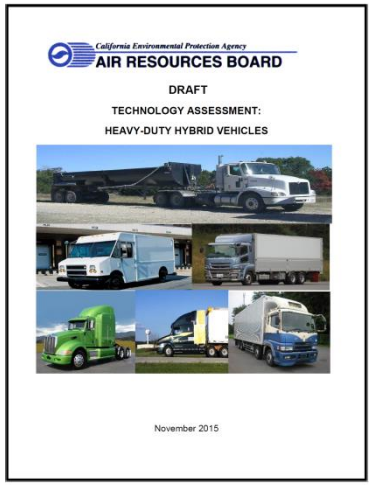
California Environmental Protection Agency

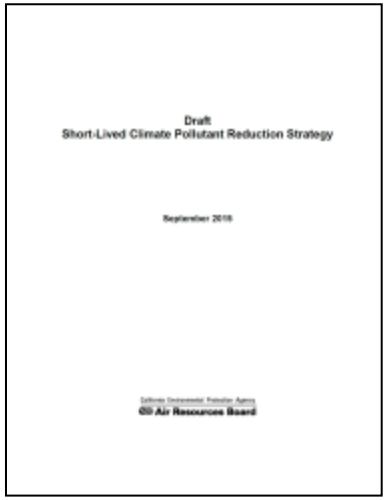
Air Resources Board

Multiple Near- and Long-Term Planning Efforts Underway

* Mobile Source Strategy framework supports multiple planning efforts
  * SIP
  * Scoping Plan
  * Sustainable Freight
* Hybrid, BEV, and FCEV Technology Assessments
  * 5 – 10 year outlook
  * For medium- and heavy-duty vehicles (8,500 lbs.+)
  * Provide technical foundation







Clear Need for Diverse Portfolio of Technologies

* Portfolio of zero- and near-zero technologies
  * Clean Combustion/Low-NOx
  * Hybrids
  * Fuel Cells
  * Battery Electric
* Renewable fuels needed for deep GHG reductions
  * Natural gas
  * Diesel/gasoline
  * Electricity
  * Hydrogen

Technology Assessments Support On-going Planning Efforts

* Inform technical foundation for future regulatory efforts
  * Potential new regulatory efforts
  * Development of renewable fuels
  * Support infrastructure investments
  * Demonstration and deployment of advanced technologies
* Investing in advanced technologies
  * Low carbon transportation
  * Air Quality Improvement Program
  * Alternative and Renewable Fuel and Vehicle Technology Program

Technology Assessments Have Been Underway since Early 2014

Early 2014	• Technology assessments begun
Dec. 2014	• Board briefing status update
April 2015	• Overview report
June 2015	• Vehicle and Drivetrain Efficiency
July 2015	• TRU and Commercial Harbor Craft
Sept. 2015	• Low NOx Diesel and Natural Gas
Oct. 2015	• Battery Electric Trucks and Buses
Nov. 2015	• Cargo Handling, Hybrid, and Fuel Cell Electric Vehicle

Key Findings Provide a Path to 2030 and Beyond

- Near-term focus on clean combustion coupled with renewable fuel
  - Maximizes NOx reductions needed for air quality attainment
  - Use of renewable fuels ensure progress towards 2030 goals
  - Zero emission vehicle deployments necessary
    - Continued technology commercialization
    - Additional localized risk reductions
- Longer-term support for growing zero-emission technology
  - Growing deployment of electric propulsion vehicles
  - Clean combustion still needed
  - Growing need for renewable fuels

Diesel and Natural Gas Assessments

Lower NOx Achievable for Both Diesel and Natural Gas Engines

* Diesel:
  * Reducing emissions during cold start and low-temperature, low-speed city driving
  * Maintaining high SCR efficiency at other times
* Natural Gas:
  * Systems approach combining advanced three-way catalysts with engine management strategies
  * 8.9 liter engine recently certified as 90% cleaner
* ARB-funded SwRI Low NOx Work
  * Target: 0.02 g/bhp-hr NOx for diesel and natural gas with minimal GHG impact

Clean Combustion Important for Near- and Long-Term Reductions

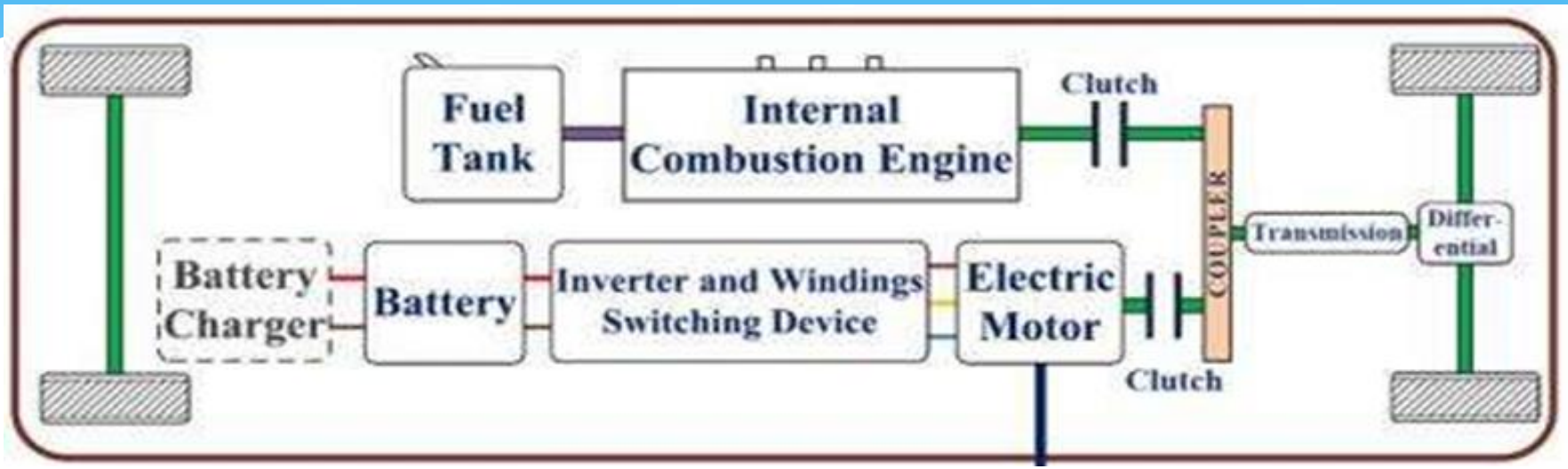
* Low-NOx natural gas engines likely to be available sooner than for diesel
  * Both are critical for attainment of air quality standards
* Well-to-wheel GHG emissions need to be addressed
  * Higher than for fuel cell and battery electric
* Renewable fuels provide potential solution
  * Available quantities could be limiting factor
* Complementary advanced technologies will needed

Advanced Clean Transit Concept: Near-Zero and Zero Emission Technologies

* Transit fleets - an ideal early application of electric and fuel cell technology
* Mix of cleaner combustion & zero-emission buses
  * Low NOx technologies
  * Use of renewable fuels
  * Phased-in adoption of zero-emission technologies
  * Natural fleet replacement rate (not accelerated)
* Increased engagement with stakeholders a priority
  * Establish transit workgroup
  * Conduct technology and regulatory workshops
  * Evaluate economics and business case, funding and incentives
* Update Board early 2016

Hybrid Vehicles

What is a Hybrid Vehicle?



Degree of hybridization:

- Micro hybrid
- Mild hybrid
- Full hybrid
- Plug-in hybrid

Hybrids Currently Best Suited for Urban Driving Cycles

* High kinetic intensity: Heavy urban start-and-stop, aggressive acceleration/deceleration events, high idle time
  - Examples: Refuse haulers, transit buses, package/delivery trucks
* Utilize electric power take-off (ePTO)
  - Examples: Utility and tree trimming services

>2,500 Medium-/Heavy-duty Hybrids On Road in CA

Vehicle Type	Technology Readiness	Number in Service in CA
Parcel Delivery	Commercially available	830
Uniform & Linen Delivery		110
Beverage Delivery		440
Food Distribution & Other Trucks		680
Buses (Transit, Shuttle, School)		470
Other		Demos: Utility/Bucket Trucks, Drayage

- Many more in use overseas, most in China, South America, Europe, India

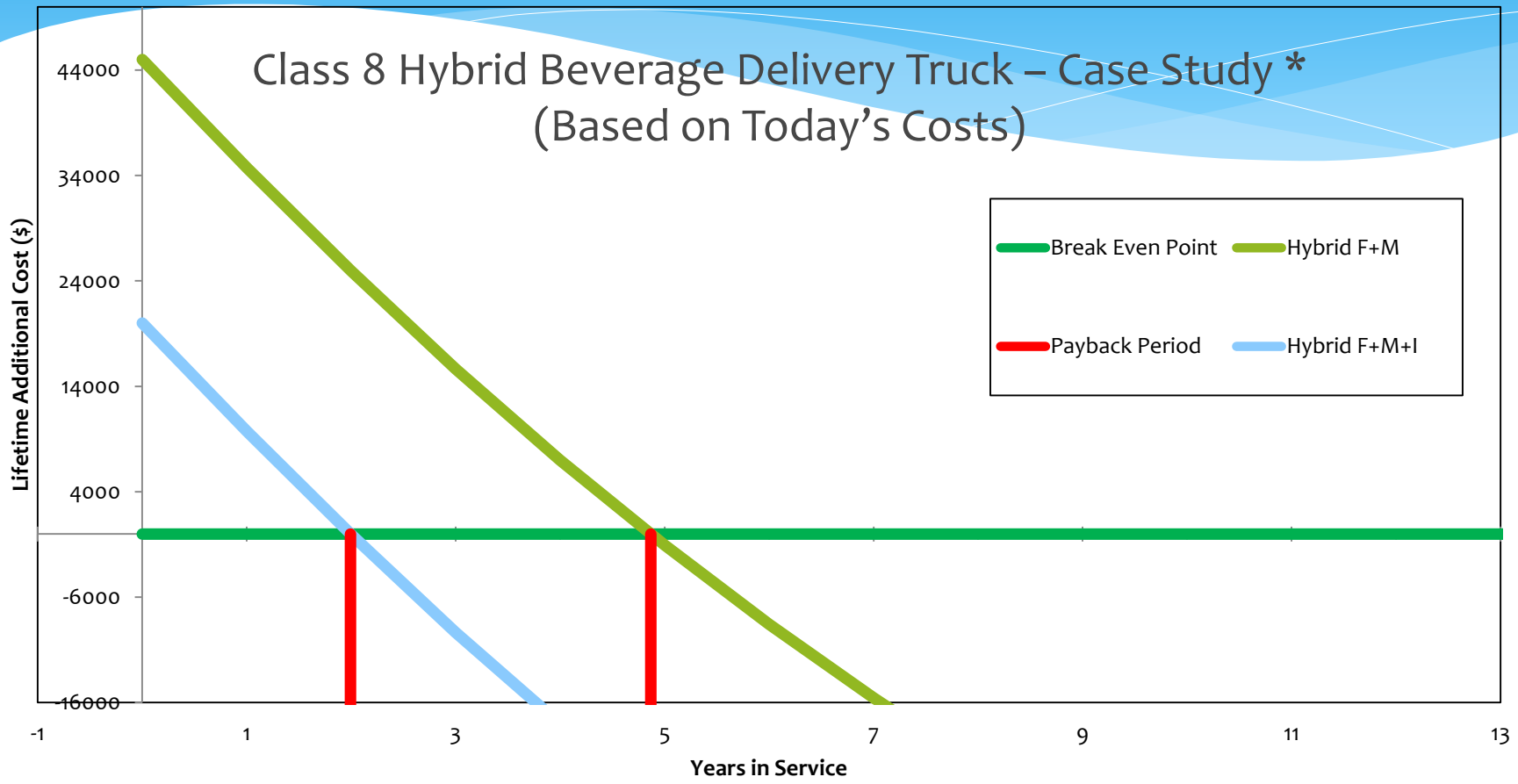
Expanding Hybrids into Additional Applications

* Class 3-8 rural/intracity and regional delivery, and drayage
* Plug-in hybrids for utility/bucket truck applications, with increased use of ePTO, plug-in drayage
* Line haul trucks may adopt mild hybridization as efficiency standards tighten

Overcoming Market Challenges

* Cost: ~20% to 50% of vehicle purchase cost
  - Costs relatively high at low volume
  - Solutions: O&M savings, incentives, increasing volumes
* Performance: High-power demand applications
  - Solutions: Battery improvements, system optimization
* Weight: Weight penalty of 300 lbs.-4,500 lbs.
  - Solutions: Light weighting, route selection
* Certification: OBD and NOx emissions challenges
  - Solutions: Innovative Technologies Regulation, improve engineering designs and system integration

Hybrid Technologies Can provide Overall Cost Savings to Fleets

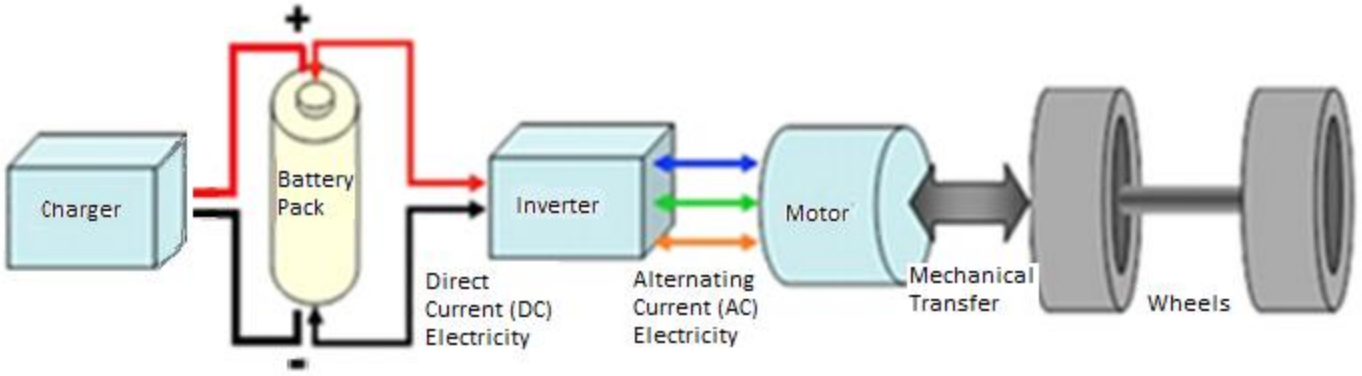


"F" = Fuel savings, "M" = Maintenance Savings "I" = Incentives

* NREL "Coca-Cola Refreshments Class 8 Diesel Electric Hybrid Tractor Evaluation: 13-Month Final Report" - NREL/TP-5400-53502 August 2012- K. Walkowicz, M. Lammert, and P. Curran

Battery-Electric Vehicles (BEVs)

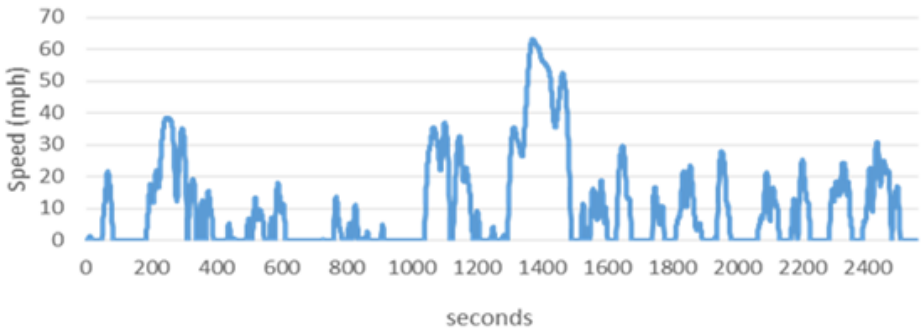
What is a Battery-Electric Vehicle?



* A vehicle using batteries as the sole source of power
* Components:
  - Electric motor
  - Battery pack and battery management system

Optimal BEV Duty Cycle is Similar to Hybrid's

* Urban or suburban routes
* Frequent start and stop
* High idle times/lower average speeds
* Daily ranges of 100 miles or less
* This makes them particular suitable in early years for:
  - Transit buses
  - Shuttle buses
  - Delivery trucks

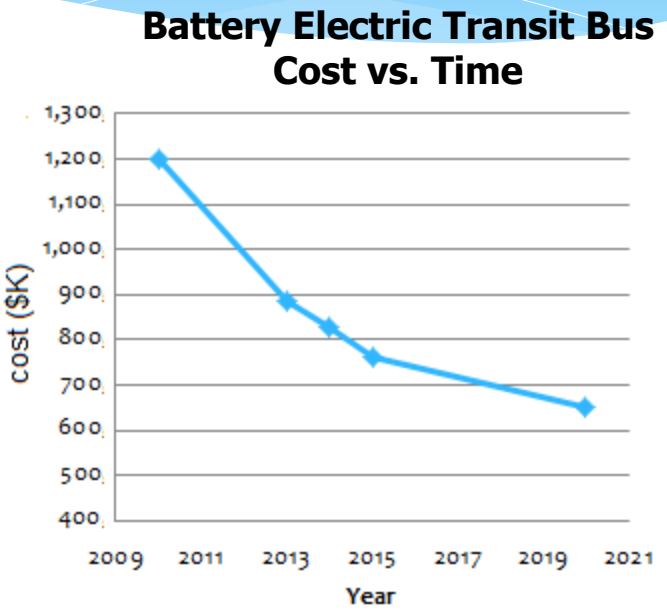


Hundreds of Medium-/Heavy-Duty BEVs in California

Vehicle Type	Technology Readiness	Number in Service
Transit Bus	Commercially Available	~40 in California, >2,500 worldwide
School Bus	Limited Commercial	4 in California
Medium-Duty	Limited Commercial	300+
Heavy-Duty (> 14,000 lbs. GVWR)	Demonstration	2 Drayage 1 Refuse

Overcoming Market Challenges

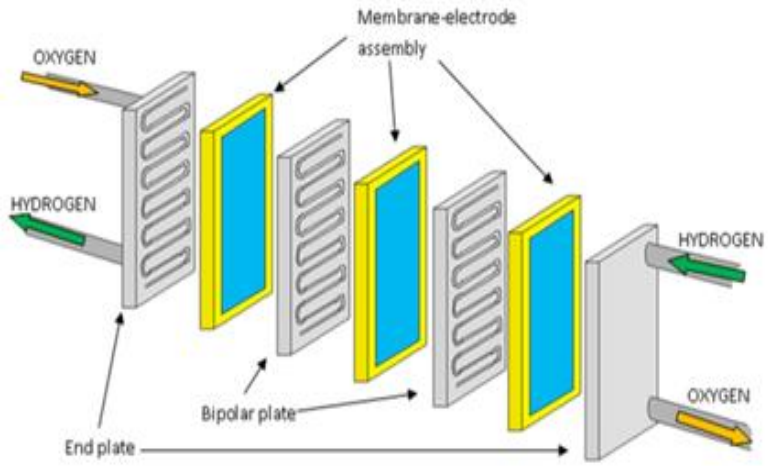
* Range
  - Solutions: Battery improvements, fast-charge technology
* Incremental cost (Bus: ~ 50% of purchase cost)
  - Solutions: O&M savings, incentives, increasing volumes
* Weight
  - Solutions: Battery improvements, light weighting
* Charging/infrastructure
  - Solution: Incentives

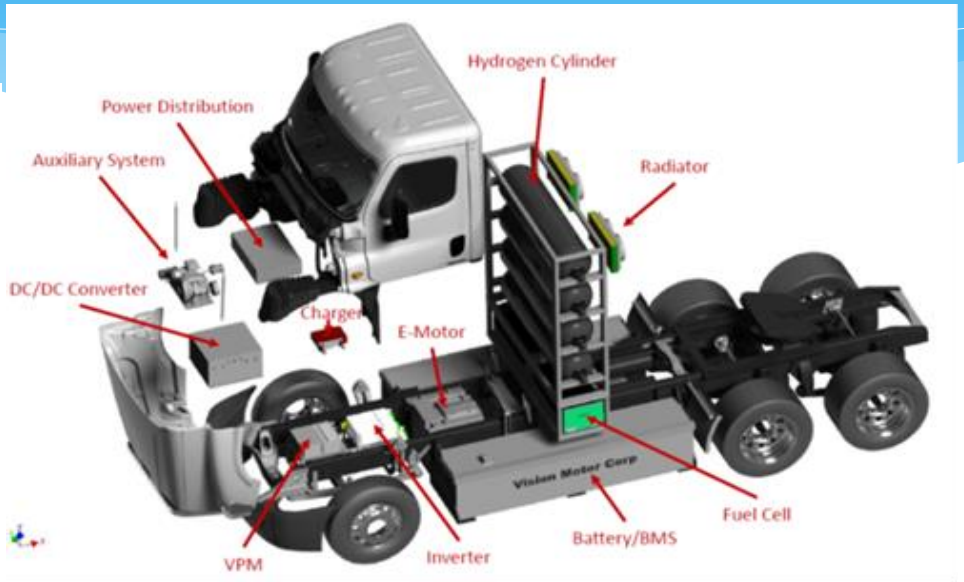


Fuel Cell Electric Vehicles (FCEVs)

What is a FCEV?

Fuel cell stack





* Fuel cell system generates electricity to propel the vehicle and operate auxiliary equipment
* Components: Fuel cell stack, drivetrain, energy storage system, hydrogen storage system, cooling systems, and DC/DC converter(s)

Dozens of Medium-/Heavy-Duty FCEVs On Road

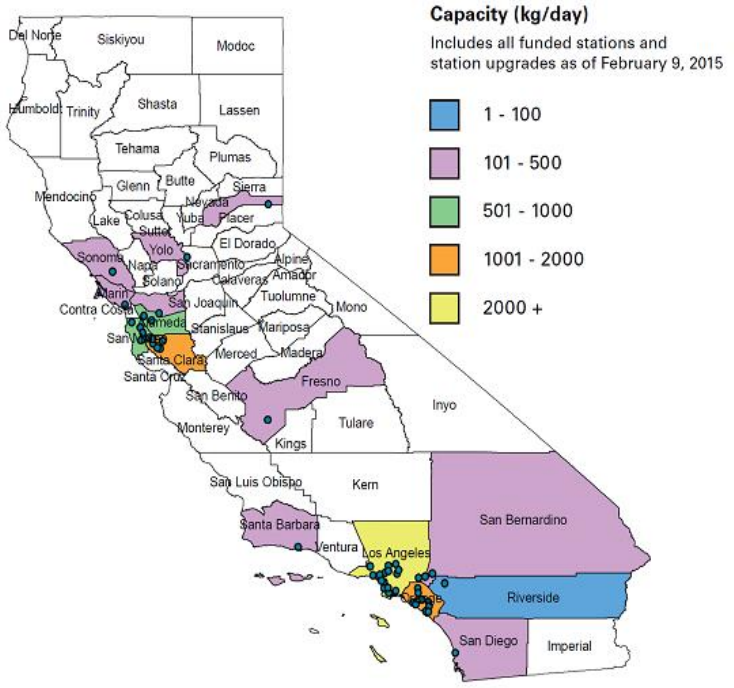
Vehicle Type	Technology Readiness	Active/Planned Demonstrations
Transit Bus	Limited Commercial	23 active/22 planned
Shuttle Bus	Demonstration	2 active/8 planned
Delivery Vehicles	Demonstration	38 active/planned
Drayage Trucks	Demonstration	12 active/planned

Overcoming Market Challenges

* Fuel Cells solve the battery range issue and have good reliability but:
  - Training maintenance staff
    - Solution: training program improvements
  - Currently slightly lower availability than diesel
    - Solutions: parts availability, training programs
  - Incremental cost still high: >100% of purchase cost
    - Solutions: increasing volumes, learning curve
  - Fueling infrastructure
    - Solutions: incentives, demand

Supporting Fueling Infrastructure Must be a Priority

- Extensive work done to plan light-duty hydrogen fueling infrastructure
  - Data gathering from manufacturers
  - ARB analytical tools project station gaps
  - $20 million annually in CEC funding
  - Network of 51 stations expected by 2016
- Medium-/heavy-duty fueling at different pressure
- Need similar effort for medium-/heavy-duty fueling



Clean Advanced Technologies Are Key to Meeting Future Goals

Advanced Technologies Will Provide Critical Emission Benefits

* Hybrids:
  - Potential NOx benefits
  - Modest GHG benefits
* BEVs :
  - Zero tailpipe emissions
  - Well-to-wheel and lifecycle GHG emission benefits
* FCEVs:
  - Zero tailpipe emissions
  - Well-to-wheel and lifecycle GHG emission benefits

Payback Periods Improving with Decreasing Incremental Costs

* Hybrids:
  - Reduced O&M costs
  - Payback period varies from 3 to 18 years
* BEVs:
  - Reduced O&M
  - Payback in 4+ years
* FCEVs:
  - Payback assessment still under development

Comprehensive Strategies to Expand Use of Advanced Technologies

* Planning efforts highlight need for diverse technology portfolio
  * Clean combustion
  * Zero-emission
  * Renewable fuels
* Public investments are supporting technology development
  * Incentives are prioritizing both clean combustion and zero-emission
  * Multiple applications targeted
* Regulatory development underway

Measures Under Development to Encourage Advanced Technologies

* Innovative Technologies – 2016
* Advanced Clean Transit – 2016
* Heavy-Duty GHG Phase 2 – 2016-2017
* Last Mile Delivery – 2017
* Zero Emission Airport Shuttle Buses – 2017-2018

Moving Forward

* Staff will continue to work with stakeholders on ARB planning and measure development
  * Near- and long-term scenarios
  * Both clean combustion and zero-emission
* Technology assessments posted as drafts
  * Accepting comments
  * Will support ARB planning and regulatory efforts
* Advanced technology trucks are here
  * Commercially available and/or in demonstration
* Challenges exist, but so do solutions