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

<table>
<thead>
<tr>
<th>Date</th>
<th>Technology Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early 2014</td>
<td>Technology assessments begun</td>
</tr>
<tr>
<td>Dec. 2014</td>
<td>Board briefing status update</td>
</tr>
<tr>
<td>April 2015</td>
<td>Overview report</td>
</tr>
<tr>
<td>June 2015</td>
<td>Vehicle and Drivetrain Efficiency</td>
</tr>
<tr>
<td>July 2015</td>
<td>TRU and Commercial Harbor Craft</td>
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<tr>
<td>Sept. 2015</td>
<td>Low NOx Diesel and Natural Gas</td>
</tr>
<tr>
<td>Oct. 2015</td>
<td>Battery Electric Trucks and Buses</td>
</tr>
<tr>
<td>Nov. 2015</td>
<td>Cargo Handling, Hybrid, and Fuel Cell Electric Vehicle</td>
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</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Technology Readiness</th>
<th>Number in Service in CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parcel Delivery</td>
<td>Commercially available</td>
<td>830</td>
</tr>
<tr>
<td>Uniform &amp; Linen Delivery</td>
<td></td>
<td>110</td>
</tr>
<tr>
<td>Beverage Delivery</td>
<td></td>
<td>440</td>
</tr>
<tr>
<td>Food Distribution &amp; Other Trucks</td>
<td></td>
<td>680</td>
</tr>
<tr>
<td>Buses (Transit, Shuttle, School)</td>
<td></td>
<td>470</td>
</tr>
<tr>
<td>Other</td>
<td>Demos: Utility/Bucket Trucks, Drayage</td>
<td></td>
</tr>
</tbody>
</table>

- 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

Class 8 Hybrid Beverage Delivery Truck – Case Study *
(Based on Today’s Costs)

“F” = Fuel savings, “M” = Maintenance Savings “I” = Incentives
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 particularly suitable in early years for:
  - Transit buses
  - Shuttle buses
  - Delivery trucks
Hundreds of Medium-/Heavy-Duty BEVs in California

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Technology Readiness</th>
<th>Number in Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transit Bus</td>
<td>Commercially Available</td>
<td>~40 in California, &gt;2,500 worldwide</td>
</tr>
<tr>
<td>School Bus</td>
<td>Limited Commercial</td>
<td>4 in California</td>
</tr>
<tr>
<td>Medium-Duty</td>
<td>Limited Commercial</td>
<td>300+</td>
</tr>
<tr>
<td>Heavy-Duty (&gt; 14,000 lbs. GVWR)</td>
<td>Demonstration</td>
<td>2 Drayage, 1 Refuse</td>
</tr>
</tbody>
</table>
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 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

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Technology Readiness</th>
<th>Active/Planned Demonstrations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transit Bus</td>
<td>Limited Commercial</td>
<td>23 active/22 planned</td>
</tr>
<tr>
<td>Shuttle Bus</td>
<td>Demonstration</td>
<td>2 active/8 planned</td>
</tr>
<tr>
<td>Delivery Vehicles</td>
<td>Demonstration</td>
<td>38 active/planned</td>
</tr>
<tr>
<td>Drayage Trucks</td>
<td>Demonstration</td>
<td>12 active/planned</td>
</tr>
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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
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
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