Heavy-Duty Hybrid Vehicles
Technology Assessment

April 22, 2015
Diamond Bar, California
Overview

- Background and Improving Fuel Economy
- Technologies Evaluated
- Costs/Economics
- Conclusions
- Contacts, Next Steps
Heavy-Duty Hybrids In California Today, Improving Fuel Economy
Background

- Over 1,800 heavy-duty hybrid vehicles in CA*
  - Many Funded Through HVIP
  - Primarily Hybrid Electric Vehicles (HEV);
  - More Recently Hydraulic Hybrid Vehicles (HHV) and Plug-in Hybrid Electric Vehicles (PHEV)

- Fuel Economy: Driver for hybrids

- Industry Manufacturers
  - Vehicle OEMs: Daimler, Freightliner, Hino, Kenworth, Mack, Volvo, Navistar, PACCAR, Peterbilt

*Data from HVIP and Transit Fleet Rule reporting database
Hybrid Performance—Improving Fuel Economy

- Fuel Economy
  - Duty-cycle dependent
  - High kinetic intensity duty cycles most beneficial
    - Transient, stop-and-go
  - Improvement range from 10% – 70%
    - Mild Hybrids: 10% – 20%
    - Full Hybrids:
      - Parallel Hybrids: 20% – 50%
      - Series Hybrids: 30% – 70%
Technologies Evaluated

Types of Hybrids, Common Elements, Emissions
Many Types of Hybrids

- Mild vs. Full Hybrid
- Parallel vs. Series Hybrid
- Hybrid Electric
- Plug-in Hybrid Electric
- Hydraulic Hybrid
- Catenary
Hybrids– Bridging Technology

- Bridging technologies to BEVs, Fuel Cell HDVs
- Components
  - Battery
  - Electric motor
  - Control System
- Manufacturing
  - Modular designs
  - Improve Efficiency
  - Lower Cost
  - Integration
Hybrid Performance–Emissions

- ARB and NREL: Chassis Dynamometer Testing Heavy–Duty Hybrid and Conventional Trucks
  - Performed at CE–CERT on 3–4 Cycles Each Vehicle (3–4 repetitions)

- Test Vehicles
  - MY 2010 or newer engines
  - Beverage delivery vehicles, parcel delivery vehicles, linen delivery vehicles – hybrid & conventional

- Hybrids showed CO₂ benefits, NOₓ increases
  - Results vary by duty cycle
  - Final report in progress now
Cost/Economics

Cost, Economics, Incentive Funding
Costs/Economics: Hybrids vs. Conventional

- Hybrids have higher capital costs:
  - Conventional: $40,000 – >$160,000
  - Hybrids: $50,000+
- Savings
  - Improved fuel efficiency, maintenance
- Role of incentives
  - Reduce capital costs, accelerate technology adoption
- Return on Investment
  - Payback period: sometimes <=5 years
  - Hybrid cost expected to come down as volume increases
    - 50 percent reduction by 2020 predicted
## Heavy-Duty Hybrid Vehicle Key Technologies

<table>
<thead>
<tr>
<th>Degree of Hybridization</th>
<th>Key Technologies</th>
<th>Potential GHG/FE Reduction (per Vehicle) from Conventional Baseline</th>
<th>Incremental Cost from Conventional Baseline</th>
</tr>
</thead>
</table>
| Micro Hybrid            | • Limited engine start/stop  
                          • Limited regenerative braking                                                   | <= 10%                                                             | <= $10,000                                  |
| Mild Hybrid             | • Engine start/stop  
                          • Increased regenerative braking  
                          • Electric motor provides supplemental tractive power  
                          • Limited level of electric only operation  
                          • More sophisticated controllers                                               | 10% - 20%                                                           | $8,000-$25,000                             |
| Full Hybrid             | • Extensive integration of hybrid components  
                          • Engine start/stop – More than Mild  
                          • Extensive regenerative braking  
                          • Electric motor provides more supplemental (parallel) or sole tractive power (series)  
                          • Increased level of electric only operation  
                          • Electrification of auxiliary components  
                          • Most sophisticated controllers                                                 | 20% - 70%                                                           | $20,000-$220,000                           |
## Heavy-Duty Hybrid Vehicle Class
### Hybrid Technologies and Availability

<table>
<thead>
<tr>
<th>VEHICLE CLASS</th>
<th>KEY HYBRID TECHNOLOGIES</th>
<th>AVAILABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 2B/3 Pick Ups and Vans</td>
<td>• Parallel electric</td>
<td>NOW</td>
</tr>
<tr>
<td>Class 3 to 6 Straight Box Truck</td>
<td>• Parallel</td>
<td>NOW</td>
</tr>
<tr>
<td></td>
<td>• Series</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Electric and hydraulic</td>
<td></td>
</tr>
<tr>
<td>Class 3 to 6 Bucket Truck</td>
<td>• Parallel Electric</td>
<td>NOW DEMONSTRATION</td>
</tr>
<tr>
<td></td>
<td>• Series Electric</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• PHEV</td>
<td></td>
</tr>
<tr>
<td>Class 8 Tractor Trailer</td>
<td>• Mild parallel with idle reduction</td>
<td>UNDER DEVELOPMENT</td>
</tr>
<tr>
<td>Class 8 Refuse Hauler and Urban Transit Bus</td>
<td>• Parallel</td>
<td>NOW</td>
</tr>
<tr>
<td></td>
<td>• Series</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Electric and hydraulic</td>
<td></td>
</tr>
</tbody>
</table>
Hybrid Vocational Payback Chart
Class 8 Beverage Delivery Truck – Case Study *
(Based on Today’s Costs)

“F” = Fuel savings, “M” = Maintenance Savings “I” = Incentives
Conclusions

Hybrid Conclusions and Contacts
Heavy-Duty Hybrids: Next Steps for ARB

- Continue to work with manufacturers to address certification, OBD issues
- Continue to provide incentives to cover some or all of incremental cost, reduce payback period
- Outreach/training to inform fleet operators of the current hybrid benefits and limitations
  - Operational and maintenance savings, best duty cycles
- Innovative Technology Regulation
  - Near-term ARB certification and aftermarket part approval flexibility
Heavy-Duty Hybrid Conclusions

- Many types of hybrids
  - Mild to full
  - Parallel more widely used now, especially for higher speed delivery routes
  - Series promising longer-term applications for stop-and-go delivery routes
- Ideal vocations for hybrids are highly transient, high-power demand, high idling time
  - Package delivery, refuse haulers, urban transit bus
- Hybrids improve fuel economy
  - 10–20% for mild, up to 70% for full
  - Payback currently > 5 years for most vocations
- Hybrids reduce CO$_2$ but can increase NO$_x$
  - Need to improve system integration, certification requirements to prevent NO$_x$ increases
  - ARB’s interim certification procedures for HDVs
Heavy-Duty Hybrid Conclusions (continued)

- Goals to improve
  - Electric motors/generators, inverter/power electronics, energy storage systems, hybrid systems optimization, electrified power accessories
  - Hydraulic energy conversion devices, hydraulic energy storage, hydraulic controls

- Hydraulic hybrid technology has great potential
  - Lower cost compared to some other hybrids
  - Fuel savings + reduced maintenance = shorter payback

- Hybrid technologies have co-benefits for zero-emission technologies
  - Series hybrid technology
  - PHEV
  - Batteries
  - Electric motors
Next Steps and Contacts

Next Steps

- Technology assessment reports to be released for review
- Final NREL report on vocational hybrid truck testing to be released

Contacts

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Conclusions

Phase 2 Overall Conclusions
Phase 2 Conclusions

- Phase 1/Phase 2 together can provide 30% – 40%+ reduction in fuel consumption
- Phase 2 technologies will reduce fuel costs and provide economic benefits
- Many Phase 2 technologies pay back quickly – within 2 years – especially for high VMT applications
- Hybrid technologies take longer to payback
- Hybrids provide a pathway to zero-emission technology
**Phase 2 Conclusions (continued)**

- NO\textsubscript{x}/CO\textsubscript{2} tradeoff can be overcome: Phase 2 technologies consistent with effective, lower NO\textsubscript{x} standard

- Stringent, national Phase 2 program will benefit the environment and fleets

- ARB expects to work cooperatively with U.S. EPA to develop lower NO\textsubscript{x} standard post-Phase 2

- If federal program doesn’t meet our needs, ARB will develop California–specific requirements for GHG/NO\textsubscript{x} reductions

- Action needed ASAP
Questions?