Heavy-Duty Hybrid Vehicles
Technology Assessment

April 22, 2015
Diamond Bar, California

California Environmental Protection Agency
Air Resources Board

Overview

- Background and Improving Fuel Economy
- Technologies Evaluated
- Costs/Economics
- Conclusions
- Contacts, Next Steps

Background

- Heavy-Duty Hybrids In California Today, Improving Fuel Economy

Background

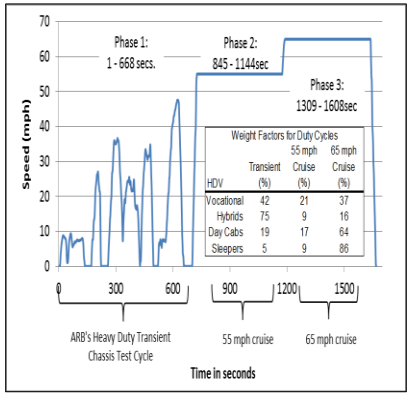
- Over 1,800 heavy-duty hybrid vehicles in CA*
  - Many Funded Through HVIP
  - Primarily Hybrid Electric Vehicles (HEV);
  - More Recently Hydraulic Hybrid Vehicles (HHV) and Plug-in Hybrid Electric Vehicles (PHEV)
- Fuel Economy: Driver for hybrids
- Industry Manufacturers
  - Vehicle OEMs: Daimler, Freightliner, Hino, Kenworth, Mack, Volvo, Navistar, PACCAR, Peterbilt
  - Powertrain: Allison, BAE, Crosspoint Kinetics, Eaton, Efficient Drivetrains, Enova, Hino, Lightning Hybrids, Odyne, Parker Hannifin, Via, Volvo, XL Hybrids

*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%

EPA GHG



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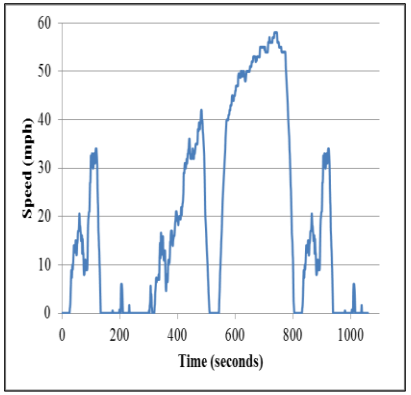

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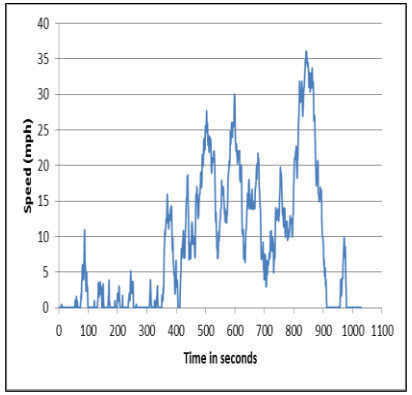

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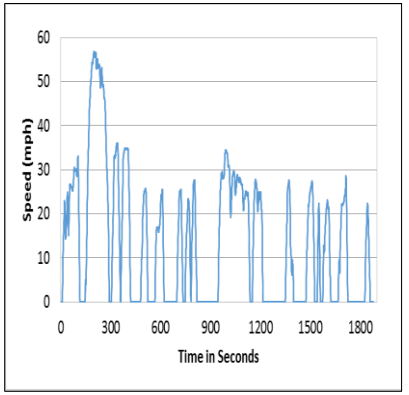


Technologies Evaluated

- 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 CO_2 benefits, NO_x 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

DEGREE OF HYBRIDIZATION	KEY TECHNOLOGIES	Potential GHG/FE Reduction (per Vehicle) from Conventional Baseline	Incremental Cost from Conventional Baseline
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

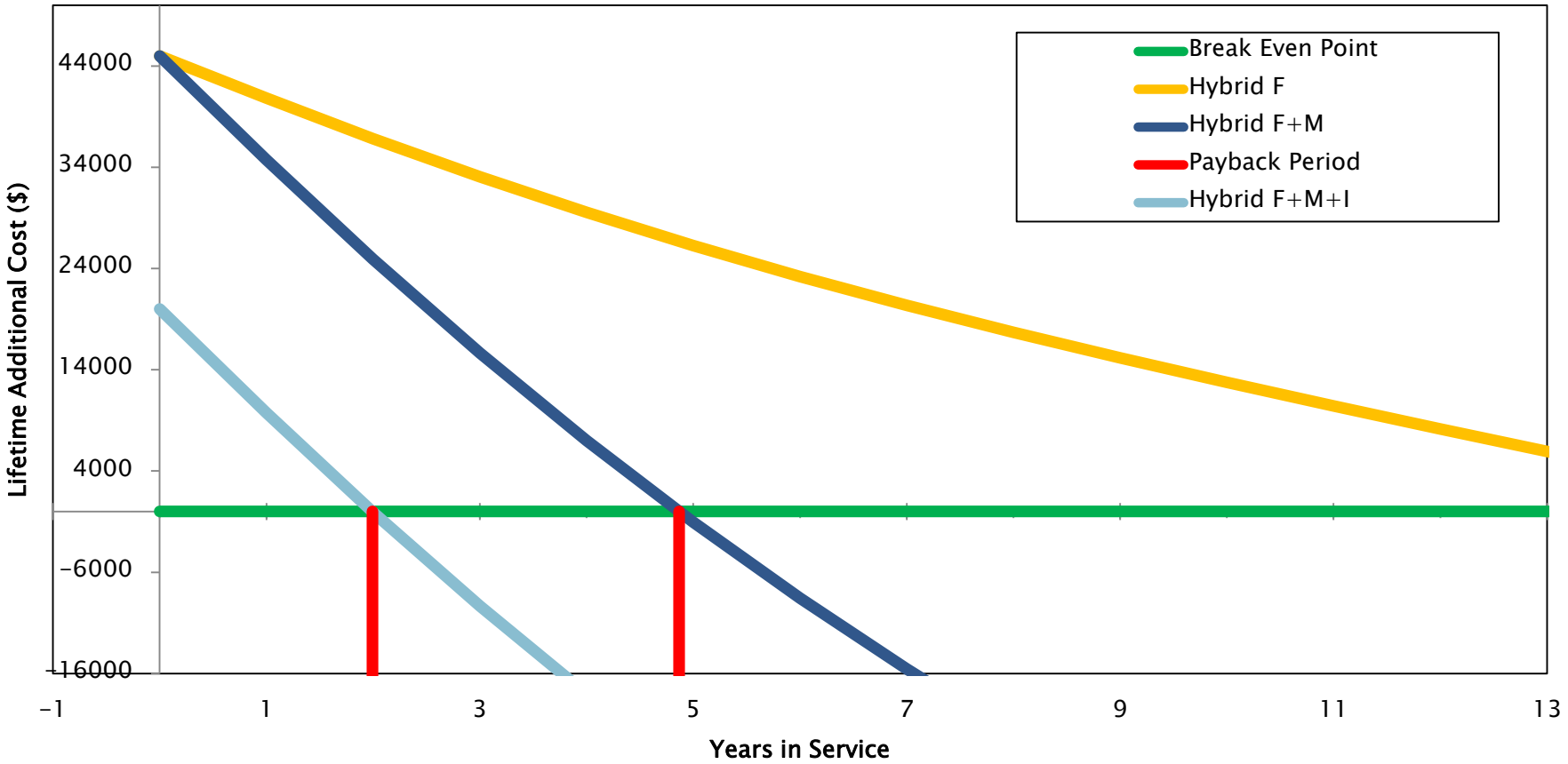
Heavy-Duty Hybrid Vehicle Class
Hybrid Technologies and Availability

VEHICLE CLASS	KEY HYBRID TECHNOLOGIES	AVAILABILITY
Class 2B/3 Pick Ups and Vans	• Parallel electric	NOW
Class 3 to 6 Straight Box Truck	• Parallel • Series • Electric and hydraulic	NOW
Class 3 to 6 Bucket Truck	• Parallel Electric • Series Electric • PHEV	NOW DEMONSTRATION
Class 8 Tractor Trailer	• Mild parallel with idle reduction	UNDER DEVELOPMENT
Class 8 Refuse Hauler and Urban Transit Bus	• Parallel • Series • Electric and hydraulic	NOW

Hybrid Vocational Payback Chart

Class 8 Beverage Delivery Truck – Case Study *

(Based on Today's Costs)



"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

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
- 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

- Truck Sector Lead:
  - Kim Heroy-Rogalski kheroyro@arb.ca.gov
  - (916) 327-2200
- Hybrid Truck Lead:
  - Robert Nguyen rnguyen@arb.ca.gov
  - (916) 327-2939

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_x/CO_2 tradeoff can be overcome: Phase 2 technologies consistent with effective, lower NO_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_x standard post-Phase 2
- If federal program doesn't meet our needs, ARB will develop California-specific requirements for GHG/NO_x reductions
- Action needed ASAP

Questions?