Air Resources Board Symposium on California's Development of its Phase 2 Greenhouse Gas Emission Standards for On-Road Heavy-Duty Vehicles

April 22, 2015

Engine/Powerplant and Drivetrain Optimization

Vehicle /Trailer Efficiency Technology Assessment

Presentation Outline

- Phase 1: California Benefits
- Scope of Technology Assessment
- Key Engine and Vehicle technologies
- Potential Fuel Consumption Reductions (FCRs) and Costs
  - Over-the-Road Tractor/Trailers
  - Short-Haul/Regional Tractor-Trailers
  - Vocational Trucks
  - Pick-Ups and Vans
- Avoiding the NOx-GHG Trade-off
- Next steps
- Contacts

Phase 1: California Benefits

- Designed to get "Off-The-Shelf" GHG control technologies on vehicles

CO2 Emissions from Affected Vehicles (in millions metric tons per year)			
Calendar Year	Baseline CO2 Emissions	CO2 Emissions with Phase 1	CO2 Reductions
2020	43.2	40.1	7.18%
2035	55.5	48.6	12.5%

Scope of Technology Assessment

- Literature search of fuel consumption reduction improvement technologies
  - Most information relative to 2010 baseline
  - Key Sources:
    - (NAS, 2010) Technologies and Approaches to Reducing the Fuel Consumption (FC) of HDV's
    - (TIAX, 2009) Assessment of FC Technologies for HDV's
    - (ICCT, 2013-2014) Various reports on SuperTruck progress, trailer technologies, heavy-duty vehicle research

How does ARB's technology assessment relate to Phase 1and Phase 2 standards?

- 2010 engine/vehicle technologies serve as the baseline for both Phase 1 and this technology assessment
- Comparing Phase 1 standards to the findings of this technology assessment provides insight into potential additional benefits and costs from Phase 2

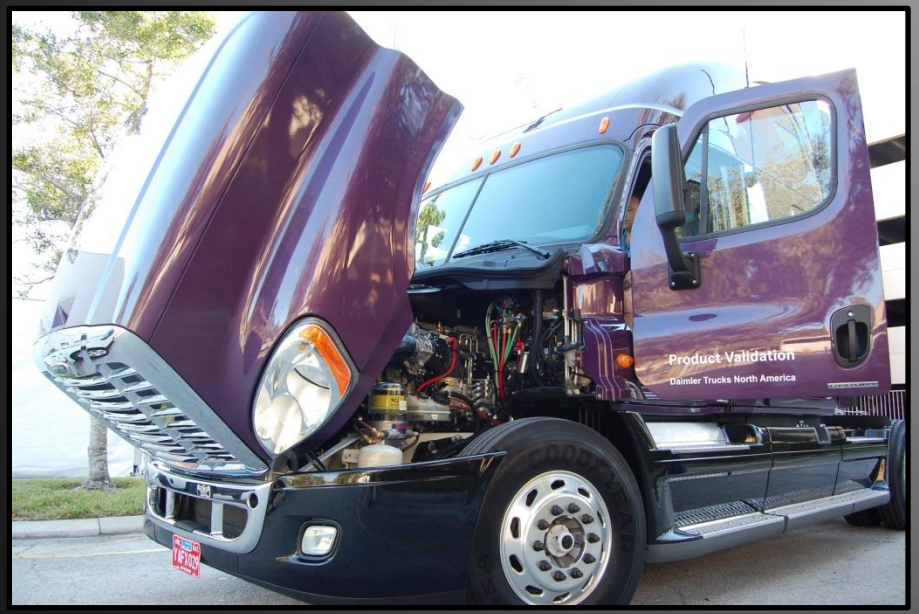
Progress Achievable Beyond Phase 1

National Academy of Sciences Estimated Potential GHG/Fuel Consumption Reduction (FCR) per Vehicle from Applying Engine/Vehicle Technologies

Category	Phase 1 Reductions from 2010 baseline	Potential from 2010 baseline (based on NAS*)	Potential Benefits from Phase 2
HD Tractor-Trailer (Class 7-8)	Up to 23%	48%	25% or more
HD Vocational (Class 3-8)	6-9%	19-33%	13-24%
HD Pick-ups and vans (Class 2b)	10-15%	32%	17-22%

* Does not include Hybrid or Electric (covered in Hybrid Technology Assessment category)

What are the key engine and vehicle technologies for the various vehicle classes? And at what costs?



Key Technologies

ENGINE TECHNOLOGIES

1. Combustion and Fuel Injection Optimization
2. Air Handling Improvements
3. Reduced Friction and Auxiliary Load Reduction
4. Engine Downsizing
5. Higher-Efficiency Aftertreatment
6. Advanced Transmissions/Engine Downspeeding
7. Waste Heat Recovery
8. Stop-Start
9. Automatic Neutral Idle
10. Cylinder De-activation

VEHICLE EFFICIENCY TECHNOLOGIES

1. Aerodynamics
2. Low-Rolling Resistance Tires
3. Automatic Tire Inflation System
4. Air Conditioning System Improvements
5. Axle Efficiency
6. Connected Vehicles (Platooning, predictive cruise control)
7. Vehicle Speed Limiters
8. Lightweighting
9. Idle Reduction

FUTURE ENGINE TECHNOLOGIES

1. Opposed Piston Engines
2. Free Piston Engines
3. LTC Combustion
4. Camless Engines

GASOLINE-SPECIFIC ENGINE TECHNOLOGIES (Class 2b and 3)

1. Lean Burn Gas Direct injection (GDI)
2. Stoichiometric GDI

Three main vehicle categories

- Heavy-Duty Tractors (Class 7-8)
- Heavy-Duty Vocational (Class 3-8)
- Heavy-Duty Pick-ups and Vans (Class 2b-3)

Class 7/8 Tractors

	Over the Road	• Younger Trucks; High Annual VMT • Mostly higher average speed, highway driving
	Short Haul/ Regional	• Between cities; Drayage; Day Cabs • Includes second use trucks; trucks with smaller engines

Class 3-8 Vocational Work Trucks

	Urban	• Cargo, freight, delivery collection • Lower VMT; Lower Average speed; Lots of stop start
	Rural/ Intracity	• Cargo, freight, delivery collection • Higher VMT; Higher Avg speed; Combined urban/ highway
	Work site support	• Utility trucks, construction, etc. • Lots of idle time; Lots of PTO use

Class 2B/3

	Pickups/ Vans	• Commercial use; Automotive OEMs & volumes

Summarizing Results from Technology Assessment

- Next slides provide an estimate of the potential fuel consumption reductions associated with suites of technologies applicable to each vehicle category
  - From a 2010 baseline
  - Highly dependent on truck class and duty cycle
- Incremental cost estimates based mostly on estimates from 2009
- Payback across all vehicle categories
  - The more miles driven, the quicker the payback
  - Some categories will not realize total payback over typical vehicle life
- Serves as starting point for further evaluation of technology packages, NOT what we recommend as cost-effective for the Phase 2 stringency
  - Technologies need to be tested as part of an integrated package

Simple Payback Analysis

- Estimate payback period Post Phase 1
- Incremental Technology Cost

Technology Assessment $	–	Phase 1 $	=	Post Phase 1$

- Summation of Annual Fuel Cost Savings

Technology Assessment: Fuel Savings	–	Phase 1: Fuel Savings	=	Post Phase 1: Fuel Savings

- Payback Period: Number of years it takes for the (Incremental Technology Costs) to equal the (Summation of Annual Fuel Cost Savings)

Heavy Duty Class 7-8 Tractors Key Technologies

Over-The-Road Tractor Trailers

	KEY TECHNOLOGIES	Potential GHG/FC Reduction (per Vehicle) from 2010 baseline		Incremental Cost from 2010 baseline	
		Tech. Assessment	Post-Phase 1	Tech. Assessment	Post-Phase 1
Engine/ Drivetrain	• Combustion and Fuel Injection Optimization • Air Handling Improvements • Reduced Friction and Auxiliary Load Reduction • Downsizing • Higher efficiency aftertreatment • Advanced Transmissions /Engine • Downspeeding • Waste Heat Recovery	43% (25%-60%)	**22%*** (8%-36%)	$37,550 ($16,800-$58,300)	**$29,100** ($8,700-$49,500)
Vehicle	• Aerodynamics • Low-Rolling Resistance Tires • Automatic Tire Inflation System • Air Conditioning System Improvements • Axle Efficiency • Predictive Cruise Control • Idle Reduction				

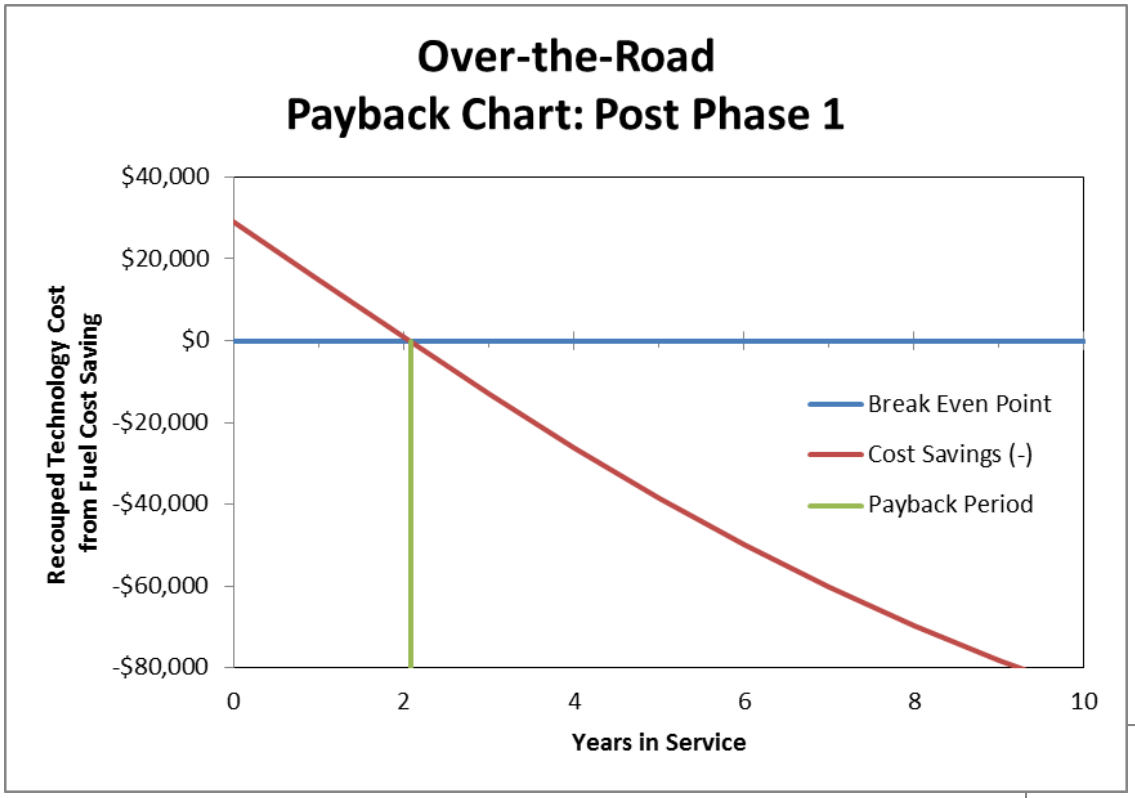
*$14,200 savings after first year

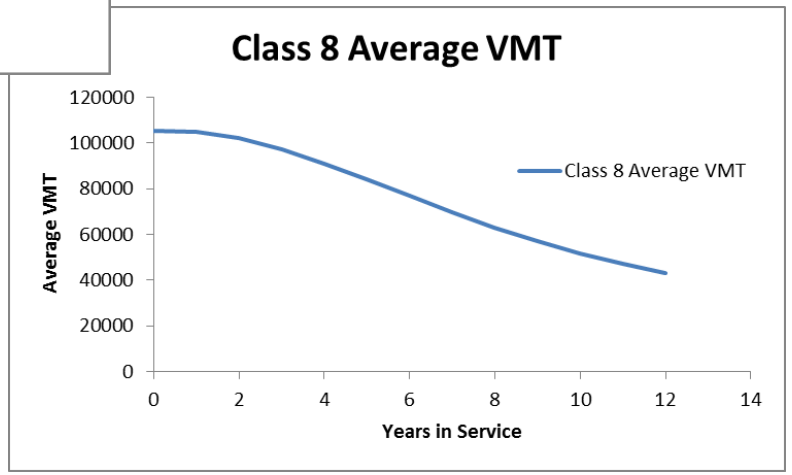
Improvements in Trailer Efficiency

- Interviews of fleet owners and manufacturers (22 total companies) conducted by the International Council on Clean Transportation (ICCT) illustrate the cost effectiveness of van trailer aerodynamic devices and the acceptance by the trailer industry.

Technology	Fuel Savings	Cost to End User		Typical payback time	Adoption in New Trailer Sales
		High	Low		
Side skirts – average	3%	$1,100	$700	1–2 years	40%
Side Skirts – best	7%			<1 year	
Boat tails – average	3%	$1,600	$1,000	2–3 years	3%
Boat tails – best	5%			1–2 years	
Gap reducers	1%–2%	$1,000	$700	2–5 years	Minimal
Underbody devices	2%–5%	$2,200	$1,500	2–5 years	3%

Payback from Post-Phase 1 Technologies





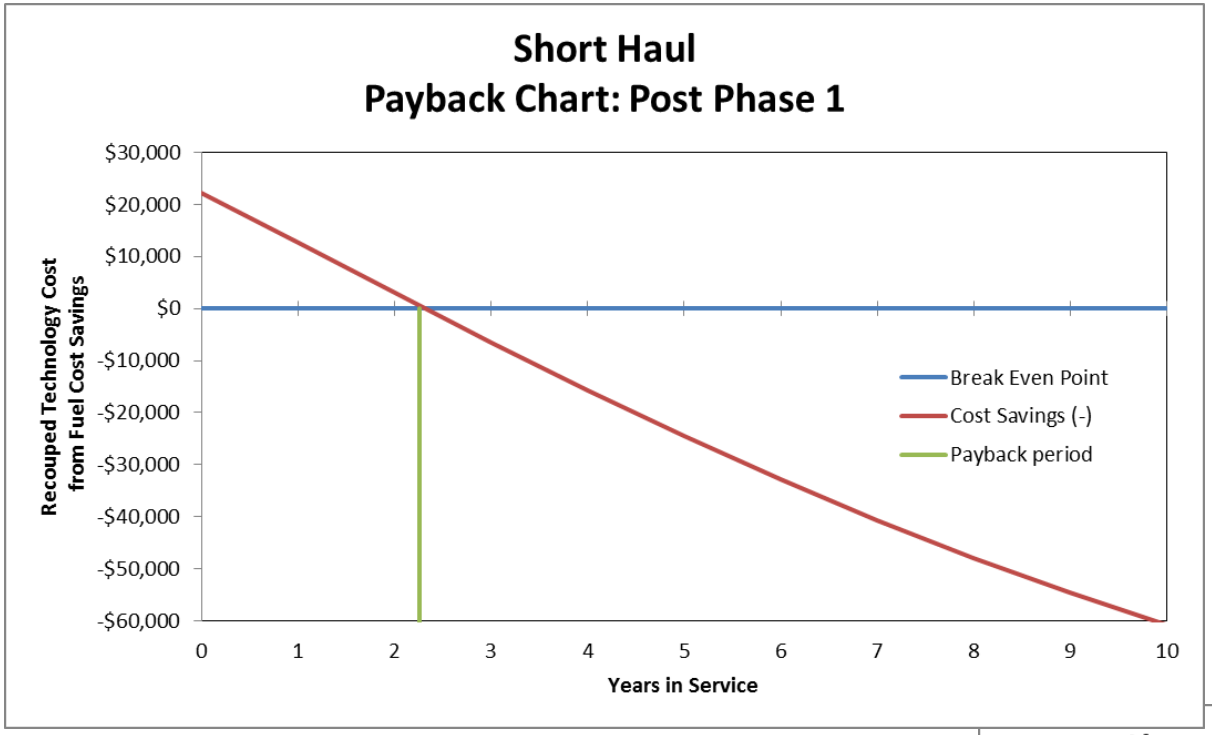
Heavy Duty Class 7-8 Tractors Key Technologies

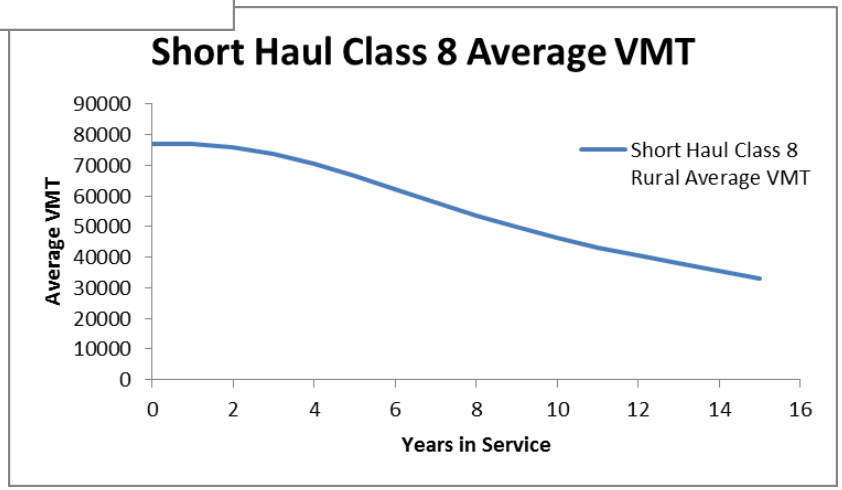
Short-Haul Regional Tractor Trailers

	KEY TECHNOLOGIES	Potential GHG/FC Reduction (per Vehicle) from 2010 baseline		Incremental Cost from 2010 baseline	
		Tech. Assessment	Post-Phase 1	Tech. Assessment	Post-Phase 1
Engine/ Drivetrain	• Combustion and Fuel Injection Optimization • Air Handling Improvements • Reduced Friction and Auxiliary Load Reduction • Downsizing • Higher efficiency aftertreatment • Advanced Transmissions /Engine Downspeeding	33% (18% -47%)	**21%*** (8%-33%)	$25,850 ($21,900-$29,800)	**$22,200** ($18,600-$25,800)
Vehicle	• Low-Rolling Resistance Tires • Automatic Tire Inflation System • Air Conditioning System Improvements • Axle Efficiency				

*$9,620 savings after first year

Payback from Post-Phase 1 Technologies



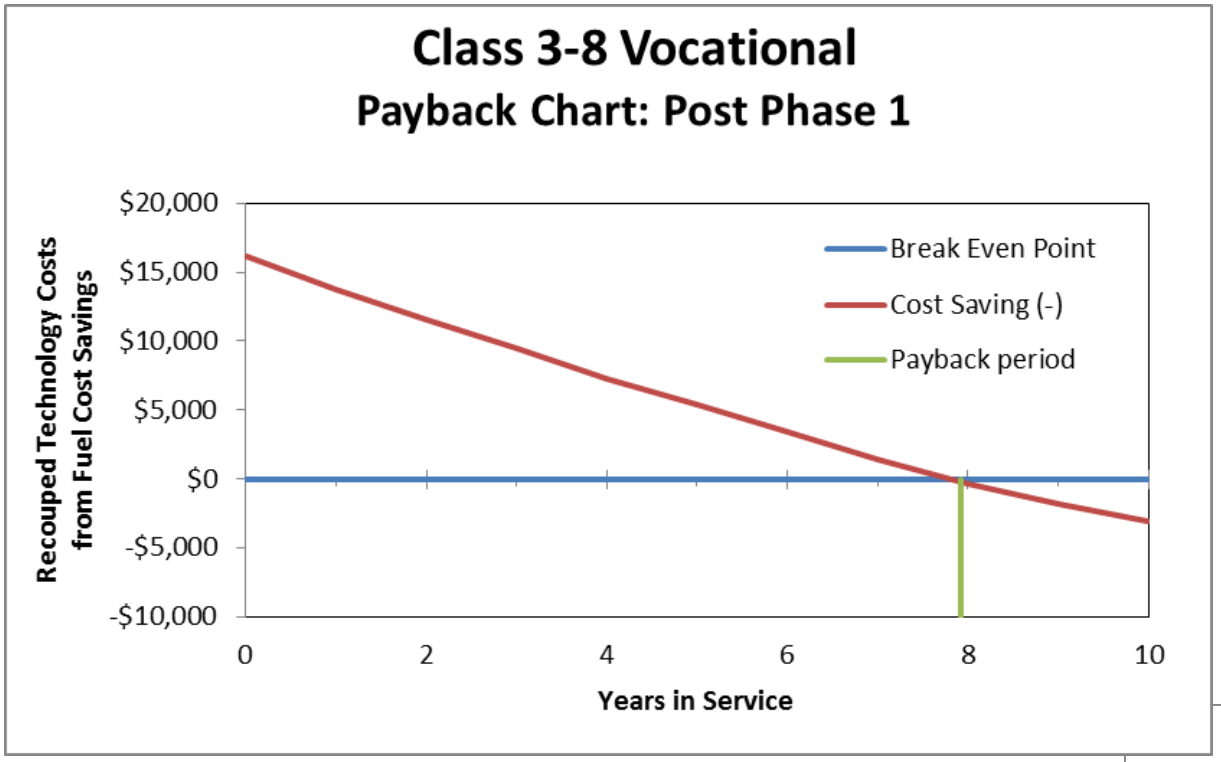


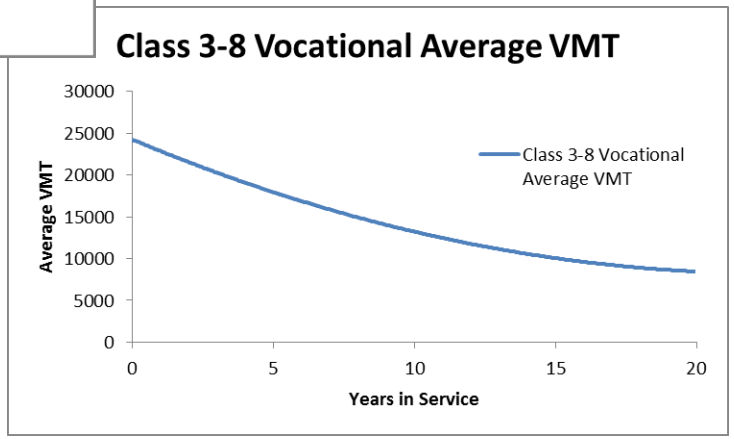
Heavy-Duty Class 3-8 Vocational Work Trucks

	KEY TECHNOLOGIES	Potential GHG/FC Reduction (per Vehicle) from 2010 baseline		Incremental Cost from 2010 baseline	
Engine/ Drivetrain	• Combustion and Fuel Injection Optimization • Air Handling Improvements • Reduced Friction and Auxiliary Load Reduction • Downsizing • Higher efficiency aftertreatment • Advanced Transmissions /Engine Downspeeding • Stop-Start	Tech. Assessment	Post-Phase 1	Tech. Assessment	Post-Phase 1
Vehicle	• Aerodynamics (Rural/Intercity) • Lightweighting • Low-Rolling Resistance Tires • Automatic Tire Inflation System • Air Conditioning System Improvements • Axle Efficiency	29% (19%-39%)	**22%*** (13%-30%)	$16,550 ($10,800-$22,300)	**$16,165** ($10,500-$21,830)

*$2,400 savings after first year

Payback from Post-Phase 1 Technologies



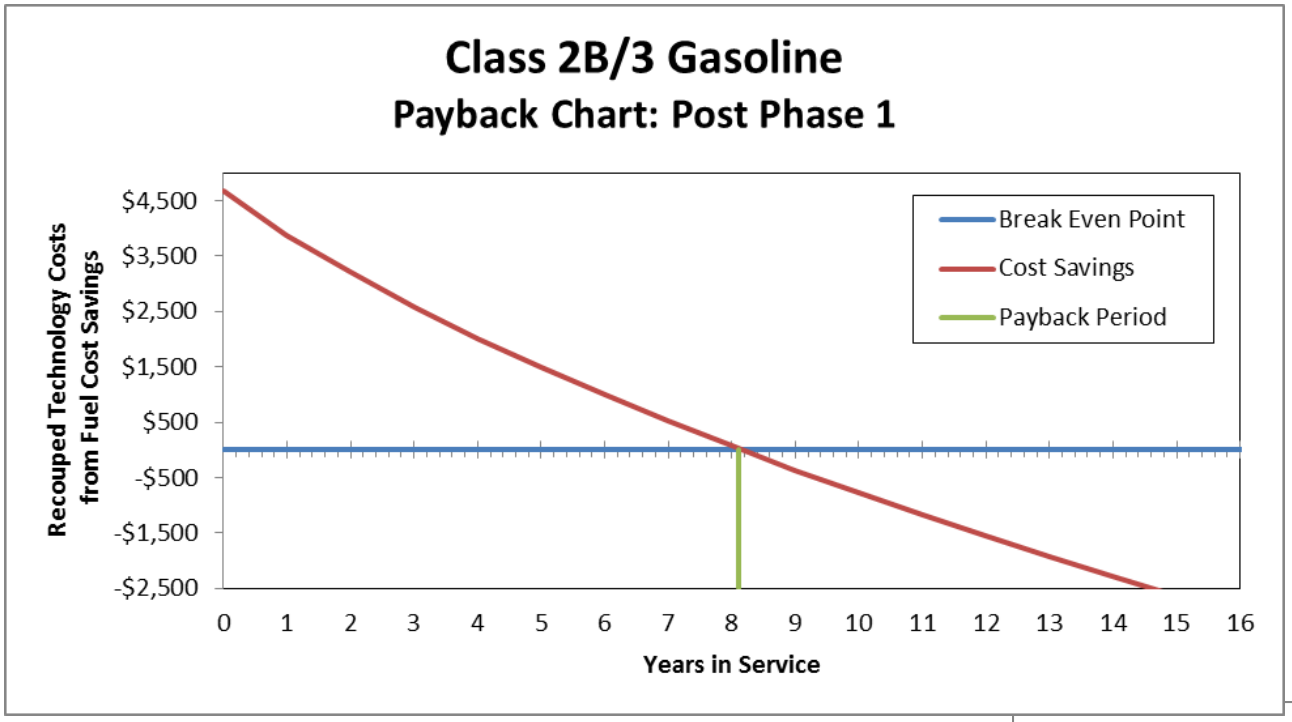


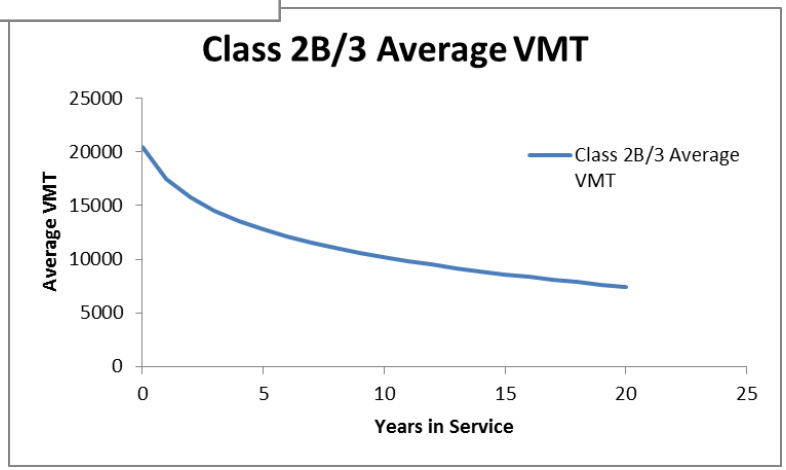
Heavy Duty Pick-ups and Vans (Class 2b-3) (Gasoline)

	KEY TECHNOLOGIES	Potential GHG/FC Reduction (per Vehicle) from 2010 baseline		Incremental Cost from 2010 baseline	
Engine/ Drivetrain	• Air Handling Improvements • Reduced Friction • Downsizing • Higher efficiency aftertreatment • Advanced Transmission/ Downspeeding • Cylinder Deactivation • Stoichiometric GDI • Stop-Start	Tech. Assessment	Post-Phase 1	Tech. Assessment	Post-Phase 1
Vehicle	• Aerodynamics • Low-Rolling Resistance Tires • Automatic Tire Inflation System • Air Conditioning System Improvements • Lightweighting	27% (19% - 35%)	**17%*** (9% -25%)	$5,900 ($3,900 - $7,900)	**$4,700** ($2,700 - $6,700)

*$800 savings after first year

Payback from Post-Phase 1 Technologies



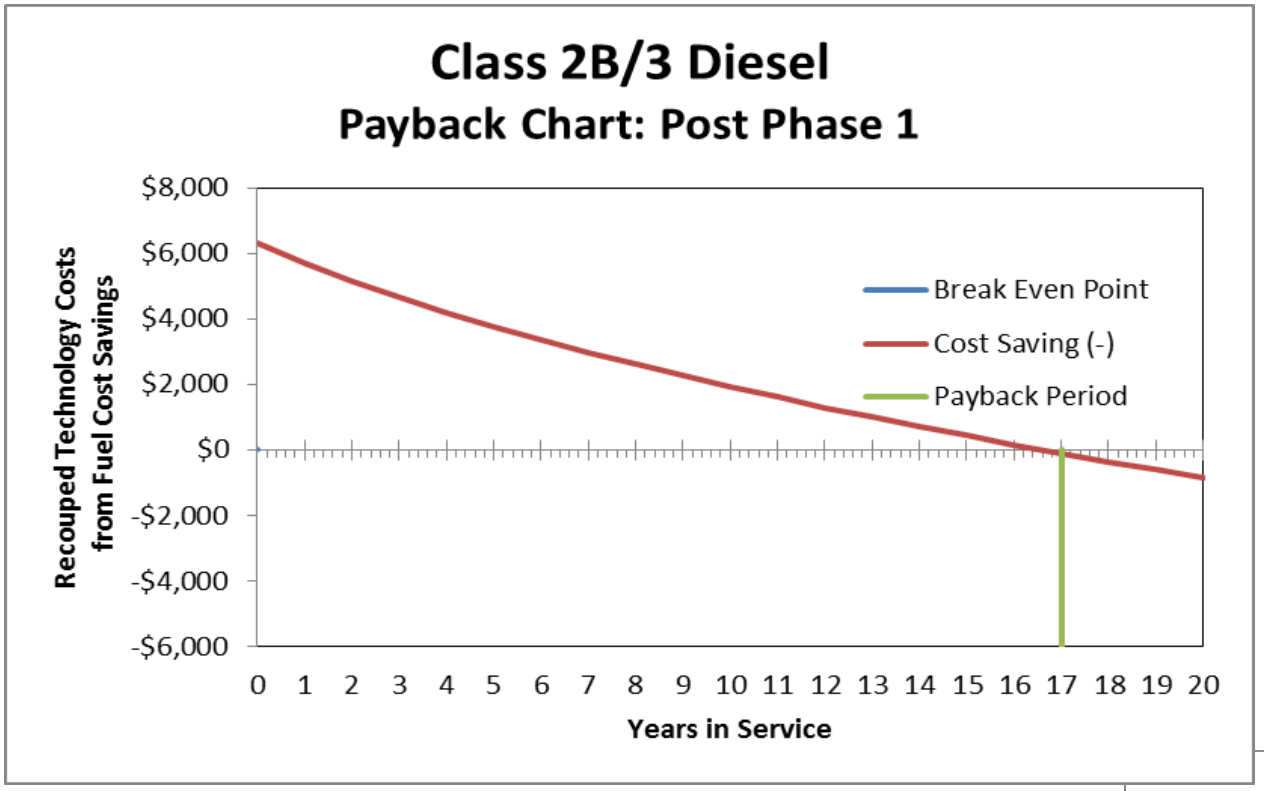


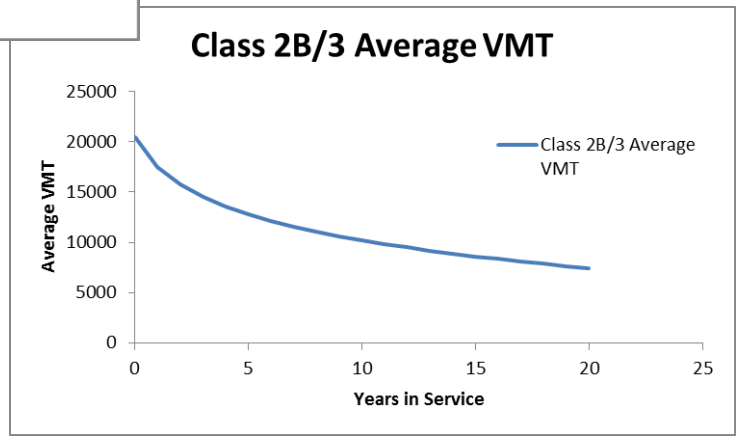
Heavy Duty Pick-ups and Vans (Class 2b-3) (Diesel)

	KEY TECHNOLOGIES	Potential GHG/FC Reduction (per Vehicle) from 2010 baseline		Incremental Cost from 2010 baseline	
Engine/ Drivetrain	• Combustion and Fuel Injection Optimization • Air Handling Improvements • Reduced Friction • Higher Efficiency Aftertreatment • Advanced Transmissions/ Engine Downspeeding • Stop-Start	Tech. Assessment	Post-Phase 1	Tech. Assessment	Post-Phase 1
Vehicle	• Aerodynamics • Low-Rolling Resistance Tires • Automatic Tire Inflation Systems • Air Conditioning System Improvements • Lightweighting	27% (17% - 36%)	**12%*** (2% - 21%)	$7,300 ($4,300–$10,400)	**$6,300** ($3,300–$9,400)

*$640 savings after first year

Payback from Post-Phase 1 Technologies





Avoiding the GHG/NOx Tradeoff in Diesel Engines

- SCR technology has allowed optimization for high fuel efficiency while achieving low NOX levels
- Need for a balanced approach to maximize both GHG and NOx reductions
  - Systems integration important
  - Engine operation and control strategies must optimize both in-use performance and emission control
- Promote technologies/strategies that have both GHG and NOx benefits
  - Improved aerodynamics, reduced friction, idle reduction
  - Connected vehicle technologies
  - Stop-start
  - Advanced combustion strategies

Conclusions

- Phase 1 GHG standards dramatically reduced GHG from heavy duty trucks
  - Phasing in now thru 2018
  - 6-23% GHG reduction depending on vehicle application
- Greater GHG reductions possible
  - Stringency options for Phase 2 currently being developed
  - Potential for up to 36% additional GHG reduction
- Many promising technologies
  - Aerodynamics, Advanced Transmissions/Downspeeding, Stop-Start, Waste Heat Recovery
  - Best options depend on truck class and duty cycle
- GHG/NOx considerations must be taken into account
  - Simultaneous reduction in both pollutants is possible

Next Steps

- Draft Technology Assessment Document Scheduled for Release April 2015
  - Comments requested by June 2015

- Related Work
  - US EPA Phase 2 NPRM Scheduled for Publication in Federal Register – Spring 2015
  - Information Board Item on Phase 2 Update – September 2015

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