DAIMLER

Super Truck Program: Vehicle Project Review

Recovery Act –Class 8 Truck Freight Efficiency Improvement Project

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Project ID: ARRAVT080

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Timeline

- Project start: April 2010
- Project end: March 2015
- Percent complete: 100%

Budget

- Total project $79,119,736
- Vehicle budget $47,486,735
  - DOE share $ 19,228,552
  - DTNA share $ 19,228,552

Barriers

- Resolve thermal & fluid dynamics tradeoffs between aero & cooling
- Rejecting more heat in a smaller, aerodynamic hood & engine compartment
- Development of safe and efficient high voltage power distribution, integrating multiple HV energy sources
- Making tradeoffs between efficiency, cost and weight
- Vehicle controls integration (aux, hybrid, powertrain, waste heat, predictive)

Partners

- Detroit Diesel
- Schneider National, Walmart
- National Renewable Energy Lab
- Oregon State University
- Strick Trailer
- Michelin
- …

Objectives and Milestones

Develop and demonstrate a 50% total increase in vehicle freight efficiency:

- *At least 20% improvement through a heavy-duty diesel engine capable of achieving a 50% brake-thermal efficiency*
- *Identify key pathways towards achieving 55% through modeling and analysis*

Timeline	Phase Description	Milestones
4/10–3/11	**Analysis:** *(1) Technology Modeling/Analysis and Initial Component Development and Demonstration*	Develop analytical roadmap: • **50% vehicle freight efficiency improvement** • 50% engine brake thermal efficiency
4/11–3/12	**Specification:** *(2) Experimental Demonstration of Technology Building Blocks for Intermediate Goals*	Experimentally demonstrate technology building blocks: • **25% vehicle freight efficiency improvement** (system level test) • 46% engine brake thermal efficiency
4/12–5/13	**Design:** *(3) Technology Identifications and Final Component Development and Demonstration*	Identify and initially develop technology building blocks: • 50% vehicle freight efficiency improvement (system level test & analysis) • 50% engine brake thermal efficiency
6/13–6/14	**Build:** *(4) Experimental Demonstration of Technology Building Blocks for 50% Engine Thermal Efficiency and 50% Vehicle Efficiency*	Experimentally demonstrate technology building blocks: • 50% vehicle freight efficiency improvement (system level test) • 50% engine brake thermal efficiency
7/14–3/15	**Test:** *(5) Final System Integration and Demonstration*	Experimental demonstration: • 50% vehicle freight efficiency improvement (entire vehicle test) • 50% engine brake thermal efficiency (engine test) • 55% engine brake thermal efficiency (engine analysis)

Phase 5: Road to 50%

A-Sample *(Performance Test, April 2014)*

- Aero hood, bumper, active grille
- Stock DD11 Engine, DT12 DD Trans. + eCoast
- Waste Heat Recovery (electrical expander & vehicle cooling)
- 6x2 Axle Config., 2.28:1 RAR + oil baffle
- GHC Hybrid B-sample (120kw eMotor, 360v, 2.4 kw-hr Li-Ion Bat)
- eHVAC (HV compressor, remote condenser, electrical fan)
- eMotor engine start
- Cab insulation package
- Clutched air compressor / electronic air control
- AccuSteer (closed center steering gear + accumulator)
- Low rolling resistance wide based single tires
- Thermal mgt. (variable speed fan, water pump)
- Trailer aero., lightweighting and solar

A-Sample

Tinker Trucks

ST Final Demonstrator

Final Demonstrator *(FE Test, Oct 2014 – Jan 15)*

A-Sample Technologies, plus…

- Full Tractor Aero
  - *cab/sleeper, underbody, drive wheel fairing, mirror cam, steer wheel, full side extender*
- 50% BTE DD11 Engine + WHR
- Predictive hybrid controller
- Predictive engine controller
- New final drive active oil management with FE gear oil
- Lightweight Aluminum Frame and cross members
- Ultra Lightweight Air Suspension
- Advanced Loadshift 6x2
- Solar reflective paint
- Enhanced Trailer aerodynamics

SuperTruck Final Demonstration Test

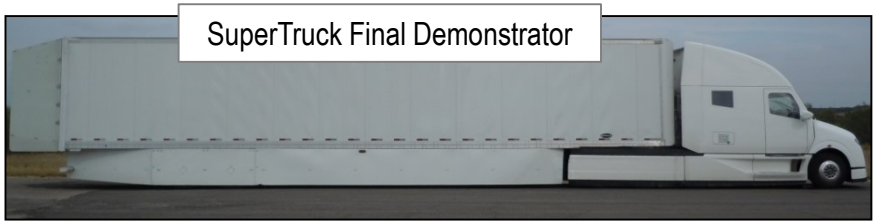
October 2014 – January 2015

Gross Vehicle Weight (lb)	
Total	**65,000**
Tare	34,000
Payload	**31,000**

2009 Baseline Cascadia

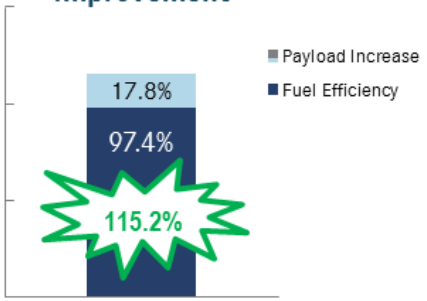
Gross Vehicle Weight (lb)	
Total	**65,000**
Tare	31200
Payload	**33,800**

SuperTruck Final Demonstrator

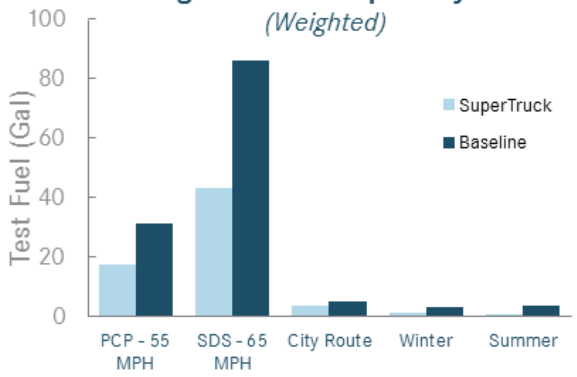


➔ **12.2 mpg average over 5 days of testing on the San Antonio – Dallas Route**

Freight Efficiency Improvement

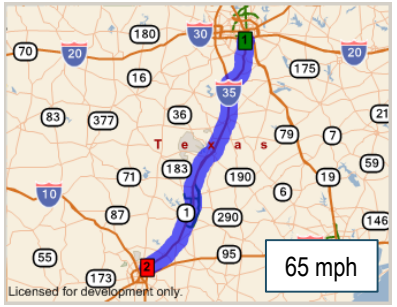


Average Fuel Consumption by Route
(Weighted)



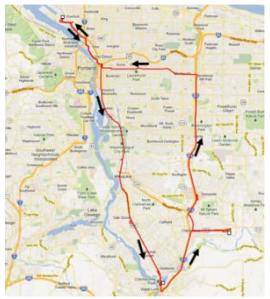
3 Drive Cycle Routes + 2 Parked Tests

San Antonio Dallas



Portland Canyonville

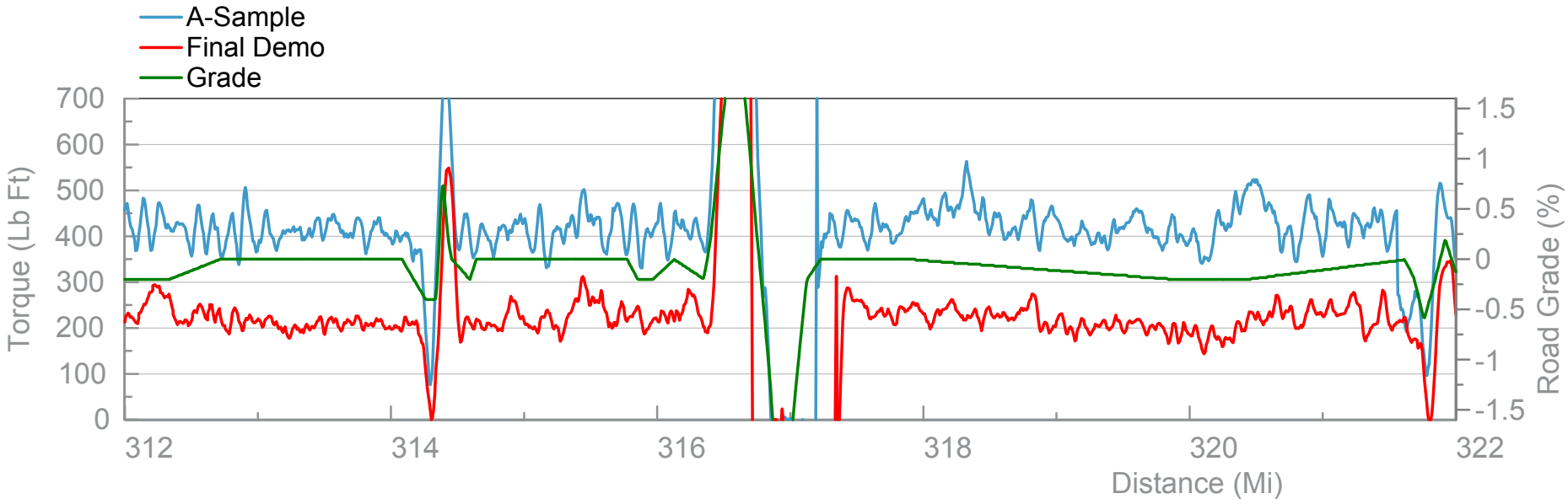
Portland City



Torque Reduction: A-Sample vs Final Demonstrator

Comparison of A-Sample and Final Demonstrator on the same section of road

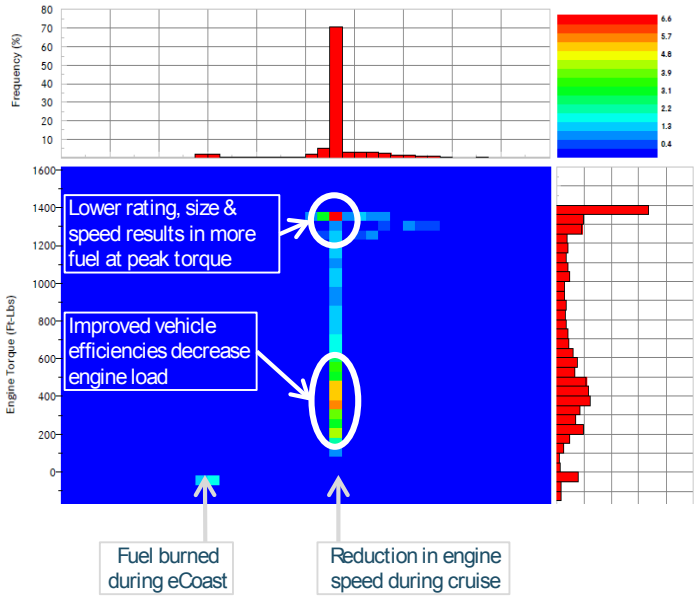
- Similar weather conditions between each run.
- Large reduction in torque on flat ground.



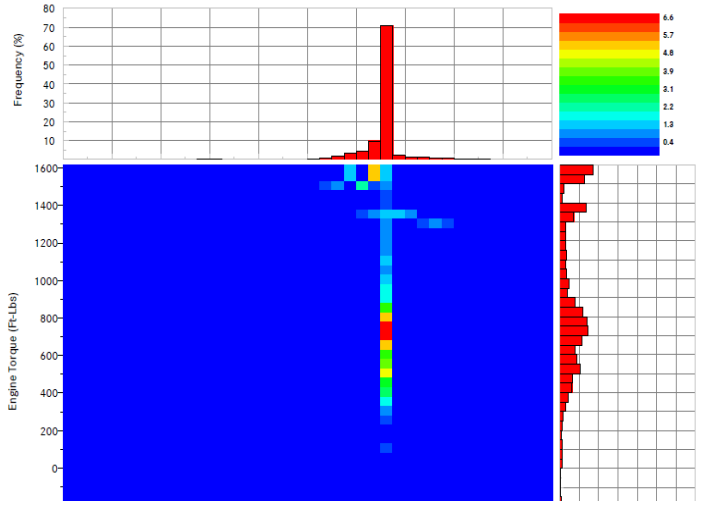
➔ Significant reduction of road load observed in lower engine torque levels

Engine Operations on Portland Canyonville Route

SuperTruck Final Demonstrator



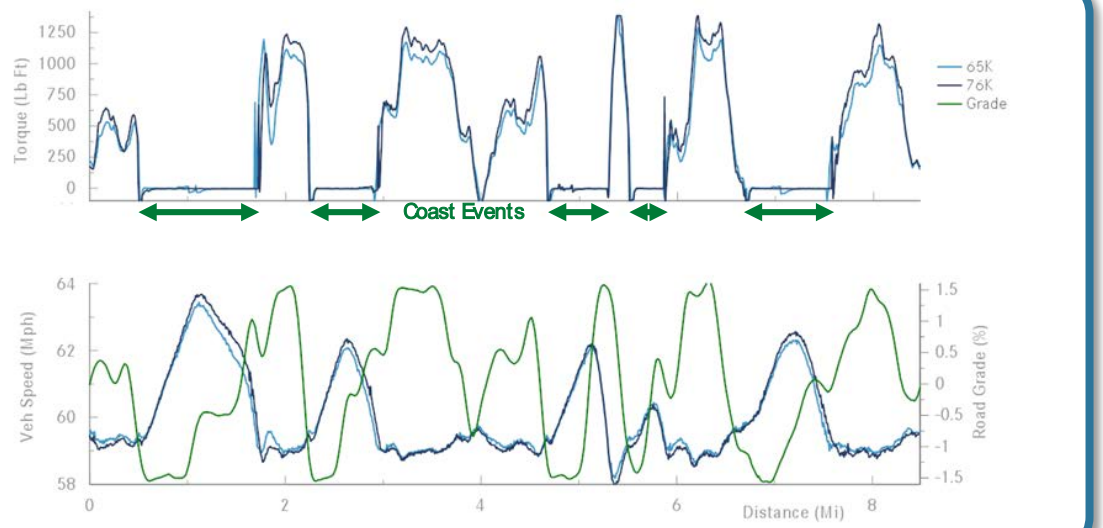
Baseline 2009 Cascadia



➔ Performance enhancements based on smaller engine spec, improve vehicle efficiency and eCoast

Note: Data extracted from representative test day 10/ 21 PCP

eCoast Benefits Enhanced on SuperTruck



Highway Test evaluation

San Antonio – Dallas Route

eCoast Performance		
	%Drive time *(green)*	eCoast Mode
Final Demo		Predictive
A-Sample		Standard
Baseline		*N/A*

Closed Test Track

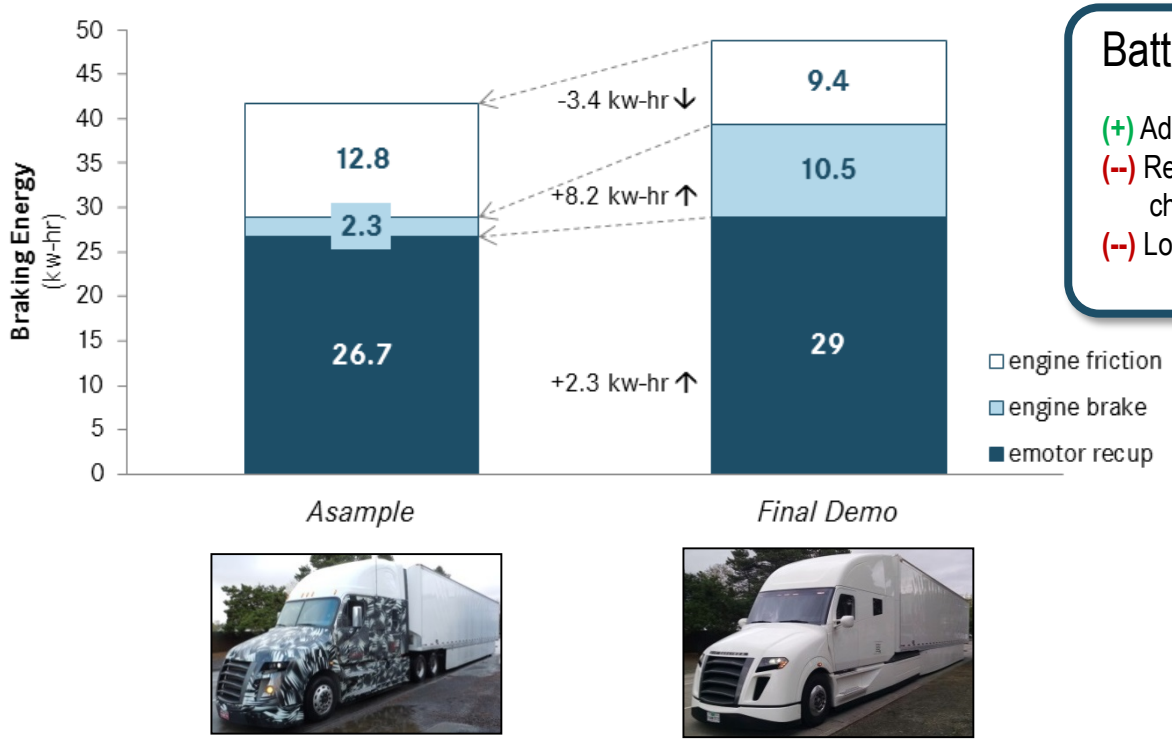
- 5 Coast Sections: 40%– 43%Coast time
- Improved vehicle extends eCoast intervals
- Hybrid enabled, but seldom used

eCoast performance enhanced

- Lower vehicle drag provides more eCoast opportunity
- Predictive Technologies enhance eCoast with 3D map data

Brake Energy Evaluation

A-Sample vs. Final Demonstrator Vehicles on San Antonio – Dallas Route

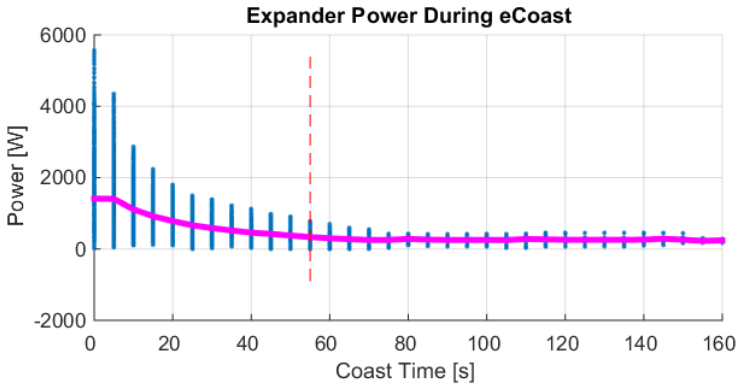


Battery Performance Results

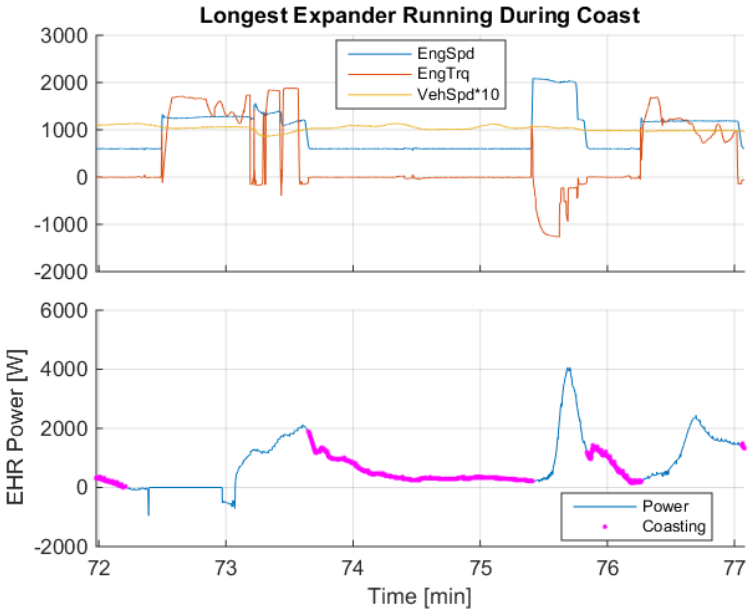
(+) Adequate Battery Sizing (sufficient SoC)
(--) Required braking power exceeded battery charging limits
(--) Long braking duration caused battery derate

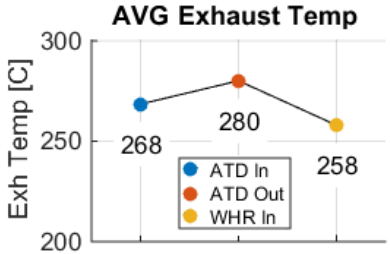
➔ An increase in brake energy on the final demonstrator translates into more engine braking, rather than hybrid recuperation

Exhaust Heat Recovery Performance Dependent on Vehicle Design and Operations



➔ Tradeoff observed: expander '*loses steam*' during coasting





➔ Exhaust insulation needed to minimize temperature loss to the EHR boiler

SuperTruck Technology Evaluation

Commercially viable technologies

- Engine *(e.g. variable water pump, rating, downspeeding)*
- Predictive Tech. *(e.g. cruise control, shifting)*
- Powertrain *(e.g. direct drive AMT, eCoast)*
- Aerodynamics *(e.g. cab/ chassis side extenders, bumper, windshield seals)*
- *Tires* *(e.g. energy efficient, wide based singles)*
- *Trailer* *(e.g. EPA Smartway aerodynamics)*

Commercialization hurdles remain

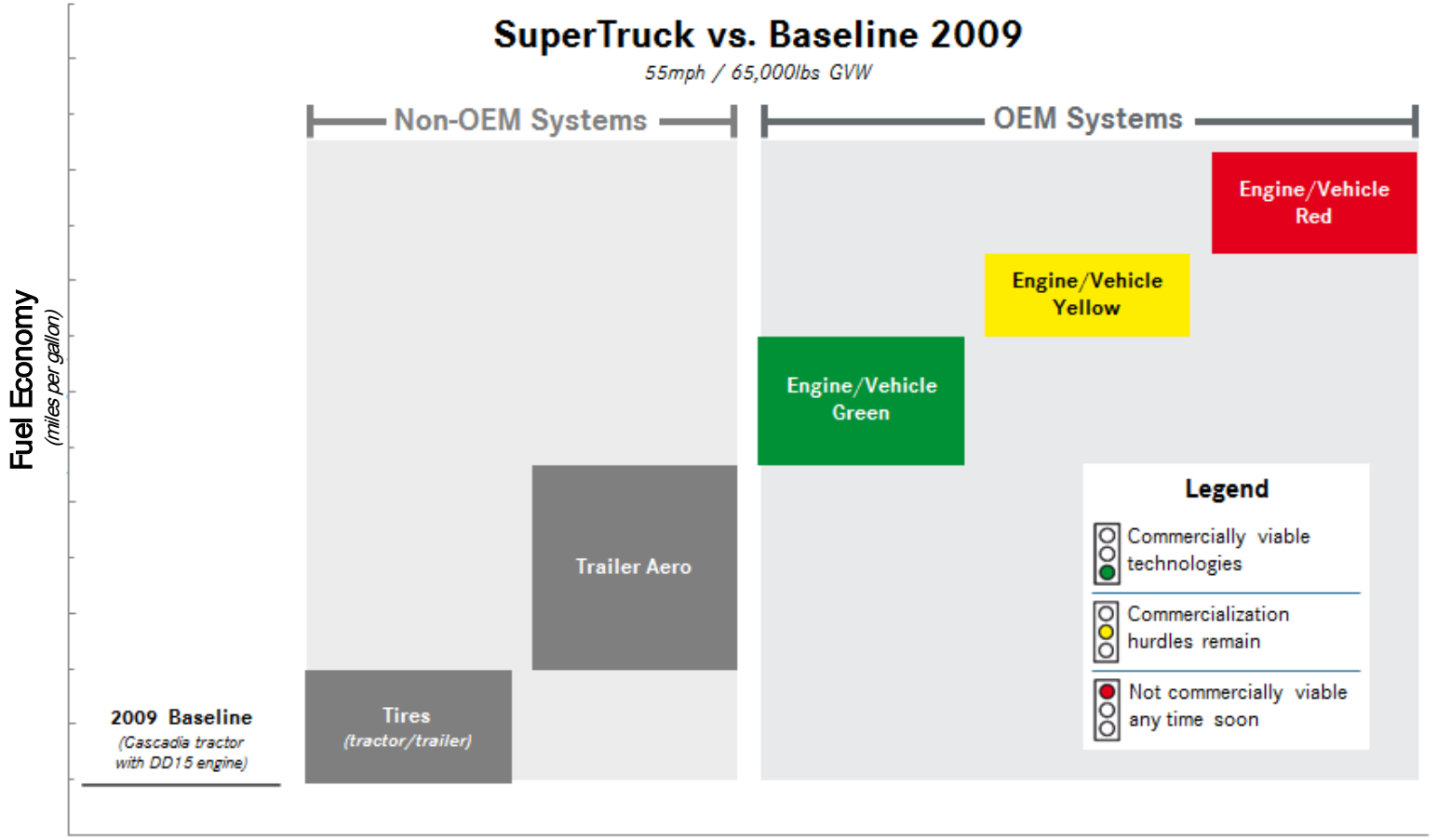
(e.g. regulatory, economic and/ or technical)

- Engine *(e.g. higher compression ratio, peak firing pressure)*
- Aerodynamics *(e.g. drive wheel fairing, under body cover, active grille)*
- MirrorCam
- Auxiliaries *(e.g. clutched compressor, power steering pump)*

Not commercially viable any time soon

- Hybrid Electric Powertrain *(predictive technologies - alternative low cost solution)*
- Exhaust Heat Recovery
- Lightweight Materials *(e.g. carbon fiber)*

Breakdown of Fuel Economy Improvements



SuperTruck Partnerships and Collaborations

Department of Energy:
- ➔ Roland Gravel
- ➔ Ken Howden
- ➔ Gurpreet Singh
- ➔ Carl Maronde

Energy Management

NREL

DELPHI

OSU Oregon State University

Telogis

Hybrid

FUSO

MBtech Mercedes-Benz technology

A123 SYSTEMS

EATON

MiaSolé

itk ENGINEERING

Mercedes-Benz

US Hybrid

Aero/Cooling

ARC AUTO RESEARCH CENTER

CD-adapco

TITANX

MEKRA LANG

FREIGHT WING

MODINE

Lightweighting

OSU Oregon State University

'TORAY'

STRICK Trailer

INMAGUSA

Powertrain/Parasitics

DETROIT Engine Transmission

CONMET Pointing the Way

MICHELIN

ACCURIDE

Parker

Bendix

ASHLAND

Fleet

SCHNEIDER NATIONAL

Walmart Save money. Live better.

Summary and Future Work

Successful completion of phases 1-5; Phase 5 targets exceeded

- ✓ 50% Vehicle Freight Efficiency target exceeded on Final Demonstrator vehicle through testing on Portland-Canyonville, San Antonio-Dallas, Portland City and Idle cycles
- ✓ 50% Engine Brake Thermal Efficiency target exceeded in engine test cell

Mission Accomplished

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Backup

Phase I Milestone Completed ✓

Analytical roadmap development to 50% vehicle FEI & 50% engine BTE

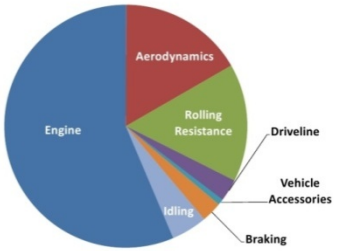
Baseline Tractor

- 2009 Cascadia 125"BBC, 72"RR
- DD15 Engine 455hp/1550 lb-ft

Vehicle Test

- Baseline Peformance Measurements
- Highway Cycle (55 &65 mph)
- Idle Cycle (summer, winter)
- City Cycle

Vehicle Energy Balance - Highway

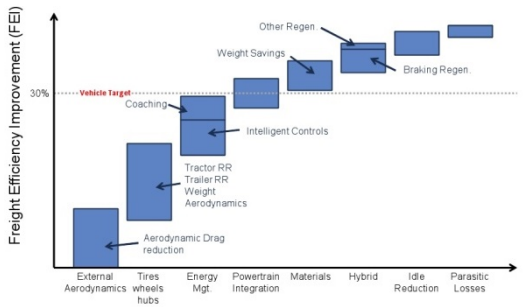


SuperTruck

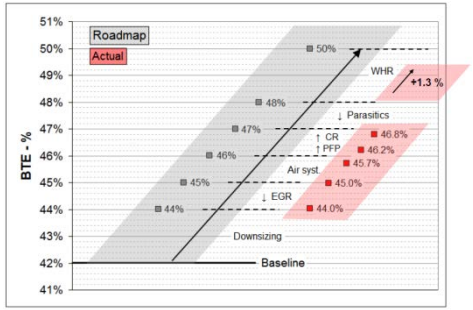
Modeling & Analysis

- Establish System Level Technical Targets

Roadmap: Vehicle



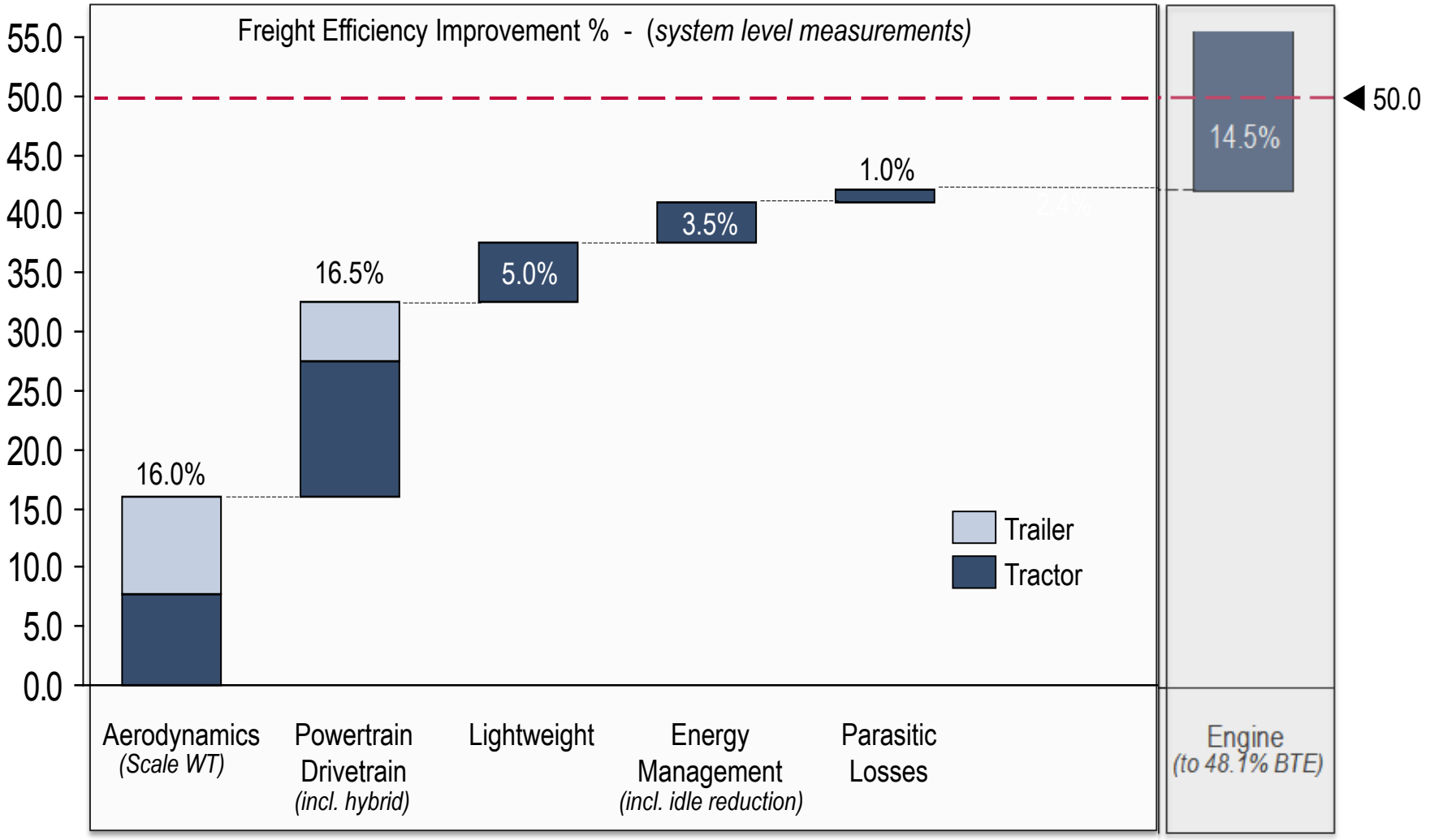
Roadmap: Engine



(Engine topics covered in separate session)

Phase 2 & 3 Milestone Status ✓

*Experimental testing to 25% & 50% vehicle freight efficiency**



** Technical Accomplishments covered in the 2012-2013 Annual Merit Reviews*

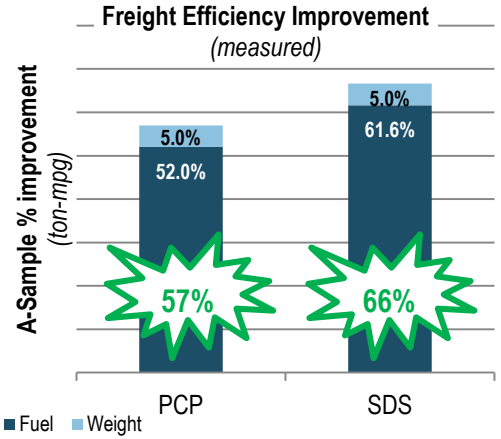
Vehicle Level Performance Test ✓

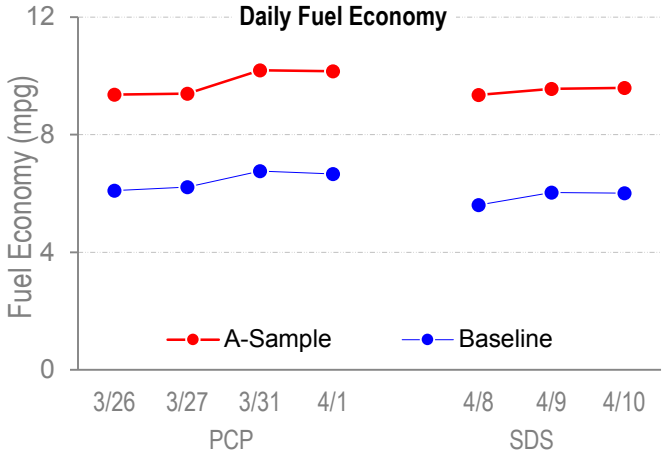
March-April, 2014: On Highway Fuel Economy Test

Gross Vehicle Weight (lb)	
Total	65,000
Tare	34,000
Payload	31,000

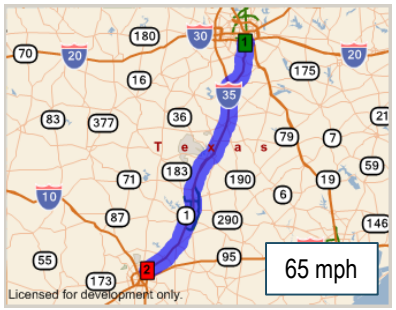
Gross Vehicle Weight (lb)	
Total	65,000
Tare	32,450
Payload	32,550

1550 lbs. additional freight on A-Sample ➔ 5% Freight Efficiency Improvement

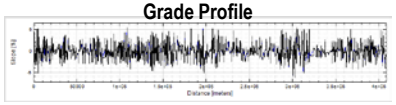




San Antonio Dallas (SDS)

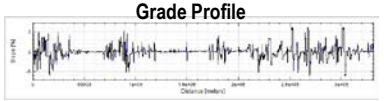


Grade Profile



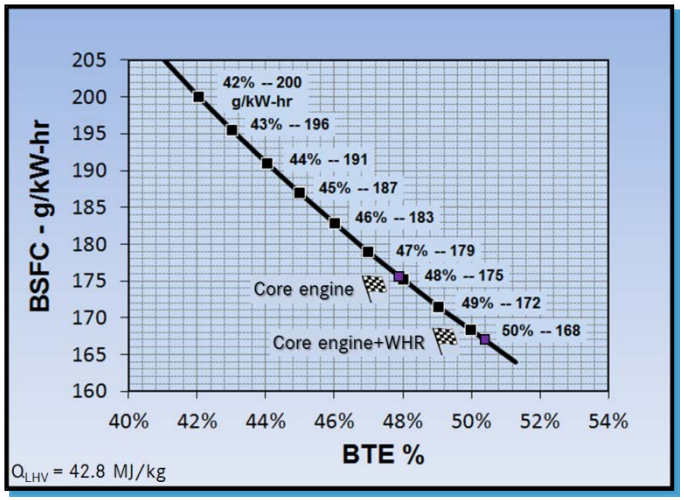
Portland Canyonville (PCP)

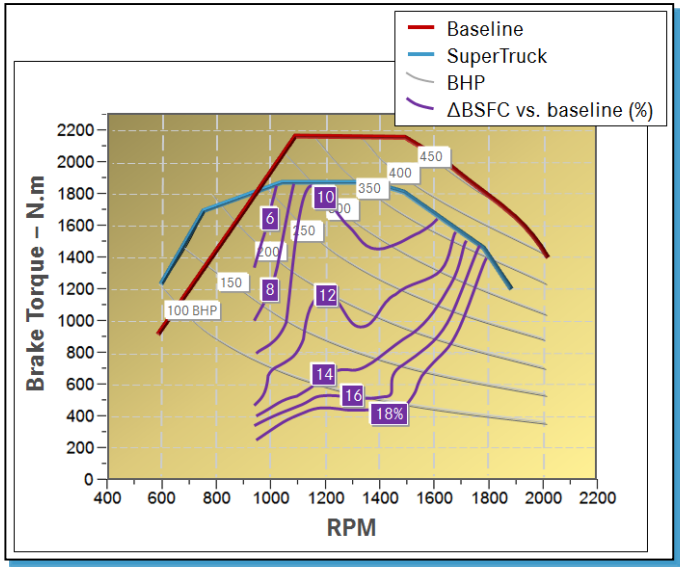
Grade Profile



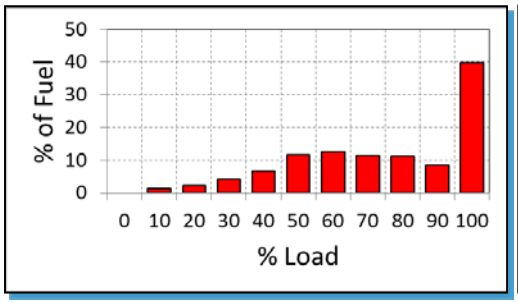
SuperTruck Engine – Final Results

- 50.2% BTE
- Large fuel economy improvement at part load relative to 2009 baseline -- resulting from optimized, downsized, down-sped SuperTruck engine
- Technical focus since last year's AMR
  - Engine & WHR hardware and design freeze
  - Software and calibration freeze
  - Model based engine controller commissioned on the SuperTruck demonstrator vehicle
  - SuperTruck vehicle integration
  - 55% BTE scoping activities
- SET: 6.9 g/bhp-hr E.O. NOx -- 0.15 g/bhp-hr T.O. NOx
- FTP: 3.0 g/bhp-hr E.O. NOx -- 0.50 g/bhp-hr T.O. NOx





Baseline on Texas route



SuperTruck on Texas route