Super Truck Program: Vehicle Project Review

Recovery Act –Class 8 Truck Freight Efficiency Improvement Project

Derek Rotz *(PI & Presenter)*
Dr. Maik Ziegler
Daimler Truck North America LLC
May 16th, 2013

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: 60%

Budget

- Total project $79,119,736
- Vehicle budget $47,486,735
  - DOE share(*) $10,430,000
  - DTNA share (*) $10,430,000

(*) through Feb, 2013 for vehicle R&D expenses only, engine R&D expenses reported separately

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 Milestone

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 I Milestone Completed ✓

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

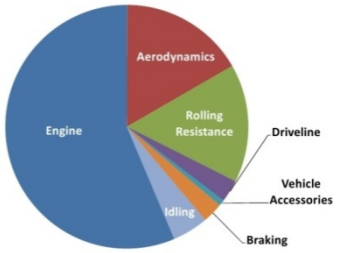
Baseline Tractor

- 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

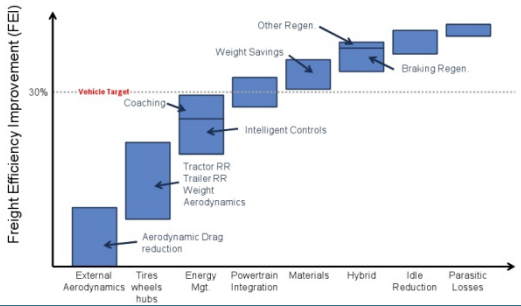


SuperTruck

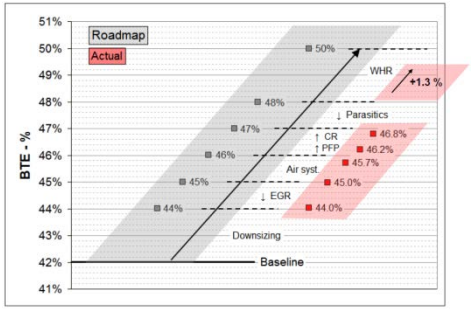
Modeling & Analysis

- Establish System Level Technical Targets

Roadmap: Vehicle



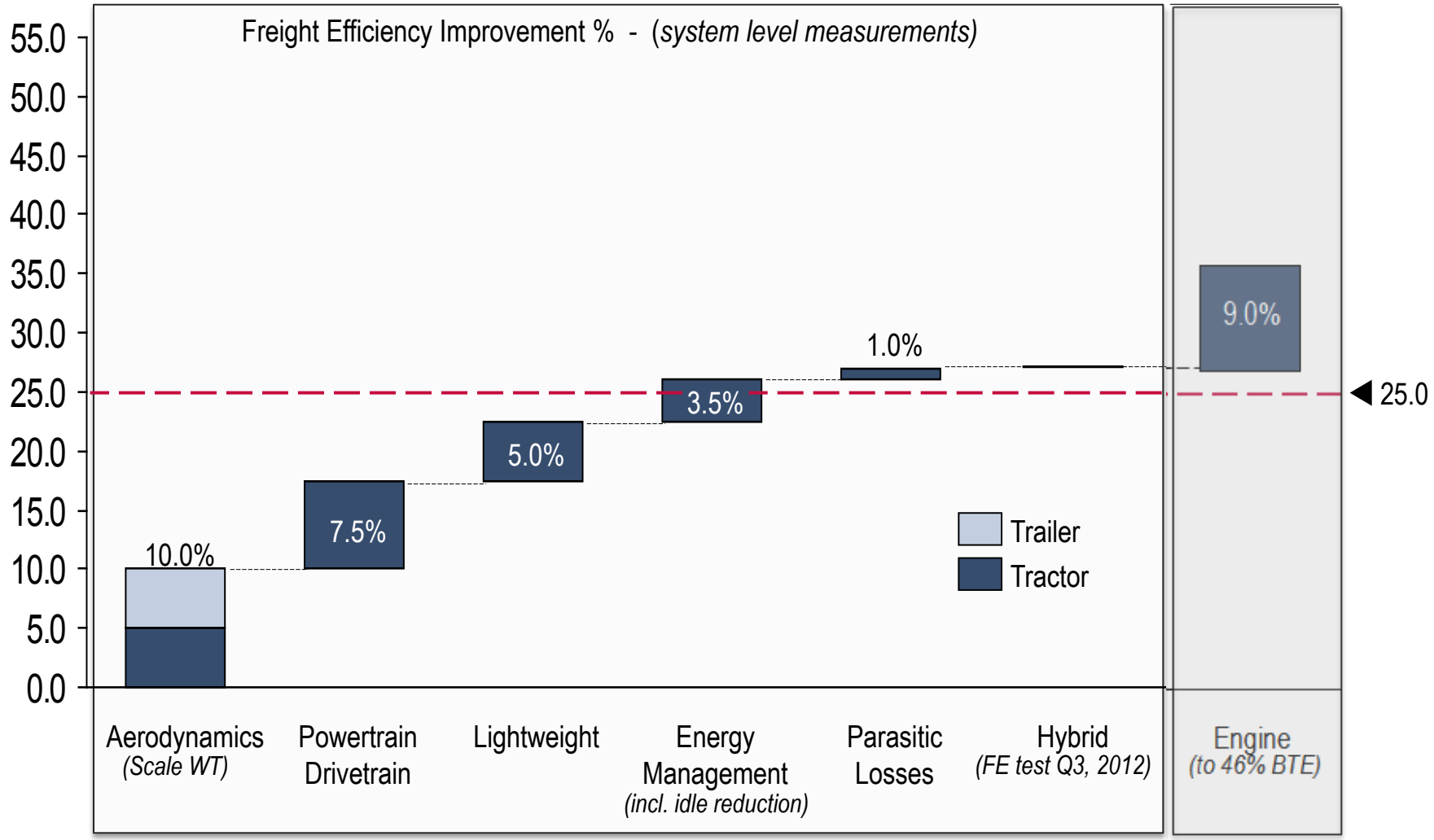
Roadmap: Engine



(Engine topics covered in separate session)

Phase 2 Milestone Status ✓

*Experimental testing to 25% vehicle freight efficiency**



* *Covered in last year's (2012) Annual Merit Review*

Phase II Accomplishments*

April 2011 – March 2012

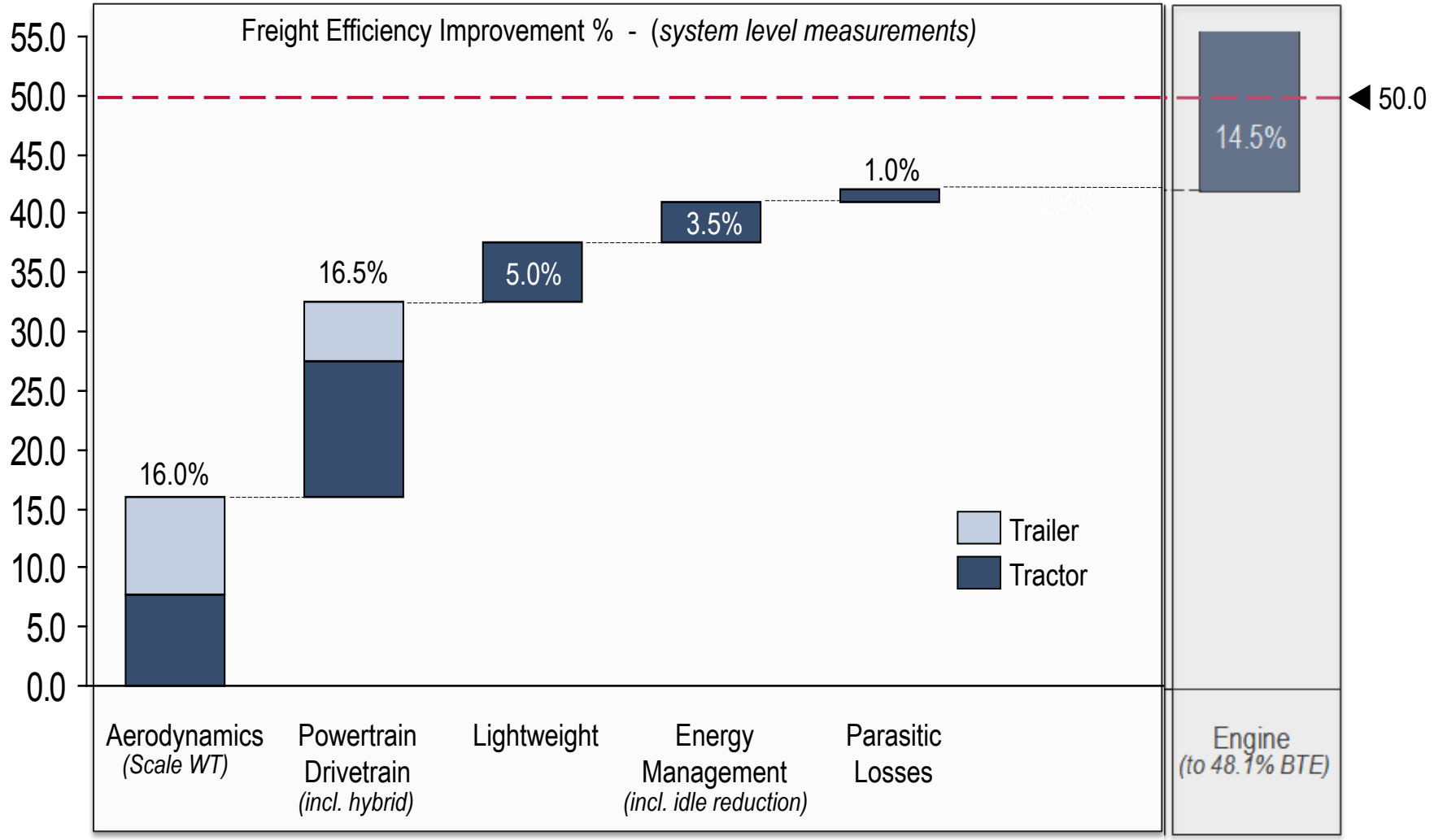
- Tractor/ trailer preliminary aerodynamics analysis and testing
- Cooling integration (engine, waste heat, a/c, hybrid)
- Lightweight frame concepts
- Transmission and axle ratio analysis (engine downspeeding)
- Tire, wheel & hub optimization
- Hybrid A-sample buildup
- eHVAC & fuel cell APU testing and down-selection
- Parasitic load reduction for air compressor & power steering
- Predictive technologies and eco-driver feedback testing

** Covered in last year's (2012) Annual Merit Review*

Phase 3 Milestone Status ✓

Experimental testing to 50% vehicle freight efficiency

➔NEXT STEP: build the truck



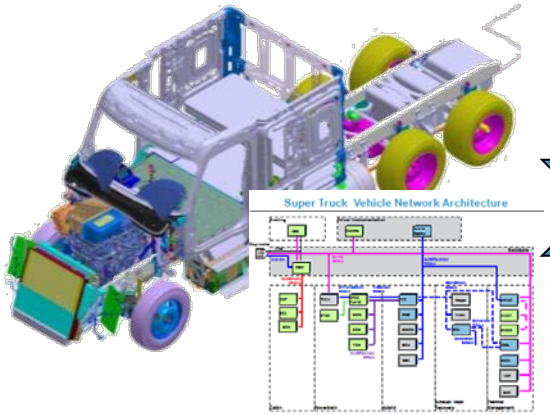
Hybrid Development & Integration Activities

Vehicle: ZZ2210
A-Sample Hybrid System ✓

- Base system design and HV vehicle integration
- Functional testing & 5000 mile shakedown complete
- eHVAC testing completed
- FE test completed

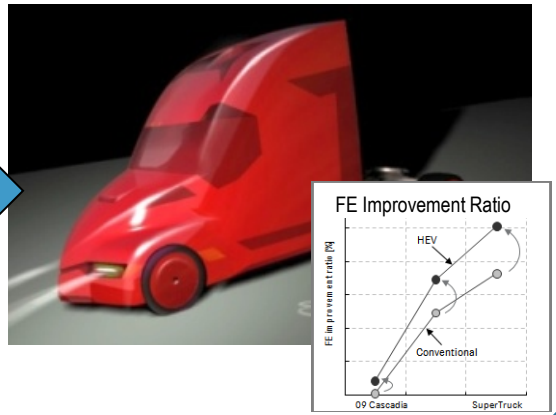
Vehicle: ZZ2215
B-Sample Hybrid System (In Process)

- Upgraded HEV components
- WHR in-vehicle integration
- High voltage interfaces
- Thermal interfaces
- Integrated in-vehicle cooling



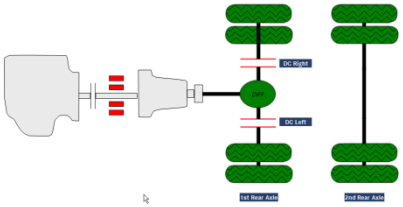
Vehicle: ZZ2660
DoE Demonstrator Vehicle

- Calibration for lower drag torque losses
- Weight optimization



Powertrain Integration Activities

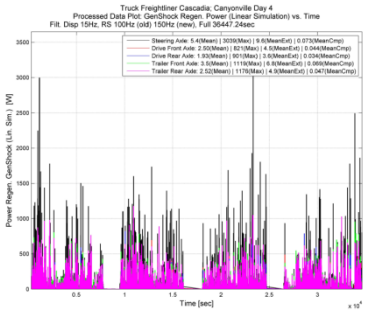
Coasting / Freewheeling



- Shift in neutral under zero torque conditions
- Adaptation to hybrid functionality
- Drag torque reduction through differential disengagement

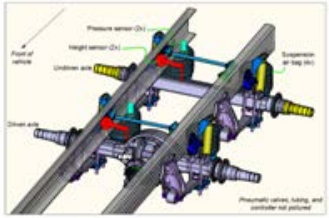
Damping Recuperation

- Measured damping forces on baseline route
- Calculated energy losses
- Energy loss too minor to pursue



Smart 6x2 Axle Configuration

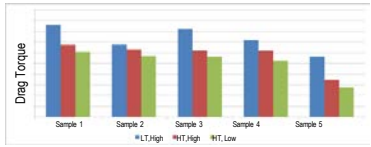
In Process



Incorporating weight shifting:

- 'Traction' mode –for increased traction
- 'Eco' mode –for improved efficiency

Gear Oil Management

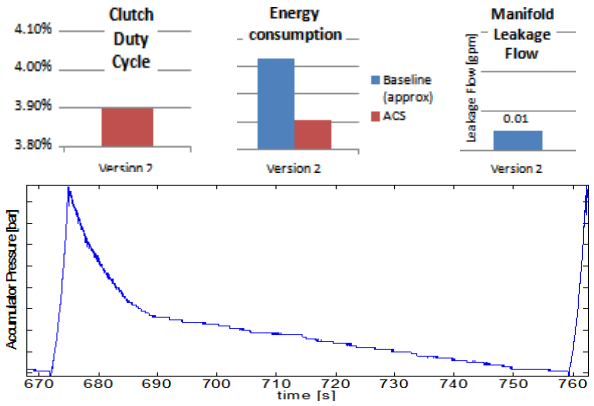


Base oils/ additive package evaluation for drive axle

- Temp, level & oil formulation

Parasitic Losses

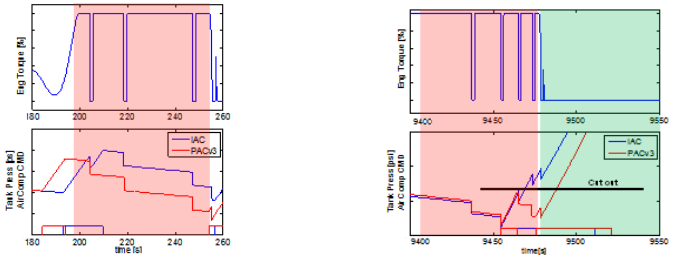
AccuSteer



- Closed center steering gear / hydraulic accumulator
- Iterated the design to reduce steering effort
- Installed & completed on-highway performance and effiicency

Instantaneous / Predictive Air Control

In Process



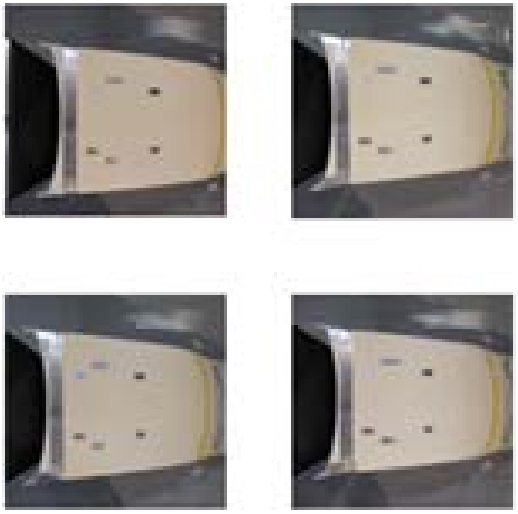
- Intelligent adjustment of cut in / cut out pressures based on predicted torque demand
  - Maximize activiations during coasting
  - Minimize activation at full torque

Aerodynamics Analysis of truck exterior systems

Roof, side extender & spoiler, etc…

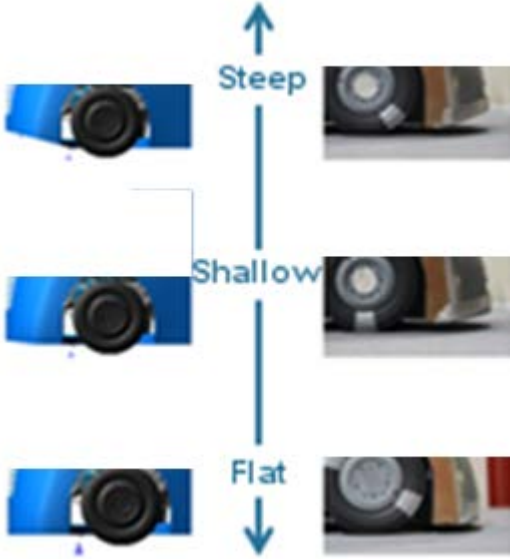
Side Extender/Roof Spoiler

- Evaluation side extenders & roof spoiler angles
- Swept several degrees from nominal



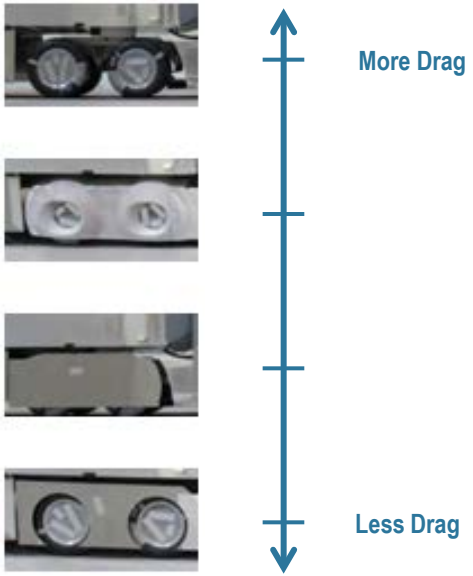
Ramp Angle

- Adjusting ramp angle has a large effect on drag



Drive Wheel Fairings

- Provides cover for turbulance created from drive wheels
- Streamline sides of vehicle



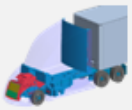
Truck Exterior Concept Refinement

Basic Shape → **Styling Themes** ✓

Evaluaton, selection and refinement

multiple styling themes ideated based on engineering surface

Basic Shape Analysis Outcomes

	Notional 1 	Notional 3 ✓ 
Aerodynamics		Slight Advantage
Thermodynamics *(Ambient Capability)*	Advantage in full engine load	
	Equal Performance under partial load	
WHR *(Power Gain)*	Equal Performance	
Weight	Equal Performance	
Chassis Packaging		Slight Advantage
Cab Impact		Advantage
Technical Risk		Advantage

- Basic shape analysis complete
- Truck theme selected

➔23% drag reduction measured on tractor in scale wind tunnel / CFD

Vehicle Integration

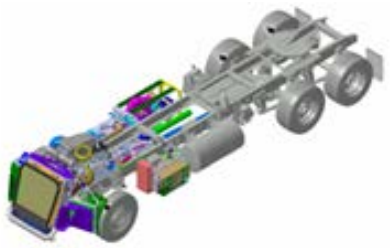
Exterior Engineering Surface

In Process

- Phase 1 - Space claim and initial packaging check
- Phase 2 – A pillar modification, windshield wipe check, door cutline & swing, mid-chassis modifications, underhood airflow optimization
- Phase 3 – Cab roof and sidewall, hood tilt, bumper development, grill, headlights

Chassis Package

In Process



- Package engine compartment systems under aerodynamic hood and with proper ground clearance
- Powertrain components including hybrid
- High voltage electrical systems including routing, cooling & HVIL
- Integration of hybrid, waste heat systems mid chassis
- Optimized airflow for engine & a/c intake air, airside exit paths for heat exchangers
- Extensive mechanical analysis incl. FEA
- Lightweight frame rail and cross member assembly

Defining Optimal Aerodynamic Trailer Configuration

Trailer Treatments

- Full length trailer skirts
- Front of trailer device
- Rear of trailer device

TT Gap Strategy

- Shorten tractor wheelbase
- Reduce tractor / trailer gap from
- Bridge remaining gap with tractor trailer treatments

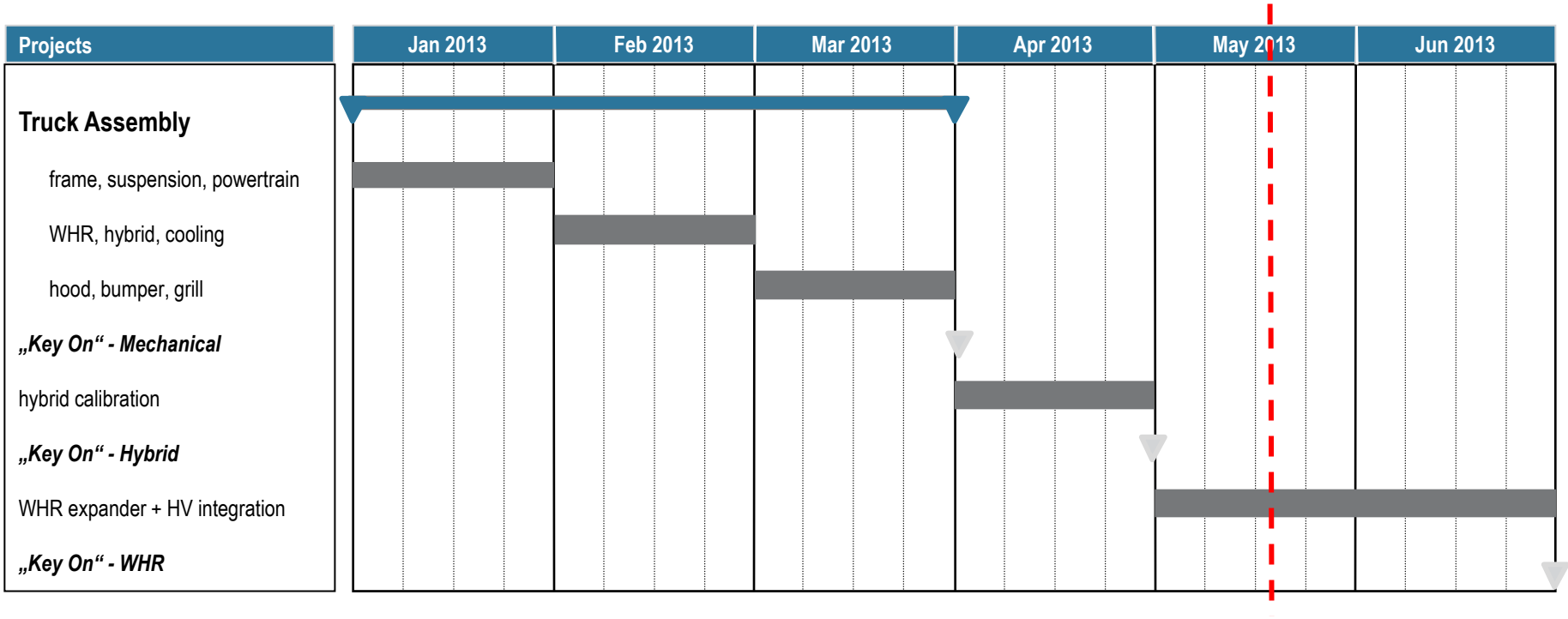
➔25% drag reduction measured on trailer in scale wind tunnel & CFD

Preliminary SuperTruck Build

In Process

Scope & Schedule

- Engine, waste heat, A/C & hybrid cooling
- High voltage power distribution
- Powertrain / drivetrain optimization
- Shift optimization
- Routing & plumbing



SuperTruck Partnerships and Collaborations

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

Energy Management

NREL
DELPHI
OSU Oregon State University
Telogis

Hybrid

FUSO
MBtech Mercedes-Benz technology
Mercedes-Benz
itk ENGINEERING

Aero/Cooling

ARC Auto Research Center
CD-adapco
MODINE

Lightweighting

OSU Oregon State University
'TORAY'
STRICK Trailer
INMAGUSA

Powertrain/Parasitics

DETROIT Engine Transmission
CONMET Pointing the Way
MICHELIN
ACCURIDE
Bendix
ASHLAND

Fleet

SCHNEIDER NATIONAL
Walmart Save money. Live better.

Vehicle Summary and Future Work

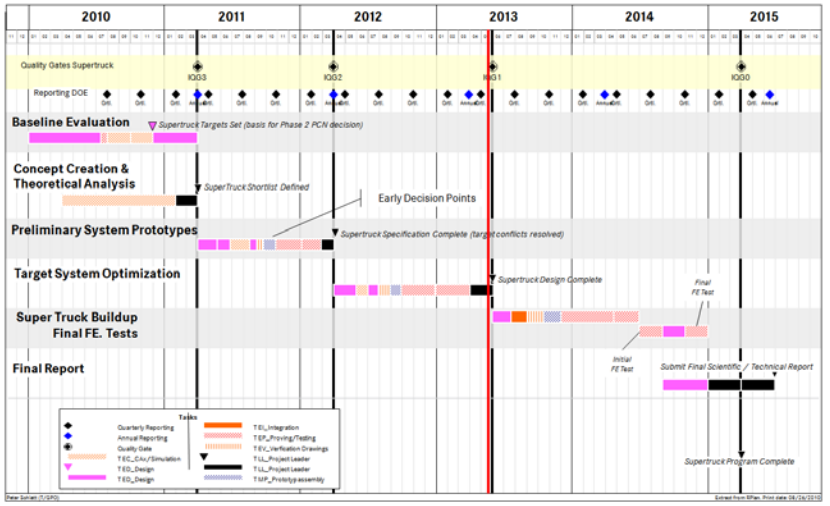
Successful completion of phase 1&2; Phase 3 targets met

Technology building blocks from 25% to 50% FEI based on system-level measurements through additional improvements in:

- Aerodynamics
- Powertrain / Parasitics / Hybrid
- Engine / Waste Heat Recovery

(Engine topics covered in separate presentation)

SuperTruck Project Plan and Milestones



Next Steps

- Complete the vehicle integration of ENG, WHR, HYB, PT
- Complete buildup of A-sample SuperTruck
- Initiate the buildup of 2 final demonstrator vehicles