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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: 80%

Budget

- Total project $79,119,736
- Vehicle budget $47,486,735
  - DOE share(*) $15,526,639
  - DTNA share (*) $ 15,526,639

(*) through Feb, 2014 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 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 I Milestone Completed ✓

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

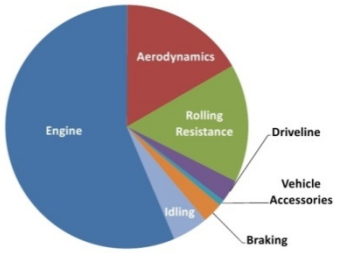
Baseline Tractor

- 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

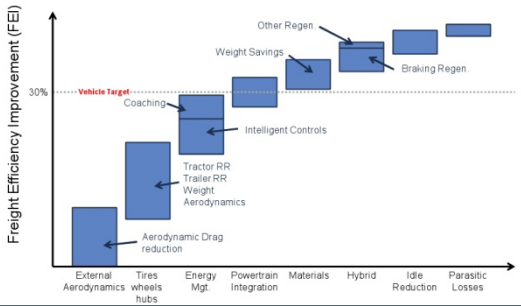


SuperTruck

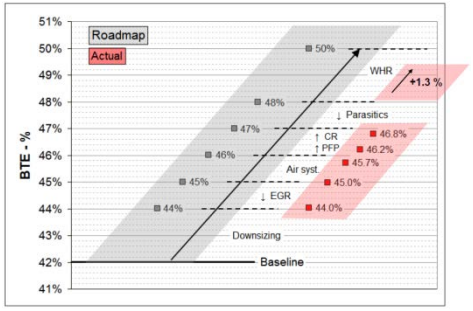
Modeling & Analysis

- Establish System Level Technical Targets

Roadmap: Vehicle



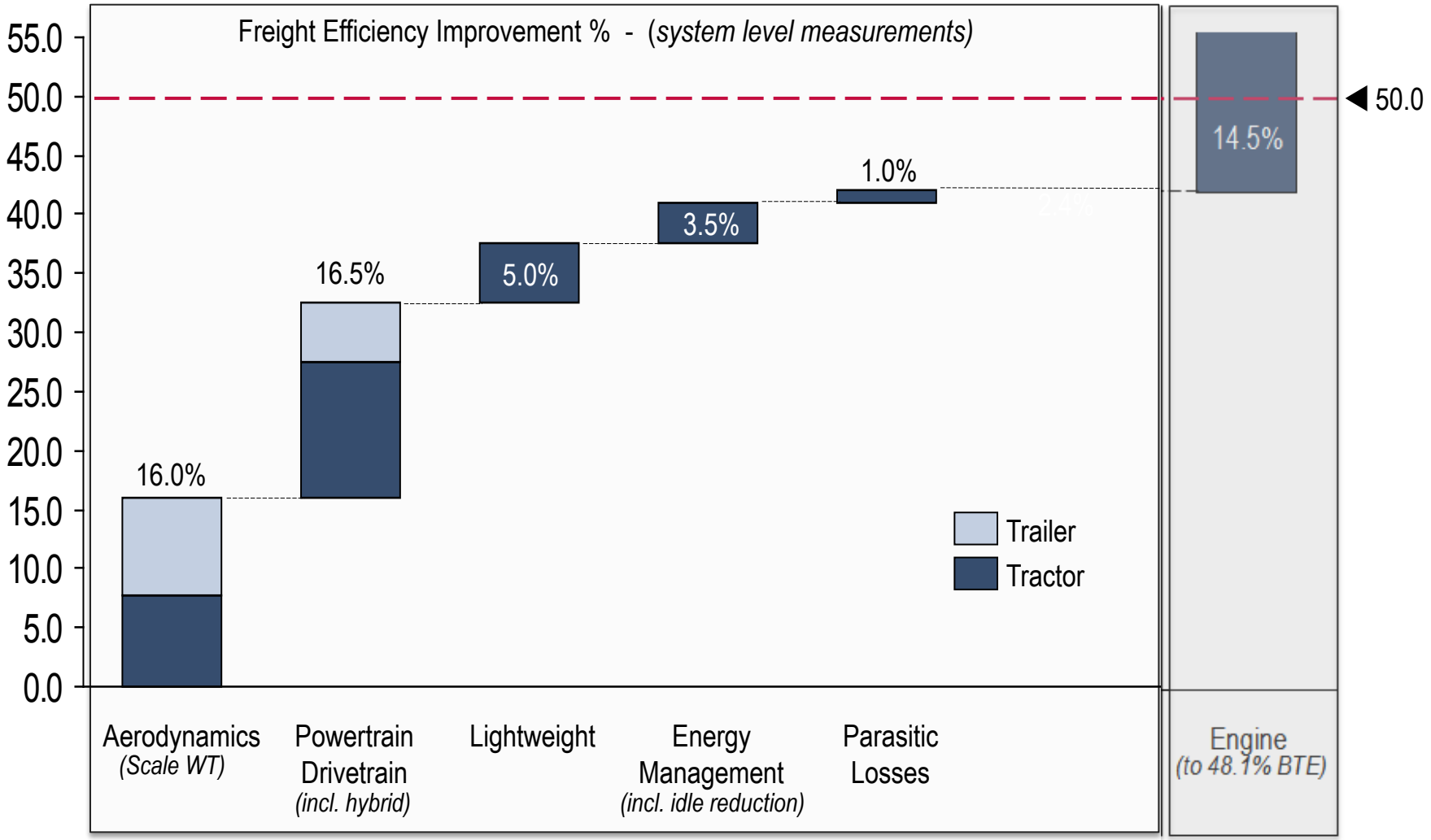
Roadmap: Engine



(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*

Phase 4: Road to 50%

A-Sample
- Aero hood, bumper, grille
- Downsized Engine, Automated Manual Trans. + eCoast
- Waste Heat Recovery (electrical expander & vehicle cooling)
- 6x2 Axle Tall RAR + oil management
- Hybrid Electric Powertrain (120kw eMotor, 360v, 2.4 kw-hr usable Li-Ion Bat)
- eHVAC (HV compressor, remote condensor, electrical fan)
- eMotor engine start
- Cab insulation package
- Clutched air compressor
- Electronic air control
- AccuSteer
- Low RR wide based single tires
- Thermal management
- Trailer aero., lightweighting and solar

Final Demonstrator

A-Sample

2009 Baseline Cascadia

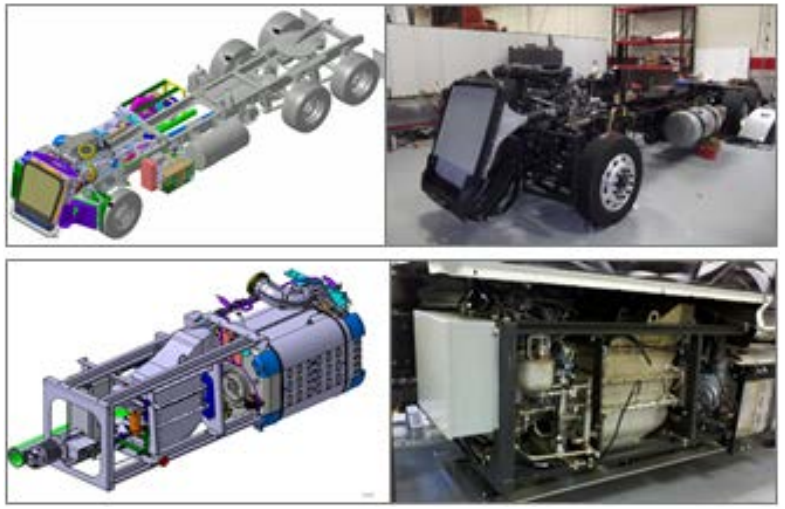
A-sample SuperTruck Build

Purpose: to prototype a functional chassis to integrate vehicle systems:

- ➔ Downsized Engine, Waste Heat, Hybrid, Cooling
- ➔ High Voltage Power Distribution
- ➔ Powertrain/Drivetrain Integration
- ➔ Software integration e.g. Shift optimization
- ➔ Packaging, Routing & Plumbing etc.

Testing completed to date:

- ➔ Full Scale Wind Tunnel (underhood airflow)
- ➔ eMotor cold start
- ➔ Thermal tunnel test
- ➔ eHVAC test & calibration
- ➔ Vehicle Performance Testing



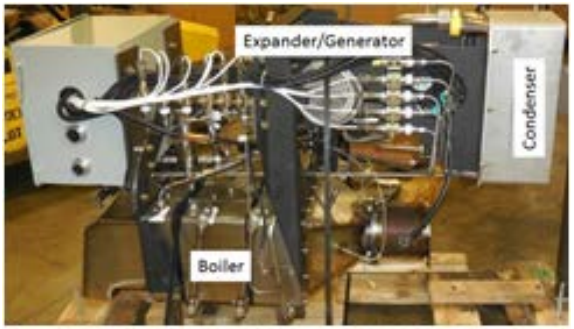
Waste Heat Recovery Status

Accomplishments

- Successful Key-on workshop in November including HV electrical components
- 6kw peak exhaust energy recovered under high load, steady state conditions

Current Tasks

- Develop de-aeration strategy
- Improve control stability during transient operation



A-Sample Thermal Tunnel Testing

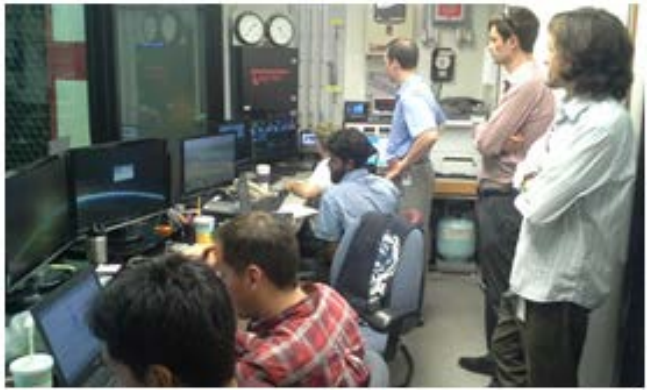
Vehicle Measurements

Ambient Capability *Engine + Waste Heat*

- 113°F (45°C) reached

Engine Air Intake

- Stayed below temperature rise limits
- Pressure measurements noisy



Fan Speed Characterization

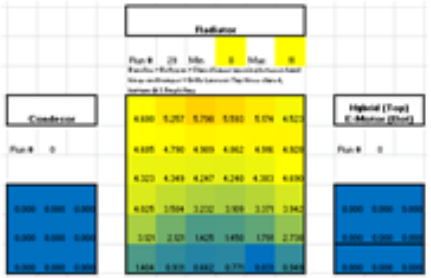
- Swept temperatures (25-40°C)
- Swept wind speeds (20-40mph)
- Grille open & closed positions
- Fan speed remained below 1000 RPM

A-Sample Air Flow Study in Wind Tunnel

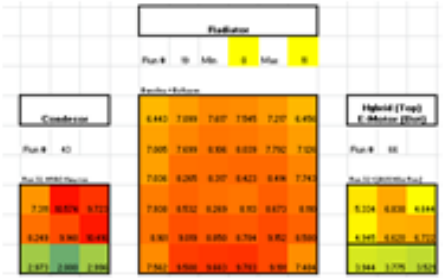
Vehicle Measurements

Mass Airflow distribution

Aero Optimized Grille



Cooling Optimized Grille



Cruise Speed (58mph)	Air Flow (kg/ s)	Drag
A-sample configuration	**Eng, WHR, CAC**	**ΔC_d** *(0° Yaw)*
Nominal	*baseline*	*baseline*
Cooling optimized grille	+3%	0%
Aero optimized grille	-57%	-6%

eMotor Cold Start Test

Vehicle Measurements

Test Procedure

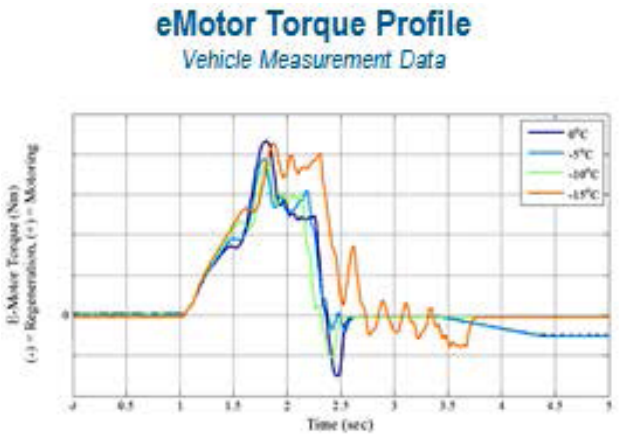
- 24 hour cold soak
- 0 to -15°C by 5° incr.

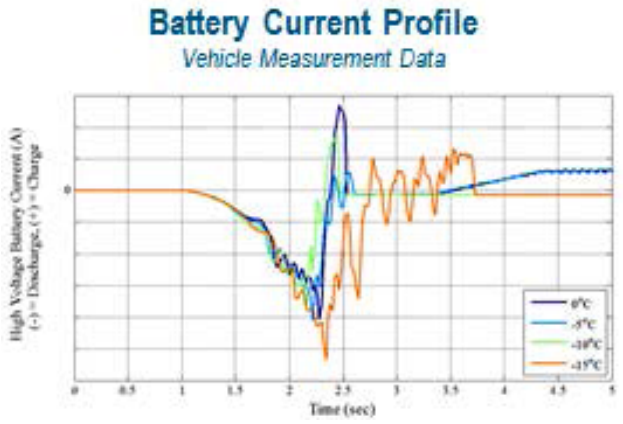
Observations

- No eMotor torque increase at lower temps.
- Peak Li-ion battery current at 112A

Conclusions

- Temperatures of -15°C easily achievable
- Data indicate -20 to -25°C starting possible
- >1% Freight Efficiency gained
  - *Omit starter and Pb-Acid starting batteries*





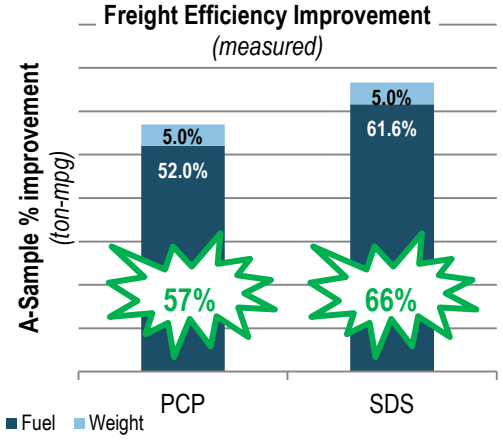
Vehicle Level Performance Test ✓

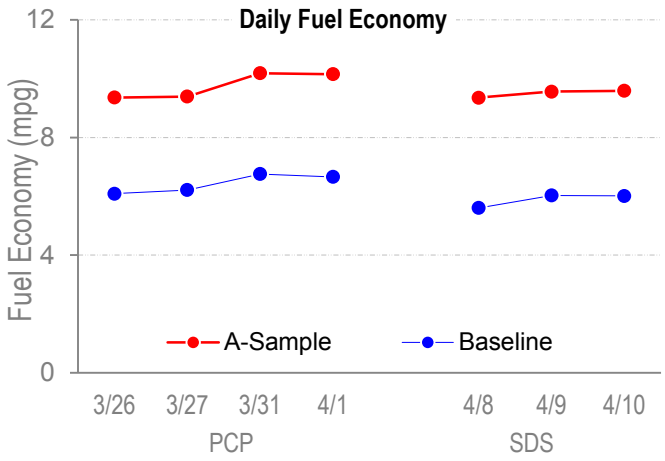
March-April, 2014: On Highway Fuel Economy Test

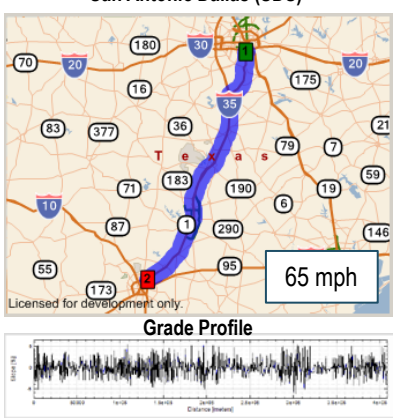
Gross Vehicle Weight (lb)	
Total	65,000
Tare	34,000
Payload	31,000

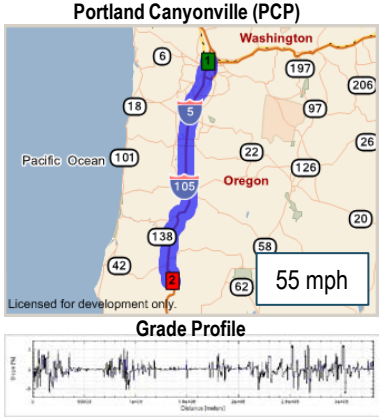
Gross Vehicle Weight (lb)	
Total	65,000
Tare	32,450
Payload	32,550

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









Phase 4: Road to 50%

2009 Baseline Cascadia

A-Sample

Final Demonstrator

Final Demonstrator

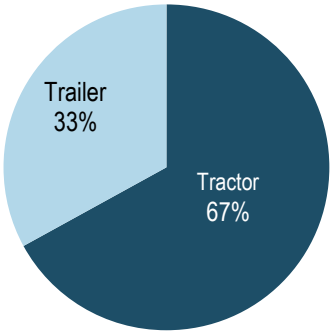
A-Sample Technologies, plus…

- Full Tractor Aero
- 50% BTE Engine + WHR
- Predictive hybrid & engine controllers
- Axle - Active oil management with FE gear oil
- Lightweight Aluminum Frame and cross members
- Ultra Lightweight Air Suspension
- Smart 6x2
- Solar reflective paint
- Enhanced Trailer aerodynamics

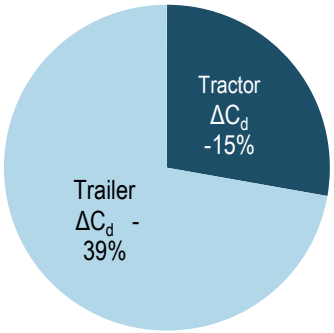
Aerodynamics Validation in Scale Model Wind Tunnel

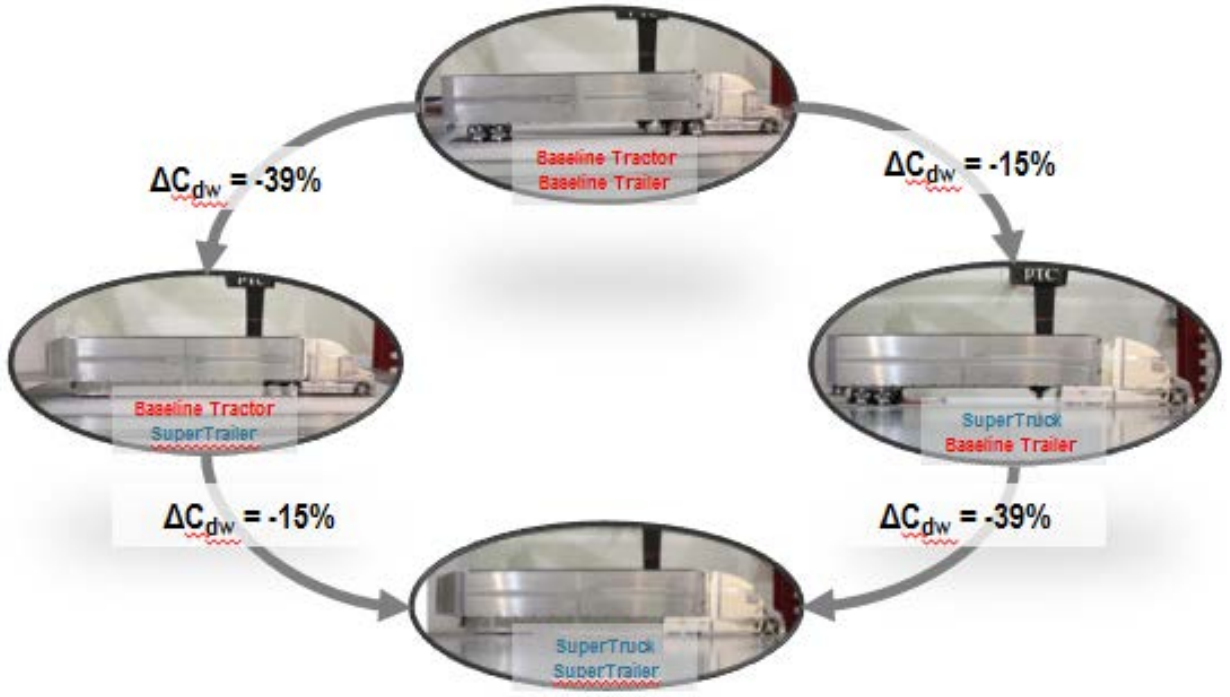
SuperTruck vs. Baseline

Percentage of Test Runs



Drag Reduction Contribution





Final Demonstrator Build

Chassis

- Frame, Suspension, Axles complete
- Powertrain & cooling Installed
- Wiring & plumbing on-going



Cab Exterior

- Design release complete incl. A&B side parts
- Molds & exterior parts 80% complete
- Pre-fit completed by June




Cab Interior

- Sleeper design complete
- Components & assy. ongoing
- Ship to Portland in June




Build progressing for Sept 1st FE test start

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
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.

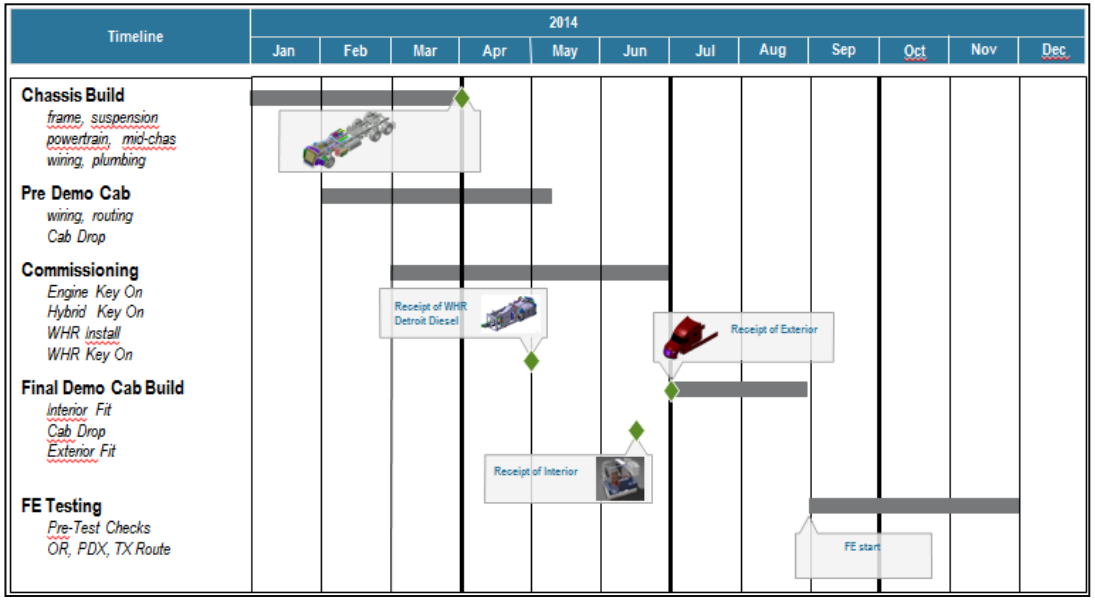
Summary and Future Work

Successful completion of phases 1-3; Phase 4 targets met

- ✓ 50% Vehicle Freight Efficiency target exceeded on A-Sample vehicle through testing on Portland-Canyonville and San Antonio-Dallas routes
- ✓ 50% Engine Brake Thermal Efficiency target exceeded in engine test cell

Next Steps

- Complete buildup of 2 final demonstrator vehicles
- Conduct fuel economy testing



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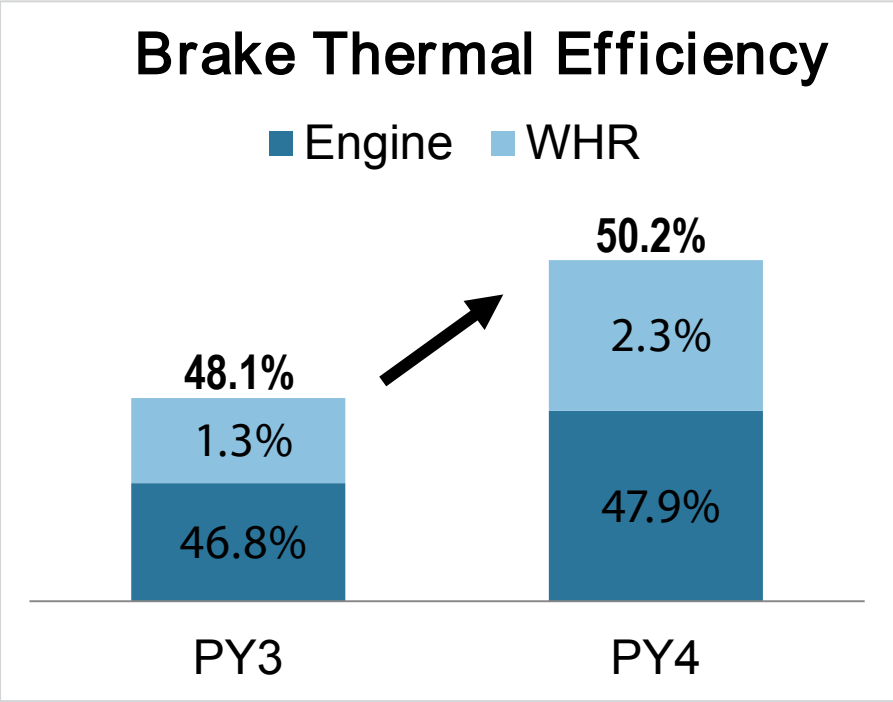
Backup

Project Year 4 (PY4) Engine BTE Improvement → 2.1% points



- PY4 Enablers
  - Further increase in compression ratio (CR), piston bowl and matching injector profile optimization.
  - 3rd Iteration of turbo-charger.
  - Optimized liner cooling.
  - EGR waste heat recovery.
  - WHR component and calibration optimization.