SuperTruck – Development and Demonstration of a Fuel-Efficient Class 8 Tractor & Trailer

Vehicle Systems

DOE Contract: DE-EE0003303

NETL Project Manager: Ralph Nine

Program Investigator : Dennis W. Jadin, Navistar

DOE MERIT REVIEW

WASHINGTON, D.C.

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National Energy Technology Laboratory

Department of Energy

Project ID: VSS064

Outline

NAVISTAR Advanced Technologies

- Program Overview
- Barriers and Technology Roadmap
- Approach
- Technical Accomplishments
- Future Work
- Summary

Program Overview

NAVISTAR Advanced Technologies

Goals and Objectives

Demonstrate 50% improvement in overall freight efficiency of a combination Tractor-Trailer
- 30/50% improvement achieved through tractor/trailer technologies
- 20/50% improvement achieved through Engine technologies

Attain 50% BTE Engine
Demonstrate path towards 55% BTE Engine

Barriers

Achieving 50% freight efficiency while balancing Voice of Customer Needs
Packaging of hybrid drive unit and Waste Heat Recovery Systems
Maintaining tractor weight while adding new systems
Availability of Suitable Battery Technology

Budget

DOE recently approved new budget periods / phases >>>>

Budget Period	Start Date	End Date
1	10/01/10	08/31/12
2	09/01/12	09/30/13
3	10/01/13	06/30/14
4	07/01/14	03/31/15
5	04/01/15	09/30/15

An increased level of resources planned in budget periods 2 & 3 will accommodate project deliverables in periods 4 & 5.

Total Project Funding:	DOE	$37,328,933
	Prime Contractor	$51,801,146

DOE Funding Received : $ 13,393,868

Partners (Collaboration and Coordination with Other Institutions)

Navistar	Principal Investigator, Vehicle Systems Integrator Controls Systems, Engine & Vehicle Testing
Alcoa	Lightweight Frame Structures & Wheel Materials
ATDynamics	Trailer Aerodynamic Devices
Behr America	Cooling Systems
Meritor	Hybrid Powertrain, Axles
Michelin	Low Rolling Resistance Tires
Wabash National	Trailer Technologies
TBD	Composite Material Structures (was TPI)
Argonne National Lab	Hybrid Drive Simulation and Controls & Battery Testing
Lawrence Livermore National Lab	Aerodynamic Testing

Barriers (Challenges)
And Technology Roadmap

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•In Progress √ Completed

System Area	Barriers	Technology Roadmap
Engine & Vehicle	Achieving 50% freight efficiency while balancing Voice of Customer Needs	✓Seek and Prioritize Voice of Customer Inputs • Rely on analysis (tradeoff) to select technology
Vehicle	Packaging of hybrid drive unit and Waste Heat Recovery Systems	✓ Redesign drive unit and batteries to achieve overall size reduction.
Vehicle	Maintaining tractor weight while adding new systems	• Optimize Body Structure Requirements for over the road usage. • Utilize Advanced Materials for Light Weighting (Polycarbonate Glazing, Composites, Alloys)
Hybrid Drive	Suitable batteries (rugged, affordable, powerful) are not commercially available Weight penalty affecting FE	✓Develop a detailed battery specification ✓Reach out world-wide to potential suppliers ✓Select new supplier • Collaborate to develop lighter SuperTruck batteries • Identify additional lightweighting opportunities

Approach:
Vehicle Vs. Chassis Efficiency

% Fuel Economy Improvement

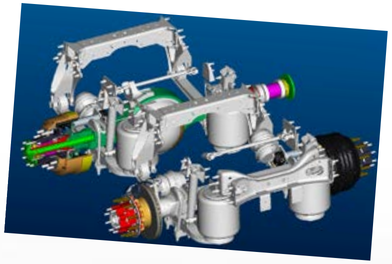
30% Target

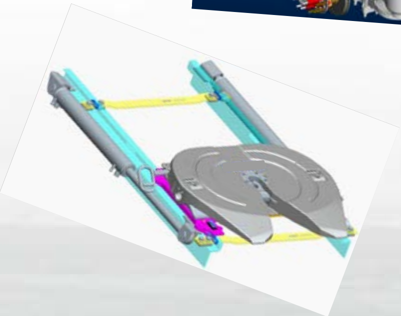
4. Hybrid
- Dual Mode Hybrid Drive
- Electrified Accessories
  - Power Steering
  - Air Compressor
  - AC Compressor

3. Driveline
- SMARTandem 6x2 Gears
- Next Gen Wide Based Singles Tires
- Tire Inflation Maintenance System
- Opti Lube Level Axle Fill
- Electronic Leveling Air Consumption

2. Lightweight
- SMARTandem 6x2 axles
- Composite Cab
- Composite Trailer Structure
- Next Gen Wide Based Singles and Wheels

1. Aero Enhancements
- Gap Reduction
- Aero Drop at Highway Speed
- Surrogate Camera Mirrors
- Tractor Shapes
- Trailer Shapes & Features





Approach:
Technology Roadmap - Vehicle

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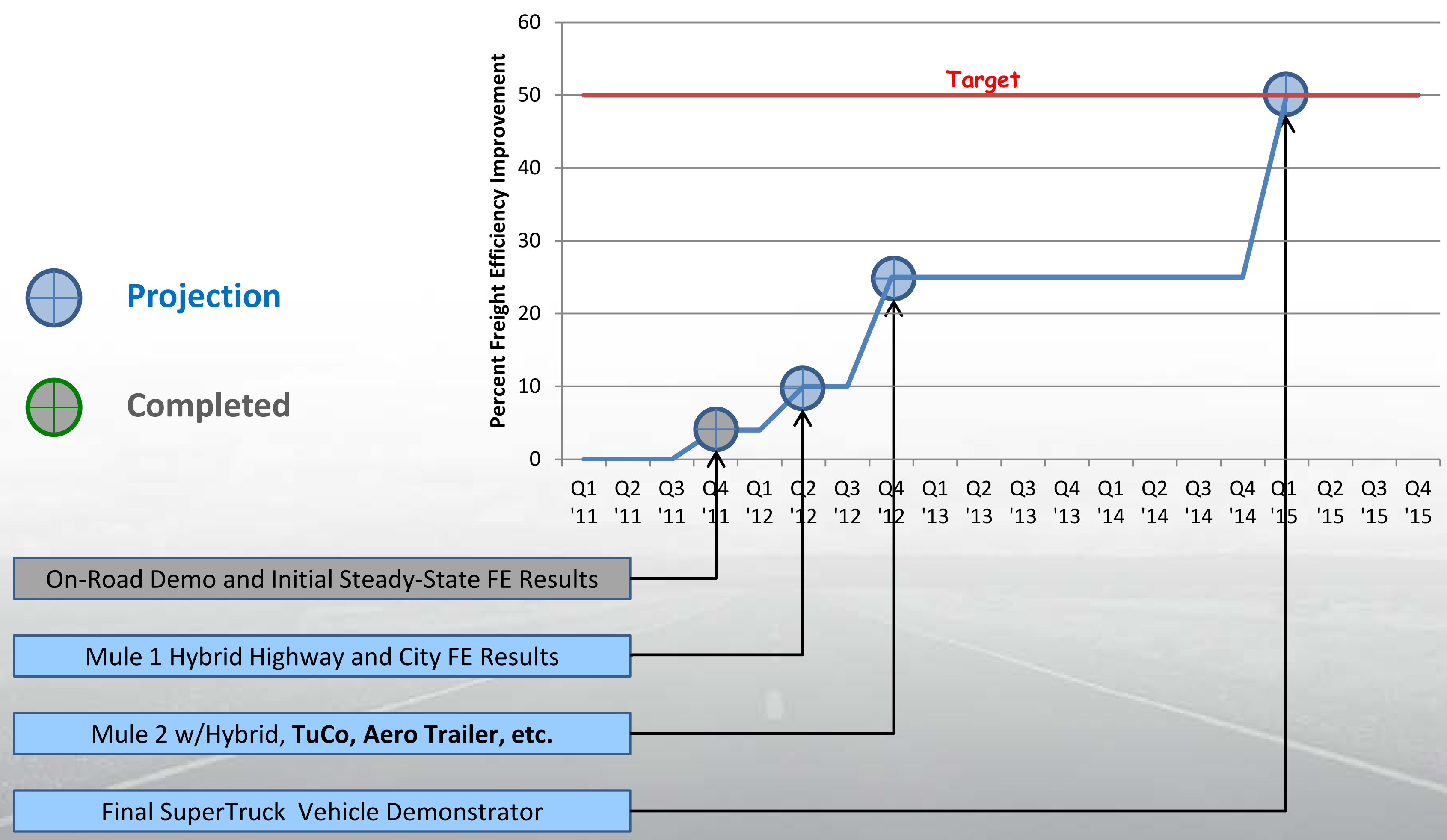

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Mule Truck #2 Build Status – Planned to do for freight efficiencies for 2012

- Dual Mode Hybrid
- Electric Turbo Compounding (TuCo)
- Active 5th Wheel
- Dynamic Ride Height (includes front air)
- Full Length Drive Wheel Skirts
- High-rise Roof Air Fairing
- ATDynamics Boat Tail
- Michelin Wide Based Single Tires (WBS Tires)
- Camera Surrogate Mirrors
- External LED Lighting, Including Headlights
- Meritor Air Disk Brakes
- Meritor SMARTandem 6x2 Axle System
- Power Steering Upgrades
- Wabash Light Weight Trailer

Mule #1 items
Mule #2 new technologies

Approach:
Technology Roadmap - Vehicle

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- In Progress (green) - Completed (gray)

Vehicle Systems Technology Rollout (2011-2012)		
Technology Category	**Area of Concentration**	**Status**
1. Aerodynamics	Advanced Tractor Shape -Speed Form Study	2Q 2012
	Surrogate Rear View Mirrors- Initial Concepts	2Q 2012
	Advanced Trailer Shapes -PIV -Particle Image Velocimetry	3Q 2011
	Tire Skirting; Steer, Drive & Trailer	2Q 2012
	Tractor-Trailer Gap Reductions; Dyn. 5th wheel, Cab Extenders	2Q 2012
	Cooling System Exhaust location Impacts on Aerodynamics	1Q 2012
	Trade-off Studies of Cooling System Concepts	2Q 2012
	Determine Thermal Management Configuration	3Q 2012
	Aero Drop, Electronic Suspension Leveling, Tractor & Trailer	2Q 2012
2. Vehicle Lightweighting	Advanced Modular Chassis Construction	4Q 2012
	Efficient Drive Axle, 6x2 Configuration	1Q 2012
	Cab Architecture Downselection	2Q 2012
	Cab Structural Design & Material Selection	4Q 2012
	Trailer Architecture Selection	4Q 2012
	Trailer Structural Design & Material Selection	4Q 2012
3. Driveline	Optimized Wide-Based Single Tires & Wheel End Equipment	4Q 2011
	Next Gen Wide-Based Single, Low Rolling Resistance Tires	4Q 2011
	Tire Pressure Monitoring and Inflation	2Q 2012
	Efficient Drive Axle, 6x2 Configuration	1Q 2012
4. Hybrid Drivetrain	Mule Vehicle #1	3Q 2011
	Electrified Accessories; Power Steering, AC & Air Compressors	3Q 2011
	Mule Vehicle #2	3Q 2012

Technical Accomplishments

1. Aerodynamics – Development Progress

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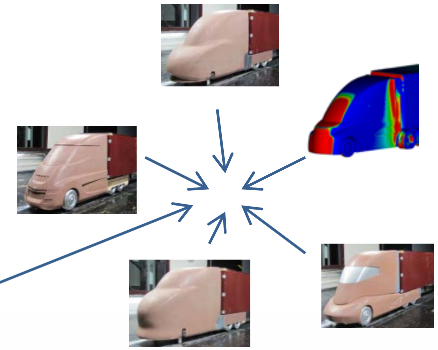
Evaluation of Trailer design modifications planned for upcoming tests

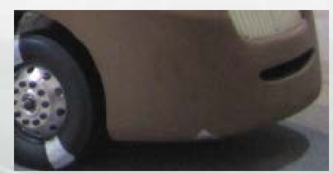


Tractor shape development through 1/8th scale Wind Tunnel testing and CFD

Boat tail and rear skirts design verification and optimization in collaboration with program partners ATDynamics

Trailer skirts design evaluation & optimization in collaboration with program partners Wabash National

Design & Testing of Tractor components such as drive wheel skirts, belly pans etc. for aero improvement



Integration of steering axle and cooling flow with minimal impact on aerodynamics

Technical Accomplishments
1. Aerodynamics – Status

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Configuration	Measured	Normalized Cd%	Freight Efficiency Impact
ProStar Short Sleeper (Baseline) 	2010	100	0%
ProStar Long Sleeper 	2007	94	3%
Aero Concept 2010-2011 (Tractor Only) 	2010	88	6%
Aero Concept 2010-2011 (Tractor & Trailer) 	2010	75	12.50%
Best Tested Feb 2012 w/Steer Axle & Cooling Flow Integrated 	2012	60	20%

Technical Accomplishments

2. Lightweighting

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- In Progress | - Completed

SYSTEM	DESCRIPTION	SAVINGS (lbs.)
Axle - Smart Tandem	Removes one drive axle (6 X 2 configuration)	-400
Brake System - Disc	Light Weight rotor & caliper yields 10#/ wheel end	-200
Single Prop Shaft	Increased tube dia. with thinner wall	-70
Tires and Wheels	Wide Based Singles with NG Aluminum Rims	-1000
Body -Cab	Composite / multi material panels	-500
Plastic Fuel Tank	Single one hundred gallon fuel tank	-110
Fuel	Second 100 gal. of fuel = 700 #	-700
Trailer	Composite load floor	-500
Trailer Suspension	Weight reduced components	-220
Chassis System	Weight reduced system	-200
Cooling Modules	Less modules	-200
Third Gen. Batteries	Modular style batteries	-600
Third Generation E motors	Improved Power density	-895
	Total Possible Reduction	-5595
	Hybrid Incremental	4700
	Net Reduction	-895
	Proposed Target Weight Reduction for FE	4000
	Lightweighting Gap	3105

Mule 1 before Hybrid Prostar 122 13L = 18140#
Mule 1 Prostar 122 13L = 22840#
22840 - 18140 = 4700# Hybrid Incremental

Technical Accomplishments

3. Driveline - Wheel End Equipment Team

Factors for Consideration		Weight	Subcategory Weight
Efficiency		50%	310
	Rolling Efficiency -Tires		10
	Aero impacts - ie. tire size, wheel size, wheel covers, suspension ride height, overall height		10
	System Weight		8
	Alignment Control / Vehicle Efficiency		3
	Bearing & Seal Drag		0
	Brake Drag		0
Design Feasibility		35%	550
	Durability / Reliability		9
	dFMEA		10
	System Temperatures (Tires, Wheels, Brakes, Seals, Bearings) difficulty to control temperatures		8
	Development Time (to Demo units)		7
	SuperTruck investment within current planned budget		6
	System Cost		
	Capital Investment		
	Improved Alignment Control / Tire Wear		
Commercialization		15%	
	Commercial Applicability / Flexibility		
	Servicability		
	Deviation from Industry Standards - positive acceptance by industry		
	Early Production		
Totals			

- New Wheel End Decision Matrix
  - Alcoa, Michelin, Meritor, Navistar
  - 25 total people participating (some full time, others part time)
  - 6 design choices plus current production
  - 3 weighted major design considerations
    - 18 total categories
- Chose the Next Generation Wide Based Single Tire for driving and trailer use.
  - 1.5% FE savings from aero drag reduction
  - Weight savings in axle and wheel ends
  - Team developing new wheel end design spec.
  - Michelin started tooling for new tire.

4. Hybrid Powertrain – Performance Modeling

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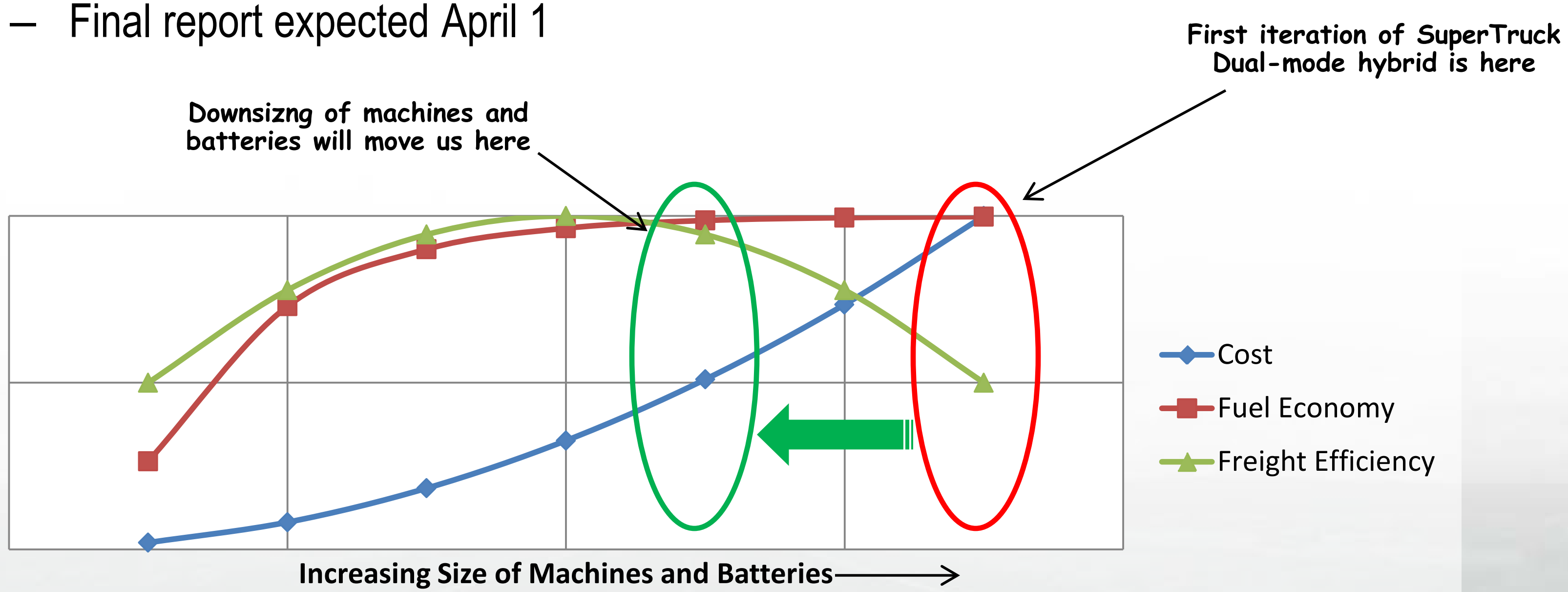
- **Trade-Off Study of Electric Machine and Battery Size**
  - A range of hybrid machines and batteries have been studied
  - Final report expected April 1



Argonne NATIONAL LABORATORY

Technical Accomplishments

4. Hybrid Powertrain – Real-World Testing

Ohio Transportation Research Center

•Fuel Economy Testing

•In progress

Michigan Proving Grounds

•Software and Calibration Development

•Summer, 2012

Navistar Proving Grounds

•Software and Calibration Development

•Fall/winter, 2012

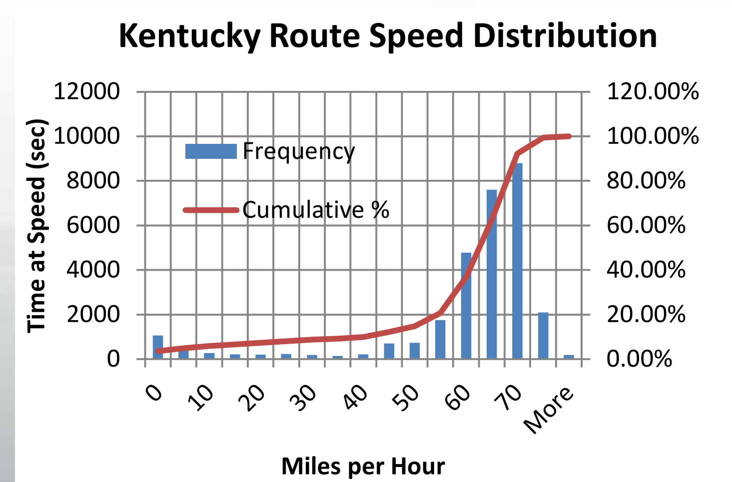
Colorado

•Highway Testing

•Summer, 2012

4. Hybrid Powertrain – Validation Route

- Navistar's "Kentucky Route" is commonly-used to quantify fuel consumption of class 8 vehicles
  - Low traffic density for good repeatability
  - Highway-type route (high speed)
  - Large database to compare to
  - 75% of the total weighting
- The remaining 25% can be a test-track urban cycle, like CILCC or HHDDT Transient



Technical Accomplishments
4. Hybrid Powertrain – Fuel Economy Testing

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Fleet Test Vehicles

	Control Vehicle	Pre-Hybrid ProStar	Hybrid Powertrain Mule 1	Hybrid Powertrain Mule 2
VIN	E4173	E2933	E2941	E2933
Model Year	2009	2010	2010	2010
Transmission	10-Spd Manual	Eaton AutoShift	Dual-Mode Hybrid	Dual-Mode Hybrid
Engine	2009 MaxxForce 13	2010 MaxxForce 13	2010 MaxxForce 13	2010 MaxxForce 13
Tractor Weight	19,150	18,320	22,060	TBD

Summer 2012

55 mph Steady-State Test Results

	Tractor Weight Diff.	MPG	Freight Eff at Constant Freight Weight (Cubed-Out)
Hybrid Relative to '09 Control Truck	+2910	3.7% Better*	3.7% Better*
Hybrid Relative to '10 Pre-Hybrid	+3760	7.1% Better*	7.1% Better*

Results not complete. More runs required to achieve statistical validity

Technical Accomplishments

Vehicle Freight Efficiency Summary

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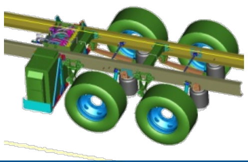
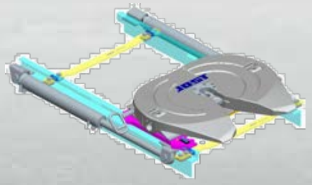
Vehicle Technologies		Target	Status	Estimate
4. Hybrid	Dual-mode Gen II w/EiG batteries	6%	3.7%*	
3. Driveline	SMARTandem & Opti Lube Next Gen WBS Tires, Electronic Leveling Electrified Accessories*	4%	-	+4% -** -*
2. Lightweight	SMARTandem, Ladder assembly Next Gen WBS Wheels & Tires Composite Cab & Trailer Structures	4%	-	+0.3% - -
1. Aero Enhancements	Dynamic 5th Wheel Dynamic Ride Height Surrogate Camera Mirrors Tractor Shapes Trailer Shapes & Features Reduced Height w/NG WBS Tires	16%	20%	+1.5% +1.5%
Total		30%	23.7%	+7.3%

* Electrified accessories are contained within the Hybrid system results.
** Next Gen WBS Tires provide improvement through reduced vehicle height and frontal area in Aero.








Future Work for 2012

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- Complete steady-state and urban driving cycles to demonstrate 5-10% improvement in freight efficiency due solely to hybrid drive
- Commission the next-gen mule 2 truck and its upgraded technologies
  - Electric turbo-compounding
  - Aero improvements (tractor and trailer)
  - Smart tandem
  - Low-rolling resistance tires
  - Air suspension
  - Active fifth wheel

- Upgrade both hybrid drive units for improved shift reliability
- Demonstrate a 25% improvement in freight efficiency using the next-gen mule 2 truck and a trailer with add-on aero features
- Build and install Gen-3 hybrid drive units and re-engineered batteries in mule trucks
- Finish 1/8th and 1/3rd scale wind tunnel testing
- Finalize the demo truck concept

Project Summary

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Relevance:

- The potential of a class 8 truck and trailer combination configured to save 9 billion gallons of diesel fuel per year, reduce our dependence on foreign oil and improve our environment by reducing green house gases has significant national and global interests.

Approach:

- Project focus is on assessing and developing both engine and vehicle technologies to improve freight efficiency while balancing voice of customer requirements in a class 8 truck and trailer integrated design.

Technical Accomplishments:

1. Several aerodynamic scale-models have been developed and evaluated in the wind tunnel. A significant improvement over the baseline has been observed.
2. The hybrid drive unit and battery pack has been redesigned. A weight reduction of approx. 1400 lbs is predicted.
3. Highly-efficient axles and tires have been selected and will be tested this year.
4. The dual-mode electric hybrid drive system has been demonstrated on-road and is generating fuel economy data

Partnerships & Collaborations:

- Cross-functional and industry partnership teams are working well together. Good mix of skills and resources to address the technical tasks in this project.

Future Directions:

- Continue to progress towards a vehicle and engine demonstration of various efficiency improvement technologies.

Technical Back-Up Slides

1. Aerodynamics – Timeline of activities

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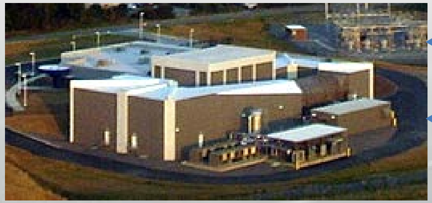
Transition to new 1/8th scale, rolling-road wind tunnel facility- moving belt better simulates vehicle moving down the road

Full scale wind tunnel testing

	2011			2012												2013		2014			
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Q1	Q2	Q3	Q4
Wind Tunnel Tests (1/8th scale)																					
Wind Tunnel Tests (1/3rd scale)																					
CFD																					
Cooling Flow																					



Phase I

Phase II

Phase I – Baseline model test
Phase II – Updated SuperTruck model test

Design verification and optimization as design evolves & details are added

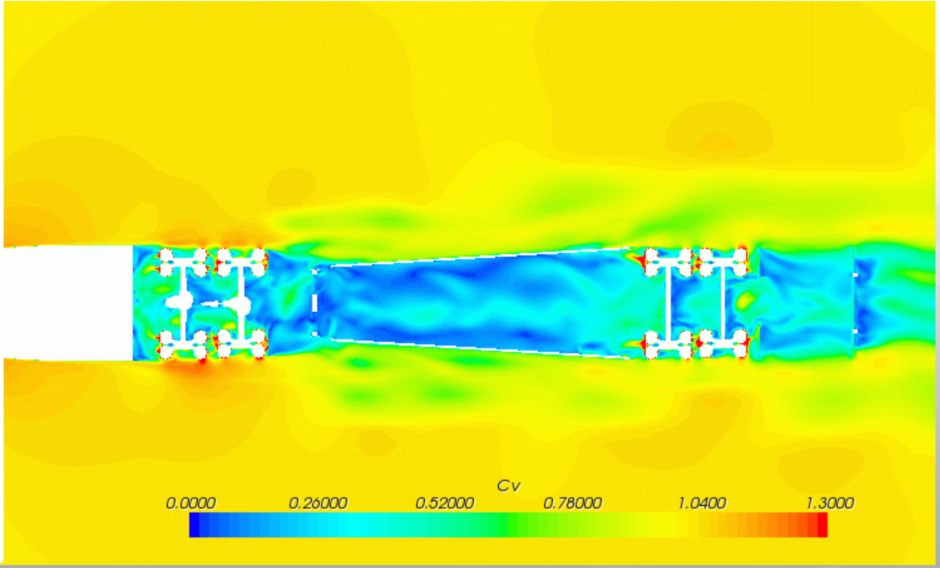
Coast down testing for aero performance validation

Technical Accomplishments

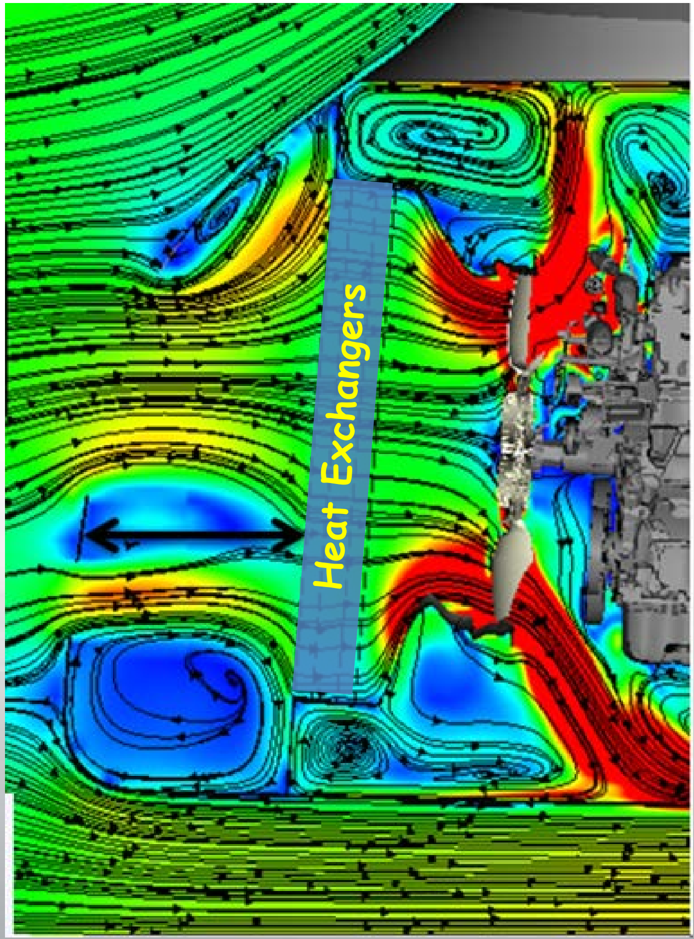
1. Aerodynamic Analysis

Vehicle Thermal Management Systems

- 1-D System Simulation Goals
  - Improve system performance
  - Minimize energy usage of fans and pumps
  - Support waste-heat recovery systems
  - Decouple sub-system interactions



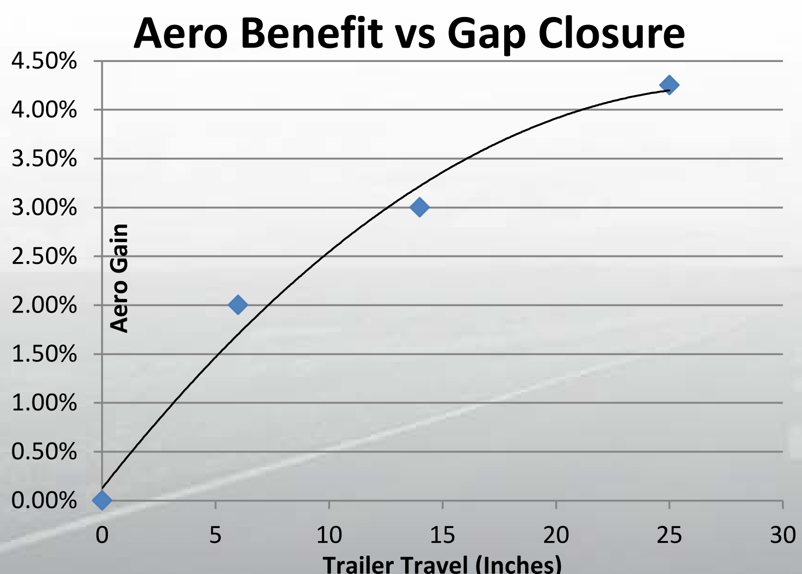
- Under-hood Airflow Analysis



1. Aerodynamics – Gap Reduction

<u>Advantages of Reduced Tractor/Trailer Gap</u>

- Projected 1.5% Highway Fuel Economy Improvement
- Systems can be independent of trailer
- Potentially better aerodynamic/fuel economy payback than trailer mounted devices for fleets with large trailer to tractor ratios



1. Aerodynamics - VTTI Camera Surrogate Mirrors

Cooperative Research Project with VTTI

- Formal kickoff meeting at Navistar being scheduled for April
- VTTI is researching suitable hardware / cameras / lenses
- Navistar arranging loan of test vehicle

Projected 1.5% FE potential savings

- Convex and Flat Mirror Replacements
- Door & Fender Camera Mounting Locations

Technical Accomplishments

4. Hybrid Powertrain – Gen -3 Hybrid Drive Unit

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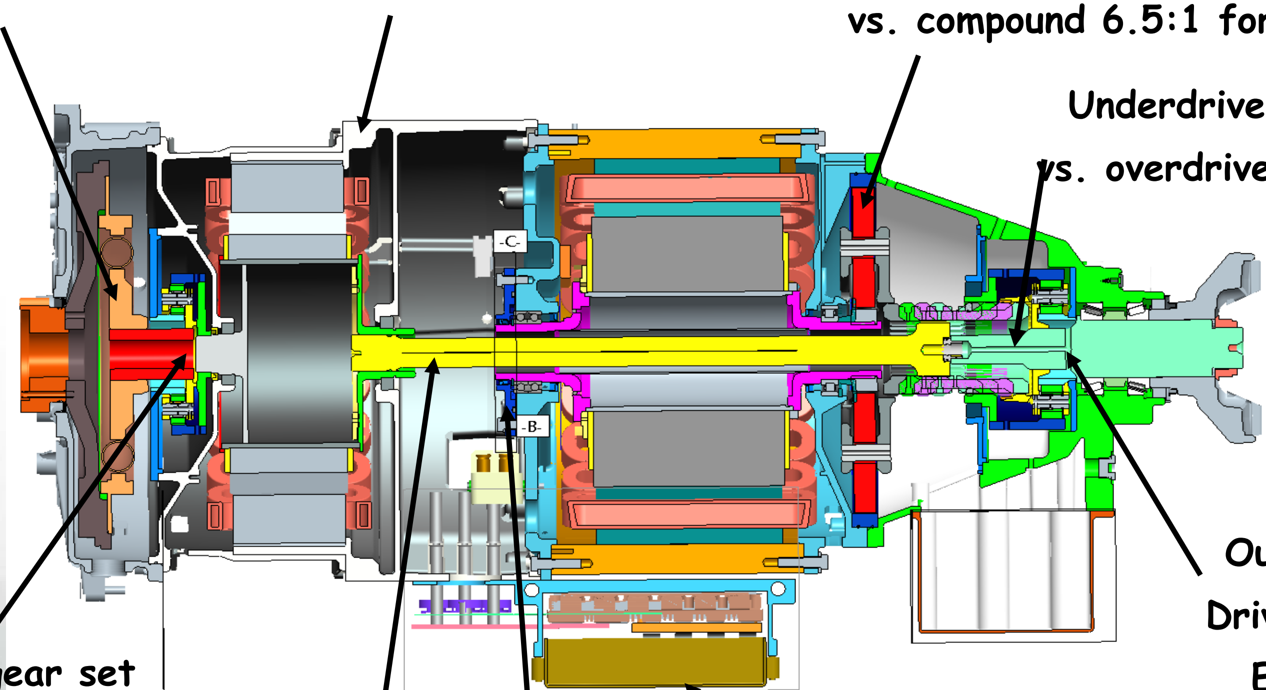
Generator housing
Integrated with mid mount

Torsional Isolator

Simple planetary reduction 5:1
vs. compound 6.5:1 for gen-2

Underdrive gear set
vs. overdrive for gen-2



Output shaft
Driven oil pump
Eliminated

Overdrive gear set
For both
Gen & Engine
1.6:1

Much shorter
Solid shaft

Sealed
Bearing

New smaller inverter
Mounted under T.M. rather than
Generator

4. Hybrid Powertrain – Touch-Screen Data Display

- Critical system parameters are displayed and monitored in the cabin
  - Electric machine
  - Battery
  - Turbo-compounding
- Will be used to make certain calibration choices and monitor diagnostic messages

Instrument Panel-Mounted Touch-Screen

Typical Display Graphics