Advanced Technologies

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

Vehicle Systems

DOE Contract: DE-EE0003303

NETL Project Manager: Samuel Taylor

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

- 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

Assemble a cost effective, robust, reduced weight technologies for 50% freight efficiency
Packaging of hybrid drive unit and supporting systems
Novel approach to cooling flow integration challenges traditional CFD Development methods

Budget

Total Project Funding:	DOE	$37,328,933
	Prime Contractor	$51,801,146
DOE Funding Received in FY2011:		$ 5,440,636

Navistar and our respective program partnerships thank the DOE Vehicle Technologies Program for their support and funding of this innovative project.

Partners (Collaboration and Coordination with Other Institutions)

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

Barriers
And Technology Roadmap

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System Area	Barriers	Technology Roadmap
Engine & Vehicle	Assemble a **cost effective**, **robust**, **reduced** (vehicle) **weight** technologies for 50% BTE.	- Rely on analysis (tradeoff) to select technology - Couple technology to road cycle selection
Vehicle	**Packaging** of hybrid drive unit and supporting systems	- Hybrid Drive Unit , Battery & Accessory design progression shrinkage - Component integration
Vehicle	**Aerodynamic correlation** between modeling and full scale vehicle powertrain cooling/underhood air flow effects on exterior Cd measurements	- Aerodynamic mapping of powertrain cooling system and underhood design features and flow characteristics during exterior aerodynamic tests

Approach:
Technology Roadmap - Chassis Efficiency

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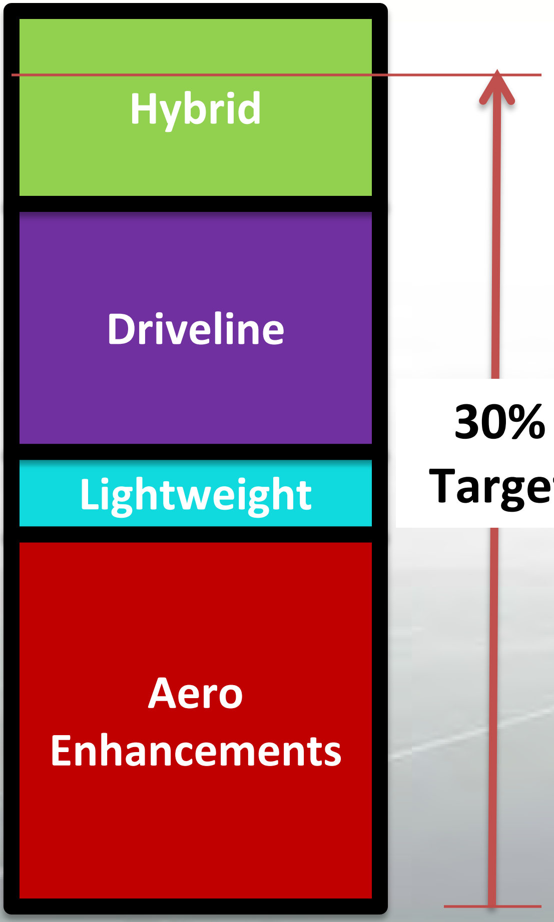
% Fuel Economy Improvement

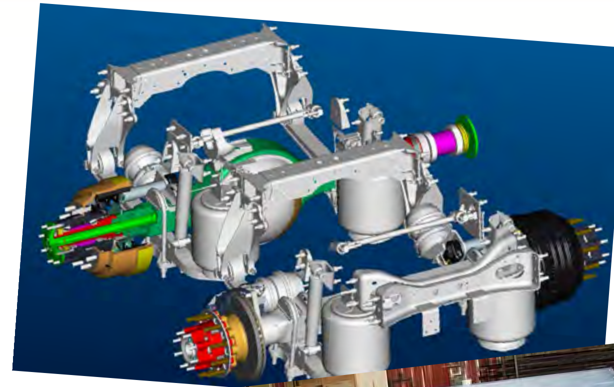


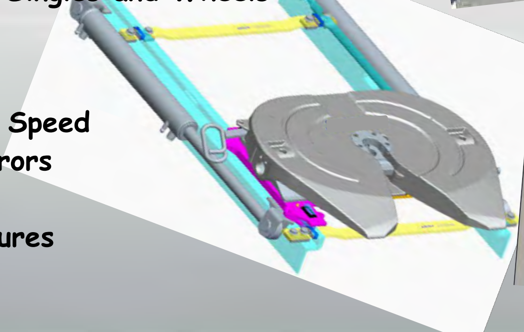
- Dual Mode Hybrid Drive
- Electrified Accessories
    - Power Steering
    - Air Compressor
    - AC Compressor

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

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

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





Approach:
Technology Roadmap - Vehicle

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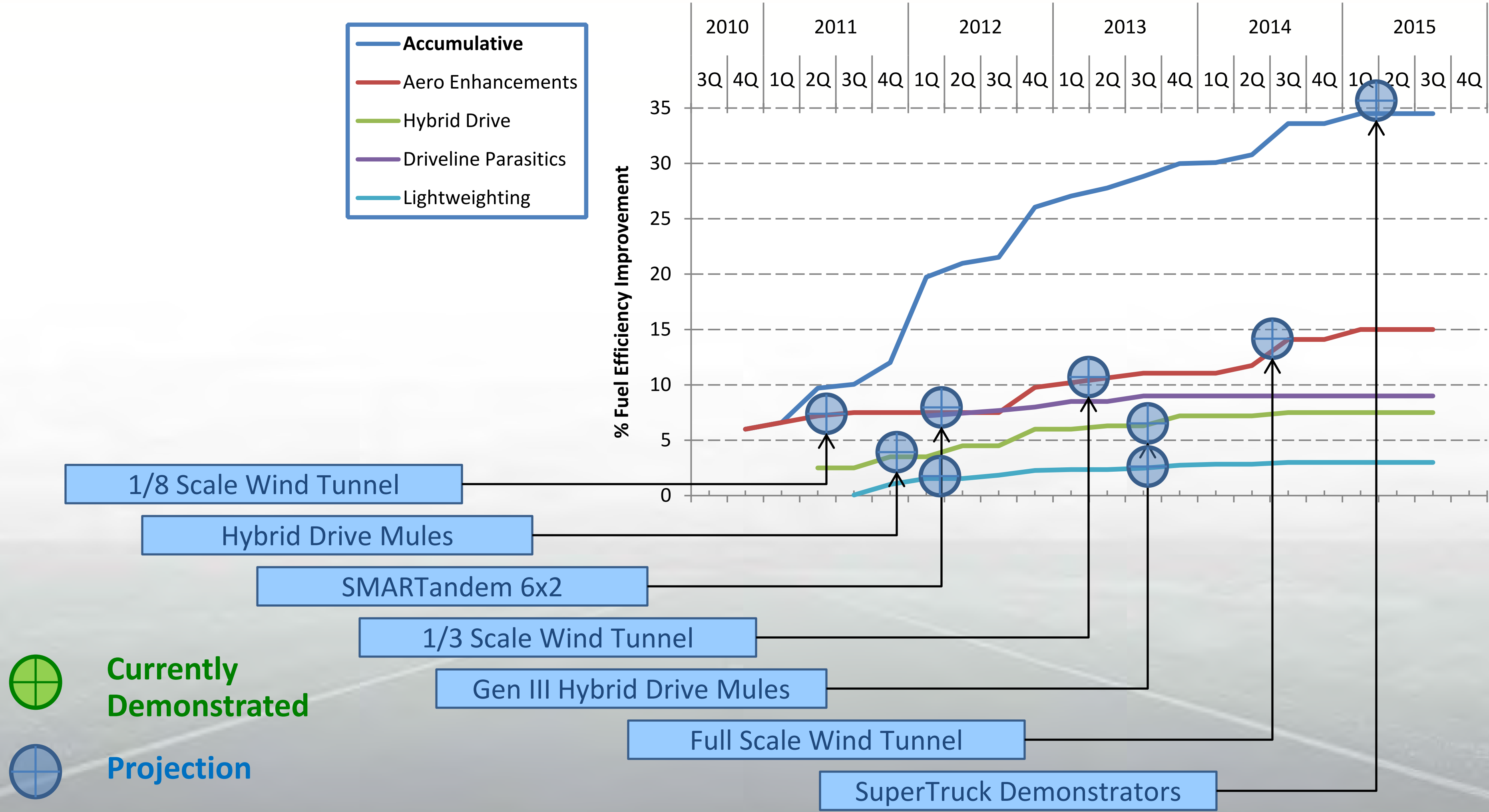

Approach:
Technology Roadmap - Vehicle

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Technologies Assembled in Vehicle Systems (highlight 2010-2011 activities)		
Technology Category	**Area of Concentration**	**Status**
Aerodynamics	Advanced Tractor Shape -Speed Form Study	Deploy April 2011
	Surrogate Rear View Mirrors	
	Advanced Trailer Shapes -PIV -Particle Image Velocimetry	July 2011
	Tire Skirting; Steer, Drive & Trailer	
	Tractor-Trailer Gap Reductions; Dyn. 5th wheel, Cab Extenders	
	Aero Drop, Electronic Suspension Leveling, Tractor & Trailer	2Q 2012
Parasitic Losses	Next Gen Wide-Based Single, Low Rolling Resistance Tires	
	Tire Pressure Monitoring and Inflation	2Q 2012
	Efficient Drive Axle, 6x2 Configuration	1Q 2012
Hybrid Drivetrain	Mule Vehicles (2)	May & June 2011
	Electrified Accessories; Power Steering, AC & Air Compressors	May & June 2011
Air Flow Management	Cooling System Modularization	
	Cooling System Exhaust location Impacts on Aerodynamics	
Vehicle Lightweighting	Advanced Modular Chassis Construction	
	Efficient Drive Axle, 6x2 Configuration	1Q 2012
	Composite Cab and Trailer Construction	
	Optimized Wide-Based Single Tires & Wheel End Equipment	

Approach:
Technology Roadmap - Hybrid Powertrain

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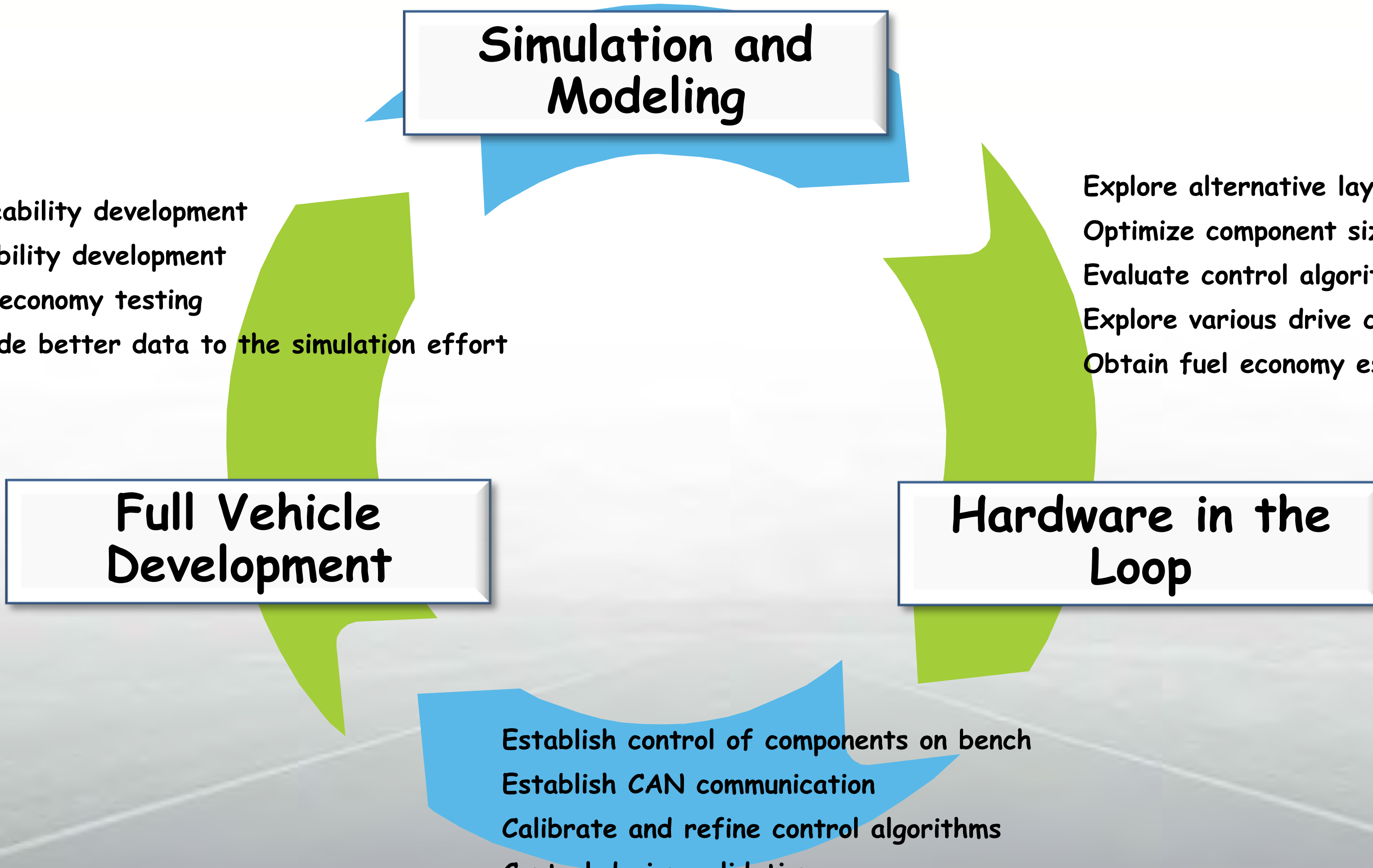


- Explore alternative layouts
- Optimize component sizes
- Evaluate control algorithms
- Explore various drive cycles
- Obtain fuel economy estimates

- Establish control of components on bench
- Establish CAN communication
- Calibrate and refine control algorithms
- Control design validation

- Driveability development
- Durability development
- Fuel economy testing
- Provide better data to the simulation effort

Detailed Vehicle Models Developed

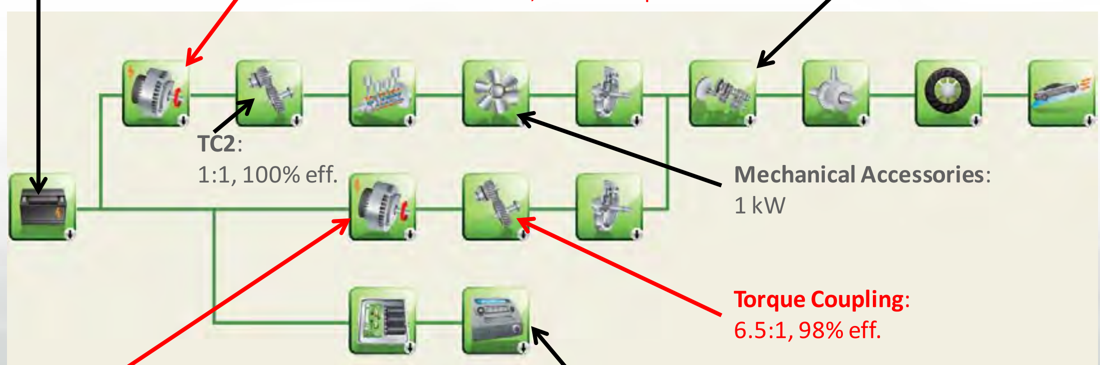
Hybrid Truck Specification

Battery:
- EIG Li-ion
- 20 Ah (cell), 40 Ah (pack)
- 28 kWh
- 500 kW (dis.) / 222 kW (chg.)
- 432 Cells

Motor 2 (Generator):
- 400 kW (Peak), 220 kW (Cont.)
- Base Speed: 2,100 RPM
- Top Speed: 3,200 RPM
- Peak Torque: 1,819 Nm
- Inertia = 1.61 kg.m2
- Switch Reluctance, Includes Spin Losses

Gearbox:
- ArvinMeritor Dual Mode
- Low Gear: 1:1 , 100% eff.
- High gear: 0.59:1, 98 % eff.

Powertrain models will be used to predict performance and evaluate hardware alternatives



TC2:
1:1, 100% eff.

Mechanical Accessories:
1 kW

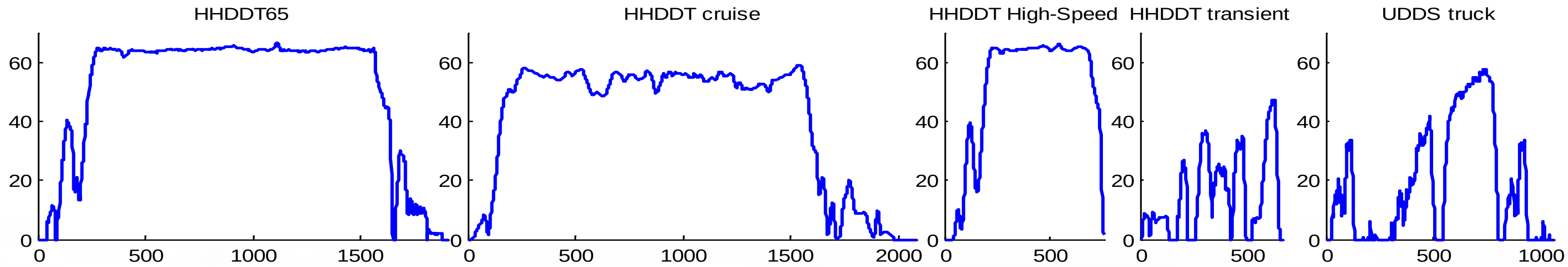
Torque Coupling:
6.5:1, 98% eff.

Motor 1 (Traction):
- 360 kW (Peak), 200 kW (Cont.)
- Base Speed: 2,100 RPM / Top Speed: 10,000 RPM
- Peak Torque: 1,637 Nm
- Inertia = 1.54 kg.m2
- Switch Reluctance, Includes Spin Losses

Electrical Accessories:
3 kW

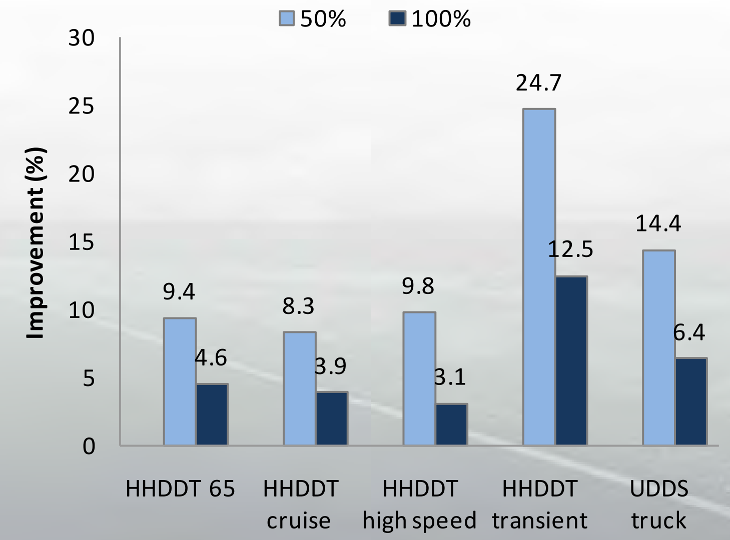
RED = DATA FROM NAVISTAR

Freight-Specific Fuel Economy (ton-mile/g) Improvements from Simulation*



Weight Assumptions

Load	Conv.	HEV
0% (empty truck)	32,925	34,925
50% (10,000 kg)	54,951	56,951
100% (GVW)	80,000	80,000



Freight-specific fuel economy improvements are significant, but dependent on drive cycle

***A 2000-lb hybrid weight penalty is assumed for the development vehicles ONLY. SuperTruck will weigh much less.**

Controls Hardware-in-Loop System is Operational

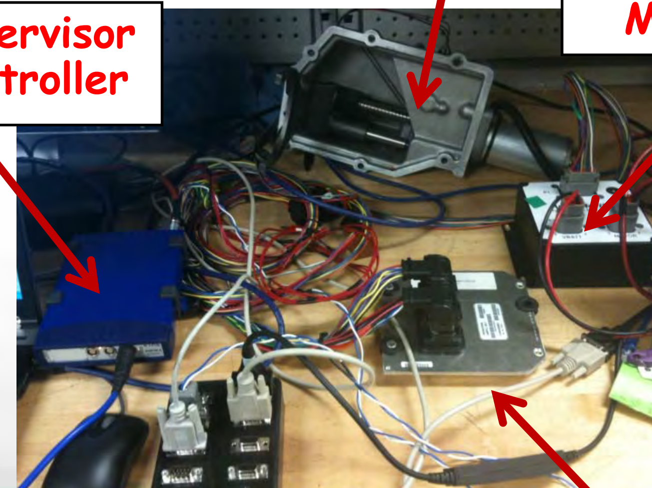
Simulated

- Route
- Driver
- Vehicle
- Powertrain

Real (articles under test)

- Engine Control Module
- Hybrid Supervisor Control Module
- Transmission Control Module
- Shift Mechanism and Actuator Module

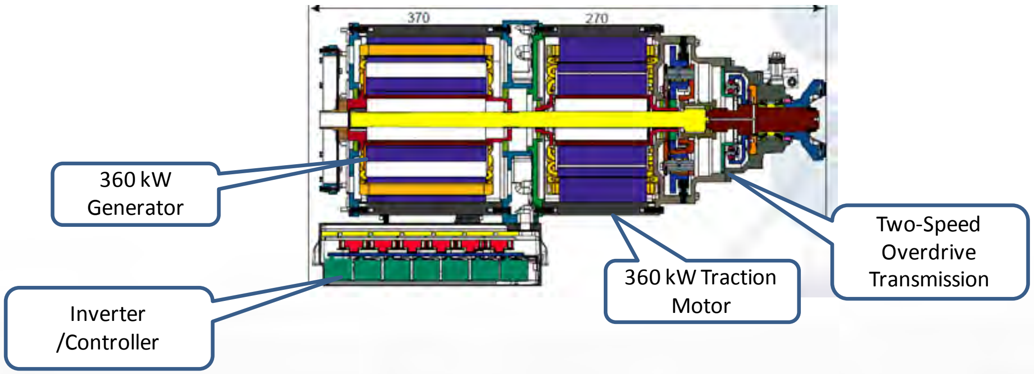
Inputs:	Various routes and drive cycles
Outputs:	All control signals and communications Physical movement of shift mechanism

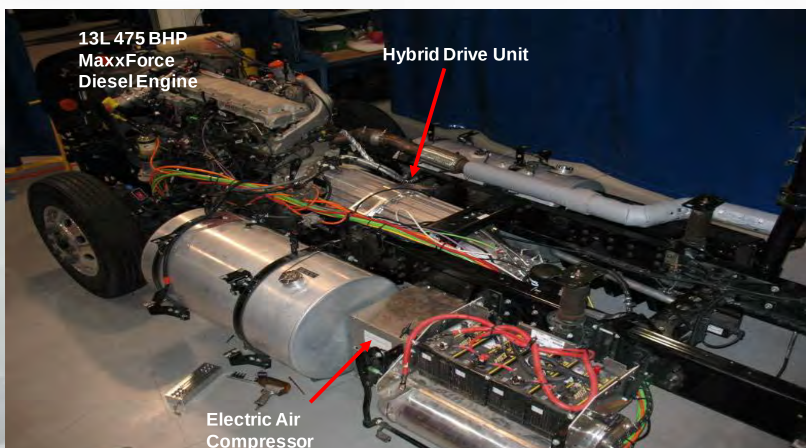


The HiL bench is an effective environment for control system development

Hybrid Powertrain Development Vehicles

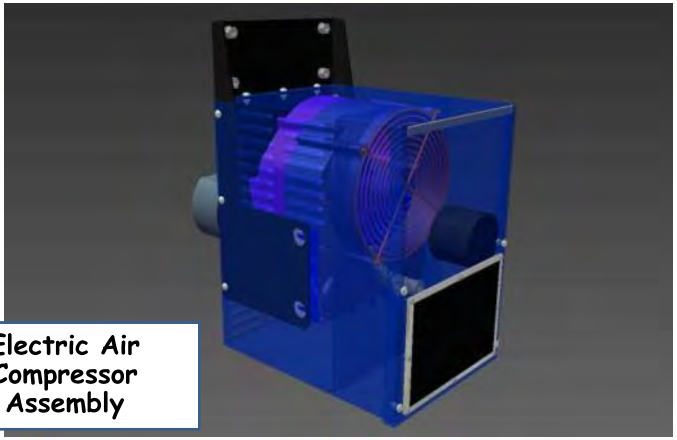
The first development vehicle is nearing completion





Hybrid Powertrain – Electrified Accessories

- Air Compressor
- Power Steering
  - Closed-center steering gear (more energy-efficient)
- HVAC Compressor
- All driven by efficient 350V motors



Electric Air Compressor Assembly

Benefits of Electrified Accessories

- Enables EV operation
- Extended engine-off hoteling
- More efficient
  - Constant rpm
  - Turn on/off as needed

Hybrid Powertrain – Component Packaging

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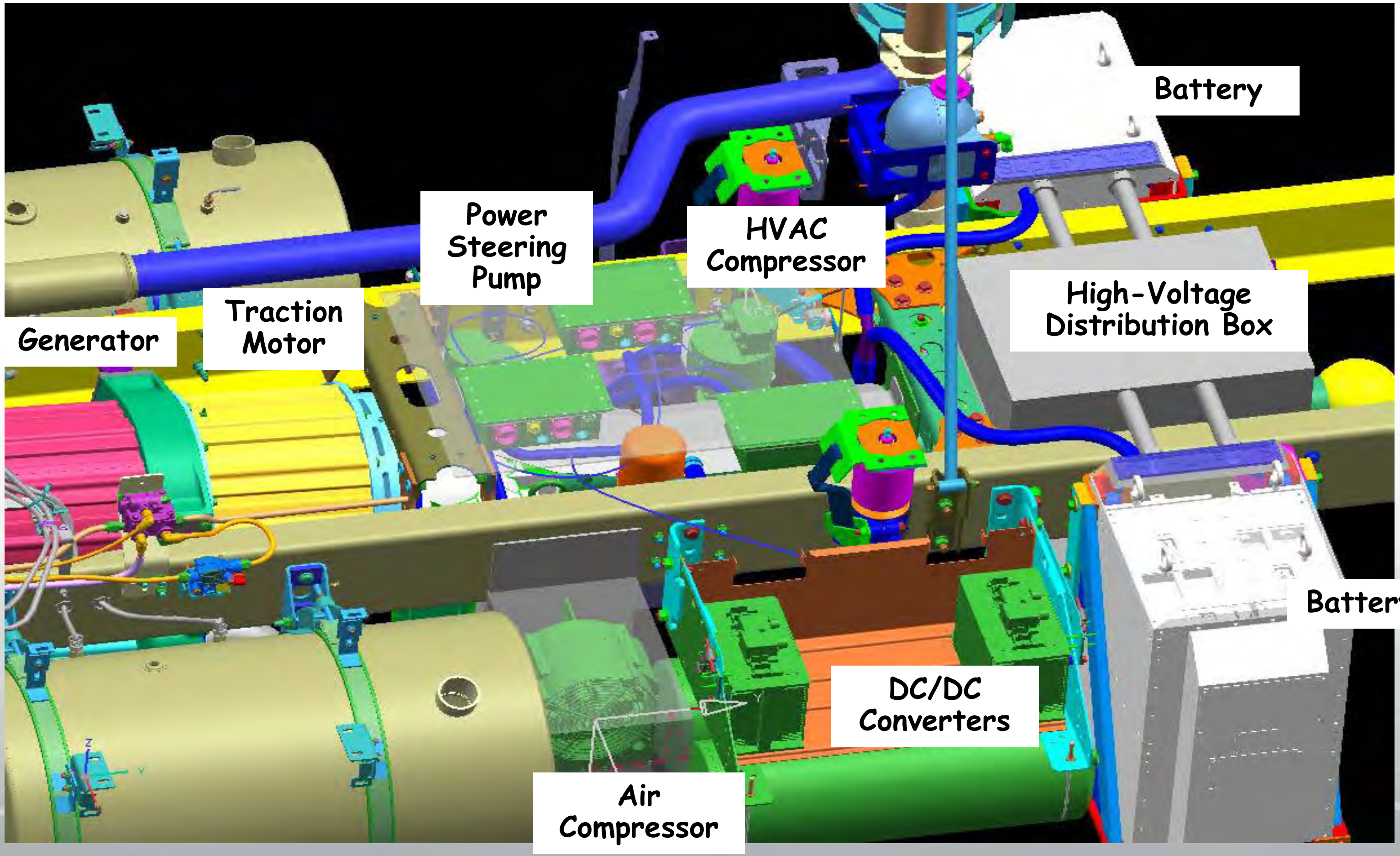
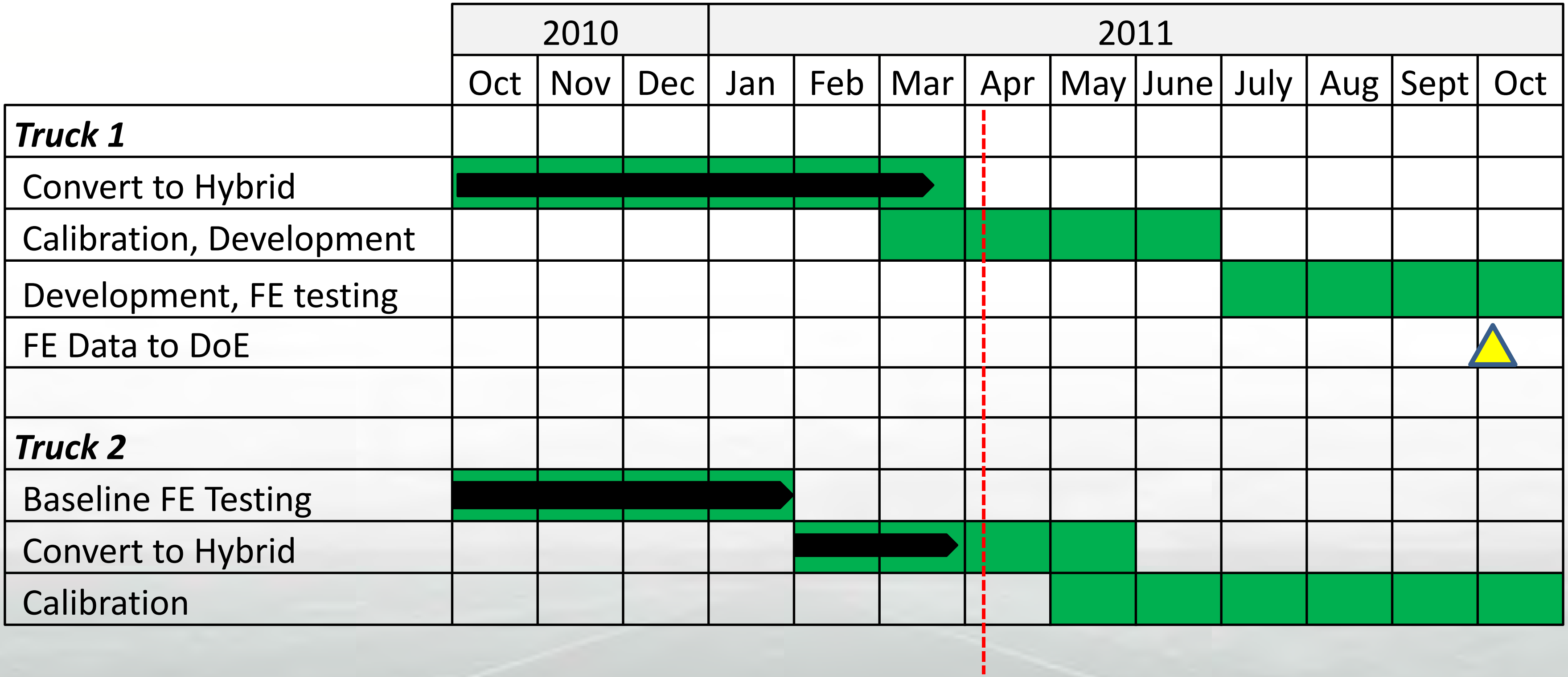


Technical Accomplishments

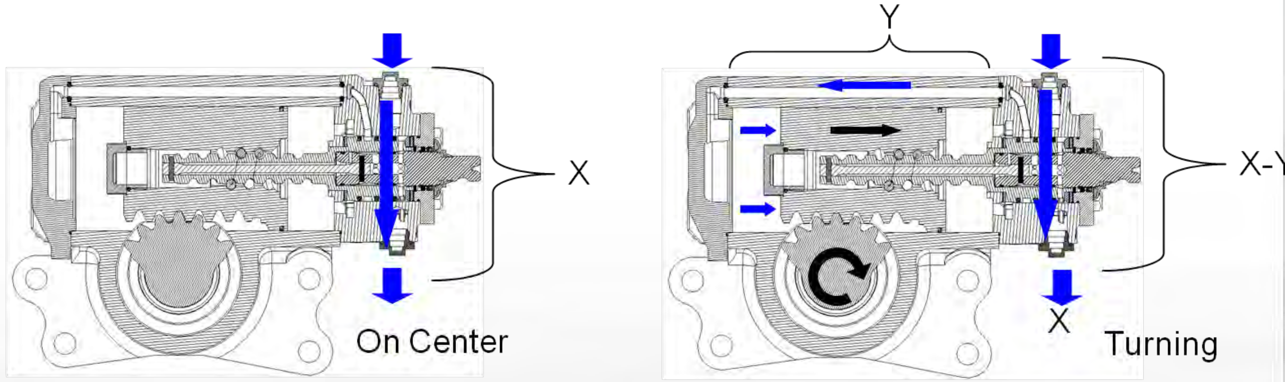
Hybrid Powertrain – Development Progress



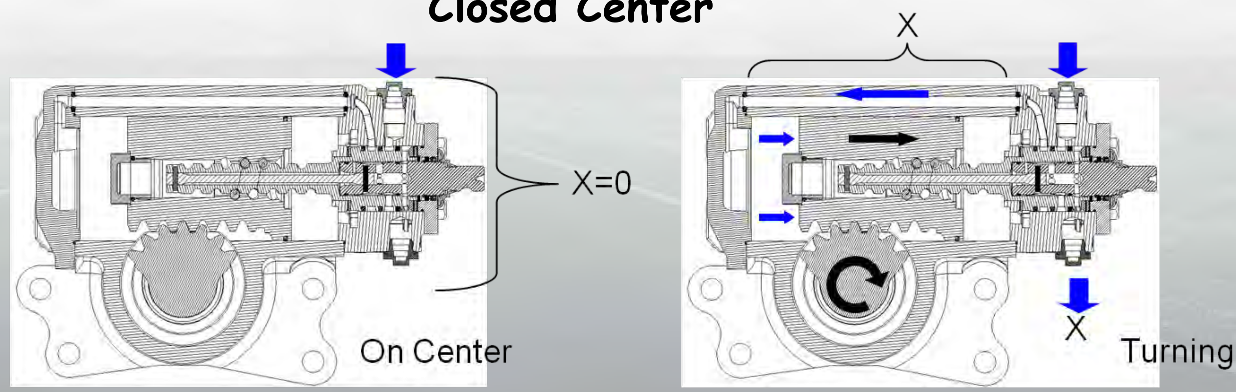
Closed Center Steering Gear required in order to provide efficient assist during EV mode operation.

- **Open Center Design** = Constant Flow / Variable Pressure
- **Closed Center Design** = Constant Pressure / Variable Flow
- Projected FE improvement in line haul application is ~0.4%
- On road evaluation in Sept, 2011

Open Center

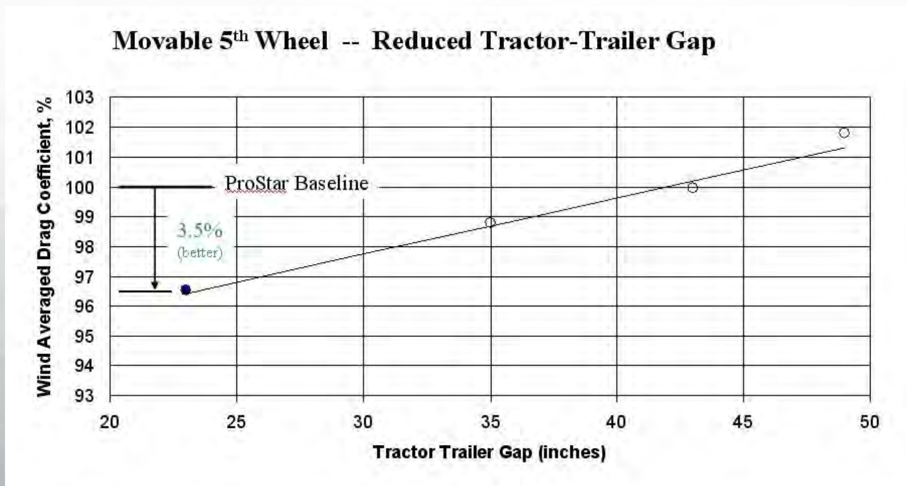


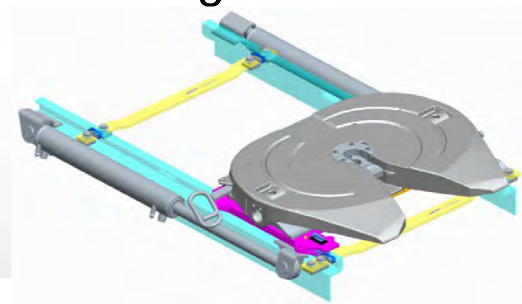
Closed Center

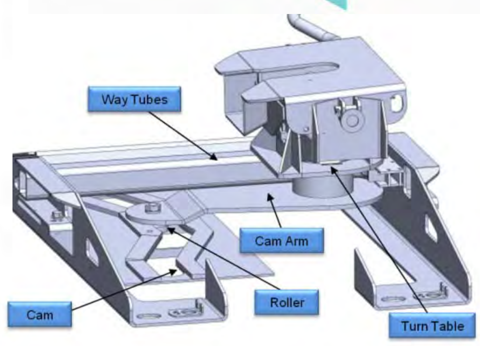


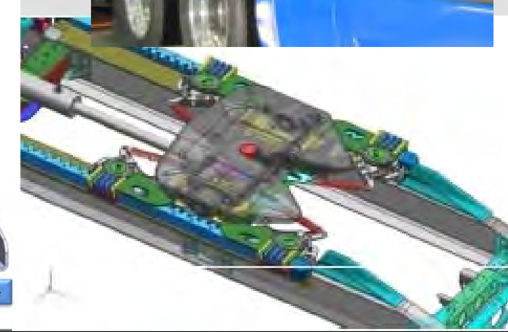
Advantages of Reduced Tractor/Trailer Gap

- Projected 1.75% 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









Technical Accomplishments
Industrial Design/Aero Shape Development

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Year 1-2: Basic exterior aerodynamic shape & form development

Baseline 1/8th scale wind tunnel testing & CFD

Year 1-2: Integration of heat exchangers & cooling system w/CFD & tunnel testing correlation

Year 2-3: Detailed exterior aerodynamic component development
Scale Models Wind Tunnel 1/3rd Scales

SuperTruck Aerodynamic Development Process Steps

Year 1: Industrial Design

Year 3-4: Full Scale Wind Tunnel Testing at NFAC 80' x 120' wind tunnel

Validation of integrated managed airflow package (exterior aerodynamics and cooling flow)

Year 5: On Road Verification

Technical Accomplishments

Vehicle Aerodynamics - Baseline

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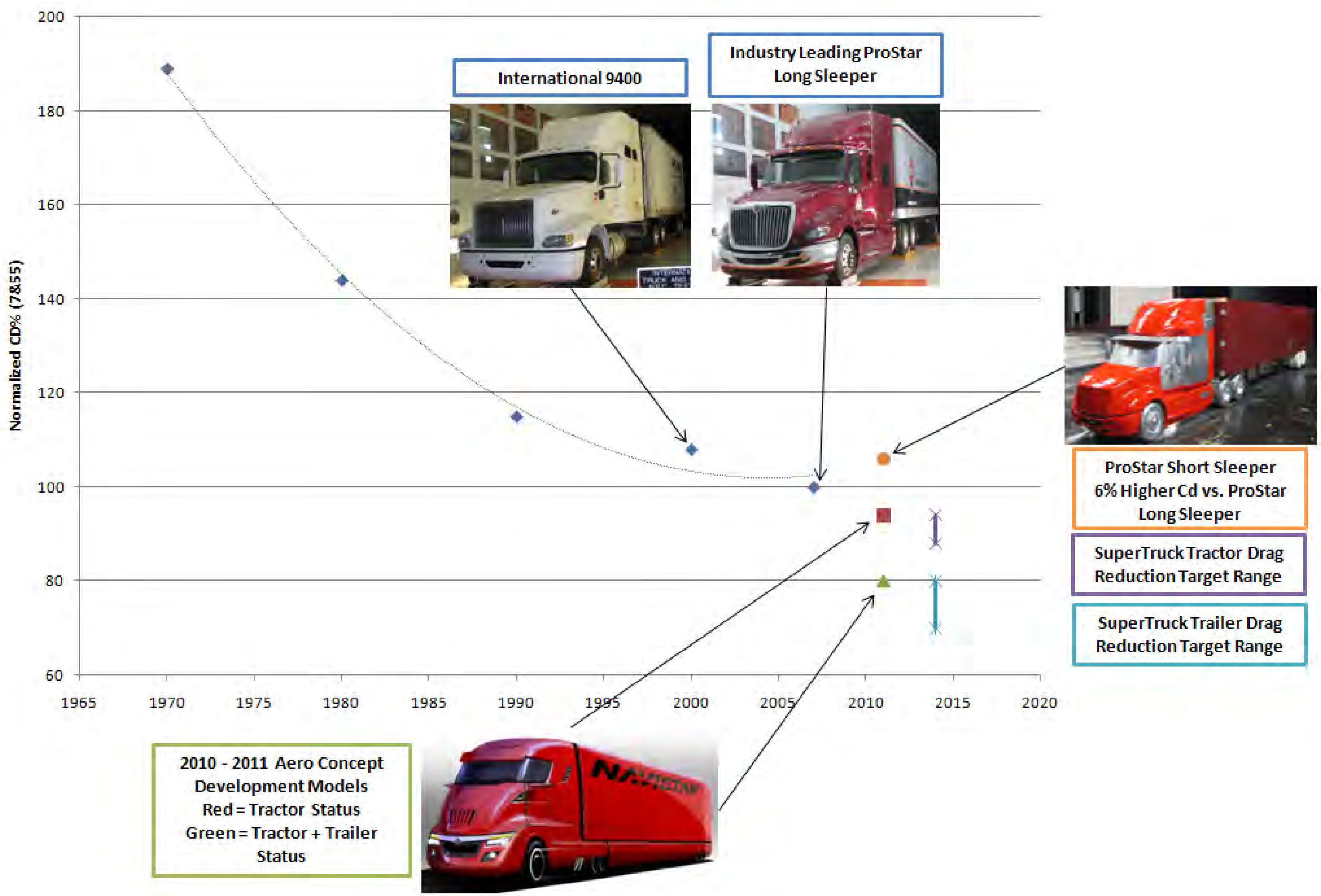

Technical Accomplishments

Aerodynamics – Development Progress

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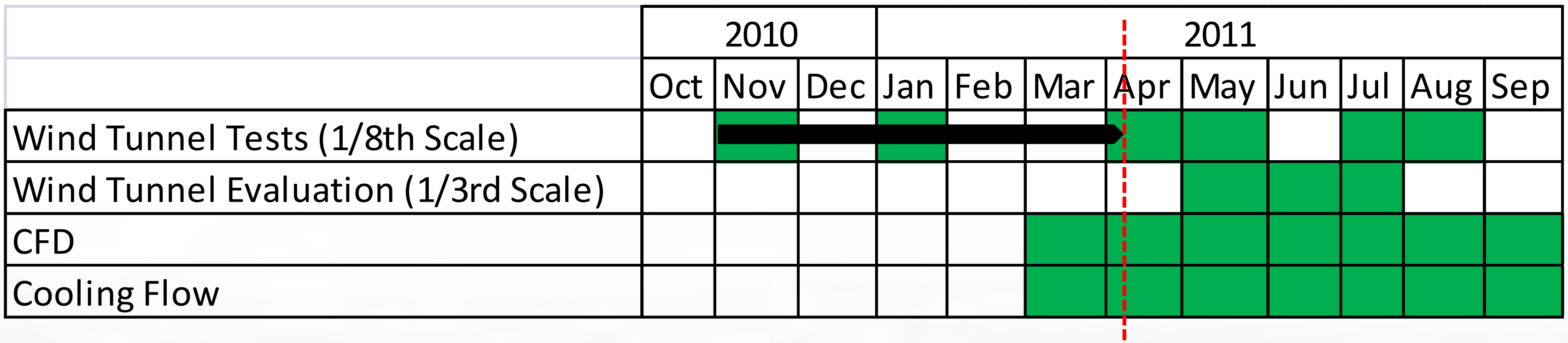

Remaining Activities for 2011

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- ***Demonstrate on road 5-10% freight efficiency improvement demonstration of ArvinMeritor GenII DMHP utilizing functional regenerative braking.***
- Complete ***Voice-of-the-Customer interviews*** with fleet partnerships
- ***Define and map real road test cycle route*** that is representative of a typical long-haul Class 8 truck consisting of minimum of 75 percent of the distance traveled under highway conditions.
- ***Complete installation*** of ArvinMeritor Dual Mode ***Hybrid Powertrain*** (DMHP), accessory electrification and electrical/cooling system modifications in two (2) ProStar development vehicles.
- Develop, optimize and evaluate ***hybrid related control system algorithms*** for DMHP regenerative braking system, battery SOC and transmission overdrive operation to rebalance energy conservation vs. on-road vehicle performance.
- Develop, optimize and evaluate ***electrified accessories*** control algorithms to rebalance energy conversation vs. real world on-road system performance.
- ***Complete CFD*** and 1/8th scale model ***wind tunnel testing*** of tractor speed shapes to allow down-selection and incorporation of powertrain cooling system aerodynamic mapping and underhood airflow assessments.

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 a balance of both engine and vehicle technologies to improve freight efficiency while providing a cost effective, robust and reduced weight combination class 8 truck and trailer integrated design.

Technical Accomplishments:

- On target to meet Phase 1 milestones and deliverables.
- Project achievements after six months since 10/1/10 contract start date has shown accelerated progress towards long term and interim targets.
- Hybrid Powertrain simulation shows promising improvement over standard industry drive cycles between 5-12%.
- In vehicle Hybrid powertrain development hardware has proceeded to allow availability of two development vehicles for start of on-road testing of non-aero subsystems in Summer 2011.
- Industrial design, CFD and baseline 1/8th scale modeling of both base line and speed form shapes have substantiated 20% improvement in Cd is achievable.

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.