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 : Dale A. Oehlerking, Navistar

DOE MERIT REVIEW
WASHINGTON, D.C.
May, 2013

National Energy Technology Laboratory

Department of Energy

Project ID: VSS064

Program Overview

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Advanced Technologies

Timeline

Project Start:	February 2010
Project End:	April 2015
Pcnt Cmplt:	25%

Goals and Objectives

Demonstrate 50% improvement in freight efficiency of a combination Tractor-Trailer

Attain 50% BTE Engine

Demonstrate path towards 55% BTE Engine

Barriers

Achieving 50% freight efficiency while balancing Voice of Customer Needs

Alignment with business needs

Maintaining tractor weight while adding new systems

Budget

Total Funding:	$89,130,079
DOE:	$37,328,933 (42%)
Prime:	$51,801,146 (58%)
DOE Funding to Date:	$13,393,868

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

Partners

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
Argonne National Lab	Hybrid Drive Simulation and Controls & Battery Testing
Lawrence Livermore National Lab	Aerodynamic Testing

Timeline with Targets and Milestones

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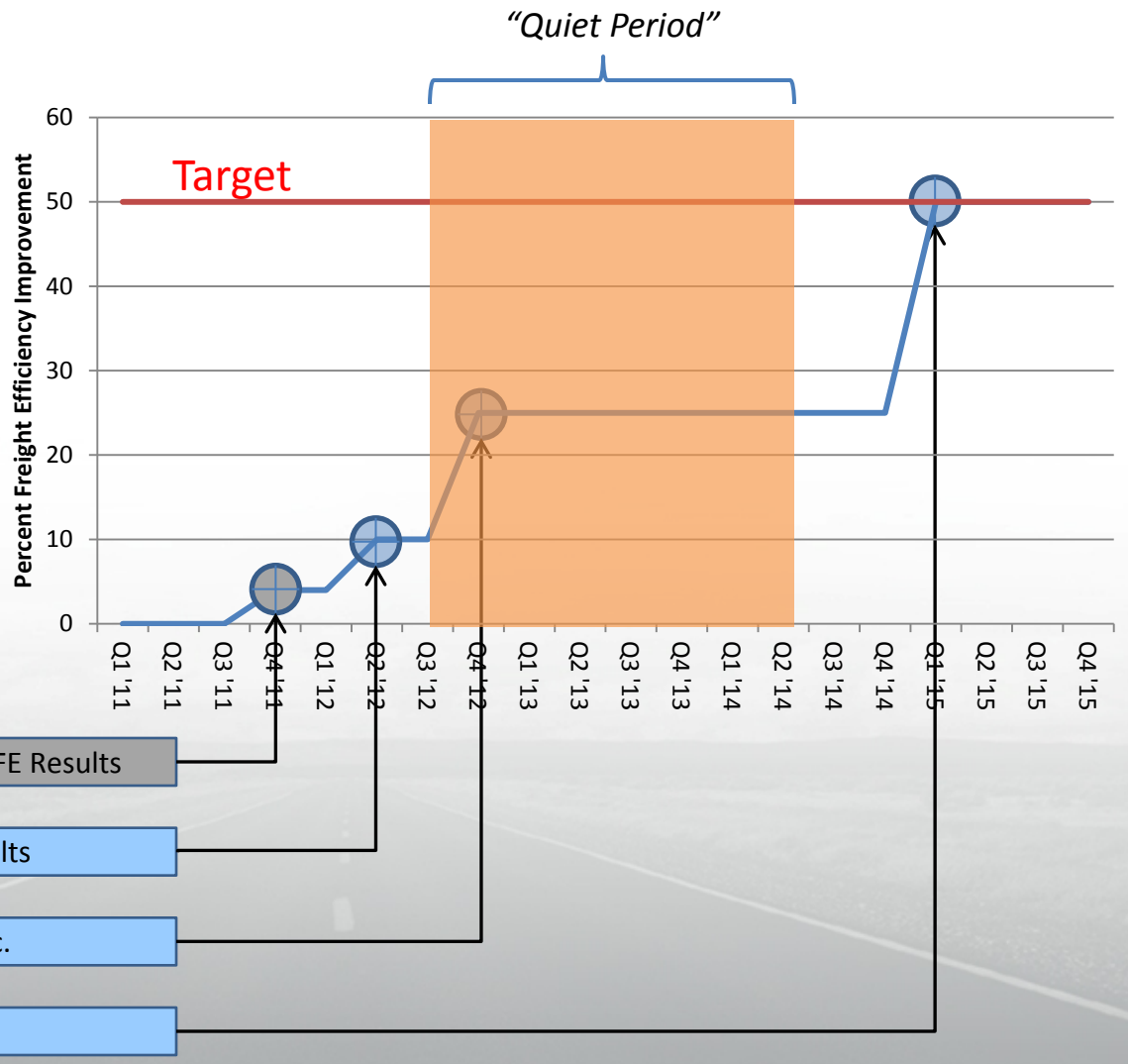
Quiet Period

- November 2012 to April 2014
- No work during quiet period
- Decide Next Steps in April 2014



Next Steps

Completed

On-Road Demo and Initial Steady-State FE Results

Mule 1 Hybrid Highway and City FE Results

Mule 2 w/Hybrid, TuCo, Aero Trailer, etc.

Final SuperTruck Vehicle Demonstrator

Technical Approach

Four Distinct Areas of Development

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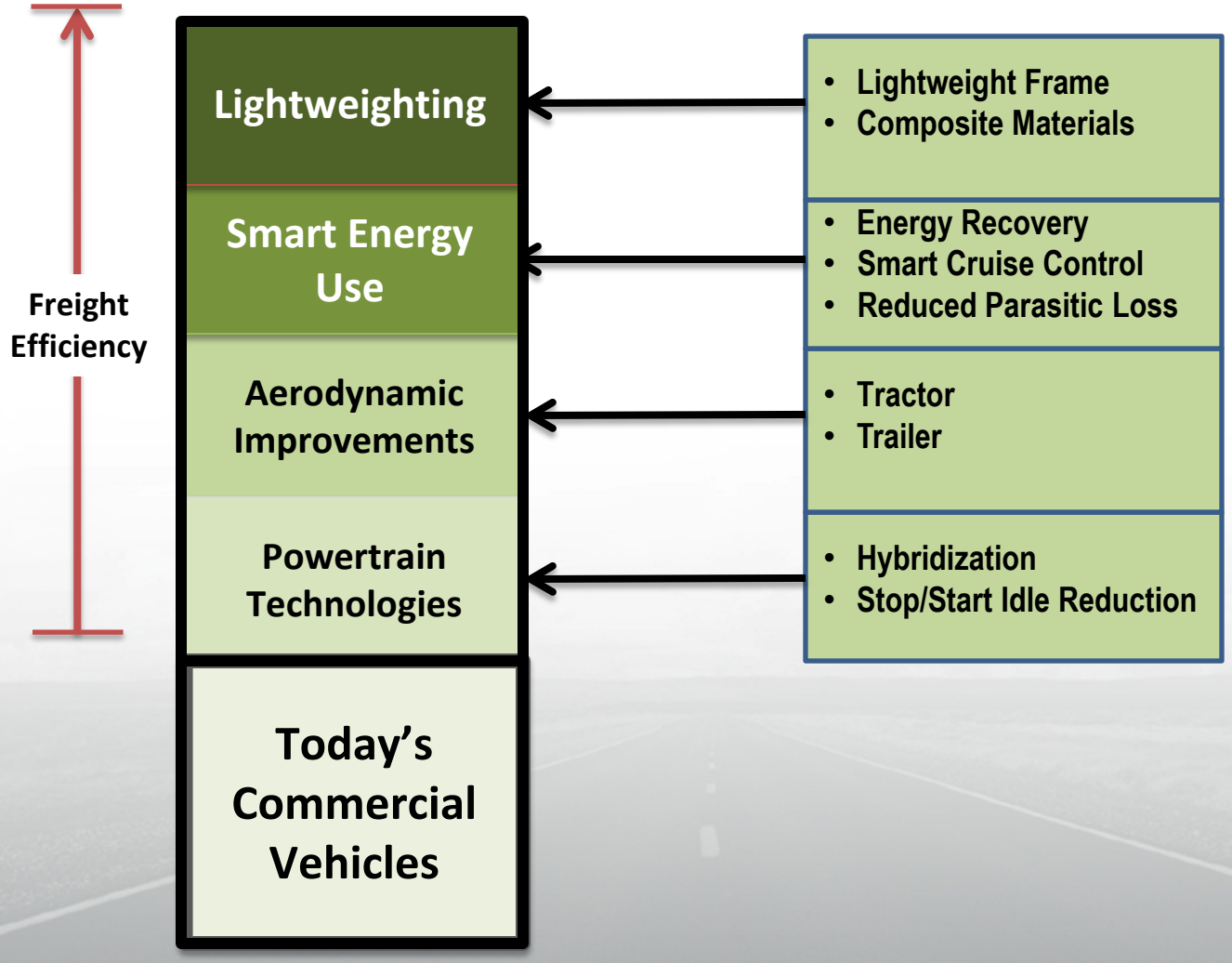


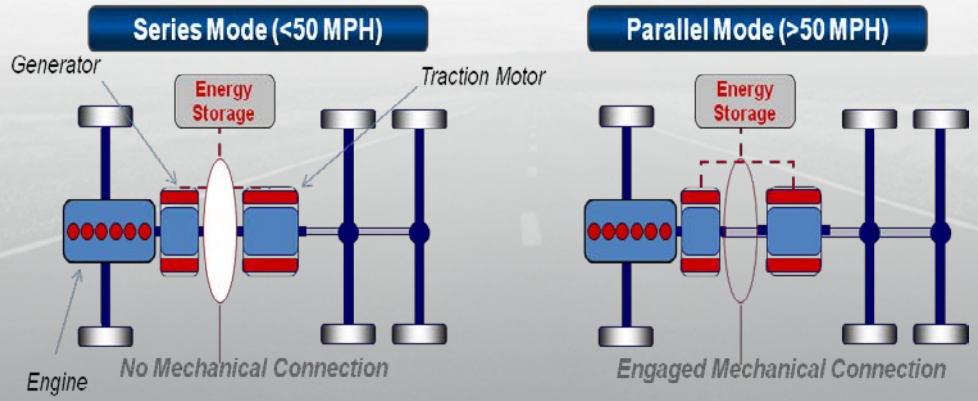
Hybrid Powertrain

Shift Development Progress

- There are no clutches in the dual-mode hybrid powertrain
- All shifts are accomplished by rev-matching and neutralizing torque
- There are 5 shift positions

Position	Description
1	Series Mode. Engine not directly connected to drive wheels,
2	Parallel Mode, low range, traction motor AND generator engaged
3	Parallel Mode, low range, traction motor disengaged, generator engaged
4	Neutral
5	Parallel Mode, high range, traction motor disengaged, generator engaged

- ***Major hardware and software upgrades provided rapid, robust shifting***



Hybrid Powertrain

Next-Gen Design Progress

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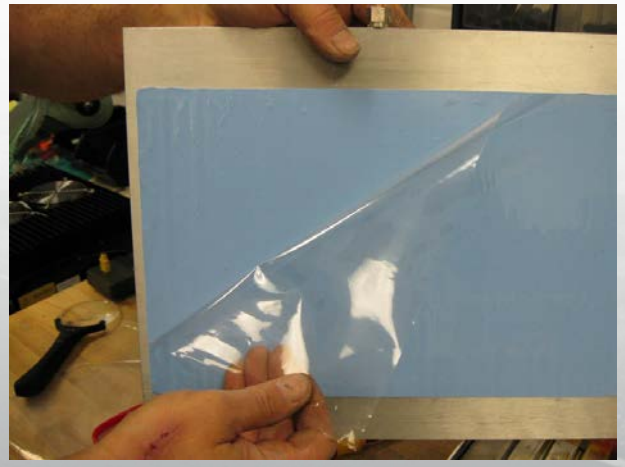
- Next Gen design intended to reduce size and weight
  - 10 inches shorter
  - Up to 800 lbs lighter
  - Similar in size and weight to conventional manual trans and clutch
  - Weight savings alone provide **2% freight efficiency improvement**

Current-Generation Drive Unit

Hybrid Powertrain

Battery Development Progress

- High-power batteries
  - 350kW Liquid-Cooled Lithium-Ion
  - 750 Volts
  - 28 kW-hrs
- Cooling System Improvements
  - Added conductive pads to aid heat transfer
- Battery Management System
  - Areas for improvement identified
  - New BMS software and hardware required (timing TBD)



Hybrid Powertrain

ProStar-Based Development Mules

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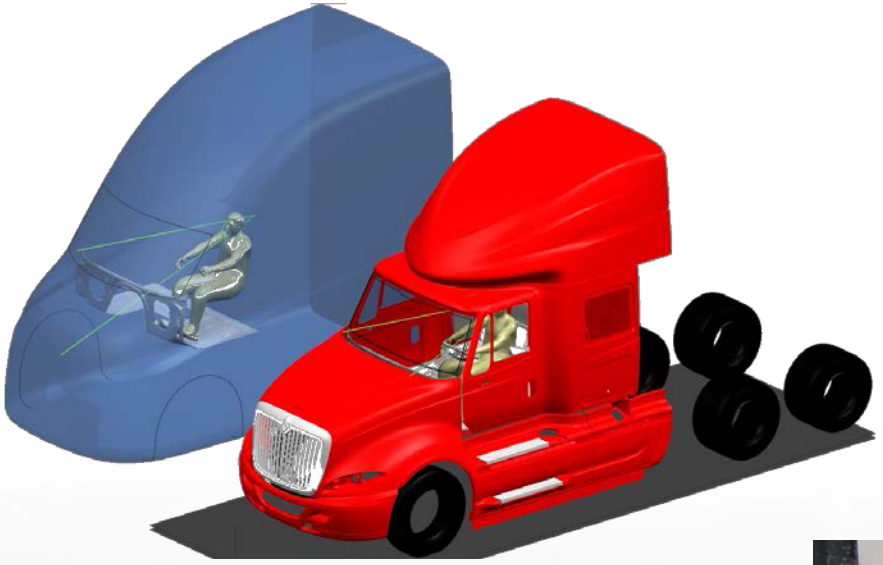
Development Mule 1

- Shift Development
- Battery Development
- Performance and Fuel Economy Testing
- Currently in Storage

Devevelopment Mule 2

- Added Technology
  - TurboCompounding
  - Active Fifth Wheel
  - Active Ride Height
  - Drive Wheel Skirts
  - Smart Tandem (6x2)
  - Battery Chiller
  - Disc Brakes
- Assembled, but Not Tested
- Currently in Storage

Aerodynamic Progress
Tractor Shape Development



Theme development and ergonomic layout

Scale-model wind tunnel testing

Aerodynamic Progress

Trailer Shape Development

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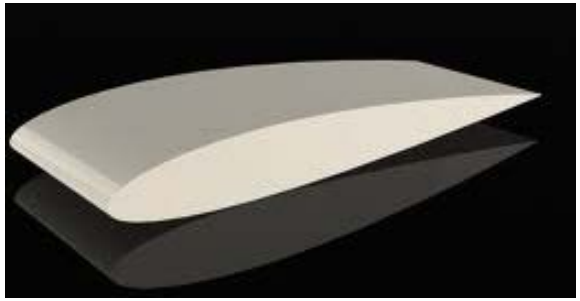
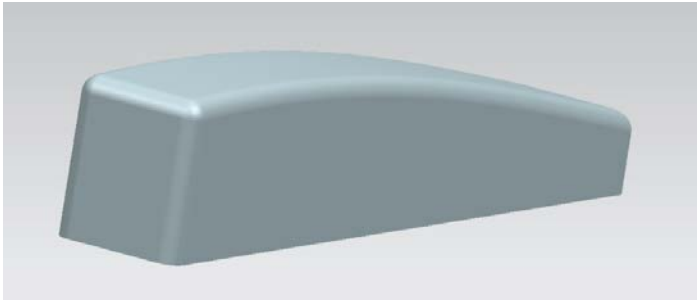
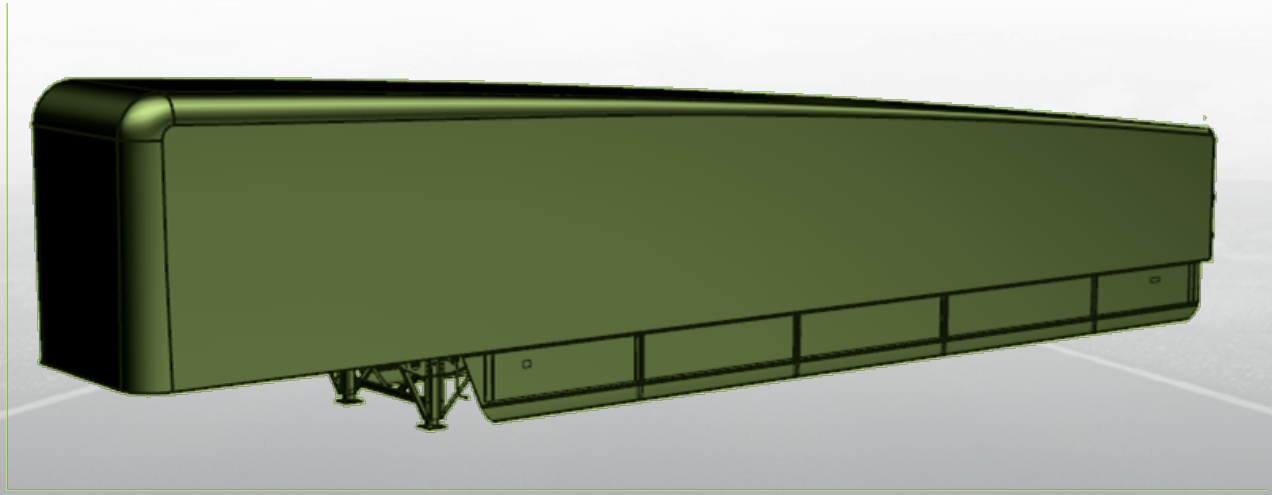
Conventional Trailer



Ideal shape for low drag

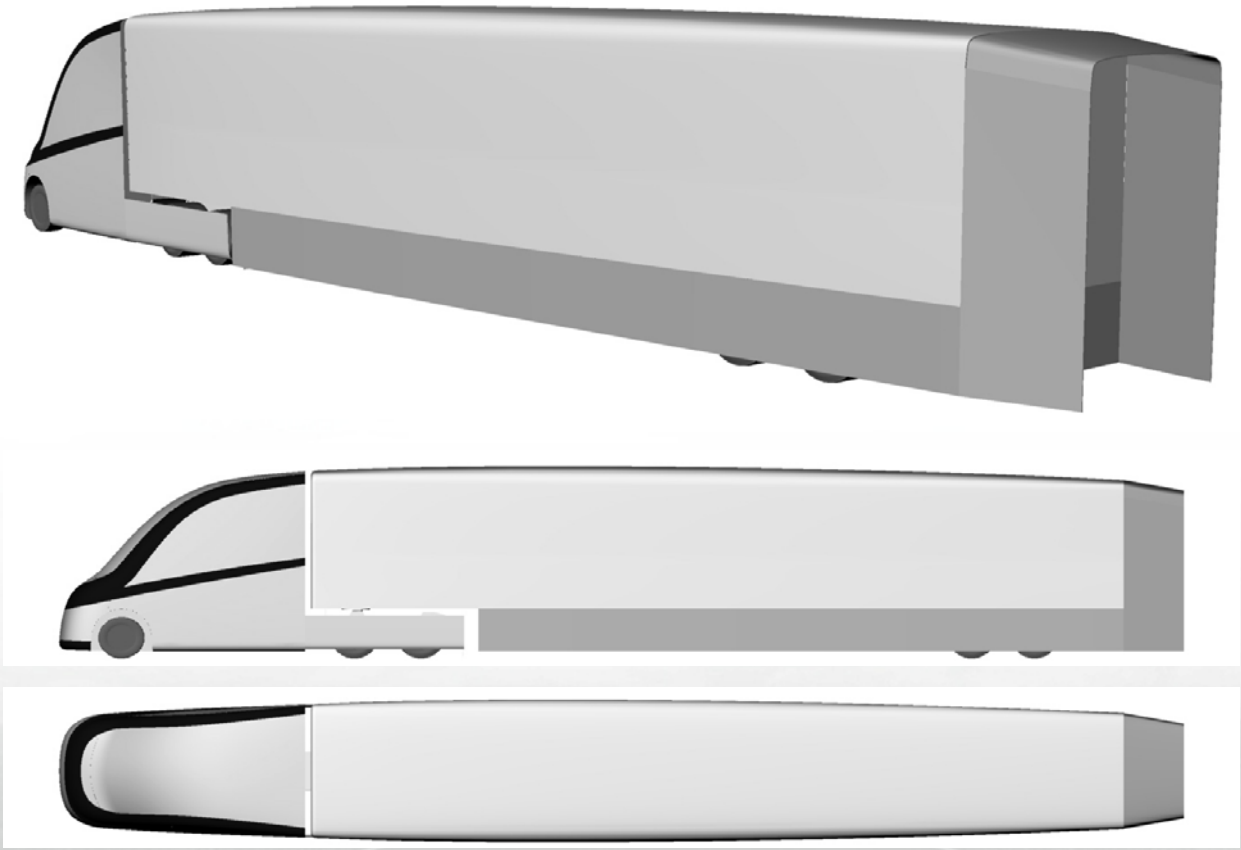


Idealized Trailer Concept



Aerodynamic Progress

Aero Trailer Concept from Lawrence Livermore Labs

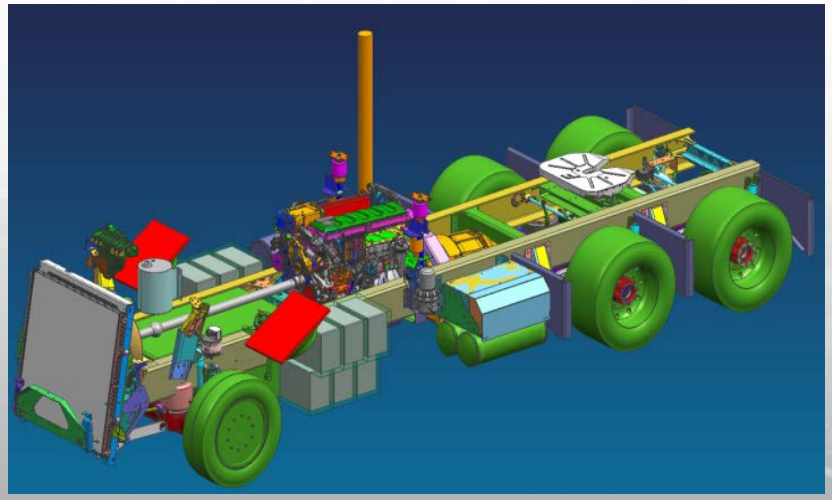


Trailer is tapered in both plan and elevation views

Vehicle Architecture

Enabler of Aerodynamic Body Shape

- Rear Engine Concept
  - Cabin floor height same as ProStar
    - Cabover-type tractors are not received well by customers
  - Moves driver and windscreen forward for improved aero
  - Only rear axle of tandem is driven (6x2 SMARTandem)



Aerodynamic Progress

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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%
Sept 2012 w/Add-On Trailer Aero 	2012	58	21%

Aerodynamic Progress

A Vision for the Future

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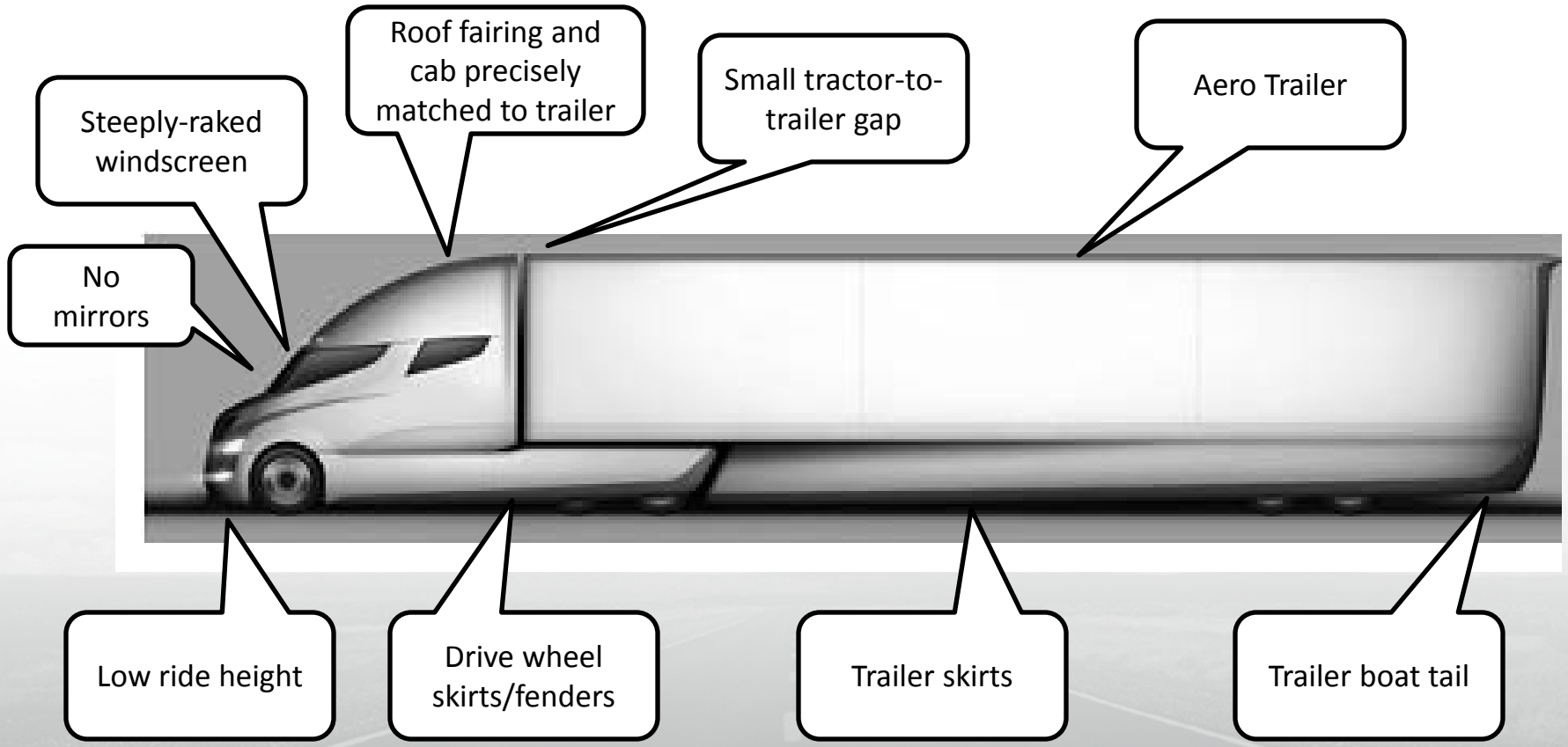
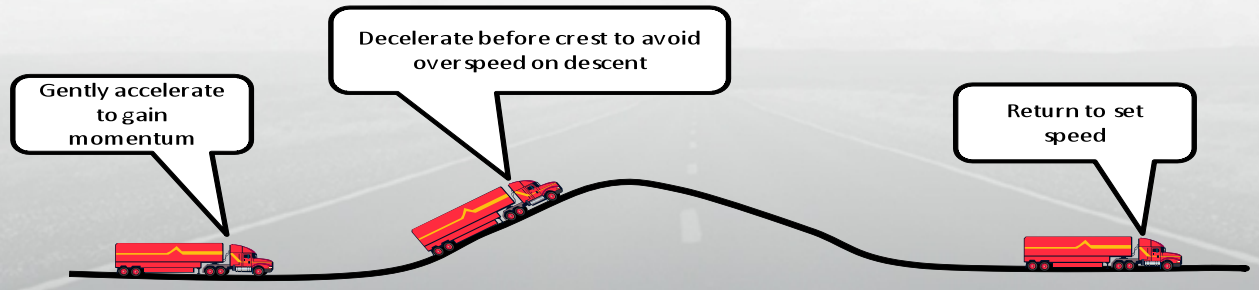


Smart Energy Use

Progress

- Opportunities for Energy Recovery
  - Regenerative Braking (a feature of the hybrid system)
  - Opportunistic Charging in Systems Not Related to the Hybrid Powertrain
    - Air System
    - 12V Batteries
  - Smart Cruise Control
    - Simulation indicates **3-10% fuel economy improvement** in hilly terrain

CONCEPT
- Use GPS to acquire foreknowledge of hills and valleys.
- Accelerate/decelerate in a way to maximize fuel economy



Fuel is saved by avoiding downshifts and unnecessary braking

Lightweighting

Alternative Frame Construction

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			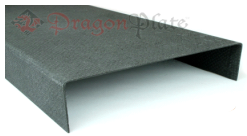				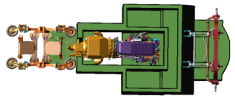		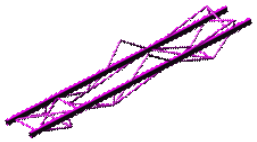		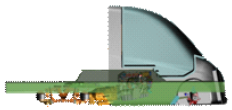	
No	**Decision Attribute**	**Attribute Weight**	**Carbon Fiber C-Channel Frame Rail**	**CF Frame Rail Total**	**Aluminum C-Channel Frame Rail**	**Al Frame Rail Total**	**Monocoque Frame**	**Monocoque Total**	**Truss Frame**	**Truss Frame Total**	**Skateboard Frame**	**Skateboard Frame Total**
1	Freight Efficiency	28.6%	9.0	2.6	7.0	2.0	3.0	0.9	3.0	0.9	3.0	0.9
2	Ease of Packaging	18.4%	9.0	1.7	9.0	1.7	1.0	0.2	3.0	0.6	1.0	0.2
3	Low Risk	10.8%	3.0	0.3	7.0	0.8	1.0	0.1	1.0	0.1	1.0	0.1
4	Environmental Sustainability	2.7%	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0
5	Stiffness	7.2%	5.0	0.4	5.0	0.4	9.0	0.6	7.0	0.5	7.0	0.5
6	Stopping Distance	5.8%	1.0	0.1	1.0	0.1	1.0	0.1	1.0	0.1	1.0	0.1
7	Cost	2.3%	3.0	0.1	9.0	0.2	1.0	0.0	3.0	0.1	1.0	0.0
8	Chassis Life Cycle	7.0%	3.0	0.2	7.0	0.5	3.0	0.2	9.0	0.6	3.0	0.2
9	Minimize Downtime/Maximize Reliability	3.7%	3.0	0.1	3.0	0.1	1.0	0.0	7.0	0.3	3.0	0.1
10	Servicibility/ manufacturability	2.1%	5.0	0.1	7.0	0.1	1.0	0.0	3.0	0.1	1.0	0.0
11	Identify Near Term Implementation Technologies	2.6%	1.0	0.0	9.0	0.2	1.0	0.0	7.0	0.2	1.0	0.0
12	Part Count	1.6%	1.0	0.0	1.0	0.0	5.0	0.1	1.0	0.0	3.0	0.0
13	Ride Quality	3.0%	1.0	0.0	1.0	0.0	3.0	0.1	3.0	0.1	3.0	0.1
14	Product Identity- Industrial Design	1.6%	3.0	0.0	1.0	0.0	9.0	0.1	3.0	0.0	5.0	0.1
15	Chassis Natural Frequency	2.7%	1.0	0.0	1.0	0.0	5.0	0.1	5.0	0.1	3.0	0.1
	Totals			**5.3**		**5.6**		**2.1**		**2.8**		**2.0**

Scale Definitions:

1 = Equal importance or preference
3 = Moderate importance or preference of one over another
5 = Strong or essential importance or preference
7 = Very strong or demonstrated importance or preference
9 = Extreme importance or preference

*A conventional-design, **aluminum ladder frame** offers the best opportunity for improvement*

Lightweighting
Carbon Fiber Composites

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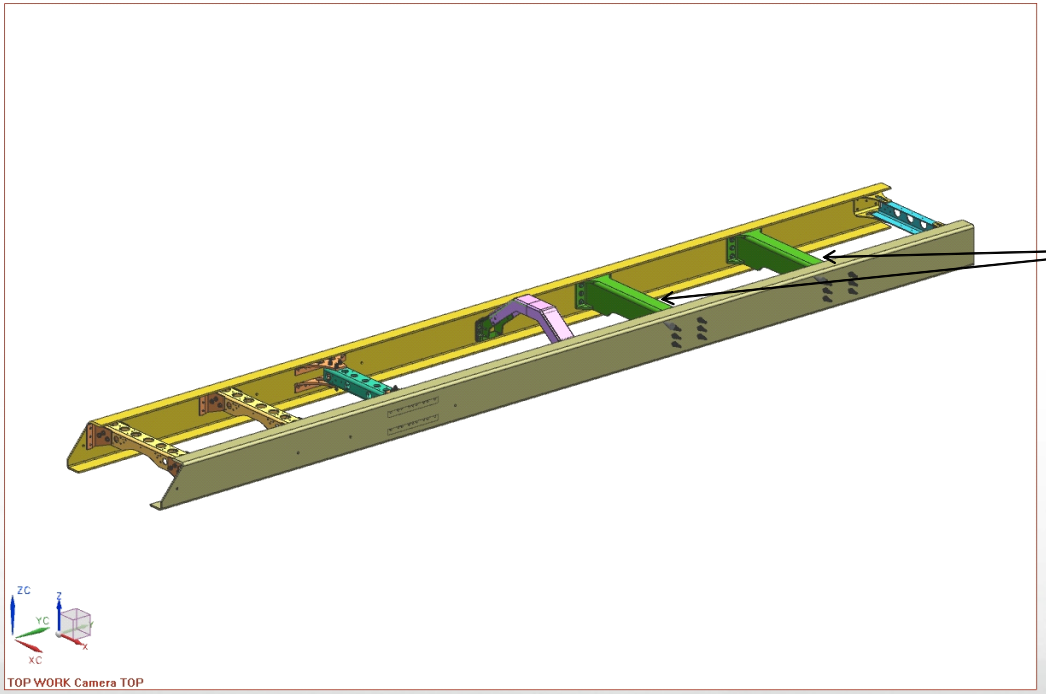
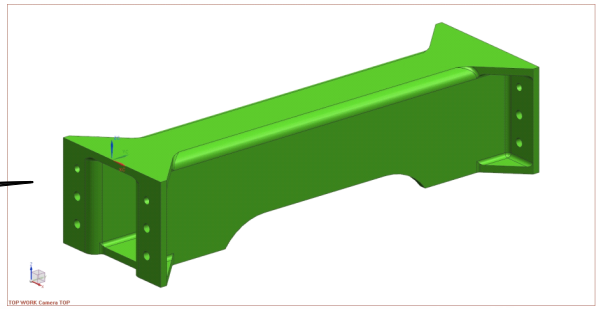


Proposed Ladder Frame Layout



Carbon Fiber IROS Crossmember

Thickness-16.6mm
Weight- 37 lb
Length= 1019.3 mm

***44 lbs** Weight Savings (two crossmembers)*

2012 Accomplishments

Four Distinct Areas of Progress

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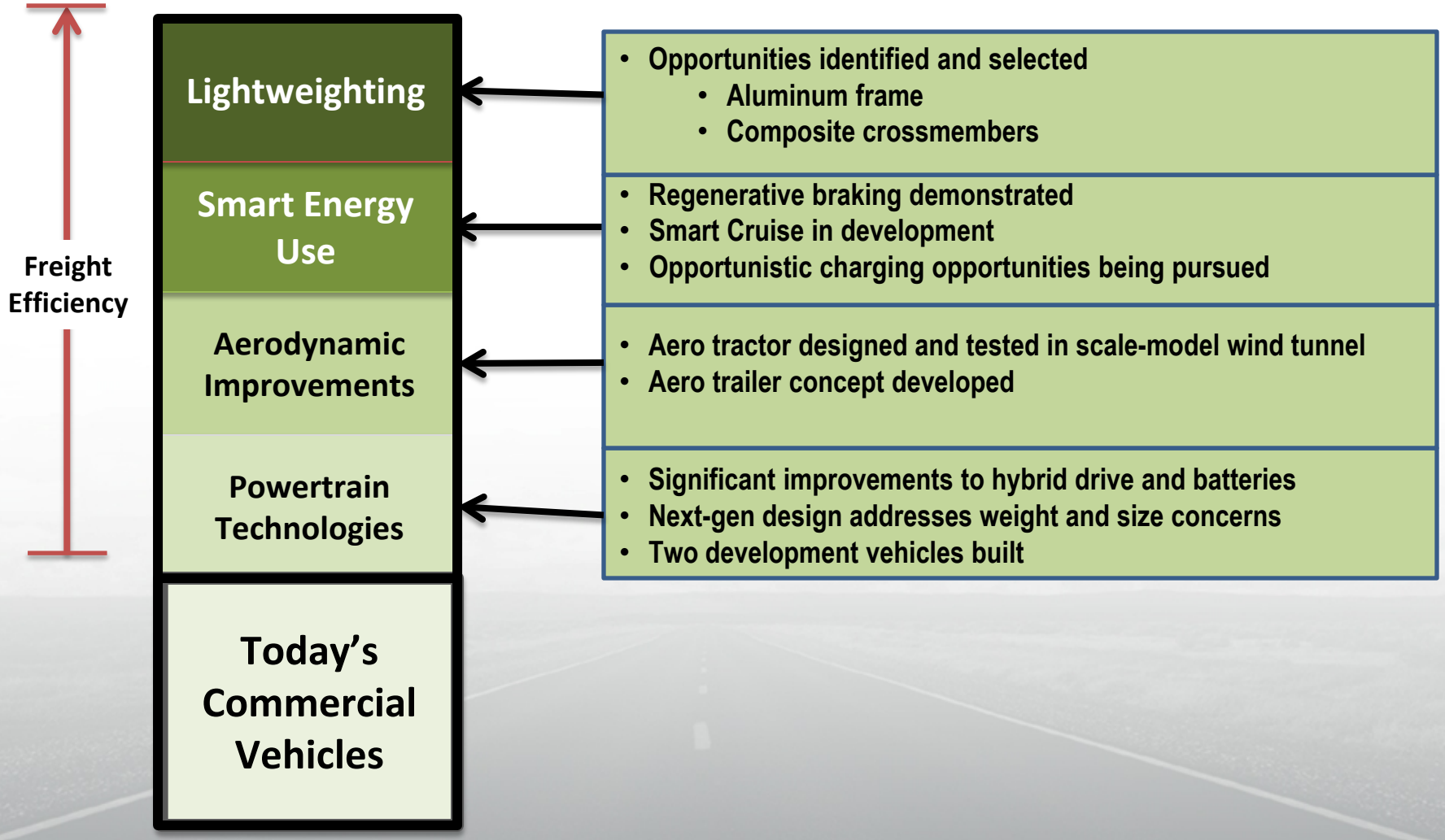
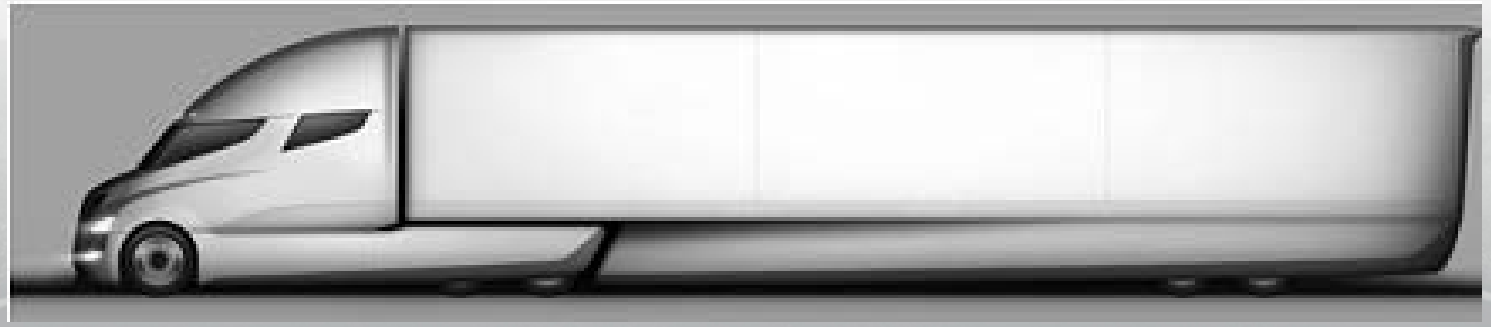


Future Work

- 2013
  - All Navistar SuperTruck material and data has been cataloged and properly stored
  - No work during 2012
- 2014
  - Navistar and DOE to reconvene in April to determine the direction of the project



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 for improved efficiency and lighter weight
3. A revolutionary rear-engine architecture has been developed which supports aerodynamic and weight goals
4. The dual-mode electric hybrid drive system has been demonstrated on-road

***Partnerships & Collaborations*:**

- Cross-functional and industry partnership teams are working well together.

***Future Direction*:**

- Quiet for now
- Direction of the project will be determined in April of 2014