Sustainable TRANSPORTATION

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

21st Century Truck Partnership – Pursuing technologies that lead to sustainable commercial truck transportation

ACEEE Workshop on Emerging Technologies for Heavy-Duty Vehicle Fuel Efficiency

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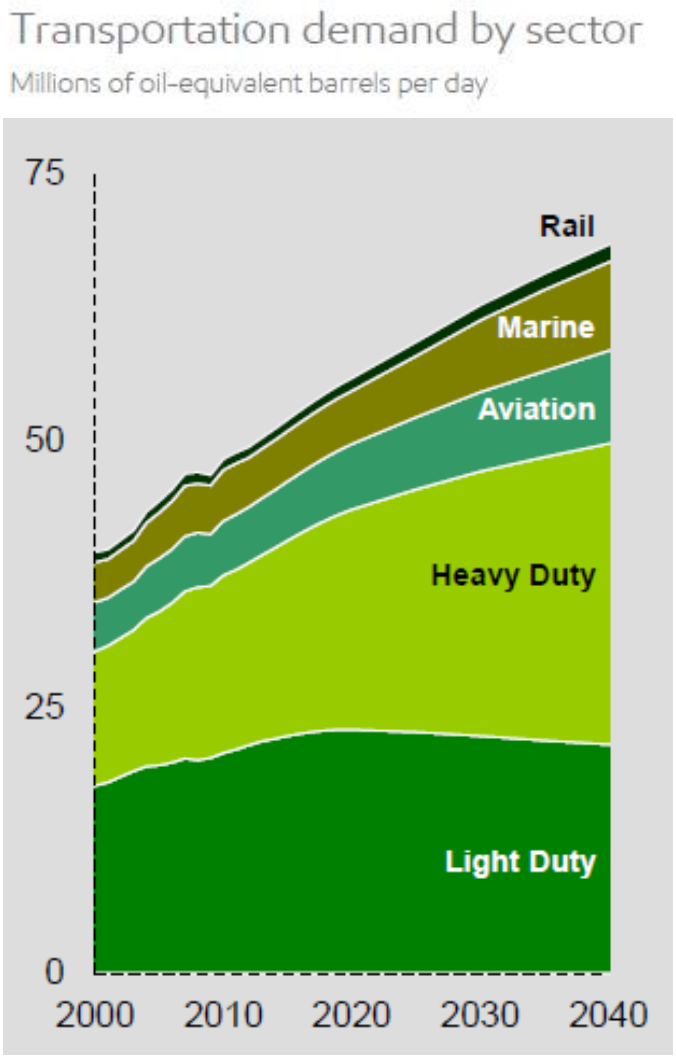
U.S. Department of Energy

July 22, 2014

Why Develop Higher Efficiency Commercial Vehicles?



Source: The Outlook for Energy - A View to 2040, ExxonMobil Corporation, 2014

75 percent

Demand for diesel and jet fuel is expected to increase by 75 percent from 2010 to 2040.

While global energy demand for personal transportation is expected to be relatively flat over the next few decades, demand for energy for commercial transportation — trucks, planes, ships and trains — will continue to grow significantly as economies expand and evolve.

Global demand for energy for commercial transportation is expected to rise by 70 percent from 2010 to 2040, driven by the projected increase in economic activity and the associated increase in movement of goods and freight.

21st Century Truck Partnership

- 21CTP mission:

  Accelerate introduction of truck and bus technologies that use less fuel, increase fuel diversity, operate more safely, are more reliable, meet future emissions standards, and are cost effective.

- Research partnership between government and industry
- Initiated in 2000
- Regulatory environment informs partnership needs/gaps/barriers
- Long-range, high-risk 21CTP goals complement nearer-term regulations

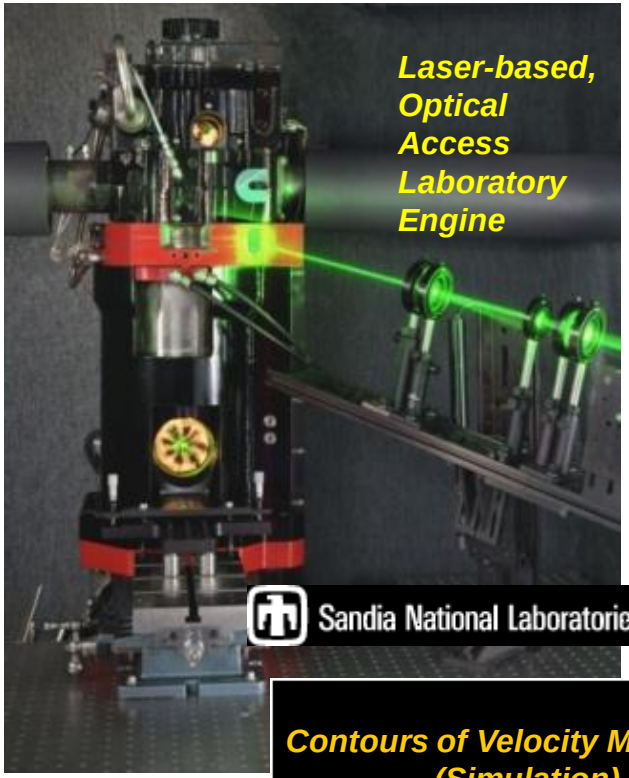
The Partners

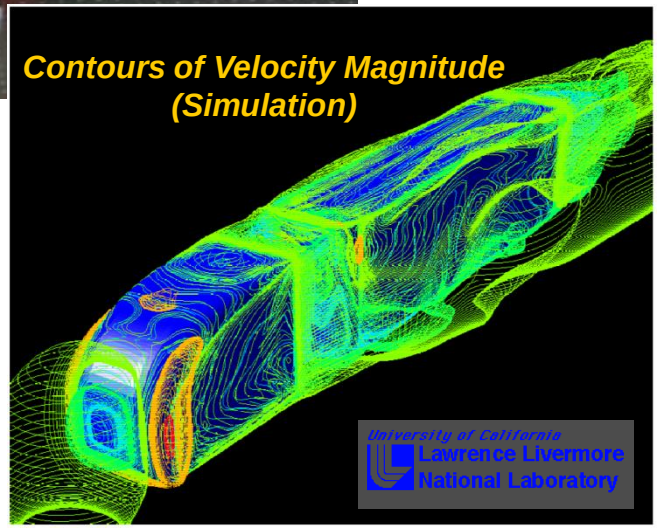
- Fifteen industrial companies coordinating with four federal agencies
- Forum for discussion of topics of common interest
- Monthly informational conference calls, internal website tools, and data distribution
- Special events and technical conferences

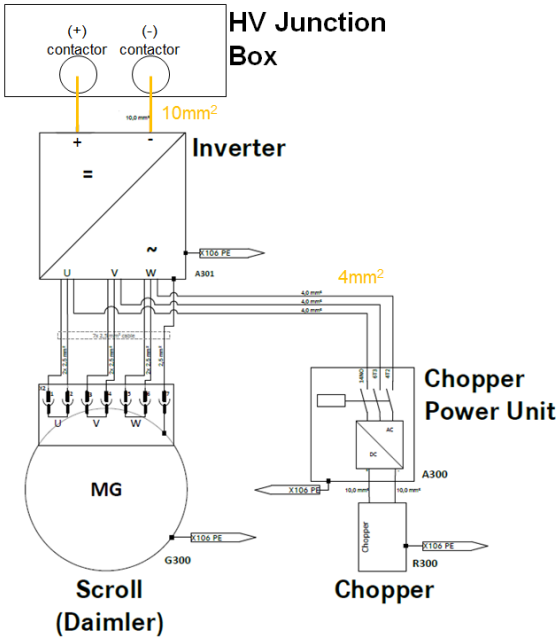
- Industrial participation led by an Executive Committee:
  Each of three main industrial sectors represented – Engines, Hybrids, and Truck OEMs

21CTP Research Focus Areas

- Engine Systems
- Heavy-Duty Hybrid Systems
- Vehicle Power Demands
- Idle Reduction
- Safety
- Efficient Operations







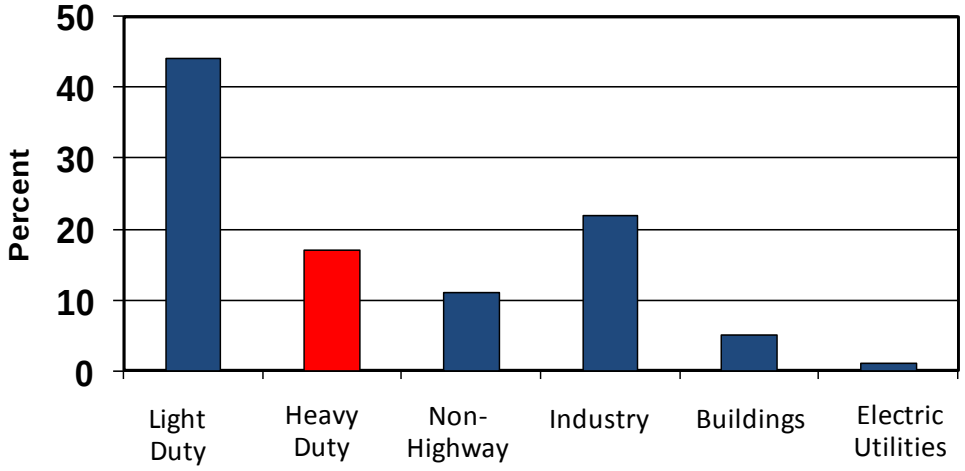
Hybrid System - Daimler Trucks North America

National Lab Activities – Commercial Vehicle Systems

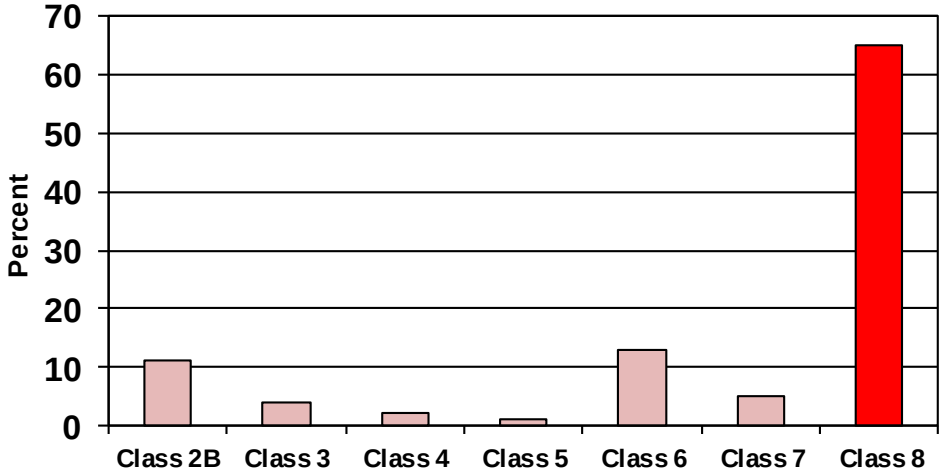
- ORNL – Heavy-duty hybrid, Engine- and Chassis-dyno engine power and emissions mapping, Wireless charging
- ANL – Autonomie vehicle modeling, Codes and Standards, Chassis-dyno simulation environment, Friction and wear, Thermal management
- LLNL – Aerodynamics modeling and simulation
- INL – Vehicle data collection, analysis, and reporting, Wired and wireless charging equipment evaluation
- NREL – Fleet DNA (drive-cycle) versus technology analysis, “Cool Cab” and HVAC system development, ReFUEL engine and chassis dyno lab, MD/HD EV and HEV data collection on in-use operation
- PNNL – Vehicle-grid integration analysis

Why Long-Haul Heavy-Duty Trucks?

- Impact will be large and near- to mid-term
  - Heavy-duty trucks comprise 4% of on-road vehicles but 18% of fuel consumption
  - Heavy trucks move 73% of freight value, 73% of freight tonnage, and log 49% of ton-mileage
- High return on investment
  - Truck operators and
  - Federal Government
- Industry is ready and willing to adopt new technology
- Growing domestic and international markets
- Saves domestic jobs



U.S. Oil Use in 2010



Fuel Use by Truck Class

Class 8 Truck Energy Balance

Base Tractor-Trailer Configuration

Average Payload	11,800 kg (26,000 lbs.)
Total Mass	27,220 kg (60,000 lbs.)
Fuel Use	14.7 gallons/1,000 ton-miles
Fuel Economy	5.8 mpg

Fuel Input (343 kW)	*Engine Losses:*	193 kW (η_{eng} = 0.43)
	Idling Fuel Use:	3.6 kW
Engine Output (146 kW)	*Accessory Loads:*	15 kW
	Drivetrain Losses:	10 kW
Tractive Power (121 kW)	*Aerodynamic Losses:*	61 kW (C_D = 0.60)
	Rolling Resistance:	44 kW (C_{RR} = 0.007)
	Inertia/Braking Losses:	16 kW

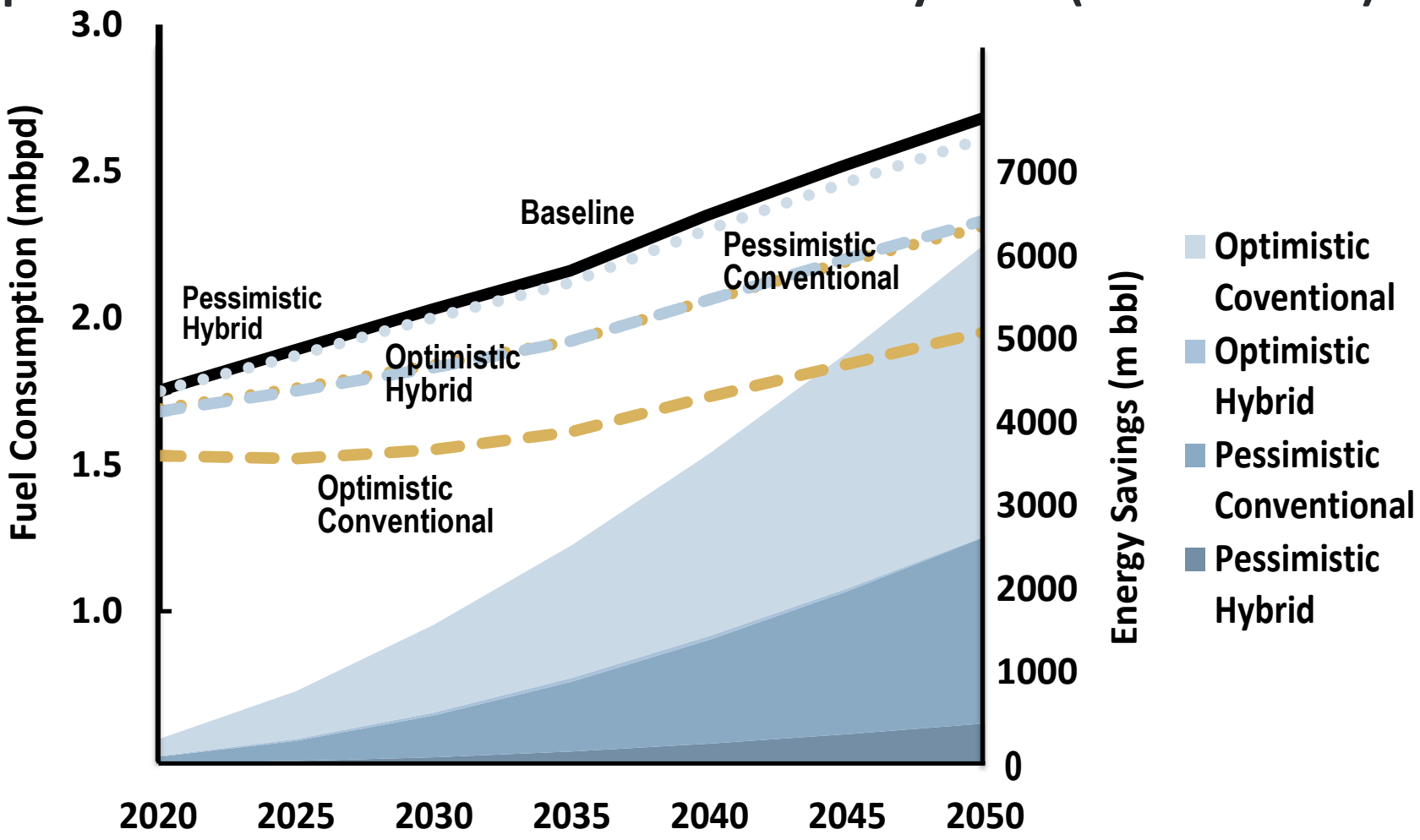
Configuration Achieving 21CTP Goals

Average Payload	11,800 kg (26,000 lbs.)
Total Mass	25,220 kg (55,600 lbs.)
Fuel Use	9.0 gallons/1,000 ton-miles
Fuel Economy	9.4 mpg

Fuel Input (211 kW)	*Engine Losses:*	105 kW (η_{eng} = 0.50)
	Auxiliary Power Unit:	0.8 kW
Engine Output (105 kW)	*Accessory Loads:*	8 kW
	Drivetrain Losses:	5 kW
Tractive Power (92 kW)	*Aerodynamic Losses:*	53 kW (C_D = 0.52)
	Rolling Resistance:	32 kW (C_{RR} = 0.0055)
	Inertia/Braking Losses:	7 kW (60% regeneration efficiency)

SuperTruck Technology Benefits Analysis

SuperTruck technologies could reduce fuel consumption nearly 30 percent and save 6 billion barrels of oil by 2050 (ROI of 500:1)



Source: *DOE SuperTruck Program Benefits Analysis Final Report (http://www.transportation.anl.gov/pdfs/TA/903.PDF)*

SuperTruck Initiative

- **Goals:** Develop and demonstrate a 50% improvement in overall freight efficiency on a heavy-duty Class 8 tractor-trailer measured in ton-miles per gallon, achieve 50% engine thermal efficiency at 65 mph and show a pathway to 55% engine efficiency.
  - Vehicle target for freight efficiency (ton-miles per gallon) improvement based on 65,000 pound GVW
  - 40% of the total improvement is required from engine technologies (50% thermal efficiency) and the remainder from vehicle system technologies.
- **Cooperative R&D Agreement Awards:**
  - Cummins Inc. with Peterbilt (ARRA Funded)
  - Daimler Trucks North America (ARRA Funded)
  - Volvo Trucks North America
  - Navistar, Inc.
- **Total project funding:**
  - DOE + Industry = $284 Million

Cummins/Peterbilt SuperTruck Team

Cooling Package and Heat Exchangers

MODINE

Power Distribution

COOPER Bussmann

Li Ion Start Batt & APU

corvus energy

Alum Hybrid Driveshaft

DANA

Route Display

Continental

Alum 5th Wheel

SAF Holland

Ceramic Brake Drums

CENTURY, INC

Light Steer Axle and Trailer Tandem

HENDRICKSON
The World Rides On Us

Downspeed-enabling Transmission

EATON
Powering Business Worldwide

Advanced Light Wheels

ALCOA

Magnesium Crossmembers

Meridian
LIGHTWEIGHT TECHNOLOGIES, INC.

Variable Gage Steel Frame Rails

Metalsa
Quality as a way of life

6x2 Rear Tandem w/ eTrac

DANA

Bendix

Integrated Air Suspension Bags

Firestone

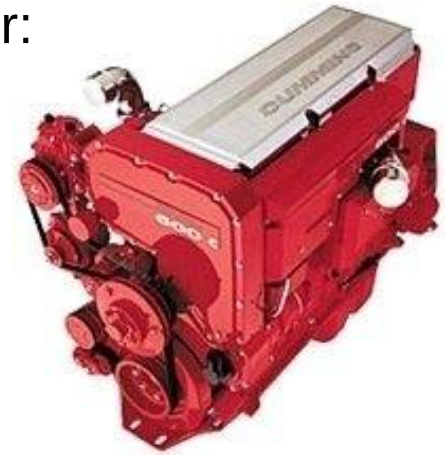
DOE Share $38.8M
Contractor Share $38.8M

Cummins/Peterbilt *SuperTruck* Status and Highlights

Cummins: Highly efficient and clean diesel engine, advanced waste heat recovery

Peterbilt: tractor and trailer combination, aerodynamic, lightweighting, battery powered auxiliary unit to reduce engine idling.

- Developed and demonstrated 52 percent brake thermal efficiency for an engine on a dynamometer:
  - Demonstrated waste heat recovery system improvements, including system simplification.
  - Compression ratio and peak cylinder pressure increased.
  - Engine system optimized and calibrated



- Demonstrated 76% freight efficiency surpassing 50% freight efficiency goal:
  - Demonstrated 25% improvement in aerodynamics
  - Advanced Automated Manual Transmission (AMT) completed.
  - The driver communication interface has been interlaced within the vehicle network and truck display systems. Cruise control in place.
  - Demo 2 truck – completed.

Daimler SuperTruck Team

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

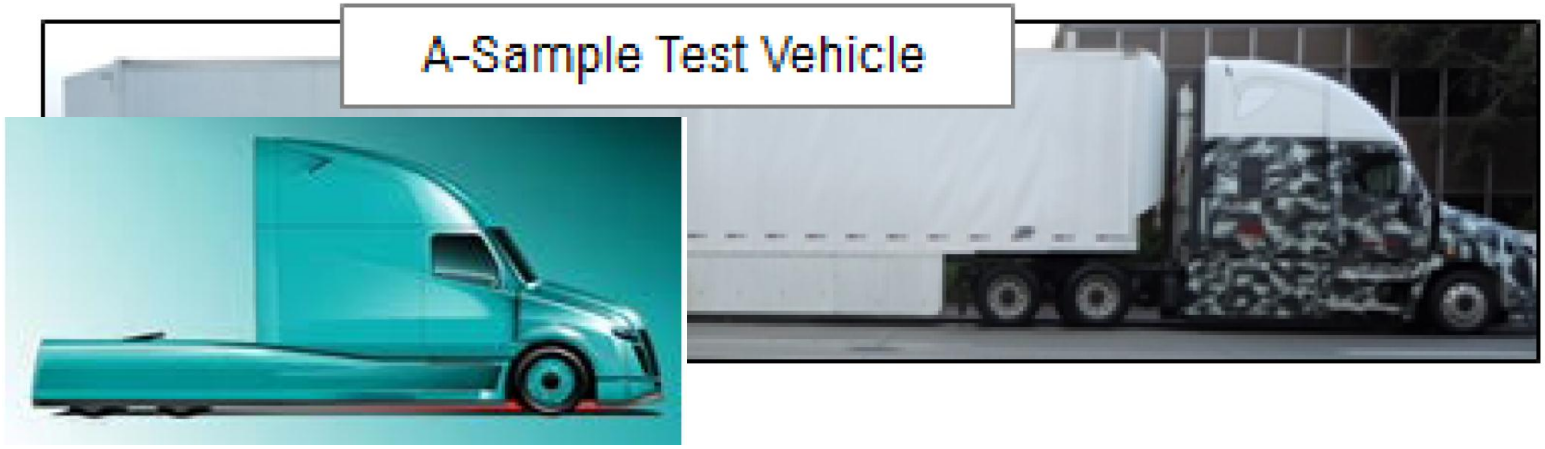
Walmart Save money. Live better.

DOE: $39,559,861

Daimler: $39,559,898

Daimler *SuperTruck* Status and Highlights

- **Priority:** hybridization, engine downsizing, electrification of auxiliary systems such as oil and water pumps, waste heat recovery, improved aerodynamics, weight reduction
  - **ENGINE:**
    - 50% Brake Thermal Efficiency target exceeded in engine test cell.
  - **FREIGHT EFF.**
    - 50% vehicle freight efficiency target exceeded on A-Sample vehicle through testing on Portland-Canyonville and San Antonio-Dallas routes



Final Demonstrator Vehicle

Volvo SuperTruck Team

Organization	Key Contribution
Volvo Technology of America	Project lead & concept simulations
Volvo Group Truck Technology	Complete vehicle integration & vehicle testing
Volvo Group Powertrain Engineering	Efficient complete powertrain solutions
Ridge/Freight Wing	Advanced aerodynamic devices for trailers
Grote	Advanced lighting systems
Penn State University	Advanced combustion modeling & simulation
Hendrickson	Lightweight trailer axle & suspension components
ExxonMobil	Advanced fuels & lubricants
Alcoa Wheels	Lightweight wheels
Michelin	Advanced low-friction tires
Metalsa	Ultra-Light Frame Assembly

VOLVO FREIGHT WING Grote PENNSTATE

Funding: Volvo (U.S.) - $19,066,700
DOE - $18,929,194
Sweden - $15M
Volvo (Sweden) - $15M

Volvo *SuperTruck* Status and Highlights

Priority: truck/engine efficiency integration; engine efficiency, truck-trailer aerodynamics, waste heat recovery, hybridization, idle reduction, and reduced rolling resistance tires.

ENGINE:

- Demonstrated 48% brake thermal efficiency of integrated powertrain system in vehicle 1.5 years ahead of schedule
- Improvements include: turbocompounding, Rankine WHR, higher pressure fuel injection system, down-sped engine, advanced aftertreatment, next generation axles, dual clutch transmission, etc.

FREIGHT EFFICIENCY:

- Demonstrated on-road 43% freight efficiency improvement

Demonstrator Truck

Concept *SuperTruck*

Navistar SuperTruck Team

Priority: aerodynamics truck-trailer aerodynamics, combustion efficiency, waste heat recovery, idle reduction, and reduced rolling resistance tires.

- **Navistar** - Principal Investigator, Vehicle Systems Integrator Controls Systems, Engine & Vehicle Testing
- Alcoa - Lightweight Frame & Wheel Materials
- AT Dynamics - 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 modeling

Project Funding: DOE $37,328,933
Navistar $51,808,146

Navistar SuperTruck Status and Highlights

Navistar, Inc.

- ***ENGINE:***
  - Achieved >47% Brake Thermal Efficiency System Level Tests.
  - Analysis projects >50% BTE possible with friction, pumping, turbo accessory, and air system enhancement

- ***FREIGHT EFFICIENCY:***
  - Achieved 23.7% of needed 30% target with aerodynamic improvement, and battery weight reduction.
  - New designs developed for path to attain >50% freight efficiency improvement:
    - » *CFD shows potential for* 20% improvement in Cd
    - » *Additional reductions in Friction/Rolling Resist and Weight*

SuperTruck Initiative On-Track

Industry Team Leads
Cummins, Daimler, Volvo and Navistar

- **Status of 50% engine efficiency:**
  - Cummins and Daimler have achieved the 50% efficiency goal
  - Volvo has demonstrated 48% engine efficiency and is testing 50% BTE technologies in component test rigs

UPI Photo

- **Status of 50% freight efficiency improvement:**
  - Cummins has demonstration on-road 76% freight efficiency improvement, exceeding the target
  - Daimler has exceeded 50% target through demonstration on sample routes
  - Volvo has demonstrated 43% freight efficiency improvements and determined a pathway to achieve greater than 50%
  - Navistar is on track to meeting efficiency goal.

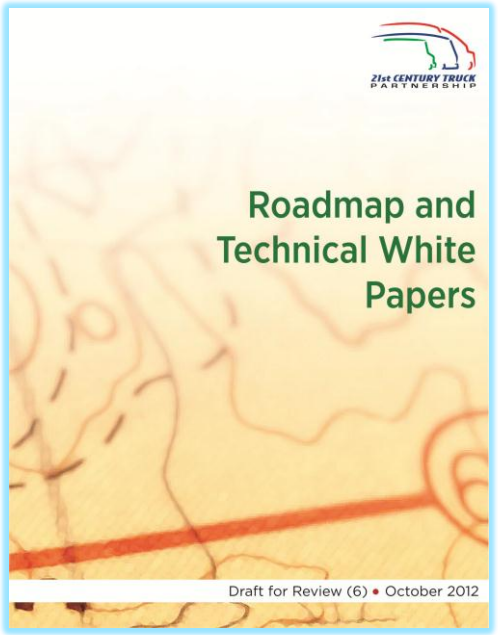
Technologies developed under SuperTruck will begin to enter the market over the next decade.

Overall 21CTP Technical Strategy

- Defined and implemented a new initiative, “SuperTruck,” for improvement of freight efficiency for Class 8 long-haul at the truck system level
  - Cummins-Peterbilt project has successfully reached engine and vehicle goals
  - The remaining three teams are progressing toward goal of 50% improvement in freight efficiency (ton-miles per gallon) and 50% engine brake thermal efficiency

- Now developing R&D strategies to increase efficiency of medium duty (Class 3 through Class 6) and regional haul (Class 7-8) vehicles to support future solicitation

- Reached consensus on new technical goals and priorities in six areas of R&D, produced updated roadmap and new web portal



2014 VTO Solicitations

- Program Wide Solicitation released in January 22, 2014

Topics
Low-cost, High Strength Automotive Aluminum Sheet
Computation Materials Engineering of Carbon Fiber Composites for Lightweight Vehicles
Beyond Lithium Ion Technologies
Commercialization of Power Electronics Using Wide Band Gap (WBG) Semiconductors
Tire Efficiency
Multi-Speed Gearbox for Commercial Delivery Medium Duty Electric Drive Vehicles
Advanced Climate Control Auxiliary Load Reduction
Development of Low Temperature Catalysts for Exhaust Aftertreatment
Dual-Fuel Technologies (Efficiency)
Fuel Property Impacts on Combustion
Powertrain Friction and Wear Reduction
Advanced Technology Powertrains For Light-Duty Vehicles
Early Market Commercialization Opportunities
Class 8 Truck Dual Fuel Commercialization

- Incubator Solicitation released January 2014
- Clean Cities Solicitation, TBD
- Zero-Emission Cargo Solicitation, TBD

Improving the Fuel Economy of American Trucks

DOE *SuperTruck* featured at the Truck Fuel Efficiency Announcement

President Barack Obama delivers remarks on improving the fuel efficiency of American trucks, at the Safeway Distribution Center in Upper Marlboro, Md., Feb. 18, 2014. (Official White House Photo) (http://www.whitehouse.gov/blog/2014/02/18/kicking-vehicle-efficiency-high-gear)

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http://www1.eere.energy.gov/vehiclesandfuels/about/partnerships/21centurytruck/index.html