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

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Why Develop Higher Efficiency Commercial Vehicles?

Transportation demand by sector
Millions of oil-equivalent barrels per day

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.

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

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**U.S. Oil Use in 2010**

- **Light Duty**
- **Heavy Duty**
- **Non-Highway**
- **Industry**
- **Buildings**
- **Electric Utilities**

**Fuel Use by Truck Class**

- Class 2B
- Class 3
- Class 4
- Class 5
- Class 6
- Class 7
- Class 8
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

**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**
- **(343 kW)**
  - Engine Losses: 193 kW ($\eta_{\text{eng}} = 0.43$)
  - Idling Fuel Use: 3.6 kW
- **(146 kW)**
  - Accessory Loads: 15 kW
  - Drivetrain Losses: 10 kW
- **(121 kW)**
  - Aerodynamic Losses: 61 kW ($C_D = 0.60$)
  - Rolling Resistance: 44 kW ($C_{RR} = 0.007$)
  - Inertia/Braking Losses: 16 kW

**Fuel Input**
- **(211 kW)**
  - Engine Losses: 105 kW ($\eta_{\text{eng}} = 0.50$)
  - Auxiliary Power Unit: 0.8 kW
- **(105 kW)**
  - Accessory Loads: 8 kW
  - Drivetrain Losses: 5 kW
- **(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 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

Power Distribution

Li Ion Start Batt & APU

Alum Hybrid Driveshaft

Ceramic Brake Drums

Route Display

Alum 5th Wheel

Light Steer Axle and Trailer Tandem

Downspeed-enabling Transmission

Advanced Light Wheels

Magnesium Crossmembers

Integrated Air Suspension Bags

Variable Gage Steel Frame Rails

6x2 Rear Tandem w/ eTrac

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
- Telogis

Hybrid
- FUSO
- MBtech
- Eaton
- MiaSolé
- itk
- US Hybrid

Aero/Cooling
- ARC
- CD-adapco
- TitanX
- Mekra
- AVF

Lightweighting
- OSU
- Toray
- Strick
- Inmagusa

Powertrain/Parasitics
- Detroit
- ConMet
- Michelin
- Accuride
- Parker
- Bendix
- Ashland

Fleet
- Schneider
- Walmart

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

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A-Sample Test Vehicle

Final Demonstrator Vehicle
## Volvo SuperTruck Team

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<th>Organization</th>
<th>Key Contribution</th>
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<tr>
<td>Volvo Technology of America</td>
<td>Project lead &amp; concept simulations</td>
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<tr>
<td>Volvo Group Truck Technology</td>
<td>Complete vehicle integration &amp; vehicle testing</td>
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<tr>
<td>Volvo Group Powertrain Engineering</td>
<td>Efficient complete powertrain solutions</td>
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<tr>
<td>Ridge/Freight Wing</td>
<td>Advanced aerodynamic devices for trailers</td>
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<tr>
<td>Grote</td>
<td>Advanced lighting systems</td>
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<tr>
<td>Penn State University</td>
<td>Advanced combustion modeling &amp; simulation</td>
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<tr>
<td>Hendrickson</td>
<td>Lightweight trailer axle &amp; suspension components</td>
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<tr>
<td>ExxonMobil</td>
<td>Advanced fuels &amp; lubricants</td>
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<tr>
<td>Alcoa Wheels</td>
<td>Lightweight wheels</td>
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<tr>
<td>Michelin</td>
<td>Advanced low-friction tires</td>
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<tr>
<td>Metalsa</td>
<td>Ultra-Light Frame Assembly</td>
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**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-spied engine, advanced aftertreatment, next generation axles, dual clutch transmission, etc.

FREIGHT EFFICIENCY:

- Demonstrated on-road 43% freight efficiency improvement
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, 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

- **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**

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<td>Computation Materials Engineering of Carbon Fiber Composites for Lightweight Vehicles</td>
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<td>Beyond Lithium Ion Technologies</td>
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<td>Commercialization of Power Electronics Using Wide Band Gap (WBG) Semiconductors</td>
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<td>Multi-Speed Gearbox for Commercial Delivery Medium Duty Electric Drive Vehicles</td>
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<td>Advanced Climate Control Auxiliary Load Reduction</td>
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<td>Development of Low Temperature Catalysts for Exhaust Aftertreatment</td>
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<td>Early Market Commercialization Opportunities</td>
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<td>Class 8 Truck Dual Fuel Commercialization</td>
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- **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