United States Department of Energy

October, 2011

Vehicle Technologies Program

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Advanced Technologies for High Efficiency Clean Vehicles

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

Hybrid Electric Systems
- Advanced Batteries
- Power Electronics
- Inverters
- Controllers & Motors
- Systems Analysis and Testing
- Aerodynamics, Rolling Resistance & Accessory Loads
- Validation

47%

Advanced Combustion Engine R&D
- Low Temp. Combustion R&D
- Emission Controls
- Light- & Heavy-Duty Engines
- Solid State Energy Conversion
- Health Impacts

18%

Tech Introduction
- EPAct/EISA
- Rulemaking
- Deployment
- Student Competitions
- Graduate Automotive Technology Education
- Education
- Safety, Codes, & Standards

11%

Fuel Technologies
- Bio-Based Fuels
- Clean/Efficient Combustion Fuel Characteristics
- Fischer-Tropsch Fuels & Blendstocks
- Advanced Lubricants

8%

Materials Technology
- Lightweight Structures
- Composite Development
- Processing/Recycling/ Manufacturing
- Design Data Test Methods
- High Temperature Materials Laboratory

16%

21CTP Partnership Members & Vision

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

The 21st Century Truck Partnership (21CTP) brings together four federal agencies (DOE, EPA, DOT, DOD) and fifteen heavy-duty OEM and supplier partners with the common goals of making trucks and buses safer, cleaner, and more efficient.

VISION: *Our nation's trucks and buses will safely and cost-effectively move larger volumes of freight and greater numbers of passengers and emit little or no pollution while dramatically reducing our dependency on foreign oil.*

21st CENTURY TRUCK PARTNERSHIP

INDUSTRY PARTNERS

Allison Transmission
ArvinMeritor
BAE SYSTEMS
CATERPILLAR
Cummins
DAIMLER
DETROIT DIESEL
EATON Powering Business Worldwide
Honeywell
NAVISTAR
OSHKOSH
PACCAR Inc
VOLVO
Mack
NOVABUS

GOVERNMENT PARTNERS

Department of Defense, United States of America
Department of Energy, United States of America
Department of Transportation, United States of America
United States Environmental Protection Agency

SuperTruck

SuperTruck projects target improving freight hauling efficiency of Class 8 trucks by 50%.

Funding: SuperTruck combines $77M of Recovery Act funds with $59M in annual appropriations and over $136M in participant cost share

The Challenge: Over 80% of US communities are served only by trucks, and Class 8 trucks haul 70% of our nation's freight. With demanding duty cycles and long driving range requirements, using all-electric or hydrogen fuel cells for propulsion is not an option. And with highly-efficient diesel engines and as many as 18 gears, Class 8 trucks are already the most efficient vehicles on the road. So how do we make them even better?

SuperTruck is a systems approach to improving fuel efficiency and includes all aspects of improving the efficiency of the overall truck system

- Goal: To demonstrate a 50% improvement in freight efficiency on a Class 8 tractor-trailer measured in ton-miles per gallon
- Awards:
  - ***Cummins Inc. -$38,831,115 -Columbus, Indiana****: Develop and demonstrate a highly efficient and clean diesel engine, an advanced waste heat recovery system, an aerodynamic Peterbilt tractor and trailer combination, and a fuel cell auxiliary power unit to reduce engine idling. (ARRA Funded)*
  - ***Daimler Trucks North America, LLC -$39,559,868 -Portland, Oregon****: Develop and demonstrate technologies including engine downsizing, electrification of auxiliary systems such as oil and water pumps, waste heat recovery, improved aerodynamics and hybridization. (ARRA Funded)*
  - ***Navistar, Inc. -$37,328,933 -Fort Wayne, Indiana****: Develop and demonstrate technologies to improve truck and trailer aerodynamics, combustion efficiency, waste heat recovery, hybridization, idle reduction, and reduced rolling resistance tires.*
  - ***Volvo - $19M – Hagerstown, Maryland****: By 2015, improve heavy truck freight efficiency by 50% (engine thermal efficiency by 20 percent) with demonstration in commercial vehicle platforms*

Navistar Supertruck Team

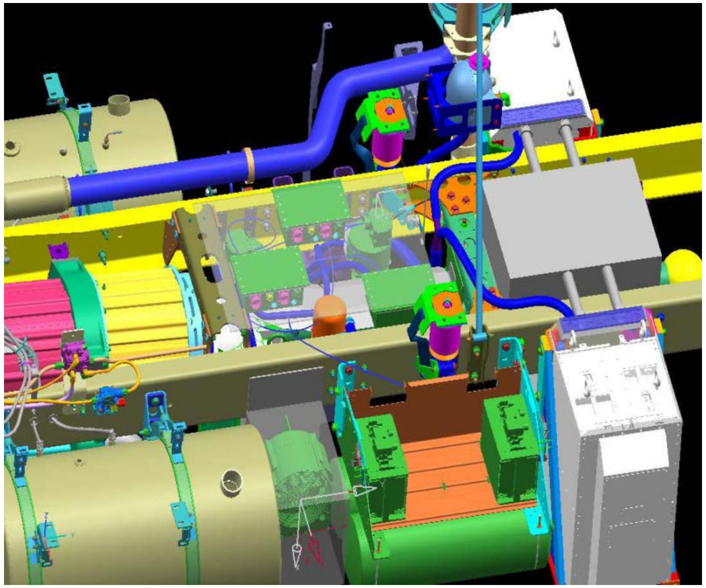
- **Navistar**, Principal Investigator, Vehicle Systems Integrator Controls Systems, Engine & Vehicle Testing
- **Alcoa** , Lightweight Frame & Wheel Materials
- **AT Dynamics**, Trailer Aerodynamic Devices
- **ArvinMeritor**, Hybrid Powertrain, Axles
- **Behr America**, Cooling Systems
- **Michelin**, 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 Testing

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

DOE Funding Received in FY2011: $ 5,440,636

Navistar SuperTruck Project Status

- To date the following engine technologies have been incorporated:
  - Extended peak cylinder pressure capability (190→220 bar)
  - Higher injection pressure (2200→2900 bar)
  - Electrical turbo-compounding with advance air system (results due July 2011)
- 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 baseline and speed form shapes have substantiated 20% improvement in Cd is achievable.



Daimler Supertruck Team

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DTNA – Vehicle Development

Detroit Diesel – Powertrain

Daimler Research – Waste Heat

Oregon State University –

- Composite Frame Analysis
- Fuel Efficient Routing

Schneider National – End User

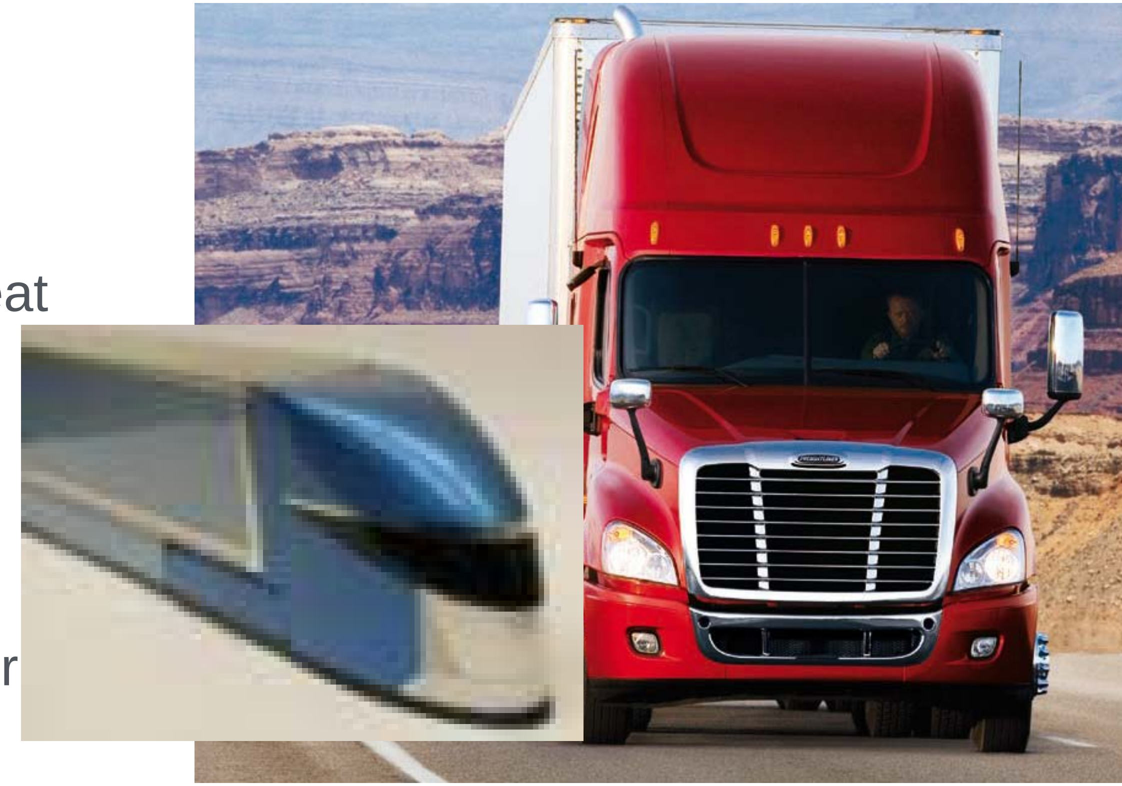
Walmart – End User

Great Dane – Trailer

ARC – Aerodynamics

Solar World Industries America –

- Auxiliary Power



Total project funding: $79,119,736
DOE: $39,559,868
Daimler: $39,559,868

2010 Total: $ 7,833,628
DOE: $ 3,917,314

Daimler Supertruck Project Status

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- Vehicle improvement targets defined based on simulation
- Initial improvements in drivetrain efficiency already demonstrated via reduced parasitics. Partnered with MIT for studies into new oils, additives, and material coatings.
- Next generation engine optimizing controller functioning well in lab and (limited) vehicle tests.
- Aftertreatment system re-design complete and prototypes demonstrated in July 2011.
- Waste heat recovery system being extensively modeled, component level testing underway, and system procurement in summer 2011.
- Completed baseline testing. Baseline vehicle & route specified.
- Concept Vehicle Hybrid & Energy Management Simulation, FEA of Lightweight Frame, and Aerodynamic/CFD Analysis complete

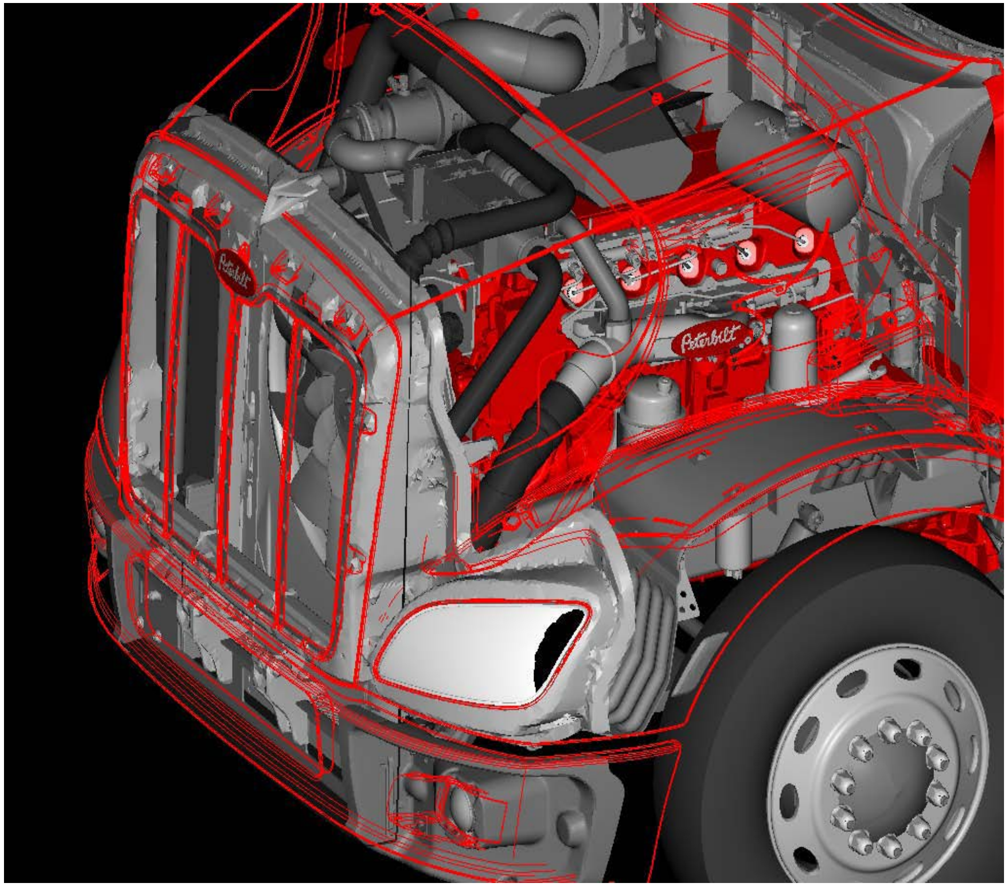
Cummins/Peterbilt SuperTruck Team

- Engine/Contract Lead – Cummins
- Modine – Cooling Module
- Eaton –Transmission
- Dana – Drivetrain
- Bridgestone – Fuel Efficient Tires
- Alcoa – Wheels
- Delphi – Solid Oxide Fuel Cell APU
- Bergstrom – eSHVAC
- Garmin – 3D Map and Display
- Exa – CFD Analysis
- Utility Trailer Manufacturing – Trailer
- End User – US Xpress

Total Project :
DOE Share $38.8M
Contractor Share $42.1M

Cummins/Peterbilt SuperTruck Status – Completed tasks

- Simulation of Path to Target for Engine and Vehicle Efficiencies
- Baseline Vehicle Testing
- CFD Analysis of Vehicle Aero
- Design of Advanced Transmission
- Performance Assessment of SOFC APU
- Integration of Cummins Waste Heat Recovery System
- Engine Demonstration of 47% BTE & US EPA Emissions



Volvo Supertruck Team

- Mack Trucks, Inc.
- Volvo Powertrain NA
- Volvo Powertrain Sweden
- Volvo technology
- Ricardo - waste heat recovery
- UCLA - waste heat recovery
- Penn State Univ. - biodiesel studies
- West Virginia Univ. - powertrain development

Funding

Volvo (U.S.) - $19M
DOE - $19M
Sweden - $15M
Volvo (Sweden) - $15M

Total: $68M

Alternative Fuel Advanced Powertrain Heavy Trucks:
Preliminary Analysis

Analysis Assumptions

- Vehicle Range: 1,300 miles except for EV Truck with 500 miles
- Powerplant Power: 370 kW for all vehicles
- New vehicle annual VMT: 143,500 miles (average annual VMT: 33k miles)
- Vehicle Lifetime: 30 years
- Durability: 1 million miles (e.g. 50 mph x 20,000 hr)
- Discount Rate: 10%
- Fuel prices and payback periods are based on today's market fuel prices:
  - Diesel (untaxed): $3.61/gal (after removing $0.50 average fuel tax)
  - LNG (unsubsidized): $2.31/diesel-gallon-equivalent
  - Hydrogen: $4.00/kg (EERE estimate based on natural gas reforming)
- Break-even diesel prices are estimated for a 4-year payback and include average diesel fuel tax ($0.50)

Note: Truck characterizations on following slides are color-coded as follows:

Worse (relative to baseline) < Neutral (relative to baseline) < Improvement (relative to baseline)

Heavy Truck: Baseline Diesel

(estimated for 2011)

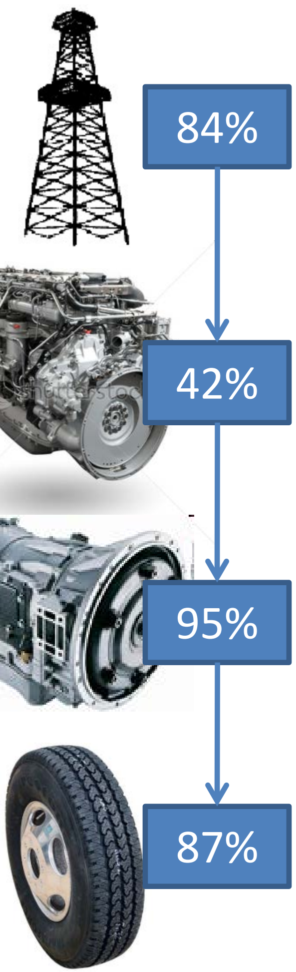
~6.5 mpdge ~29% WTW η Petroleum reduction: 0%	Fuel+Tank Weight: 1500 lbs (100% of baseline) Fuel+Tank Volume: 190 gal (100% of baseline)	Lifecycle Cost of Driving: 1.0x baseline Payback Period: n/a Breakeven diesel price: n/a

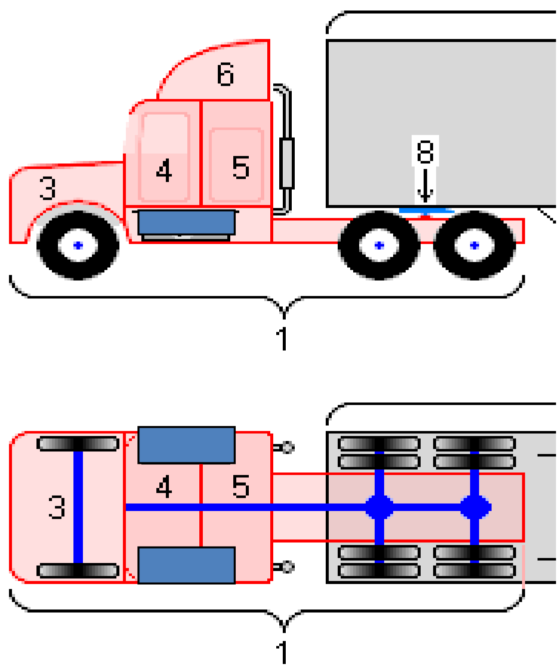
Diesel (upstream and refining)

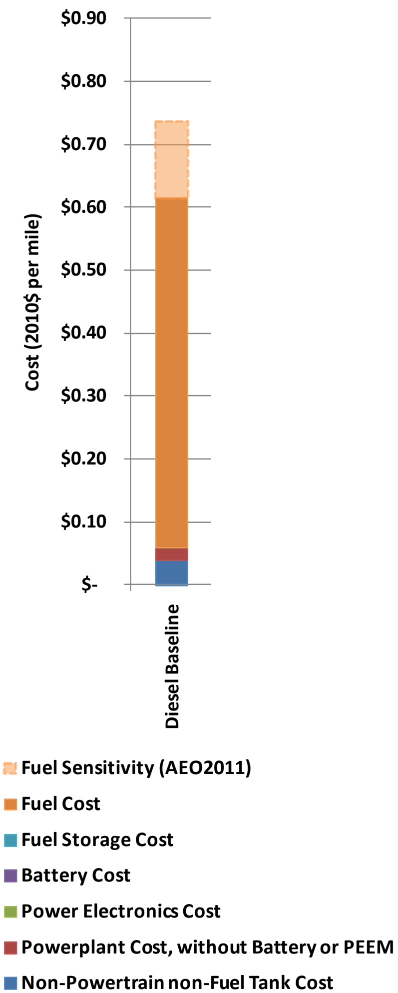
Average engine efficiency

Transmission and drivetrain efficiency

Aero, rolling resistance efficiency







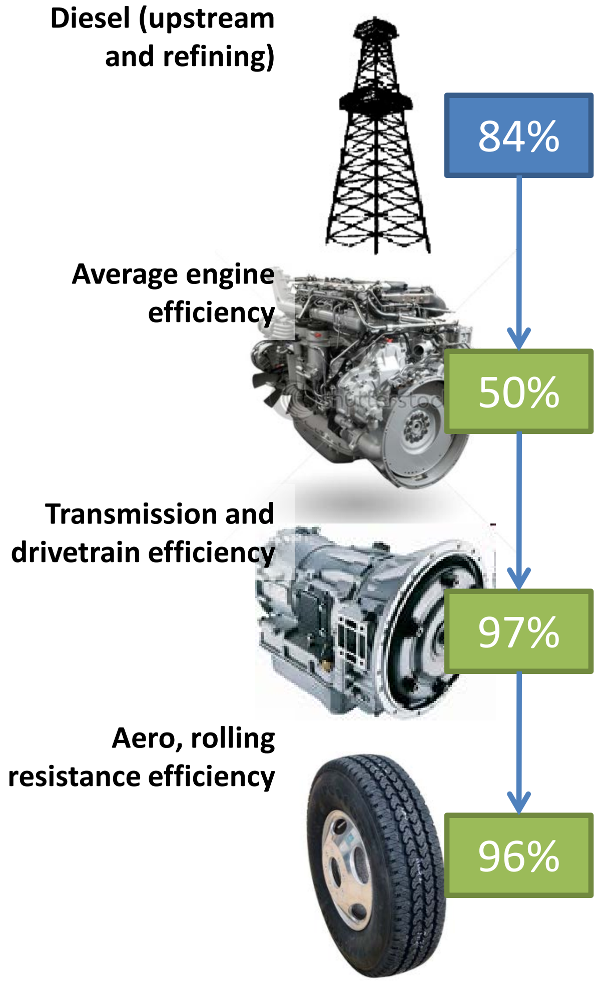
Heavy Truck: SuperTruck (ST) Diesel

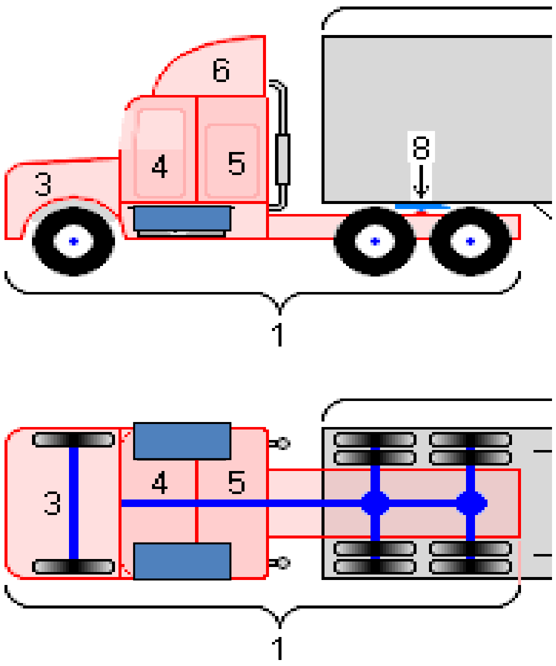
(estimated for 2020)

~10 mpdge
~40% WTW η
Petroleum reduction: 35%

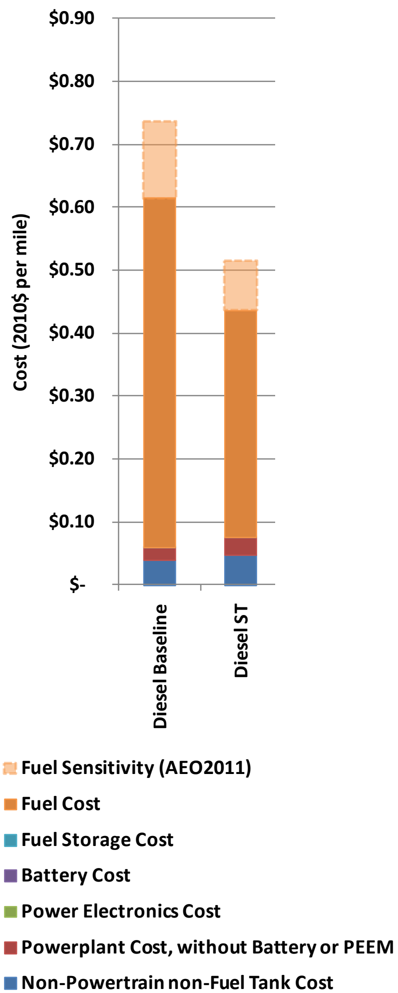
Fuel+Tank Weight: 1000 lbs
(65% of baseline)
Fuel+Tank Volume: 120 gal
(65% of baseline)

Lifecycle Cost of Driving:
0.7x baseline
Payback Period: 0.75-1.25 years
Breakeven diesel price: $3.50





Aligns with 2010 NAS Report: 50% fuel economy improvement for $22k (cost).



Heavy Truck: ST LNG ICE

(estimated for 2020)

~10 mpdge
~40% WTW η
Petroleum reduction: 99%

Fuel+Tank Weight: 1600 lbs
(110% of baseline)
Fuel+Tank Volume: 200 gal
(110% of baseline)

Lifecycle Cost of Driving:
.5x baseline
Payback Period: 1.5 years
Breakeven diesel price: $2.95

NG (upstream and liquefaction)

84%

Average engine efficiency

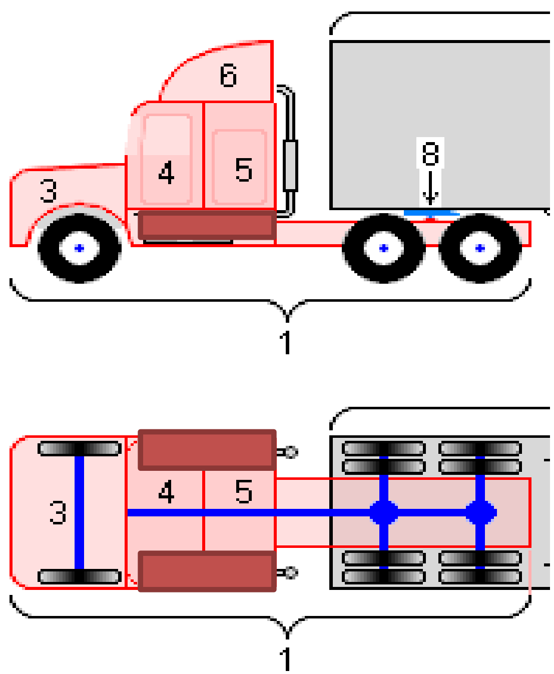
50%

Transmission and drivetrain efficiency

97%

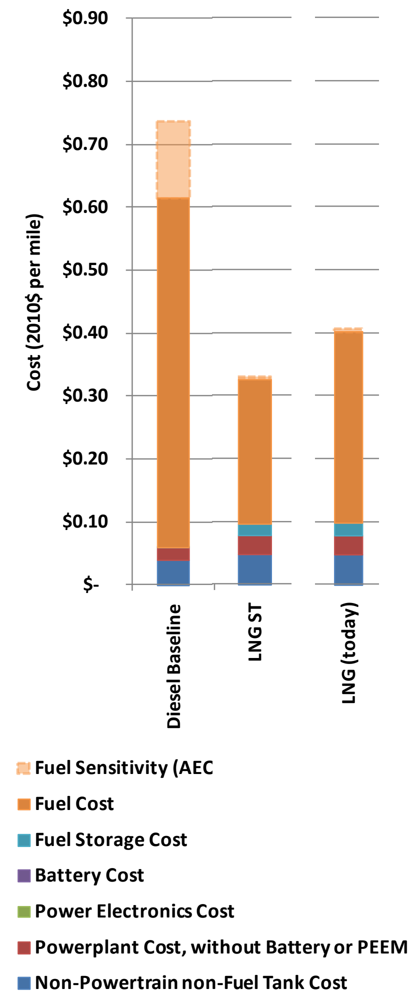
Aero, rolling resistance efficiency

96%



Fuel Storage:

* Oversized tanks



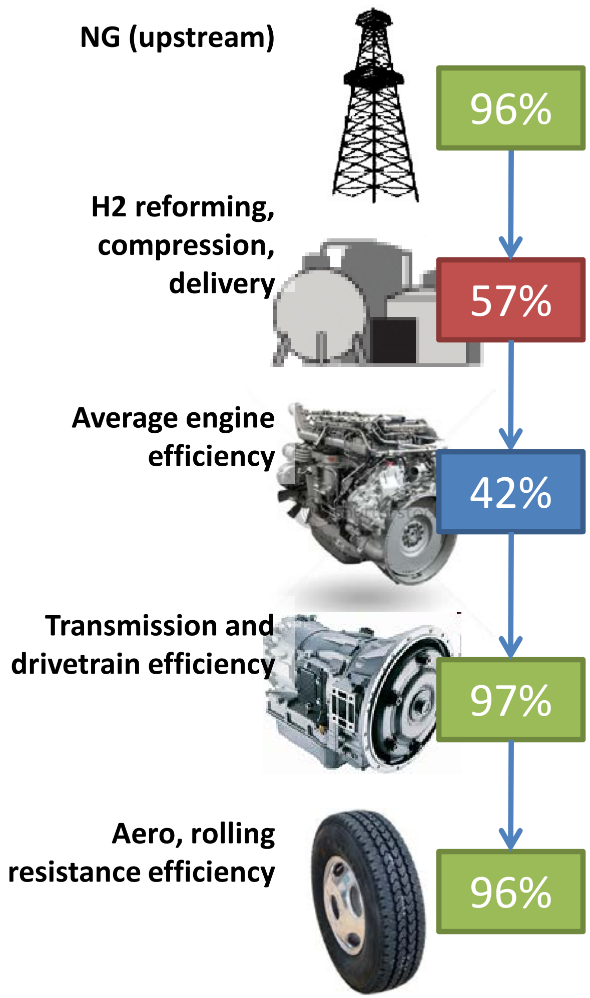
Heavy Truck: H2 ICE (compressed tanks)

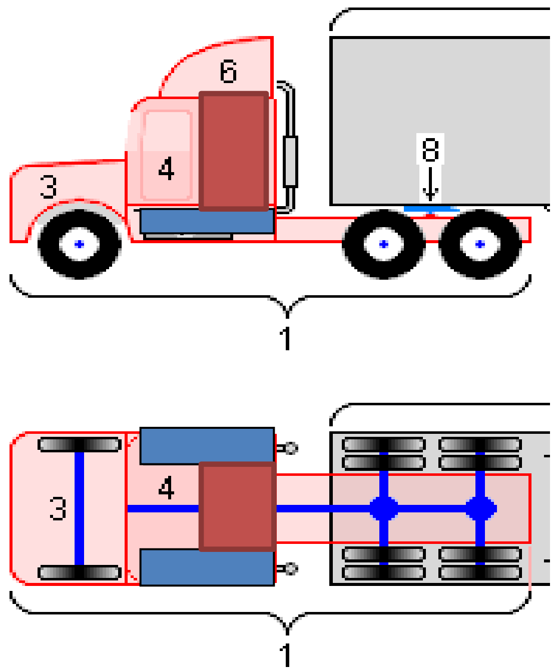
(estimated for 2020)

~8.7 mpdge
~23% WTW η
Petroleum reduction: 98%

Fuel+Tank Weight: 6500 lbs
(440% of baseline)
Fuel+Tank Volume: 1200 gal
(640% of baseline)

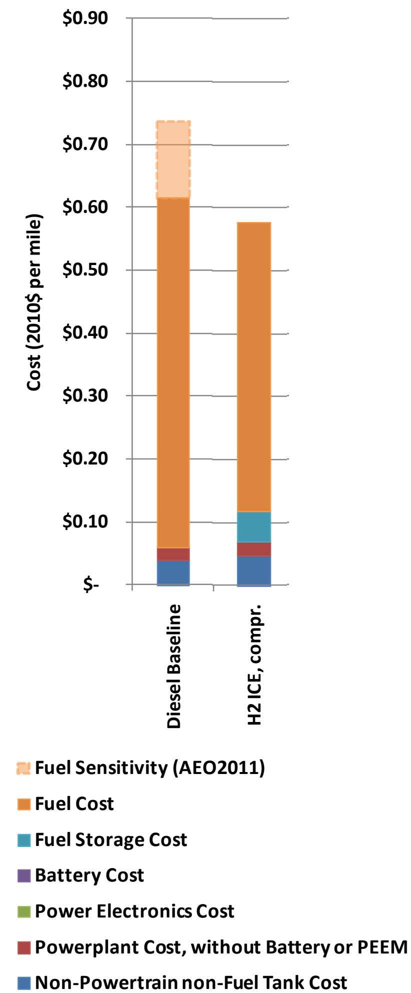
Lifecycle Cost of Driving:
.95x baseline
Payback Period: 13-17 years
Breakeven diesel price: $4.80





Fuel Storage:

* Sacrifice 50% of cab
* Lose 10% of payload weight



Heavy Truck: PEM H2 FC on-board reforming

(estimated for 2020)

~6.1 mpgge
~24% WTW η
Petroleum reduction: 98%

Fuel+Tank Weight: 3000 lbs
(200% of baseline)
Fuel+Tank Volume: 360 gal
(200% of baseline)

Lifecycle Cost of Driving:
0.9x baseline
Payback Period: 16-19 years
Breakeven diesel price: $5.10

NG (upstream and liquefaction)

84%

H2 on-board reforming

67%

Fuel cell efficiency (at high load)

54%

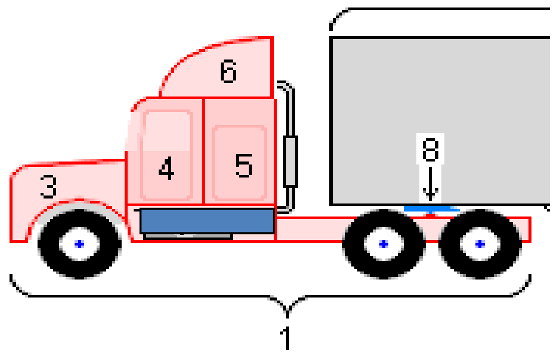
Electric motor and drivetrain efficiency

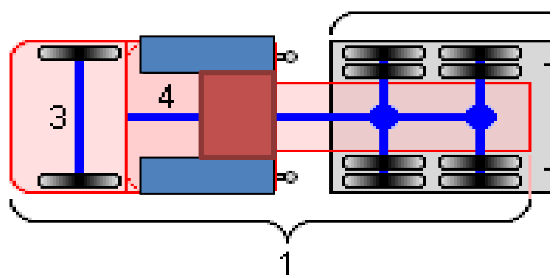
84%

Aero, rolling resistance efficiency

97%

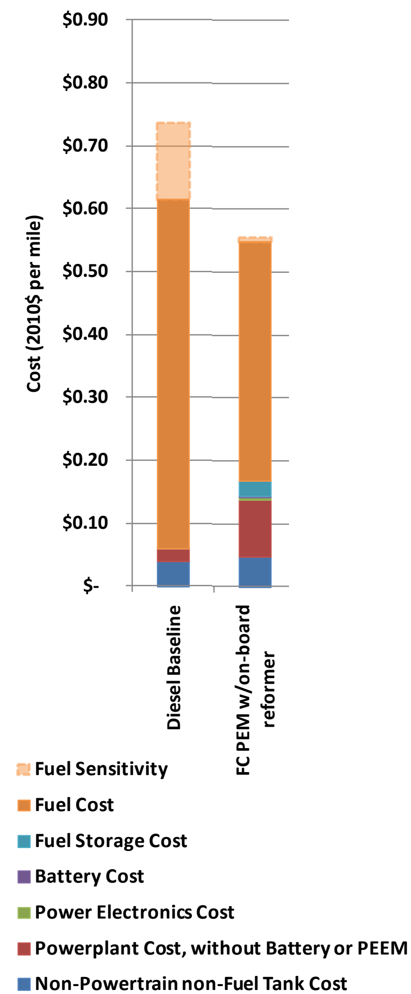
(Note: regen braking from 250kW, 25kWh Li-ion battery)





Fuel Storage:

* Sacrifice 10% of cab



Heavy Truck: Solid Oxide FC

(estimated for 2020)

~10.1 mpgge
~41% WTW η
Petroleum reduction: 98%

Fuel+Tank Weight: 1750 lbs
(120% of baseline)
Fuel+Tank Volume: 220 gal
(120% of baseline)

Lifecycle Cost of Driving:
0.6x baseline
Payback Period: 5-5.5 years
Breakeven diesel price: $3.89

NG (upstream and liquefaction)

84%

Fuel cell efficiency (at high load)

60%

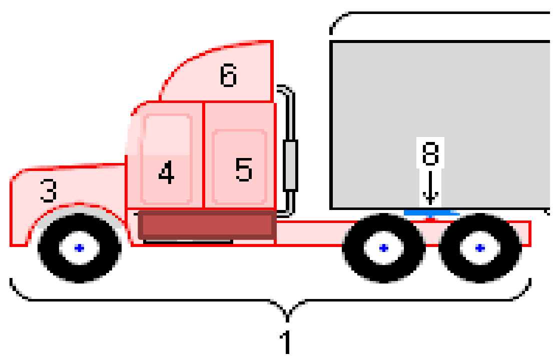
Electric motor and drivetrain efficiency

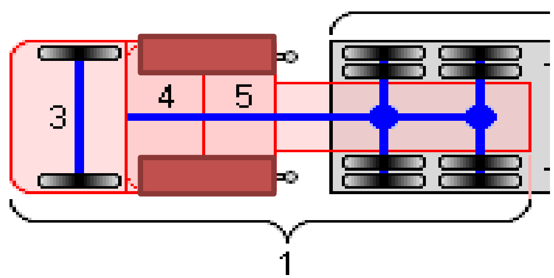
84%

Aero, rolling resistance efficiency

97%

(Note: regen braking from 250kW, 25kWh Li-ion battery)

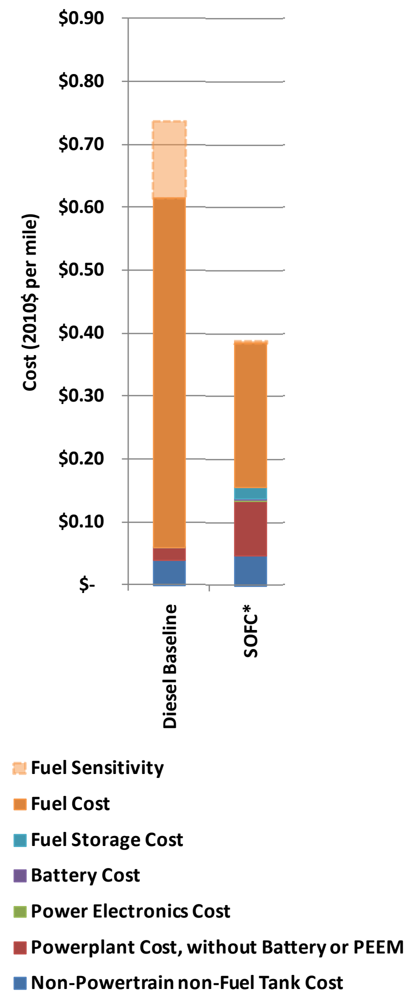




Fuel Storage:

* Oversized tanks

**Significant warm-up and transient response penalties*



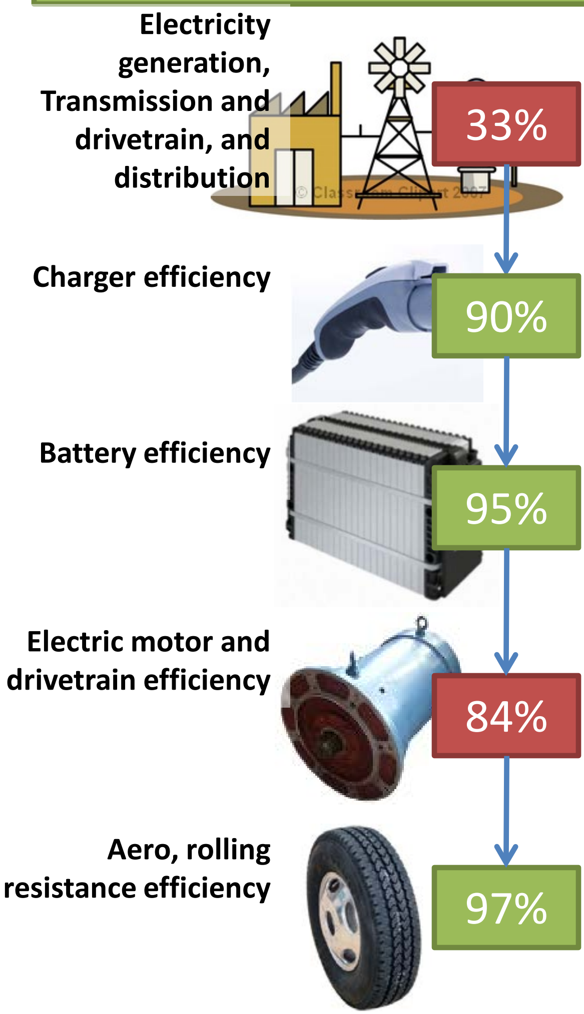
Heavy Truck: Battery Electric

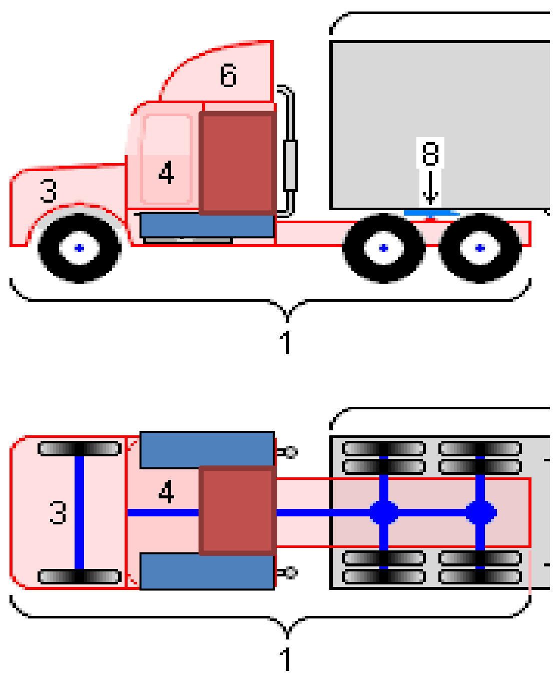
(estimated for 2020)

~13.1 mpgge
~23% WTW η
Petroleum reduction: 98%

Battery Weight: 17,500 lbs
(1,100% of baseline)
Battery Volume: 1,250 gal
(625% of baseline)

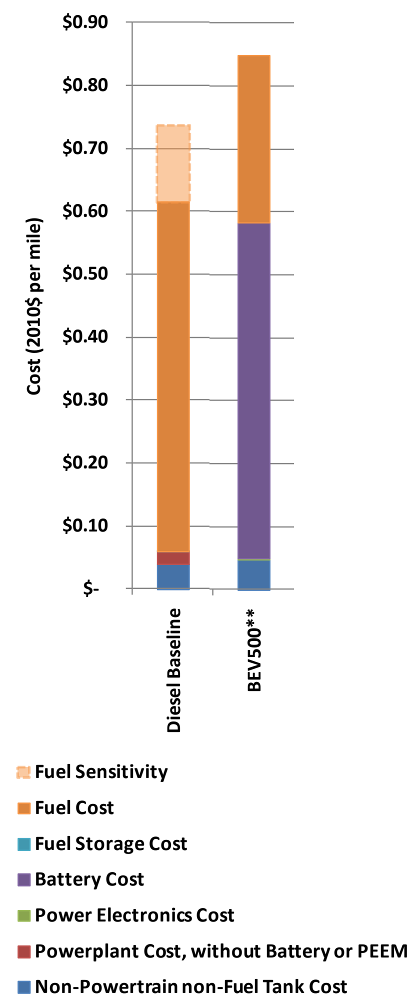
Lifecycle Cost of Driving:
1.5x baseline
Payback Period: none
Breakeven diesel price: $10.90





Internal Storage:
sacrifice 40% of cab;
or External Storage:
none

Limited range; recharge and weight capacity penalties



Contact Information

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