US DOE SUPERTRUCK INITIATIVE

Alicia K. Birky, PhD

Energetics Inc.

December 3, 2015

PRESENTATION OUTLINE

- SuperTruck overview
- Project teams' status
- Outcomes
- Resources

SIGNIFICANT FINDINGS

- Vehicle system focus is important:
  - Vehicle-level targets drive more innovation compared to component-level targets;
  - Synergies and dis-synergies and the corresponding design challenges (e.g., emissions aftertreatment and multiple waste heat recovery systems);
  - Systems optimized for most frequent operation, not maximum load or performance.
- Technologies with greatest near-term potential are already being commercialized:
  - Matched engine – transmission, including downspeeding;
  - Improved aerodynamic treatments for tractor and trailer.
- Grade is a significant factor in fuel consumption and in the potential for savings.
- Hybrid and predictive cruise / coast compete for same energy savings:
  - Predictive cruise is simpler (software only), cheaper, and likely to see greater driver acceptance.

SUPERTRUCK OVERVIEW

- Goals:
  - Achieve 50% engine brake thermal efficiency (BTE)
    - Dyno test representative of flat road, 65 mph
  - Demonstrate 50% improvement in freight efficiency (FE), measured in ton-miles per gallon
    - Class 8 tractor trailer, 65,000 lbs
    - ≥ 20% of improvement from engine
    - Drive cycle defined by the industry team
  - Identify pathways toward a 55% BTE HD diesel engine

- Four cooperative R&D agreement awards to integrated teams led by
  - Cummins Inc. with Peterbilt (ARRA Funded)
  - Daimler Trucks North America (ARRA Funded)
  - Navistar, Inc
  - Volvo Trucks North America
- Total project funding, DOE + Industry = $284 Million

SCOPE OF RESEARCH

- Engine / powertrain system:
  - Improved in-cylinder combustion,
  - Engine mechanics,
  - Friction reduction,
  - Downsizing,
  - Downspeeding,
  - Waste heat recovery (turbo-compounding and organic Rankine cycle),
  - Emission control,
  - Materials,
  - Electrification and intelligent control of accessories, and
  - Reduced ancillary loads.
- Engine and vehicle controls.
- Hybridization.
- Drivetrain efficiency:
  - Advanced transmissions - continuously variable (CVT), automated manual (AMT), dual clutch, etc., and
  - Axles.
- Fuels (non-food feedstocks).
- Lubricants.
- Aerodynamic drag reduction.
- Rolling resistance reduction.
- Weight reduction.
- Idle / hotel load reduction.

CUMMINS / PETERBILT: PROJECT COMPLETE

- Demonstrated **51% BTE** engine on dyno, including WHR
- Organic Rankine cycle WHR from EGR, exhaust, coolant, and charge air
- Validated analytical roadmaps to 55% BTE engine for diesel and dual fuel approaches
- Single clutch AMT
- Net weight reduction: 1,305 lb

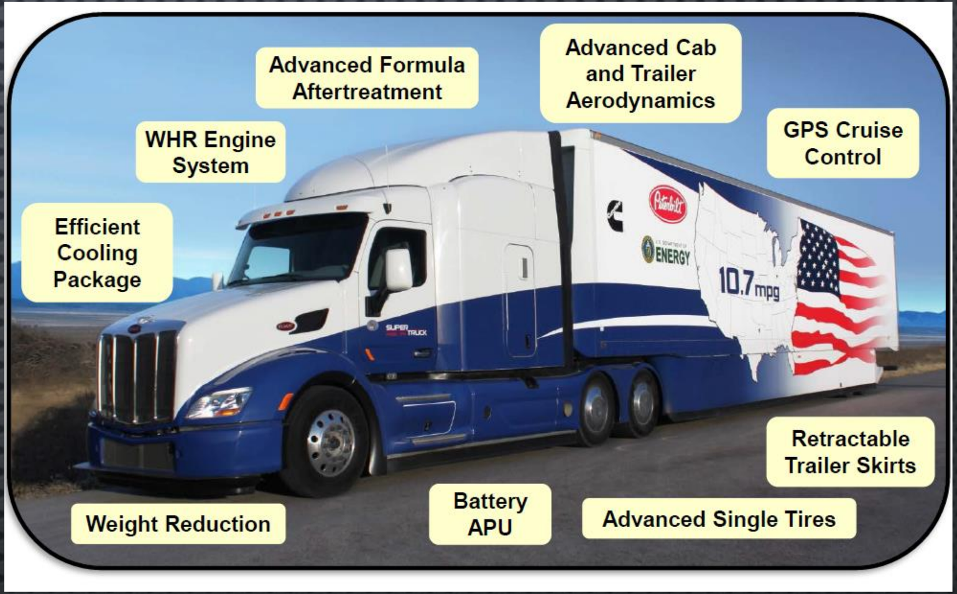


Image source: D. Koberlein, 2015 AMR presentation ACE057.

- 46% reduction in aerodynamic drag coefficient – matched tractor and trailer
- Demonstrated freight efficiency improvements:
  - **76%** in long-haul drive cycle test
  - 86% in 24-hr cycle test (includes overnight hotel loads)
    - lithium ion battery APU
- Achieved **10.7 mpg** (65 mph cruise)

DOE: $38.8M
Industry: $38.8M

DAIMLER: PROJECT COMPLETE

- Demonstrated **50.2% BTE** engine + WHR
  - Downsized
  - Improved combustion & turbocharger
- Parallel hybrid: 120 kW motor, 2.4 kWh battery
- Electrified auxiliary systems
- WHR – ORC electrical power for:
  - HVAC and other hotel loads
  - hybrid motor or battery recharge
- Trailer roof solar panels
- Tractor redesign + trailer aero pkg: 54% reduction in drag coefficient
- 12-speed AMT; 6x2 axle
- Net 2,800 lb weight reduction
- eCoast

- Demonstrated freight efficiency improvements
  - **96-120%** over drive cycle
  - 115% over 24-hr duty cycle
- Achieved **12.7 mpg**

DOE: $39.6M
Industry: $39.6M

VOLVO: IN PROGRESS

- Began June 2011; expected completion June 2016
- Priority: truck/engine integration
- Demonstrated 48% BTE (phase 1) ahead of schedule
  - Downsized, down-sped
  - Turbo-compound
  - Volvo-designed Rankine WHR:
    - 5 stage axial turbine
    - Significant size reduction
- Phase 2 engine **48% BTE without WHR**; build complete, integration and test in progress
- Verified combustion simulation for PPC; simulated 56.2% BTE capable engine

- Dual clutch transmission
- Predictive cruise + eCoast
- LED lighting and light wiring harness
- Aggressive weight reduction
- Electrified HVAC
- Tractor roof solar panels
- Battery power for hotel loads
- First demonstrator: **43%** improvement in freight efficiency

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

NAVISTAR: IN PROGRESS

- Initiated in 2010Q1 but "paused" in 2012Q4; project resumed Nov. 2014. Expected completion Dec. 2016
- Initial concept – series hybrid, 360 kW, 700 V – was dropped
  - Expensive, heavy, complex
  - Modest fuel savings attributed to hybridization in this drive cycle
- Current concept - stop-start, 48 V motor/gen, 48 V NiZn batteries
- Demonstrated **48.3% BTE without WHR**
- Projected 50.7% BTE engine:
  - Downsize
  - Downspeed
  - Driven eturbo
- ORC WHR possible for 55% BTE goal

- 6x2 drivetrain with direct drive Eaton Ultrashift
- "Smart" subsystems (cruise, auxiliaries)
- Tractor and trailer aerodynamics
- Aggressive weight reduction targets from tractor (3,250 lb) and trailer (3,700 lb); net not known

DOE: $37.3M
Industry: $45M

RESULTS: COMMERCIALIZED TECHNOLOGIES

Peterbilt EPIQ package

- Aerodynamic enhancements and closeouts
- PACCAR MX-13 engine + Fuller Advantage automated manual transmission + optimized communication technology
- SmartTire Tire Pressure Monitoring System (pressure and temp)
- Low rolling resistance tires
- SmartAir no-idle A/C

International ProStar ES

- Aerodynamic enhancements
- Optional Cummins Eaton SmartAdvantage: downsped Cummins ISX-15 + 10-speed Eaton AMT + efficient axles

RESULTS: COMMERCIALIZED TECHNOLOGIES

Freightliner Cascadia Evolution options

- Aerodynamic enhancements (standard)
- Wide-base tire options
- Integrated powertrain: DD15i + DT-12 direct drive AMT with common controller
- Intelligent powertrain management – terrain maps integrated into engine and transmission functions
- eCoast – disengages transmission when coasting
- RunSmart predictive cruise

Volvo

- "The SuperTruck first demonstrator propshaft, combustion system, axles, down-speeding technology (and more) will be in production soon, some are already available for purchase." (Gibble, 2015 AMR)
- XE package:
  - Downspeeding + high torque
  - Adaptive gearing

NEAR TERM COMMERCIALIZATION

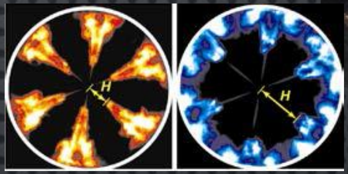
- Technologies already available:
  - Advanced aerodynamic designs,
  - Enhanced trailer skirts,
  - Integrated and downsped powertrains,
  - Intelligent controls, including torque management,
  - Predictive cruise,
  - eCoast,
  - Next generation wide base single tires.

- Promising technologies that require additional product development to improve market acceptance, cost, durability, and reliability:

  - Additional aerodynamic improvement,
    - Gap improvement,
    - Trailer boat tail enhancements,
  - Light weight drive shafts and frame rails,
  - Tire auto inflation,
  - Engines designed for higher thermal efficiency, including parasitic loss reductions,
  - Advanced AMTs,
  - Improved aftertreatment.

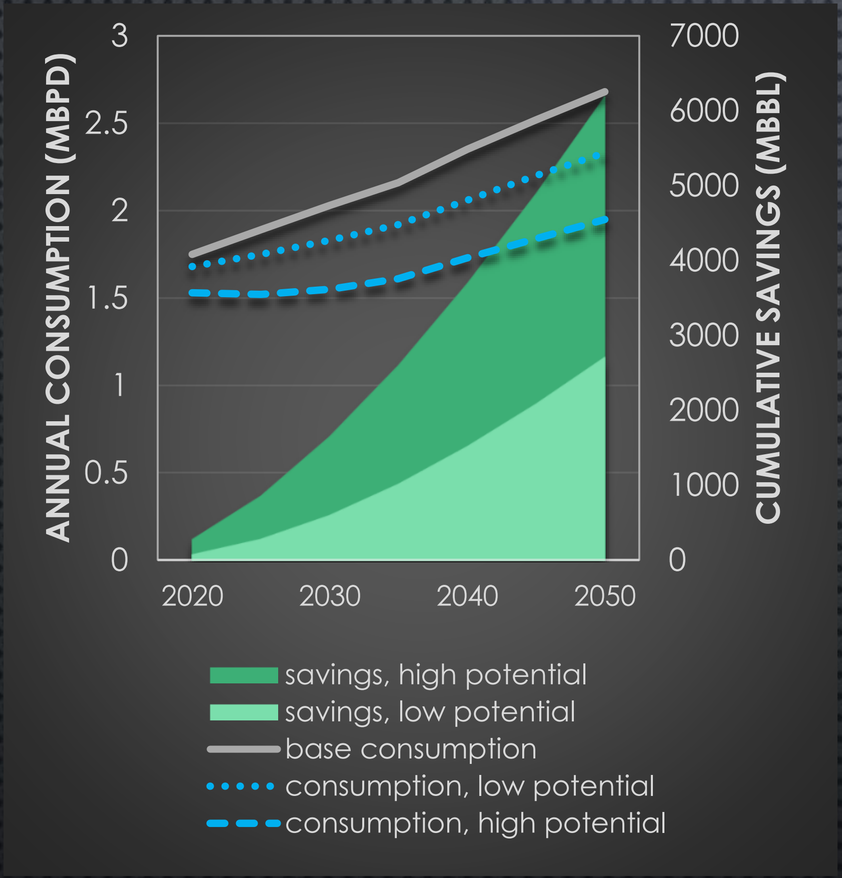
PERSPECTIVE ON MID- TO LONG-TERM COMMERCIALIZATION

- Technologies with long-term potential that require additional development to determine true market viability and cost effectiveness:
  - Active aerodynamics,
  - Waste heat recovery (Rankine cycle),
  - Controllable or electrified auxiliaries,
  - Mild hybridization,
  - Technologies for 55% efficient engine,
  - Radical tractor and trailer designs,
  - Further weight reduction (aluminum, carbon fiber),
  - Novel tire compounds,
  - Solar energy harvesting.



- Market complexity limits transferal of research results to real-world fuel savings:
  - e.g., tractor vs trailer: manufacturers and ownership; useful lifetimes and replacement schedules; fleet size (dry van trailers outnumber tractors 3:1)
  - Multiple trailer types and uses (dry van, reefer, container, flat bed, etc.);
  - Aerodynamic drag reductions comparable to the SuperTruck demonstrations (~50%) should not be expected in production vehicles soon:
    - Requires matched tractor and trailer;
    - Some ST concepts not necessarily suitable for real world use – would need redesign and test;
    - Potential trailer benefits 2-3x those obtainable from tractor, even with complete redesign.

PROJECTED BENEFITS



Source: DOE SuperTruck Program Benefits Analysis Final Report, December 2012 (https://anl.box.com/s/3dfq5bvqrjni0veon68by33im7gsgchn)

- Analysis performed in 2012 assuming technologies to meet goals would be fully commercializable.
- Results for two cases:
  - Low potential – high technology cost and reference oil price,
  - High potential – low technology cost and high oil price,
  - Technology cost estimates based on TIAX for NAS (2009),
  - Baseline fuel consumption and oil prices from AEO 2011 and 2012 early release.
- Updated analysis underway with gradual technology deployment based on current understanding of commercial potential.
- Market adoption rates vary according to annual mileage and associated payback period; new truck population divided into 11 mileage cohorts.

QUESTIONS?

RESOURCES

- Source references:
  - DOE Vehicle Technologies Office Annual Merit Review Presentations: http://www.annualmeritreview.energy.gov/
  - National Academy of Sciences, Review of the 21st Century Truck Partnership: Third Report, http://www.nap.edu/catalog/21784/review-of-the-21st-century-truck-partnership-third-report
- See Also:
  - http://energy.gov/eere/vehicles/vehicle-technologies-office
  - OEM press releases.
- Contacts:
  - abirky@energetics.com
  - roland.gravel@ee.doe.gov