Development and Demonstration of a Fuel-Efficient Class 8 Tractor & Trailer SuperTruck Vehicle Systems (Project ID: ace_103)

DOE Contract: DE-EE0007767
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DOE MERIT REVIEW
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# Overview: Navistar & DOE SuperTruck II

## Timeline
- **Start Date**: 12-2016
- **End Date**: 12-2021

## Budget
Total Project Funding:
- **DOE Share**: $20M
- **Navistar Share**: $35M

## Technical Barriers and Targets
- **#1**: Greater than or equal to 55% engine brake thermal efficiency (BTE)
- **#2**: Greater than 100% improvement in vehicle freight efficiency (FE) (on a ton-mile-per-gallon basis)
- **#3**: Development of technologies that are commercially cost effective

## Partners and Laboratories
- Department of Energy
- Argonne
- Lawrence Livermore
- Bosch
- TPI - Composites
- Dana
Resources Navistar Utilizes in DOE ST II Program

**Partnerships and Laboratories**

- Navistar
- **DOE**
  - Argonne
  - Lawrence Livermore
- **Bosch**
- TPI Composites
- **Dana**
- **U-Michigan**
- Integrated Product Development (IPD)
- SuperTruck I Processes, Practices
- Product Development Process
- Program management
- Advanced Technology & Global Innovation
Program Plan

MILESTONES

Budget Period 1 Requirements / Technology Assessment & Initial Hardware Testing

Budget Period 2 - Technology Development & Concept Readiness Demonstration

Budget Period 3 - Technology Finalization & Validation

Budget Period 4 - Tractor/Trailer Fabrication, Integration & Commissioning Demonstration

Budget Period 5 - Fuel Economy & BTE; and Program Completion
Program Milestones

Budget Period 1
Requirements / Technology / Assessment & Initial Hardware Testing

Budget Period 2
Technology Development & Concept Readiness Demonstration

Budget Period 3
Technology Finalization & Validation

Budget Period 4
Tractor/Trailer Fabrication, Integration & Commissioning Demonstration

Budget Period 5
Fuel Economy & BTE; and Program Completion

2017 2018 2019 2020 2021
Engine Objective

- Attain greater than or equal to 55% BTE demonstrated in an operational engine at a 65-mph cruise point on a dynamometer.
- Develop engine technologies that are commercially cost effective.
- Contribute to greater than 100% improvement in vehicle freight efficiency (FE) relative to a 2009 baseline.

Technologies development identified to achieve 55% BTE.
Engine Technical Accomplishments & Progress

Combustion & Fuel System

- Combustion system focus remains on optimizing the combustion process
- Key parameters of fuel-injection configurations include number of holes and nozzle flow rates
- Rapid break-up of spray core results in faster combustion
- Peak efficiencies achieved through optimizing air utilization and mixing process control
- Increasing PCP improves combustion efficiency
Engine Technical Accomplishments & Progress

- Analysis had shown a significant amount of heat rejection to engine coolant
- A low-heat transfer liner was procured and investigated to minimize the heat loss to coolant
- The results showed that block heat rejection was reduced as expected – however, an increase of oil heat rejection was observed
- As a result, the BSFC remains similar between the baseline and the low-heat transfer liner
Engine Technical Accomplishments & Progress

Thermal Management

• High-temperature pistons investigated

• New piston design resulted in higher exhaust temperature – helpful to ORC, but worse for BSFC

• As a result of this work, we found that increasing oil temperature by ~100°F resulted in 1% BTE gain
• Based on the temperature characteristics of the heat sources, the ORC system was optimized.
• Different working fluids were evaluated, including refrigerant.
• The expander’s efficiency has a direct impact to ORC BTE gain.
• A 10% increase in expander efficiency results in a gain of 0.5% in ORC BTE for the same working fluid.
ANL – Gasoline Compression Ignition (GCI)

• GCI Goal: Increase portion of premixed combustion, using three strategies (focused at ST I A50 condition):
  • Early pilot injection (EP)
  • Late pilot injection (LP)
  • Early/late pilot injection and port fueled injected/direct injection (PFI/DI)
• Two gasoline fuels selected for evaluation:
  1. EEE, EPA Tier II Certification Gasoline
  2. E85, blended in-house with 85 vol% dry ethanol and 15 vol% EEE
• Results:
  • EEE gasoline performed best with late pilot injection strategy
  • E85 gasoline performed better with PFI/DI strategy
  • Both EEE & E85 could achieve better brake efficiency than the diesel baseline
Aftertreatment Technical Accomplishments & Progress

Emission Control
Mixer Development and AT Architecture

- Evaluation of close-coupled SCR (CCSCR) showed the best performance when using a large diameter.
- CCSCR brick was installed upstream of the DOC and packaged within a common converter.
- Smaller diameter CCSCR system displayed high restriction; bypass valve did not package well.
- Next Steps: System assessment in progress for optimal AT design and installation.

Components installed near turbo outlet (currently using design C)
Balancing NOx conversion Over Upstream and Downstream SCR

- TP NOx over composite FTP and RMC is below 0.2 g/hp.hr
- AT system provided over 98% NOx conversion over composite FTP
- Adjusting calibration table allowed for dynamic dosing
- Upstream SCR efficiency 70%-95% composite FTP and 80%-95% hot FTP
- Goal is tunable from 50% to 95% (composite)
- No evidence of DEF deposits at upstream DEF dosing

Benefits of Upstream SCR

- Rapid light-off observed ➔ within first minute of cold FTP
- High NOx conversion
- Addition of AMOX zone minimized N₂O formation ➔ no NH₃ slip to DOC/DPF

![SCR Conversion Split](image_url)
Vehicle Objective

Research, develop, and demonstrate a vehicle that achieves the following goals:

- Greater than 100% improvement in vehicle freight efficiency (FE) (on a ton-mile-per-gallon basis) relative to a 2009 baseline with a stretch goal >140% improvement.
Vehicle Technical Accomplishments & Progress

Aerodynamics

- Body, Aero, Trailer and Composite Frame Rail execution continued through detailed design phase.
- Employed aerodynamic ducting approaches to reduce pressure in stagnant leading surfaces for overall reductions.
- Initial composite material selection was done with a completive production cost. Carbon-fiber utilization minimized.
- Estimated mass reduction for body structure, hoods, and exterior aero devices is >500 lb.
- Trailer will utilize high-level of composite material.
Vehicle Technical Accomplishments & Progress

**Composite Frame**

- Simulation indicates up to a 25% mass savings vs. a steel-frame ladder, assuming integrated crossmembers and channel design.
  - Mass reduction – On target (mass reduction over steel frame ladder)
- Design Status: Recovery loads
  - Horizontal Towing – Pass
  - 45-deg conical Recovery – Pass
  - Frame Deflection – Pass (comparable to metal frame)
  - Racking Loads (Turning) – Conditional Pass (comparable)
  - Chassis twist – Conditional Pass (comparable)
  - Cross twist – Conditional Pass (comparable)
- Remaining Analysis/Testing/Development
  - Develop epoxy matrix material properties – Targeting a matrix material Need to develop fatigue curve with chosen matrix material
  - Consolidate connection points – Design to limit or reduce the number of through-bolts.
Vehicle Technical Accomplishments & Progress

Advanced Cooling

Continued optimizing the cooling-system configuration for the truck

- Radiator to handle engine cooling with smart flow control
- Low-temperature loop will be used to supply coolant for battery, electric motor/generator, and other accessories
- Electric fans will be used for cooling
- Eclectic driven water pump.
- AC condenser and fan will be a stand-alone unit
- Continued the cooling-system-packaging study, with preliminary results illustrated.

Aerodynamic team and Analytic Group are evaluating cooling-module placement, together with the truck frontal design themes
Vehicle Technical Accomplishments & Progress

Completed 3D-CAD packaging study to fit extra components on the truck
- Sized-up 48V Lithium batteries pack
Completed (Build Books)
- Procured all major components and required installation parts:
  - AMT transmission
  - DANA Ultra fast drive axle
  - DANA Carbon Fiber composite drive shaft
  - Lightweight prototype hub design from Timken for ST II tag axle
- 3+ lb/hub weight reduction vs. ST I
- Aluminum casting with integrated Gen.2 PDEF bearing.
Connected Cruise Control

Improving Fuel Economy of Heavy Duty Vehicle in Traffic using Connectivity and Automation

- Continued development on ACC/CCC
- Moved development to vehicle
  - Collected data necessary for developing feed-forward-control portion of algorithm
  - Creating response maps for a given control input.
- Down-selection of components is complete.
- Evaluating code and port to the new API

Beyond-line-of-sight detection [3]

Fuel economy oriented 5-15% fuel benefit compared to cruise control

Bridge the gap of fuel economy between 0 to 15% Also keep safe

Traffic following oriented Limited economy evaluation available

Vehicle Technical Accomplishments & Progress
Summary: Budget Period 2

Technology Development & Concept Readiness Demonstration

**Approach:** Develop & implement detailed R&D path for required components/subsystems, ensuring successful completion of overall program goals

**Overall**
- Continued economic & energy impact analyses of component technologies to prepare for BP3

**Engine: ≤ 55% BTE Architecture**
- Continued investigation of further reductions related to friction model
- Completed exhaust and EGR system design modifications; continued air system turbocharger efficiencies
- Used optimized WHR model configurations
- ANL, used new GCI strategy to continue evaluation of system and fuel performance opportunities
- Aftertreatment demonstrated dual DEF dosing concept that is capable of reducing high engine-out NOx to less than 0.2 g/hp.hr over the FTP and RMC

**Vehicle: >100% improvement in FE**
- Finished Mule build, including addition of hybrid transmission, wiring harnesses, and lightweight tag axle; evaluating integrated disc brakes
- Upgraded control strategy, GPS-based gear shift optimizer; and improved drive-off and overall shift quality
- Worked to increase battery life and performance (e.g., hybrid batteries)
- Optimized cooling system configuration (e.g., radiators, fans, water pumps, cooling-module, HVAC system)
- Continued controls architecture development, evaluating braking strategies, integration of ZF systems, and ACC/CCC
Budget Period 3 - Technology Finalization and Validation

Complete economic & energy impact analyses of component technologies, as well as GCI combustion and nanofluid development

Approach:

- Finalize down-selection of:
  - In-cylinder combustion systems
  - Hybrid powertrain systems
  - Advanced vehicle electrification system
  - Advanced aftertreatment systems

- Continue evaluation and selection for:
  - Waste Heat Recovery (WHR) system development
  - Drivetrain & chassis efficiency improvements
  - Aerodynamics improvements
Questions - Comments