Overview

Timeline

Begin: 10/1/2016
End: 9/30/2021
50% complete (03/19)

Barriers

Engine Efficiency $\geq 55\%$ BTE
Freight Efficiency $\geq 100\%$ FTE
Cost effective solutions

Budget

Total Project: $40M
$20M DoE - $20M Partners

Total Spent: $25.2M
$12.6 = Partners
$12.6 = DoE

Partners

Cummins – Powertrain
Eaton - Transmission
Peterbilt - Vehicle
Bridgestone – Tires
Walmart – Customer counsel
Relevance: Objectives

- Demonstrate a *minimum* of 55% BTE at a 65 mph cruise, on an engine dynamometer test stand
  - Same engine systems also demonstrated in vehicle, operating on real world drive cycles
- Achieve a *minimum* of 125% Freight Ton Efficiency (FTE).
  - FTE = MPG*Tons of Freight
- Track, promote and report on cost effective solutions
  - Prioritize solutions that have ~3 year payback period
  - Utilize customer counsel for understanding payback variables
Relevance: Energy Consumption

- Approximately 20% of U.S. transportation petroleum goes to the production of heavy truck fuel. Proposed improvements would save more than 400 million barrels of oil per year.*
  - Reduce imports and improve energy security
  - Reduce the cost of moving goods
- Heavy Truck GHG emissions account for a CO2 equivalent 420.7 MMT per year (35th edition of the Transportation Energy Data Book).
  - Improved air quality
  - Protect the public health and environment

## Milestones by Quarter

<table>
<thead>
<tr>
<th>FY 2018</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mule tire samples built</td>
<td>Tire samples built and tested, model data confirmed and included in overall system model</td>
</tr>
<tr>
<td>Weight budget confirmed</td>
<td>Chassis, cab/sleeper, trailer and powertrain targets established</td>
</tr>
<tr>
<td>Base engine at 50% BTE</td>
<td>Dynamometer demonstration of base engine at 50% BTE</td>
</tr>
<tr>
<td>Cooling system direction confirmed</td>
<td>Cooling system simulation with various routes and ambient conditions</td>
</tr>
</tbody>
</table>
## Milestones by Quarter

<table>
<thead>
<tr>
<th>FY 2019</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Cd via simulation, confirmed</td>
<td>Final adjustment required for produce ability of prototype hardware</td>
</tr>
<tr>
<td>Tire RRC confirmed/tested</td>
<td>On-Road/Rig data</td>
</tr>
<tr>
<td>ACEM Features selected</td>
<td>Inertia restart, Coasting feature, weather, etc. included in mule testing and validation</td>
</tr>
<tr>
<td>HHRR combustion system and Low voltage hybrid</td>
<td>New combustion system for final demonstration and 12/48V system for energy recovery</td>
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</tbody>
</table>
Program Level Milestones

- **50% BTE Base engine**
- **Final Cd confirmed**
- **Mild hybrid demo in Mule vehicle**
- **55% BTE demo on dyno**
- **Demo vehicle & trailer mated**
- **Complete vehicle testing**

All proposed future work is subject to change based on funding levels.
Approach: Cummins Powertrain

New engine, transmission, and axle technology to meet freight / efficiency objectives.
Technical Approach
– SuperTruck II Target –

\[ MPG = \frac{BTE \times \text{Energy/Gallon}}{\text{Work/Mile}} \]

Graph showing the relationship between Base engine efficiency, WHR, Drive cycle – Engine BTE, Engine Work/mile, and Energy recovery, Vehicle Aero, Tires, Transmission, Axle.
Accomplishments
Cummins Energy Recovery Drive (CERD)

- Hardware integration confirmed
- Validation of controls systems integration
- Correlation of simulation results to test data
- Transmission shifting validated
- Great collaboration with ORNL!
- 3.4% fuel savings expected
Accomplishments
50% BTE Milestone Achieved

- Clean Sheet Base Engine
  - Without WHR

- New Technology applied
  - High Heat Release Rate Fuel System
  - Increased Compression Ratio
  - High Efficiency Turbocharger
  - Variable oil pump and PCN's
  - Low Friction Power Cylinder
  - Low Heat Transfer Exhaust

- 50% BTE optimized in power range from flat road cruise to fuel centroid

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**Achievements**

- 50% BTE Milestone Achieved
Approach for 55% BTE

- Build on 50% BTE Success
- Assess Theoretical Opportunity
- Additional Technology for 55%
  - WHR: Charge air, EGR, Coolant, Exhaust
  - Reduced Engine Friction
  - Improved Efficiency Turbocharger
  - Low Heat Transfer Cylinder Head & Piston
  - Improved Targeting of Injector Spray Angle
- 55% BTE Engine System will be Applied in 125% Freight Efficiency Demo Vehicle

![Split of Losses Diagram]

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<tbody>
<tr>
<td></td>
<td>50.3</td>
<td>7.5</td>
<td>3.7</td>
<td>0.8</td>
<td>0.2</td>
<td>0.7</td>
<td>2.4</td>
<td>3.4</td>
<td>34.4</td>
<td>4%</td>
</tr>
</tbody>
</table>

Target:
- Mech Efficiency: 96%
- Closed Cycle: 53%
- Open Cycle: 101%
- WHR Contrib.: 4%
Accomplishments
Disengage-able Tandem Technology

- Forward axle disengages fully
- 2.4% Efficiency gain
- Minimal weight penalty
- Controls system developed
  - Integrated into ECM with battery cooling system
  - Smooth re-engagement
- 2 Test trucks, including Powertrain Mule vehicle
  - >4000 miles / 4500 shifts

In Collaboration with:
Ken Damon
Peterbilt Motors
Prior AMR Comments/Questions

“It seems like there was a lot of effort on weight reduction and with only a few fleets able to really add payload.”

- Weight Management is a Standard Project Tracking Metric
- Peterbilt Offers Lightweight Options
- ST2 Design is Efficient
  - Purpose-built Cab and Interior
  - Short Wheelbase
  - No Exotic Materials

<table>
<thead>
<tr>
<th>System</th>
<th>Weight Delta (lbs)</th>
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<tbody>
<tr>
<td>Powertrain/Cooling</td>
<td>(285)</td>
</tr>
<tr>
<td>Chassis Systems</td>
<td>(1540)</td>
</tr>
<tr>
<td>Outer Body</td>
<td>(150)</td>
</tr>
<tr>
<td>Energy Storage</td>
<td>(615)</td>
</tr>
<tr>
<td>Trailer</td>
<td>(2095)</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>(4685)</strong></td>
</tr>
<tr>
<td><strong>GOAL</strong></td>
<td><strong>(3800)</strong></td>
</tr>
</tbody>
</table>
“It is not clear why single wide base tire was not selected for this program.”

- Current Market: 90% Dual

- Market Sensitivities
  - Highest Tire Life: Duals
  - Highest Retread Rate: Duals
  - Lowest Weight: Wide Base

- Tire Construction
  - Vastly Different
  - Not Transferrable

- Commercial Value > Weight Penalty
Technical Approach: Path to Target

- Aerodynamics
- Engine
- Transmission/Axle
- Downspeeding
- Lightweighting
- Route Management
- Rolling Resistance
- Mild Hybrid/Solar
Technical Progress: Path to Target

- 55% Engine Efficiency
  - On Target

- Goals vs. Baseline
  - 56% Drag Reduction
    - Ahead of Target
  - 3800lb Weight Reduction
    - Ahead of Target
  - 30% Reduced Rolling Resistance
    - Ahead of Target

Freight-Ton Improvement

- 150% Projected
- 125% Target
- 100% DoE Goal

2009 386 (Baseline)
Technical Accomplishments

- **Technology Mule:**
  - Initial Build Complete
  - First Technology Upfit Complete

- **Demonstrator:**
  - Door Technology Selected
  - Outer Body Surfaces Complete
  - Body in White Design Complete
  - Interior Theme Selected
  - Interior Design in Process
Technical Accomplishments

Model 579 Technology Mule (1.0)

- Cameras/Displays
- Advanced Transmission
- High Efficiency Engine
- Elec. Steer Assist
- 6x4 Disconnect Tandems
- Gen 1 Low Crr Tires
- Chassis Height Control
- Lightweight Chassis
Technical Progress/Future Research

• Mule 2.0 Complete
  • Hybrid Motor Generator
  • 48v Storage Cell

• Mule 2.1 (3Q19)
  • Waste Heat Recovery (WHR) System
  • 48v Cooling Fans
  • 48v Electric/Hydraulic Steer
  • 48v eHVAC

• Hybrid Drive Algorithm Development
  • 4Q19 Through 2020
Technical Progress: Outer Body

- Digital Surfaces Complete
  - Scaled Clay Model (Sept ‘18)
  - Cab/Sleeper Surfaces (Oct ’18)
  - Hood/Bumper Surface (Apr ’19)
  - Fairing Surfaces (May ‘19)

- Outer Body Freeze (Nov ’19)
Technical Progress: Demonstrator

- Cab/Sleeper Body in White
  - Co-developed with Magna
  - Design Complete 2Q19

- Hood/Bumper, Fairings, Extenders
  - Internal Resources
  - Work in Progress 2Q19

- In Process Co-Development
  - eHVAC: Bergstrom
  - Wipers: Valeo
  - Interior: Point Innovation
  - Light/Aerodynamic Trailer: Great Dane
Future Research: Driver Environment

- Full Scale Cab Buck
- Operator Experience
  - Ingress/Egress
  - Spatial Appreciation
  - Visibility
  - Feature Ergonomics
  - In-Cab Dynamics/HMI
- Augmented Reality Studies
  - Digitally Developed Interior
  - Halolens Technology
  - Customer Voice (Walmart, FedEx…)

Peterbilt
Technologies and Collaboration

- Active Extenders
- Chassis Height Control
- Forward-Looking Yaw Sensor
- 6x4 Disconnect Tandems
- Cameras/Displays
- MMC Brake Drums
- Lightweight Chassis
- Aerodynamic Body
- 24.5” Aluminum Wheels
- High Efficiency Engine/Transmission
- Gen 2 Low Crr Tires
- Advanced Cycle Efficiency Manager
- Mild Hybrid Driveline
- 48v eHVAC

Companies: Stoneridge, OADS, IMI NORGREN, MERITOR, Metalsa, Walmart, ZF, Bridgestone, Cummins, Eaton, Bergstrom, MAHLE, Great Dane, MAGNA, Arconic.
Future Work

- 2016:
  - Program Award
  - Program Kick Off

- 2017:
  - Outer Body Theme Selection

- 2018:
  - Aerodynamic and Cooling Packaging Studies

- 2019:
  - Technology Mule Build (M579)
  - Powertrain Evolution

- 2020:
  - Vehicle Design Development
  - Outer Body Design Freeze
  - Component Sourcing and Vehicle Design
  - Demonstration Vehicle Complete
  - Demonstrate >125% FTE

- 2021:
Proposed Future Research

- **55% BTE Demo Work**
  - Develop and refine technology for added base engine efficiency
  - Dual loop EGR control strategy for FE/NOx optimization
  - WHR system integration and calibration

- **Deliver Cost Effective Solutions**
  - Refine cost/payback model optimization
  - Assess manufacturing alternatives for low heat transfer components

- **Demonstrate >125% FTE improvement**
  - Powertrain Mule truck evolution
    - Integrate & develop mild hybrid system, EGR, & WHR
  - Refine and build Demonstrator truck and trailer
    - Develop adjustable ride height control system
    - Demonstrate active aerodynamic controls

All proposed future work is subject to change based on funding levels.
Program Summary

- **Powertrain**
  - Powertrain development in mule vehicle is on plan
  - Engine development on plan toward 55% BTE target
  - Powertrain targets on plan to meet FTE

- **Vehicle**
  - New aerodynamic system is ahead of target
  - Lightweight chassis has been prototyped in PT Mule
  - Bridgestone is ahead of aggressive Crr reduction target

- Cummins and Peterbilt will deliver a minimum 125% FTE and 55% BTE!
THANK YOU!

QUESTIONS