2019 Annual Merit Review
Cummins/Peterbilt SuperTruck II

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13 June 2019

Project ID:ACE102

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Overview

Timeline

Begin: 10/1/2016

End: 9/30/2021

50% complete (03/19)

Barriers

Engine Efficiency ≥ 55% BTE

Freight Efficiency ≥ 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

* https://energy.gov/eere/vehicles/vehicle-technologies-office-moving-america-forward-energy-efficient-vehicles

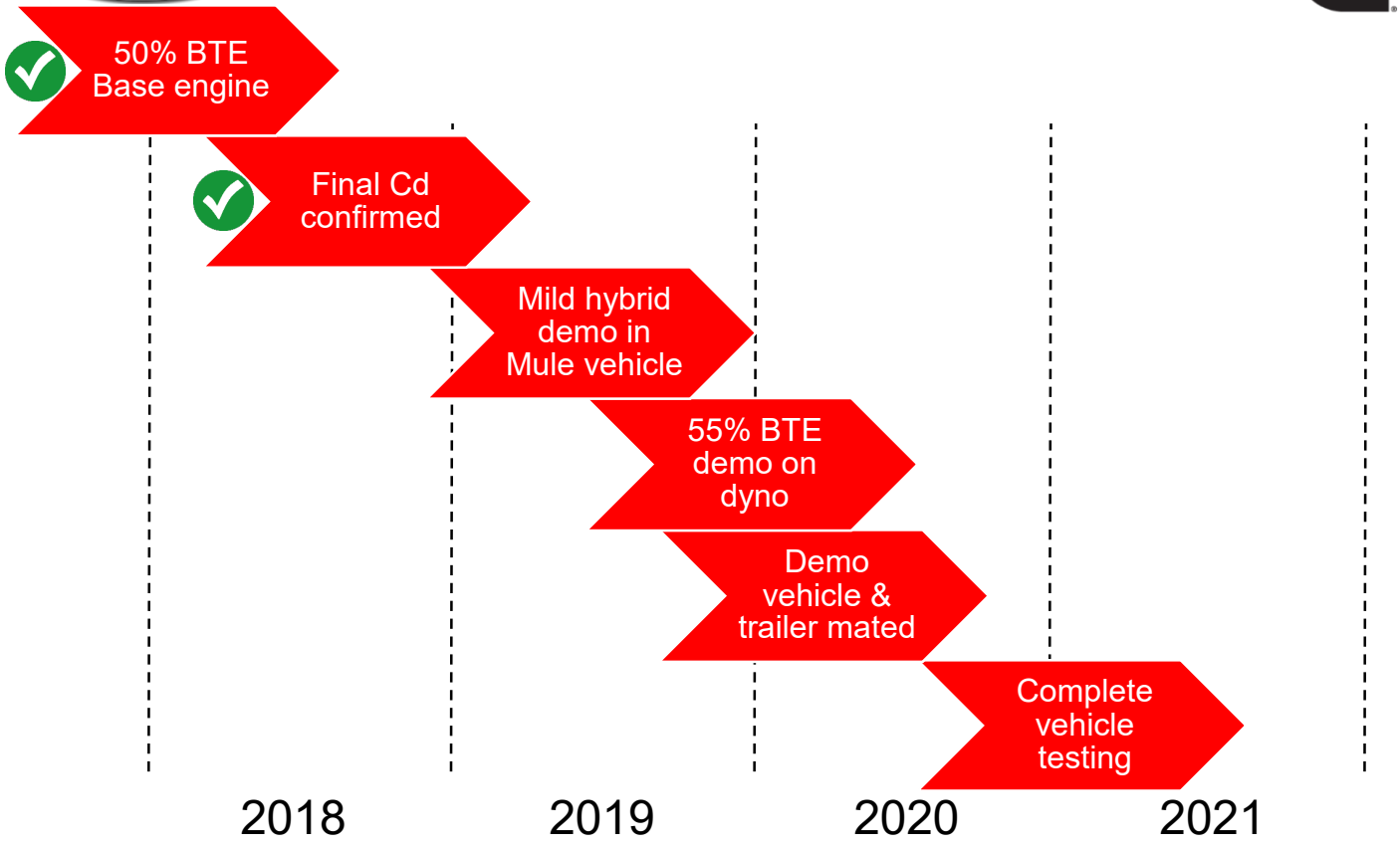
Milestones by Quarter

FY 2018	Description
Mule tire samples built 	Tire samples built and tested, model data confirmed and included in overall system model
Weight budget confirmed 	Chassis, cab/sleeper, trailer and powertrain targets established
Base engine at 50% BTE 	Dynamometer demonstration of base engine at 50% BTE
Cooling system direction confirmed 	Cooling system simulation with various routes and ambient conditions

Milestones by Quarter

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

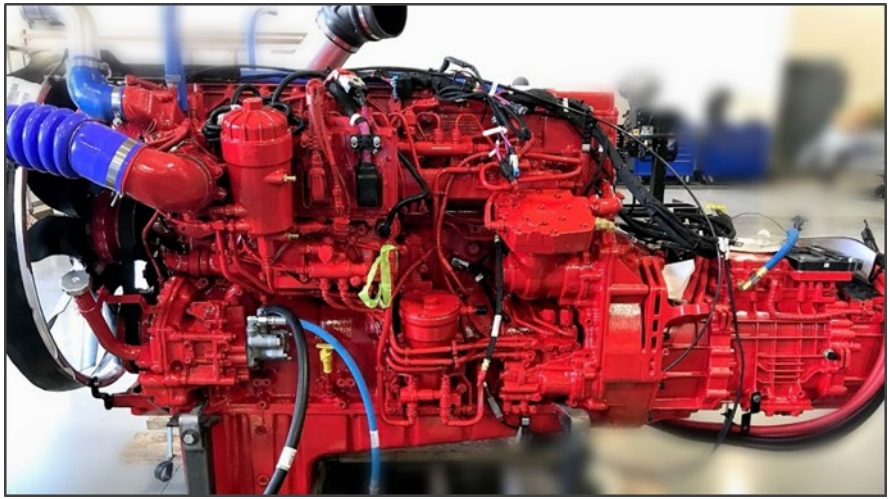
Program Level Milestones



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

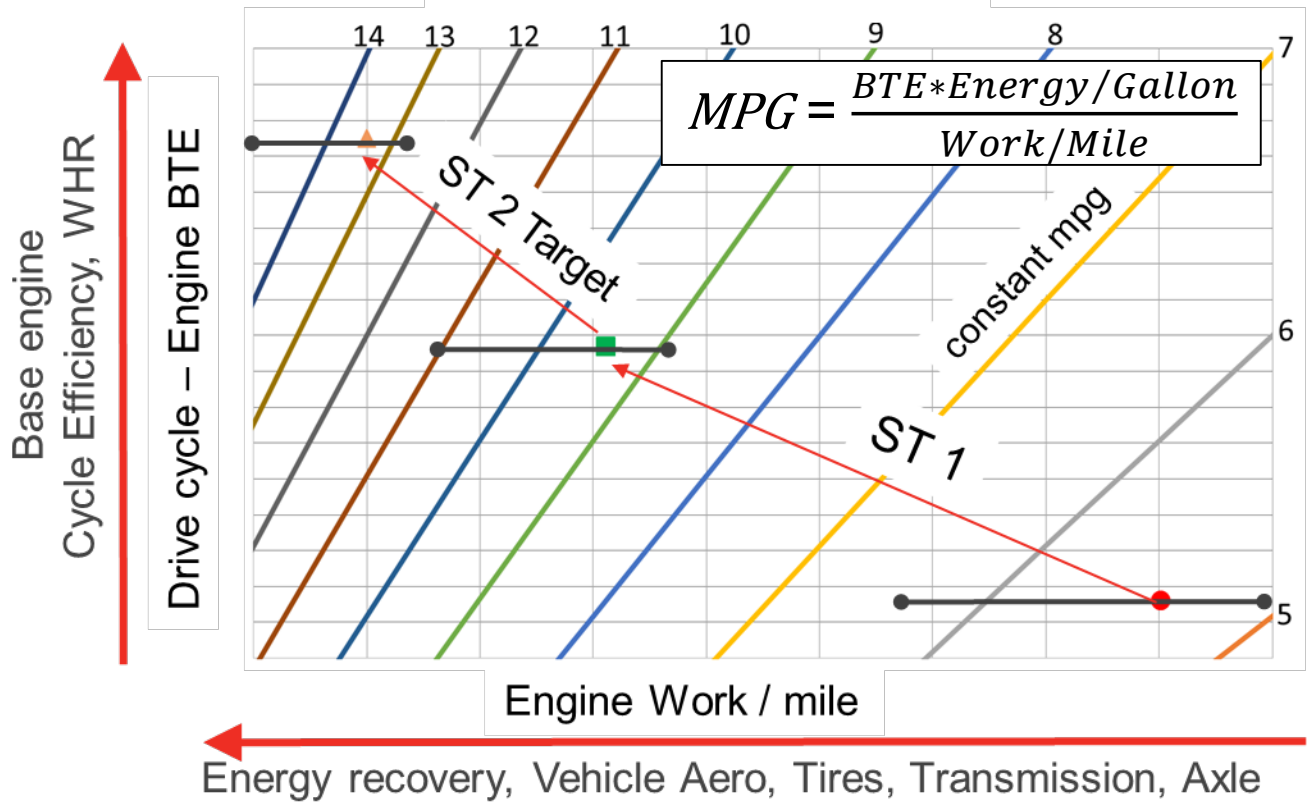
Approach:
Cummins Powertrain

ENGINE TRANSMISSION DRIVE AXLE



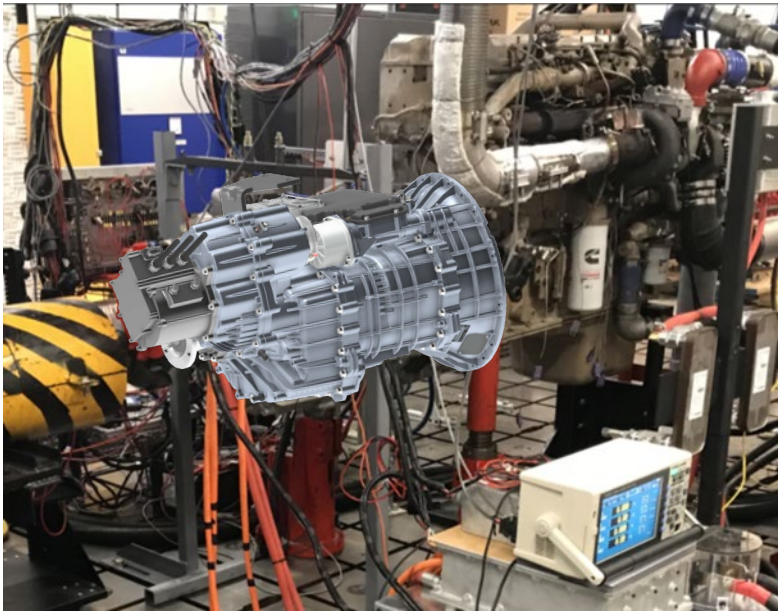
New engine, transmission, and axle technology to meet freight / efficiency objectives.

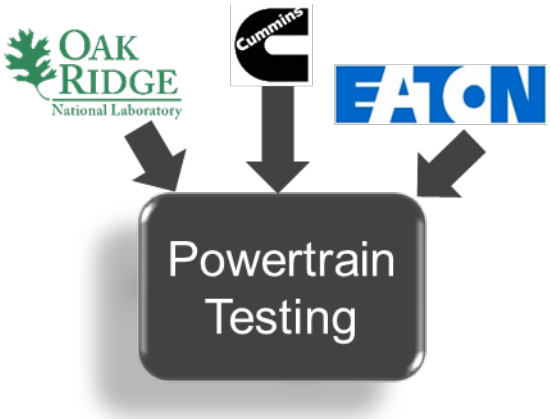
Technical Approach
– SuperTruck II Target –



Accomplishments

Cummins Energy Recovery Drive (CERD)





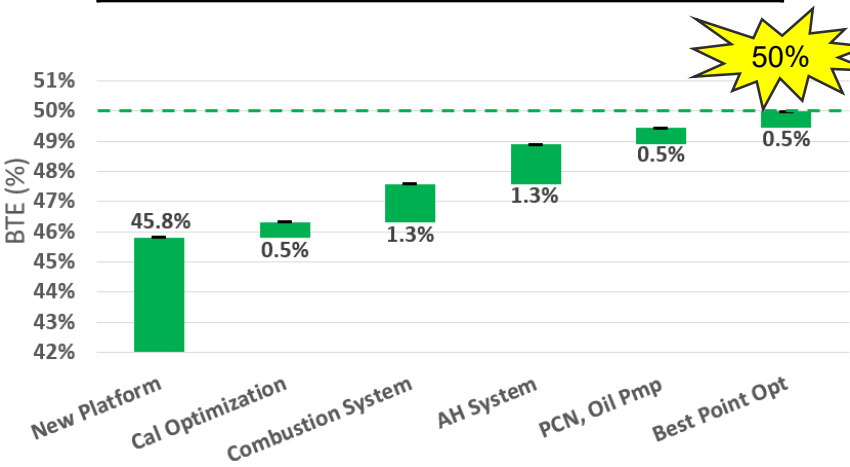
- Hardware integration confirmed
- Validation of controls systems integration
- Correlation of simulation results to test data
- Transmission shifting validated
- Great collaboration with ORNL!
- 3.4% fuel savings expected

Accomplishments

50% BTE Milestone Achieved

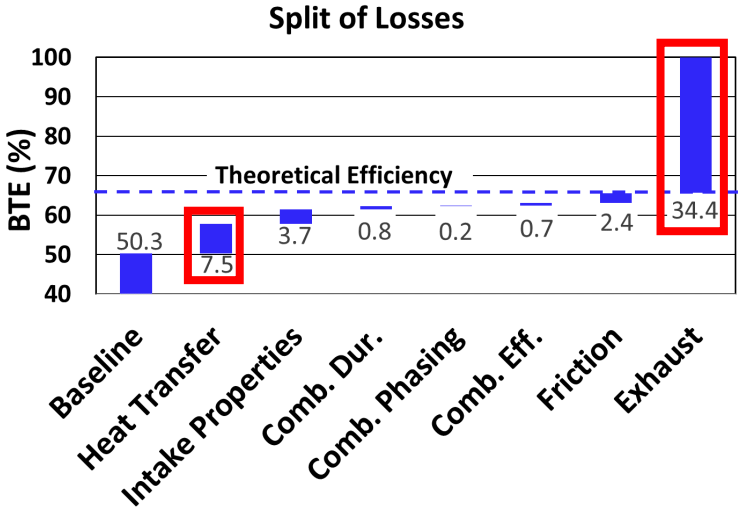
- Clean Sheet Base Engine
  - Without WHR
- New Technology applied
  - High Heat Release Rate Fuel System
  - Increased Compression Ratio
  - High Efficiency Turbocharger
  - Variable oil pump and PCN's
  - Low Friction Power Cylinder
  - Low Heat Transfer Exhaust
- 50% BTE optimized in power range from flat road cruise to fuel centroid

	Target	Demonstrated
Mech Efficiency	94.7%	95.2%
Closed Cycle	53.0%	52.6%
Open Cycle	100.0%	100.3%



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

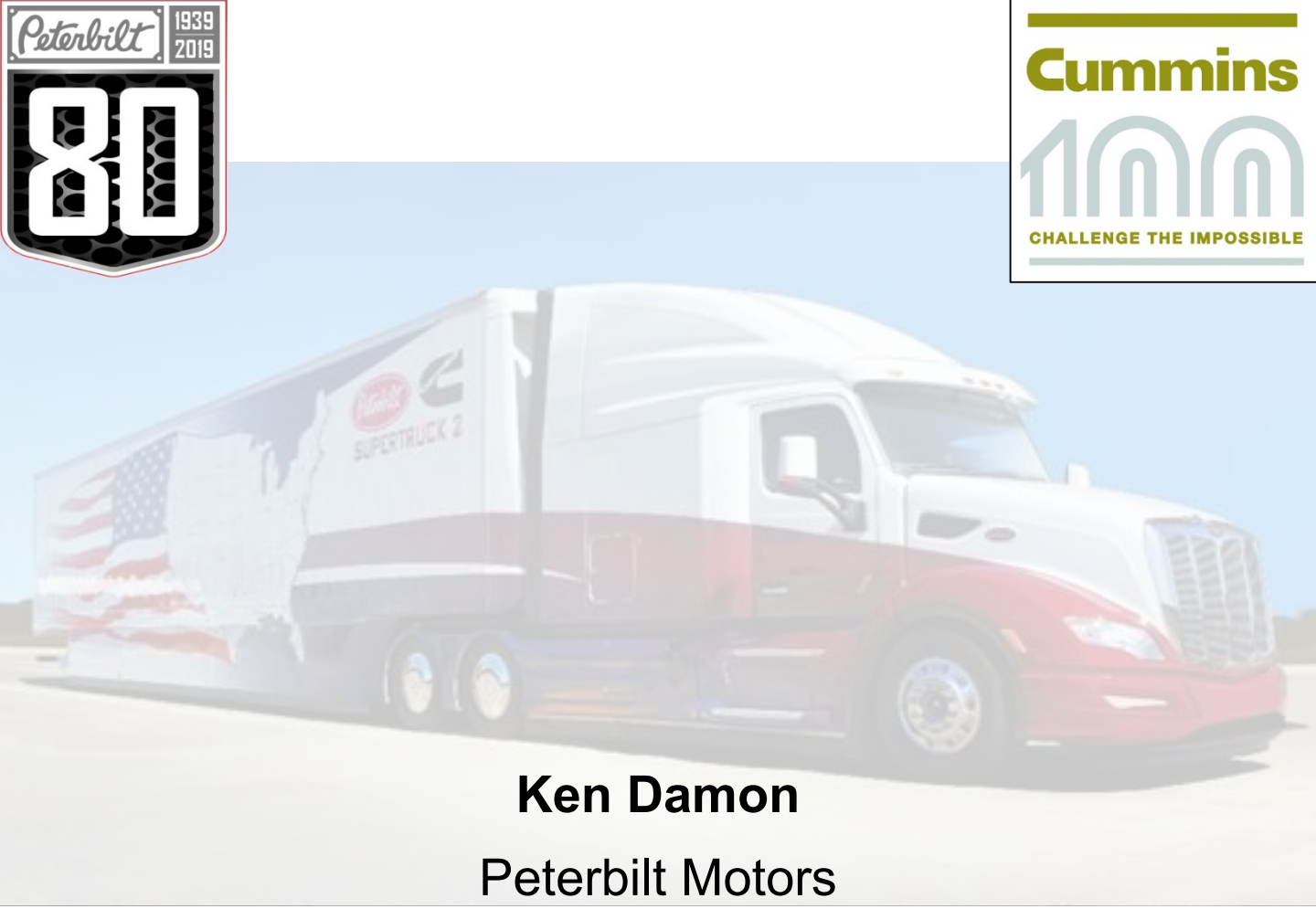


	Target
Mech Efficiency	96%
Closed Cycle	53%
Open Cycle	101%
WHR Contrib.	4%

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: MERITOR



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

System	Weight Delta (lbs)
Powertrain/Cooling	(285)
Chassis Systems	(1540)
Outer Body	(150)
Energy Storage	(615)
Trailer	(2095)
TOTAL	(4685)
GOAL	(3800)

Prior AMR Comments/Questions

"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

Duals vs. Wide Base

Technical Approach: Path to Target

Aerodynamics

Engine

Transmission/Axle

Downspeeding

Lightweighting

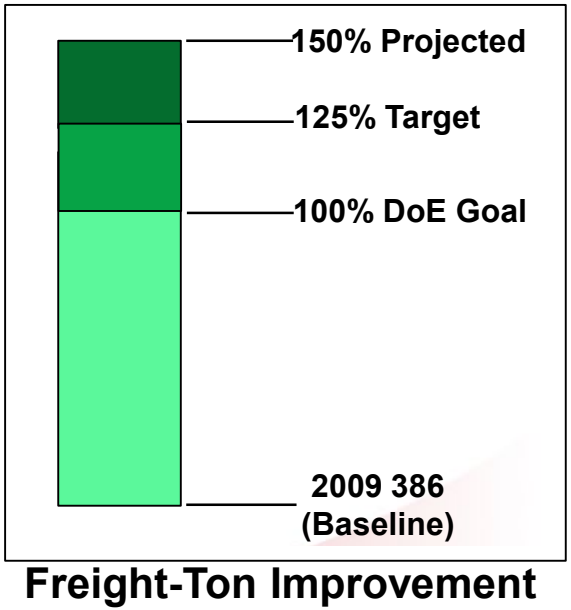
Route Management

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

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

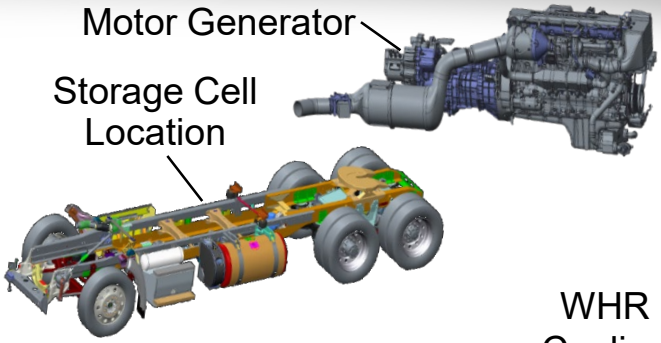
Technical Accomplishments

Model 579 Technology Mule (1.0)

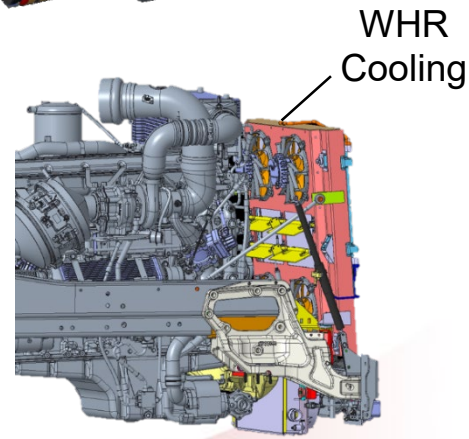
- Cameras/Displays
- Advanced Transmission
- High Efficiency Engine
- 6x4 Disconnect Tandems
- Elec. Steer Assist
- Gen 1 Low Crr Tires
- Chassis Height Control
- Lightweight Chassis

Technical Progress/Future Research

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



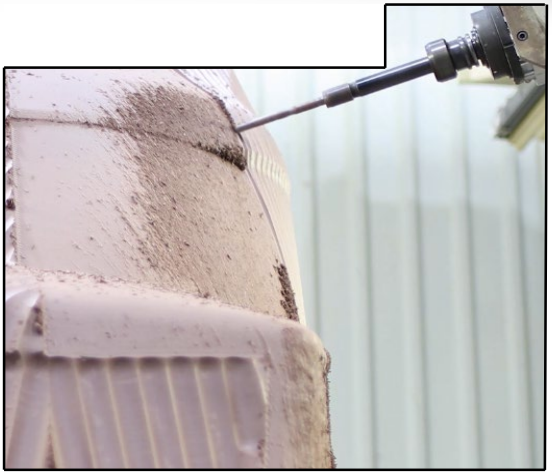
- Mule 2.1 (3Q19)
  - Waste Heat Recovery (WHR) System
  - 48v Cooling Fans
  - 48v Electric/Hydraulic Steer
  - 48v eHVAC



- 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)

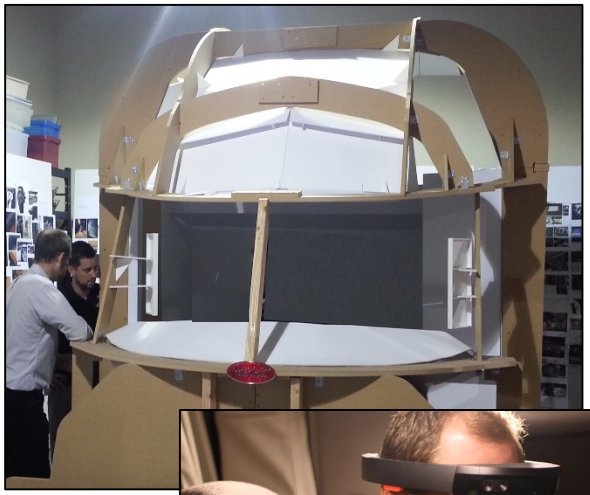


Technical Progress: Demonstrator

- 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…)



Technologies and Collaboration

Peterbilt

IMI NORGREN

Active Extenders

Stoneridge

IMI NORGREN

ght Control

MERITOR

Forward-L

Cameras/Displays

OADS

6x4 Disconnect Tandems

ZF

MMC Brake Drums

48v Power Steering

MAGNA

Aerodynamic Body

Metalsa

Quality as a way of life

BRIDGESTONE

Lightweight Chassis

Gen 2 Low Crr Tires

High Efficiency Engine/Transmission

ARCONIC

Cummins

Advanced Cycle Efficiency Manager

Bergstrom

24.5" Aluminum Wheels

Mild Hybrid Driveline

EATON

Powering Business Worldwide

MAHLE

Technologies and Collaboration

Peterbilt

Stoneridge

OADS

IMI NORGREN

MERITOR

Metalsa
Quality as a way of life

Active Extenders

Chassis Height Control

BRIDGESTONE

ZF

Forward-Looking Yaw Sensor

Walmart

6x4 Disconnect Tandems

Cameras/Displays

MMC Brake Drums

48v Power Steering

Aerodynamic Body

Lightweight Chassis

Gen 2 Low Crr Tires

High Efficiency
Engine/Transmission

24.5” Aluminum Wheels

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EATON
Powering Business Worldwide

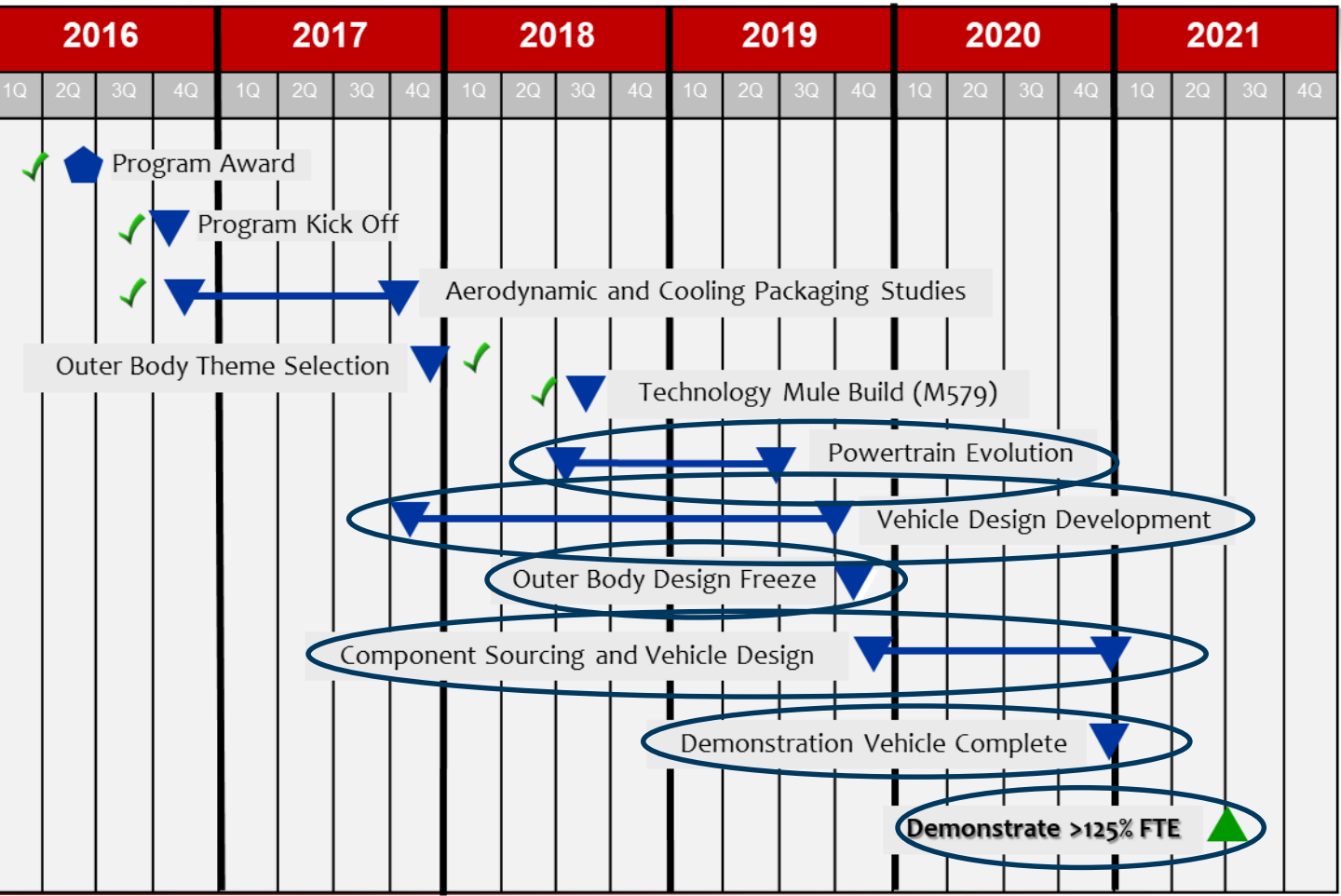
Bergstrom
Climate Control Systems

MAHLE

Great Dane

MAGNA

Future Work


2016
2017
2018
2019
2020
2021
1Q 2Q 3Q 4Q 1Q 2Q 3Q 4Q 1Q 2Q 3Q 4Q 1Q 2Q 3Q 4Q 1Q 2Q 3Q 4Q 1Q 2Q 3Q 4Q
Program Award
Program Kick Off
Aerodynamic and Cooling Packaging Studies
Outer Body Theme Selection
Technology Mule Build (M579)
Powertrain Evolution
Vehicle Design Development
Outer Body Design Freeze
Component Sourcing and Vehicle Design
Demonstration Vehicle Complete
Demonstrate >125% FTE

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

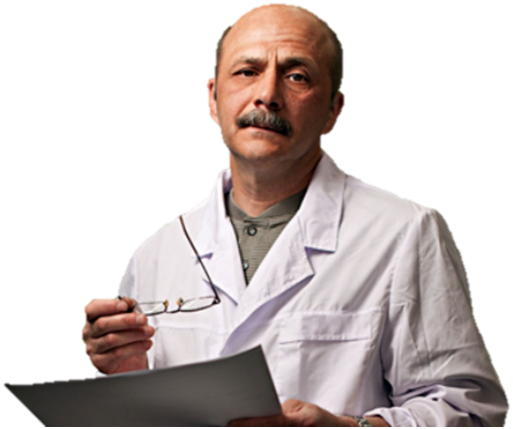
All proposed future work is subject to change based on funding levels

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