2017 Annual Merit Review

Cummins/Peterbilt SuperTruck II

Michael Ruth – Principle Investigator,
Cummins Inc.

Ken Damon – Peterbilt Motors Company

8 June 2017

Project ID:ACS102

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview

Timeline

Begin: 10/1/2016

End: 9/30/2021

~10% complete (4/15/2017)

Barriers

Engine Efficiency ≥ 55% BTE

Freight Efficiency ≥ 100% FTE

Cost effective solutions

Budget

Total Project: $40M

$20M DoE - $20M Cummins

Total Spent: $920K

$451K = Cummins

$451K = DoE

Partners

Cummins – Powertrain

Eaton - Transmission

Peterbilt - Vehicle

Bridgestone – Tires

Walmart – Customer counsel

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

- 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

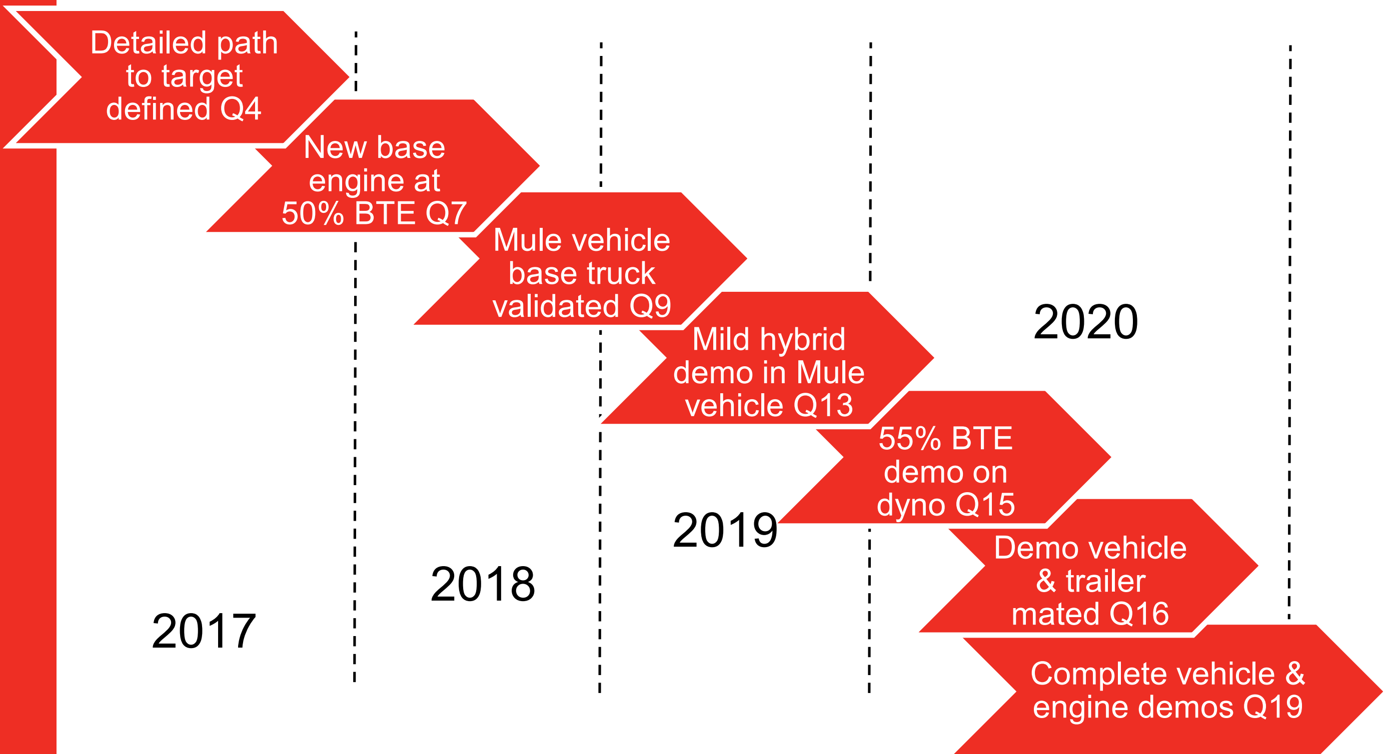
FY 2017	Description
Subcontracts completed	Subcontracts with all contributing partners completed
ACEM* Definition	I/O and supervisor structure defined
Customer route DNA completed	Customer route analysis via NREL tools, routes identified for program
Outer body shape definition	Design direction to meet aerodynamic goals

*ACEM – Advanced Cycle Efficiency Manager

Milestones by Quarter

FY 2018	Description
Tire samples built	Lab testing on A-samples completed
Weight budget confirmed	Chassis, cab/sleeper, trailer targets established
Base engine at 50% BTE	Mule vehicle powertrain supports 50% BTE
Cooling system	cooling system direction; indirect cooling for WHR performance vs. aero improvement

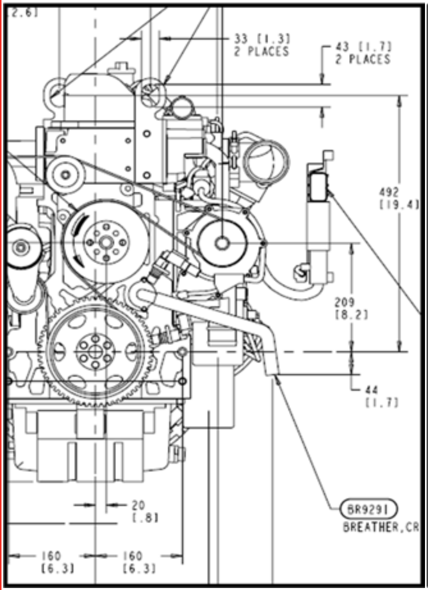
Program Milestones



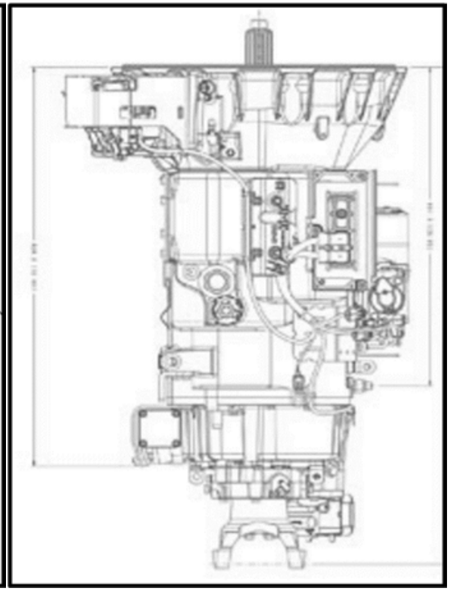
All proposed future work is subject to change based on funding levels

Cummins Powertrain

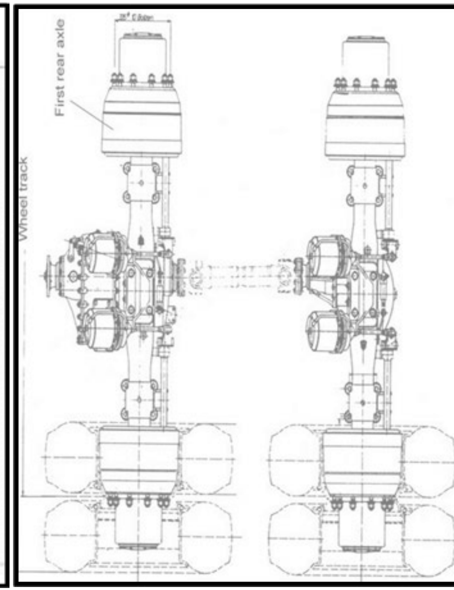
ENGINE



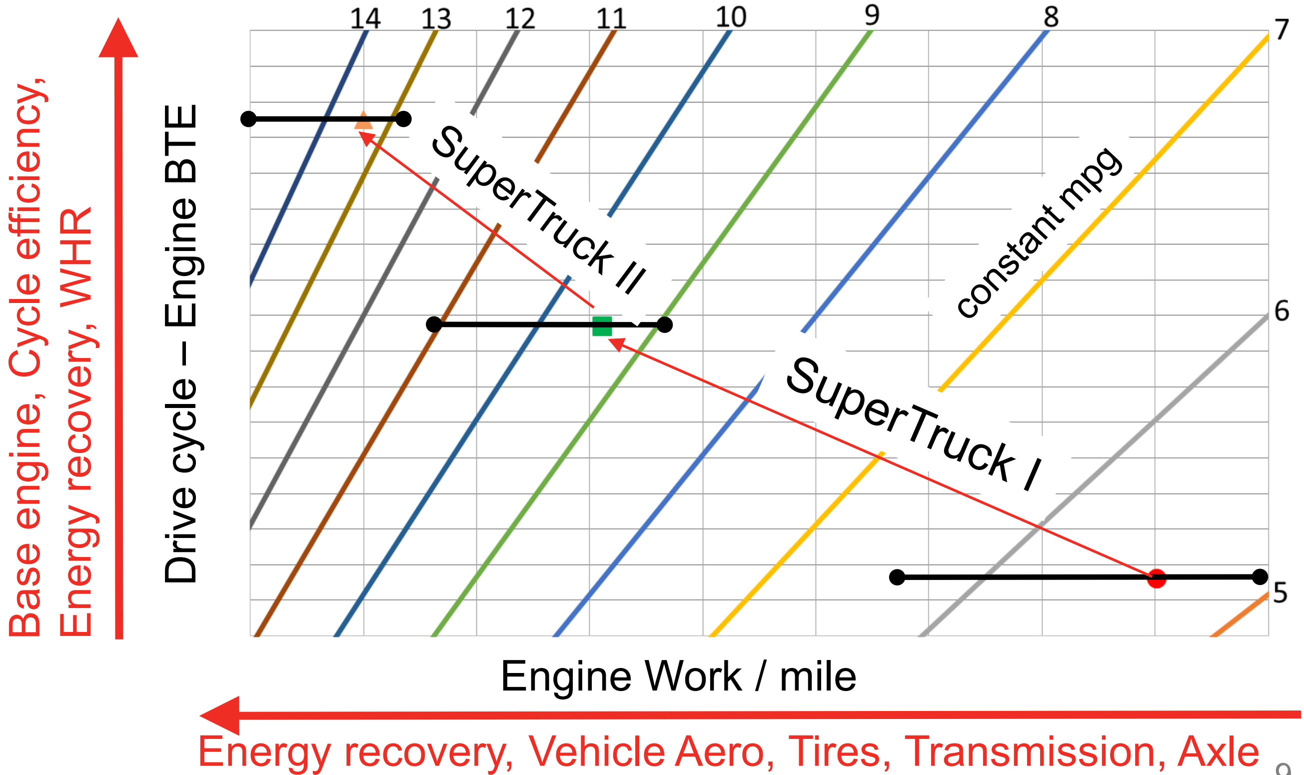
TRANSMISSION



DRIVE AXLE



Technical Approach – SuperTruck II Target –

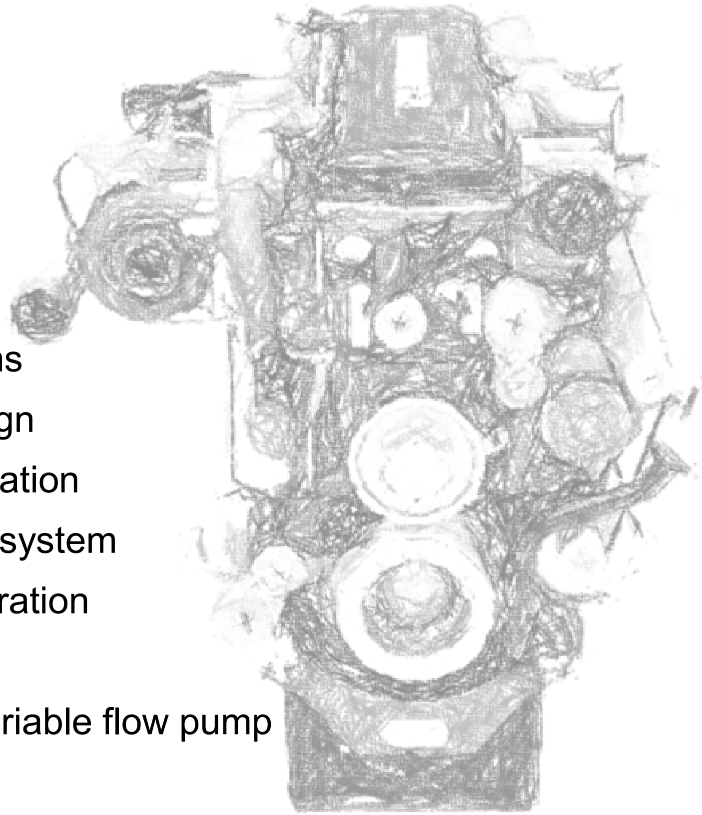


Technical Approach
– ST1 to 55% BTE –

Subsystem	55% BTE (Additional or Replace)	Expected Benefit
Combustion System	Higher CR, Insulated Surfaces, No/Low Piston Cooling, Higher Temp Coolant	+1.3% BTE
Fuel System	High Flow Injectors (3x faster injection)	+1.3% BTE
Air Handling System	Dual Loop EGR & Larger Turbocharger, Consider Twin Entry WG	+0.6% BTE
WHR System	HP EGR, LP EGR, Exhaust, Coolant, Lube, Charge Air Cooler	+0.2% BTE
Aftertreatment System	DOC+SCRF Close-Coupled + SCR	NOx Control
Mechanical System	Low Tension DLC Coated Rings, Plasma Coated Liners, No/Low Piston Cooling, Variable Flow Pumps, Reduce Valve train Parasitic loads	+0.6% BTE

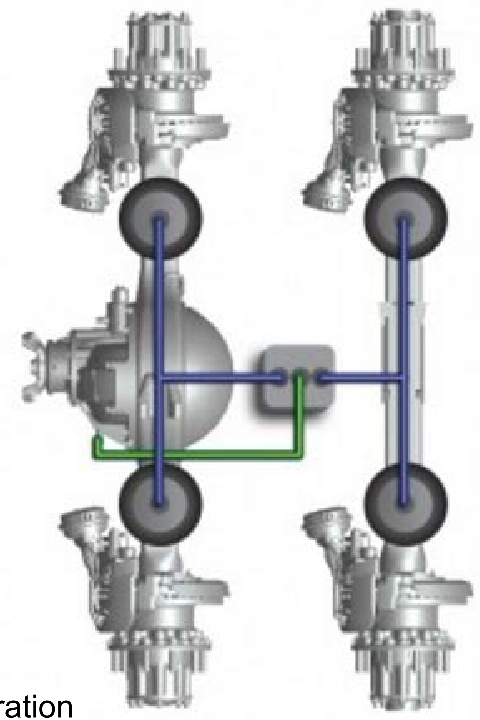
Technical Approach – Base Engine System –

- 13L class packaging space
- ~150 kg lighter than ST1 base engine
- High efficiency enabling technologies
  - High cylinder pressure capability
  - Low dP ports and manifolds
  - Low parasitic lube & cooling systems
  - State-of-the-art power cylinder design
- Enable high technology content integration
  - Powertrain mounted aftertreatment system
  - Waste Heat Recovery system integration
  - Clutched air compressor
  - Feedback and control circuits for variable flow pump systems



Technical Approach
– Axle and Transmission –

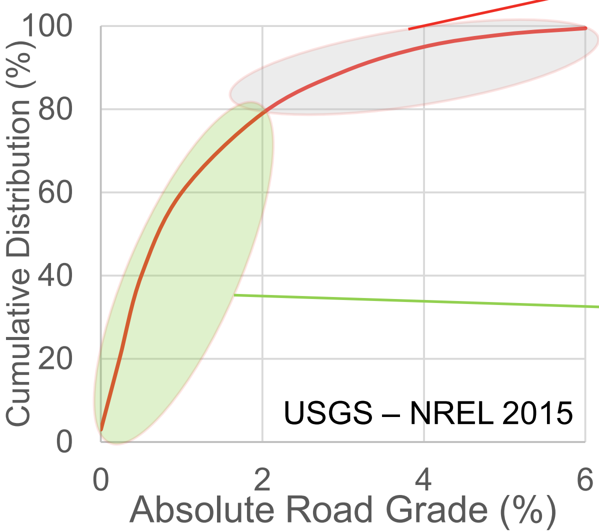
- Efficiency improvements
  - Lube oil viscosity, reduced churn
  - Gear finish
  - Bearing systems
- Weight reductions
  - Extensive use of aluminium



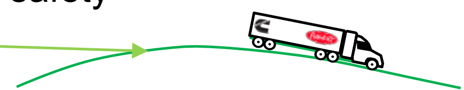
SmartTandem® is a registered trademark of Meritor Corporation

Technical Approach – Energy Recovery Strategy –

Nearly 80% of highway miles traveled on US roads <2% grade*



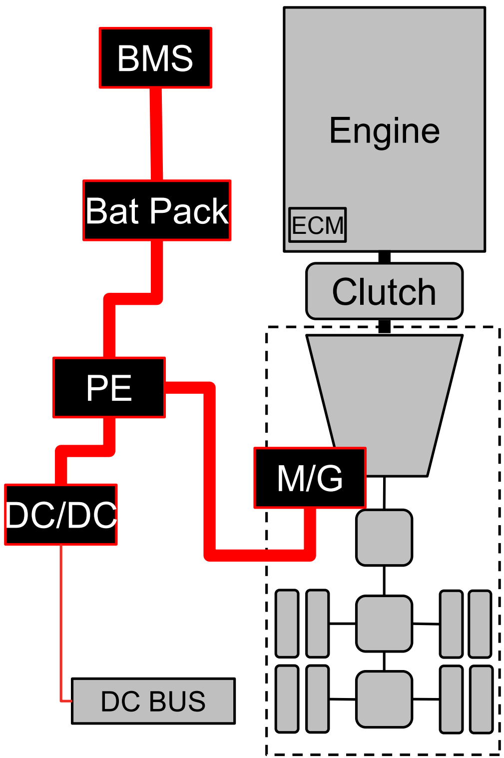
- High voltage, high battery capacity
  - Limited opportunity outside of braking
  - Cost penalty
  - Weight penalty – batteries and safety



- Low voltage, moderate battery capacity
  - Capable on a majority of routes
  - Lower cost
  - No special safety
  - Lower weight

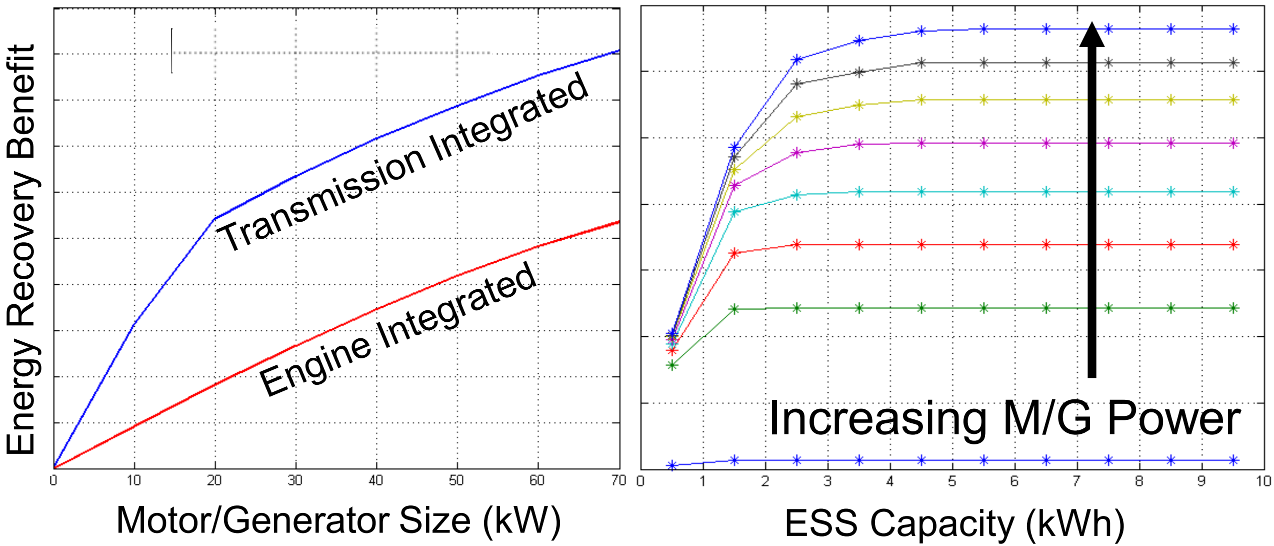
*GHG route cycle is 90% < 2% grade

Technical Approach
– Energy Recovery Strategy –



- **Mild Hybrid Technology**
  - Decouple engine (EOC) on gentle down grades
  - Use with engine brake on steep down grades
  - Use with service brake in slow / city traffic
  - Shave power on gentle inclines or flat roads
  - Supplement power on accelerations, in traffic and on inclines

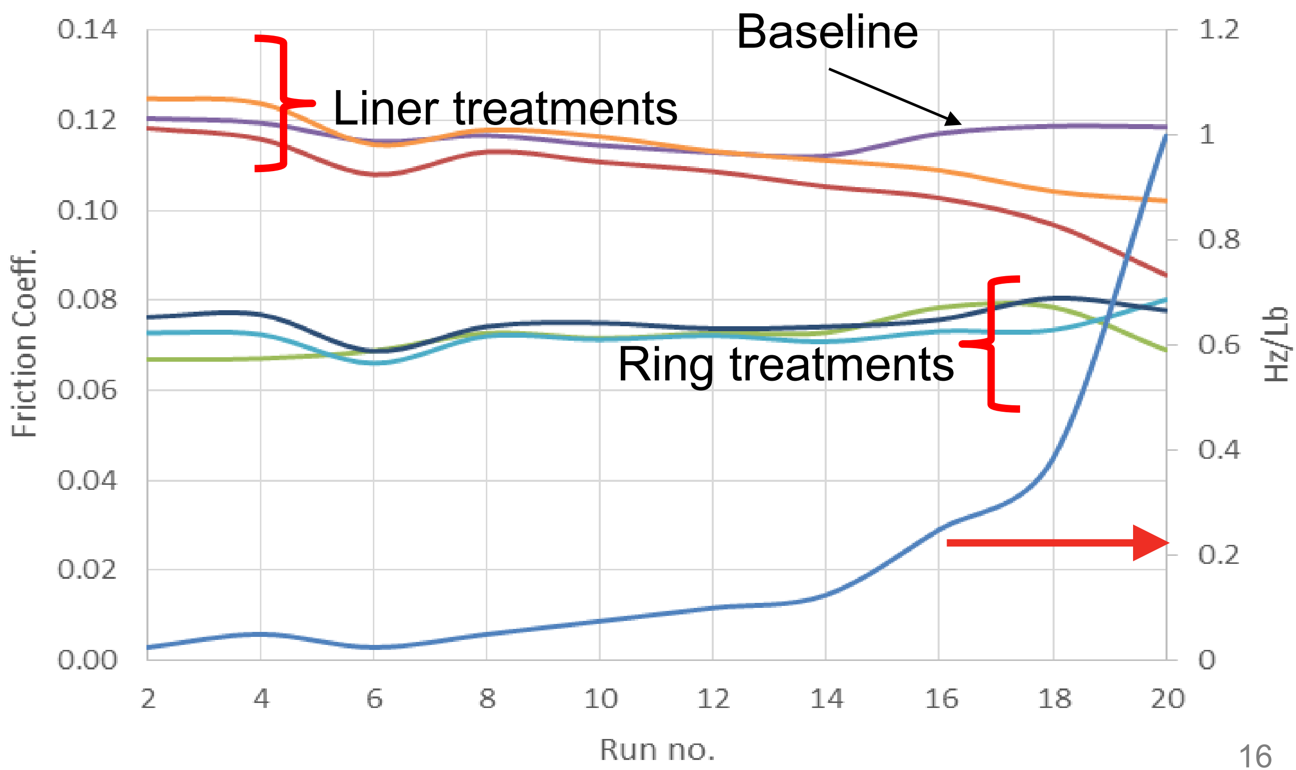
Accomplishments – Energy Recovery Analysis –



- A generic Energy Recovery system analyzed using constant Motor-Generator and Battery Efficiencies
- Motor size > 30 kW and Battery Size above 3-4 kWhr gives diminishing returns for demonstration route

Accomplishments

— Liner/Ring Friction Testing Completed —



Accomplishments

— New Engine Platform Design Completed —

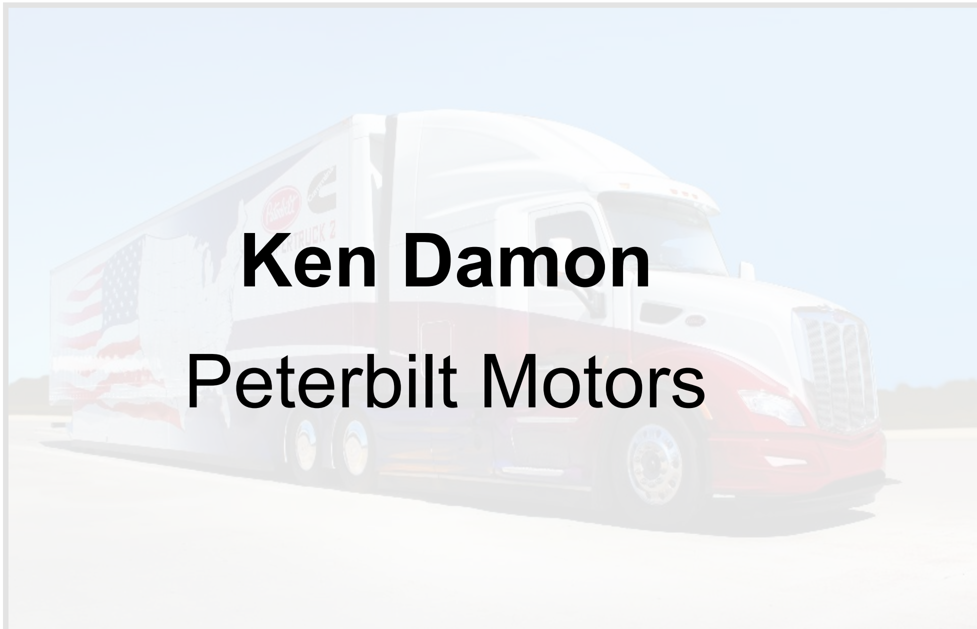
Engine design and analysis completed, procurement work is beginning;

- Weight targets confirmed
- Base engine package size achieved
- Powertrain layout (engine + trans, all A/T, WHR and Energy recovery system are mounted on module)

Accomplishments

– Route/Vehicle Model Completed –

- Routes Mapping
  - Walmart routes used for financial analysis
  - NREL logging and analysis – 100K+ miles, 3 locations, 56 total vehicles
- Purdue University + Autonomie
  - Base model nearing completion (April ‘17)
  - Route data work to be used for validation
  - Shared with partners for technology assessment and development



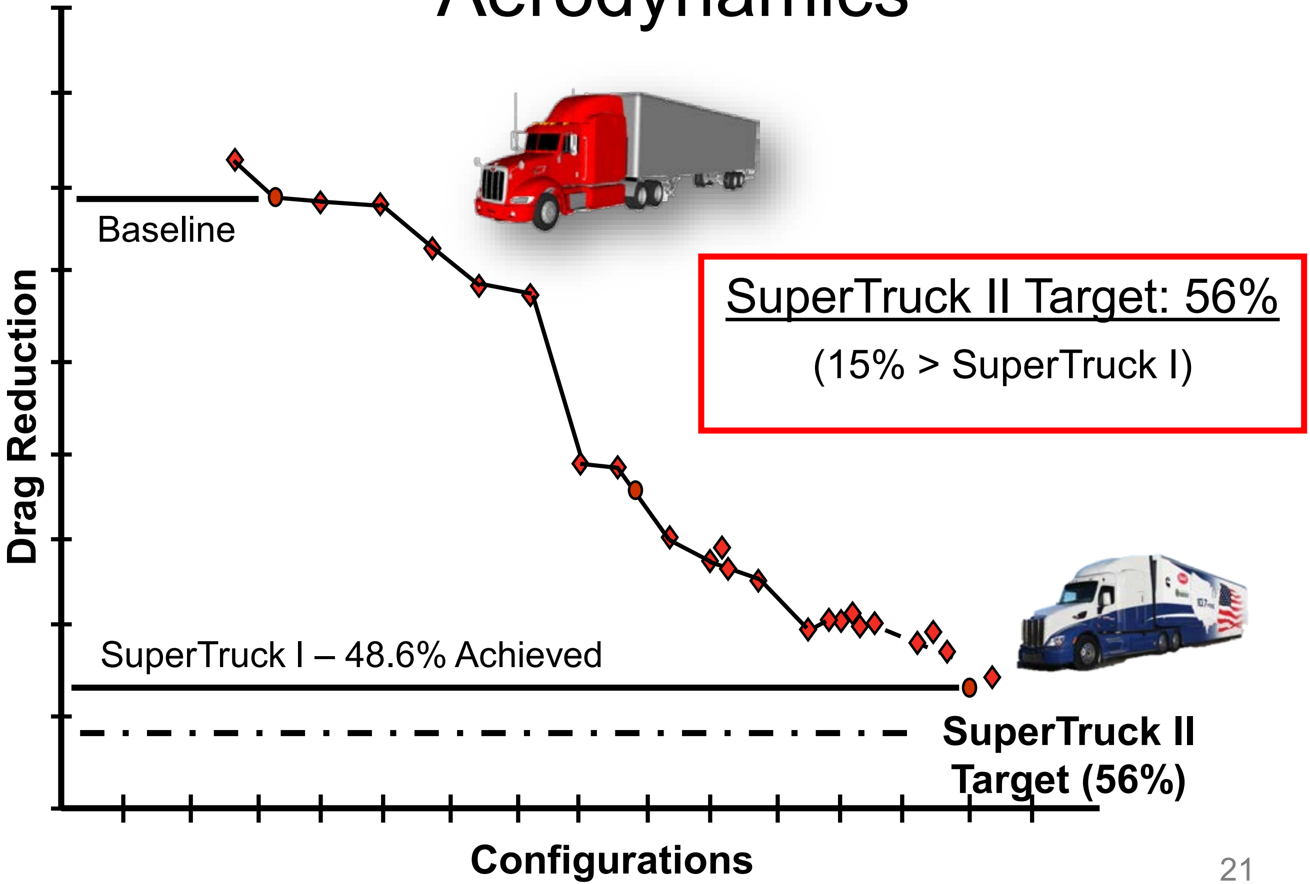
Ken Damon

Peterbilt Motors

Technical Approach – Enabling Technologies –

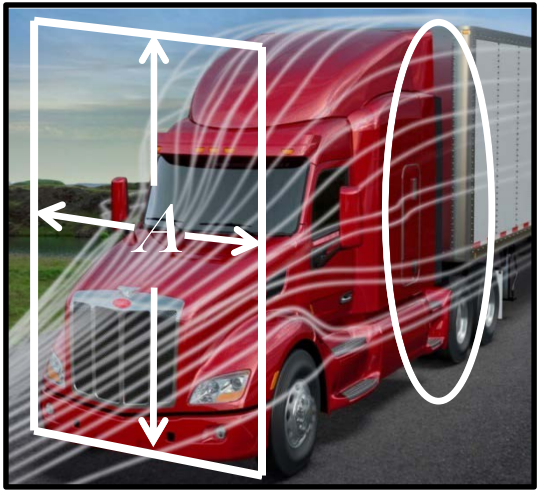
- Efficient Powertrain
- Aerodynamics
- Parasitic Reduction
- Lightweighting
- Driver Assist

Technical Approach – Aerodynamics –



Technical Approach
– Aerodynamics –

- Advanced Vehicle Shape
- Trailer Gap Treatment
- Yaw Mitigation Techniques
- Advanced Speed Control
- Reduced Vehicle X-Section



Technical Progress – Aerodynamics –

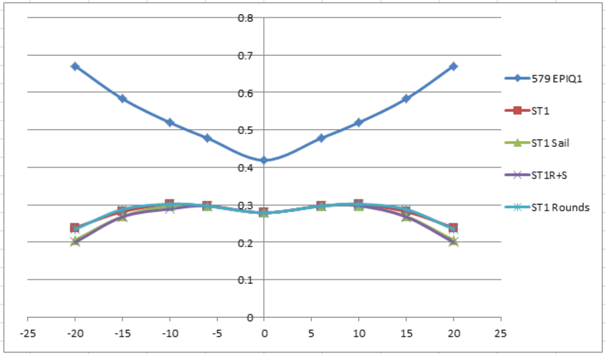
- Goal: 15% Drag Reduction vs. ST1
  - 0º and 6º Yaw Boundaries (GHG)
- Two-Phase Analysis Path
  - Evolutionary - Build Upon ST1
  - Clean Sheet - Ground Up
  - Peak Achievement: ~27%
  - ~10% Historic Loss in Execution
- Drag Summary: Target Achievable

ST1 Evolutionary Path

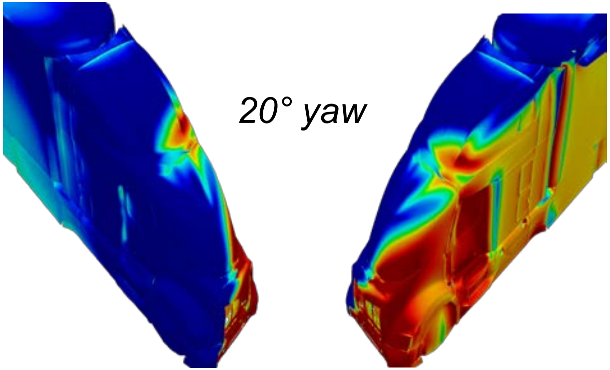
Clean Sheet Path

Technical Progress – Aerodynamics –

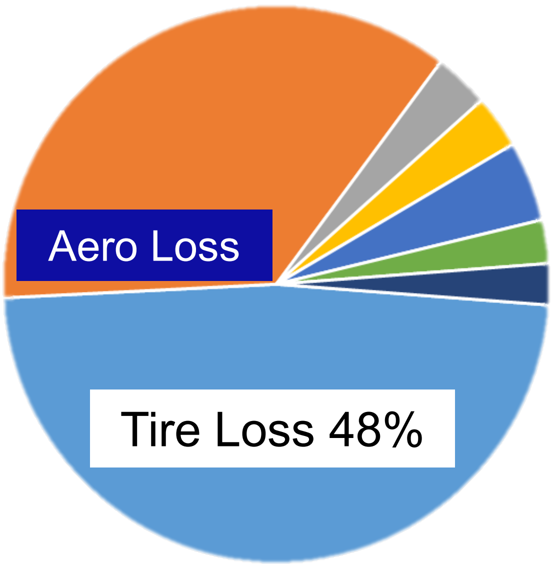
- High Yaw Design
  - Beyond GHG Limits
  - Experienced in Real World



- Yaw Mitigation Strategies
  - Flatten Drag Polar
  - Reverse Upward Trend



Technical Approach
– Parasitic Loss –



- Significant Technical Opportunity
- Improve Rolling Resistance (Crr)
- Review Contact Patch
- Reduce Tire Diameter

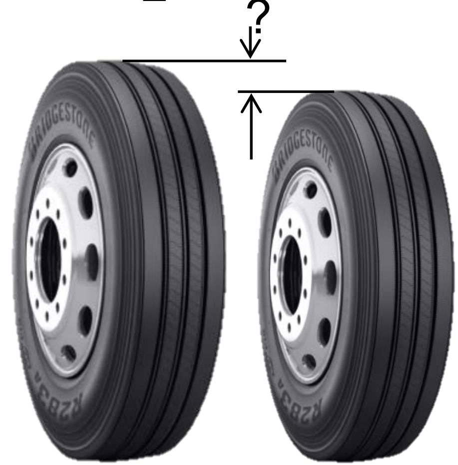
Technical Approach
– Parasitic Loss –

- Partnership with Bridgestone

- Three Tire Positions

- 30% Rolling Resistance Reduction
  (~6% Fuel Economy)

- Dual Path Development
  – Low Crr in Conventional Diameter (295/75R22.5)
  – Low Crr in Reduced Diameter

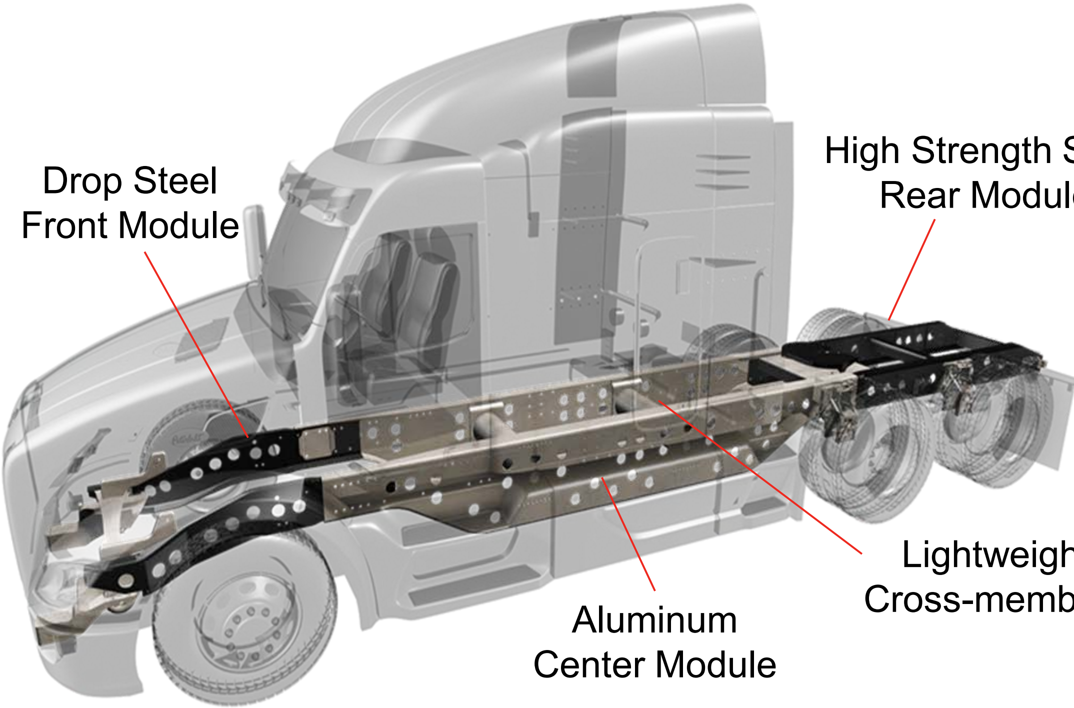


Dual Path Development

Technical Progress – Parasitic Loss –

- Identified Technical Approach for Mule and Demo Samples
- Developed Tire Specifications for Mule Truck Tires
- Created Finite Element Analysis Models for Tread Compound/Tire Construction
- Initiated FEA of 5 New Low Profile Sizes
- Initiated Lab Studies on New Mix Technologies
- Created Prototype Mold Tooling to Evaluate New Sipe Technology

Technical Progress
– Chassis Concepts –



500lb Weight Reduction Target

Technical Approach – Trailer Development –

- SuperTruck I
  - 48% Vehicle Drag Reduction
  - 66% of Vehicle Drag Reduction Due to Trailer Technology
- SuperTruck II
  - Integrated Trailer Solutions
  - Aerodynamics
  - Dynamic Enablers
  - 500lb Weight Reduction
  - Designs Vetted w/ Customer Counsel

Technical Approach

– Route and Technology Selection –

- Walmart Route Analysis: NREL
- Current/Future Shipping Practices
  - Long Haul
  - Slip Seat
  - Regional
- Legislation Changes
  - Cameras
  - Length Laws
  - Combination Vehicles
- Technology to Match Mission

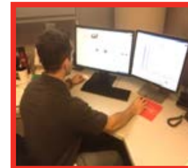
Current Route Analysis

NREL

Future Route Vision

Commercial Focus

- Develop
  - Focused Team Vets Technology
  - Integrate into Demonstration Vehicle
  - Feed Product Development Pipeline
- Harvest
  - Deploy Features/Options
  - Robust/Competitive Product Profile
- Deliver
  - Regulatory Compliant Products
  - High Value for the Market



Summary

- Cummins and Peterbilt Technologies shall Deliver
  - 55% Brake Thermal Efficiency
  - 125% Freight Efficiency
    - Weight Reduction
    - Aerodynamic Improvements
    - Tire Rolling Resistance Reduction
    - Engine and Cycle Efficiency Improvements
- Maximize the Production Potential through
  - Smart Design
  - Financial Analysis
  - Customer Input

Thank You!