PACCAR SuperTruck II

2023 Annual Merit Review

Development and Demonstration of Advanced Engine and Vehicle Technologies for Class 8 Heavy-Duty Vehicle (SuperTruck II)

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PACCAR Inc.

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Project ID: ACE124

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

PACCAR SuperTruck II

Overview

Timeline

- **Start Date:** October 2017
- **End Date:** December 2023
- **Percent Complete:** 85%

Budget

Total Project Funding

DOE: $20M

Partnership: $20M

FY 2022 Funding: $40M

Barriers

Identifying Cost Effective, Production Representative Process For Cab Structure

Cost, Robustness And Packaging Needs Of Engine Technologies To Achieve 55% BTE

Ability To Demonstrate Benefits In More Than One Application/Use Case

Partners

KENWORTH, EATON, AVL, University of Washington, DAF, PACCAR Technical Center, NREL National Renewable Energy Laboratory, The Ohio State University

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Objectives and Relevance

- **Overall Objectives**
  - > 120% Freight Efficiency Improvement Relative To a 2009 Baseline
  - ≥ 55% Engine Brake Thermal Efficiency
  - 3 Year Payback Period on Developed Technologies
- **Objectives This Period**
  - 55% BTE Engine and WHR Demonstration
  - Complete Powertrain Proof-of-Concept
  - Vehicle Demonstrator Build
  - ROI Calculations
- **Impact**
  - Evaluation of Higher Risk Technologies With Potential For Energy Efficiency
  - Potential Modernization of Key Technologies in Freight Transport Industry
  - Evaluation of Impact of Technologies in More Than One Real-World Drive Cycle

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Program Outline

Budget Period 1

Analysis & Baseline Testing

- Simulation To Evaluate Engine, Powertrain And Vehicle Efficiency Building Blocks
- Baseline Testing

Budget Period 2

Design & Prototype Build

- Engine Design
- Powertrain And Controls Architecture Selection
- Prototype Builds
- Cab And Chassis Development

Budget Period 3

Component Test And Validation

- Vehicle Controls Development
- Proto Vehicles Testing
- New Engine Technologies Testing
- Hybrid Powertrain Testing
- WHR Integration And Initial Testing

Budget Period 4

Powertrain Testing & Engine Build

- Powertrain And Vehicle Integration
- Engine Efficiency Demo
- Initial Testing Of Drivability & Fuel Economy
- Engine & WHR 55% BTE Demo

Budget Period 5

SuperTruck Build & Freight Efficiency Demo

- SuperTruck Vehicle Build
- SuperTruck Freight Efficiency Demo >120%
- ROI on New Technologies

Remaining Milestones

Milestone	Type	Description
SuperTruck II Vehicle Build is Complete	Technical	SuperTruck II Vehicle is Built
SuperTruck II Vehicle Field Test Complete	Technical	Powertrain for SuperTruck II Demonstrates viability of greater than 100% Improvement in Freight Efficiency in Powertrain Test Cell
Simple Payback Demonstrated	Technical	SuperTruck II Vehicle is Field Tested

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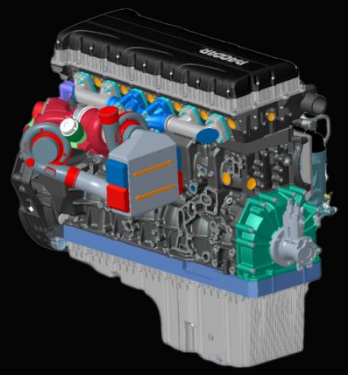
Key Technologies

Engine — Next Gen. PACCAR MX

- Long Stroke Concept
- Engine Efficiency Over WHR
- 48V Aux. / FEAD Removal
- Ultra Low NOx Compliant

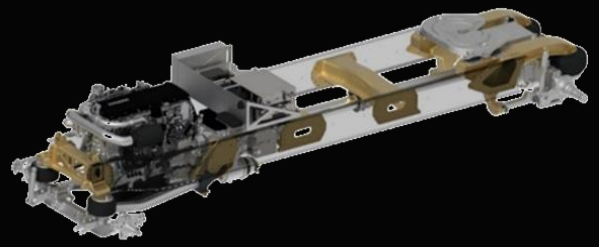


Powertrain — 48V Mild-Hybrid

- 30kW P2.5 e-Motor / Generator
- Supports Vehicle Aux. Electrification
- Dev. of 48V Components
- Next Gen. Li-Ion Batteries

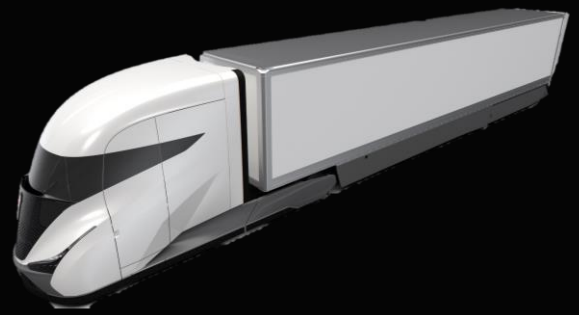
Chassis — Light-Weight & Modular

- Supports All New Powertrains
- 30% Weight Savings Chassis and Suspension
- Ease of Manufacturing
- e-Steering



Tractor — Aerodynamic Cabin

- Energy Efficient
- e-HVAC
- Predictive e-Hoteling
- System Level Energy Management



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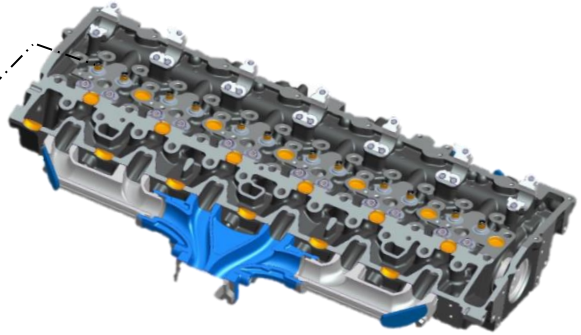
Engine Concept

Charge Air Cooler High and Low Pressure

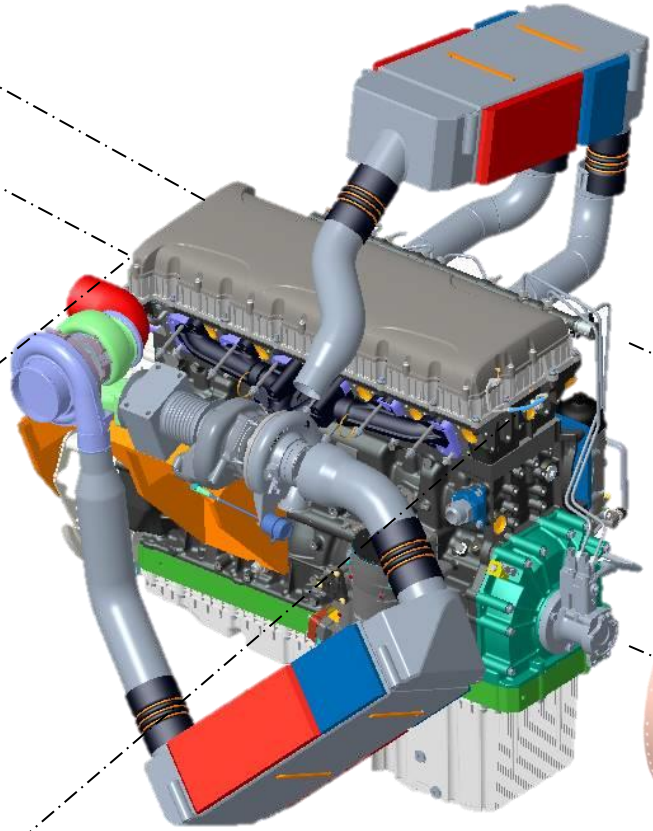
48V EGR Pump

Miller Cam-timing

Redesigned Cylinder Head
- Exhaust Pulse Turbo Charging

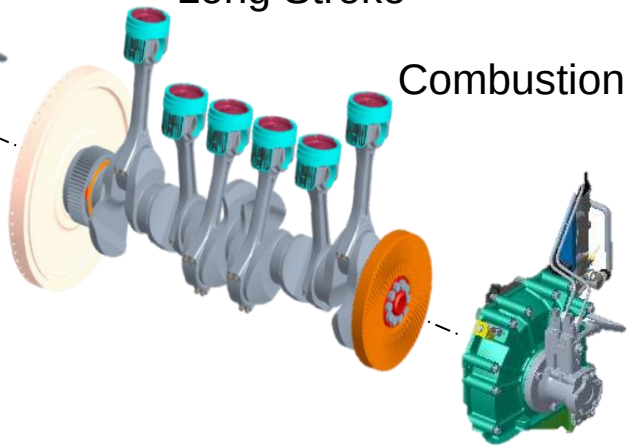


Two Stage Turbo Charging



Long Stroke

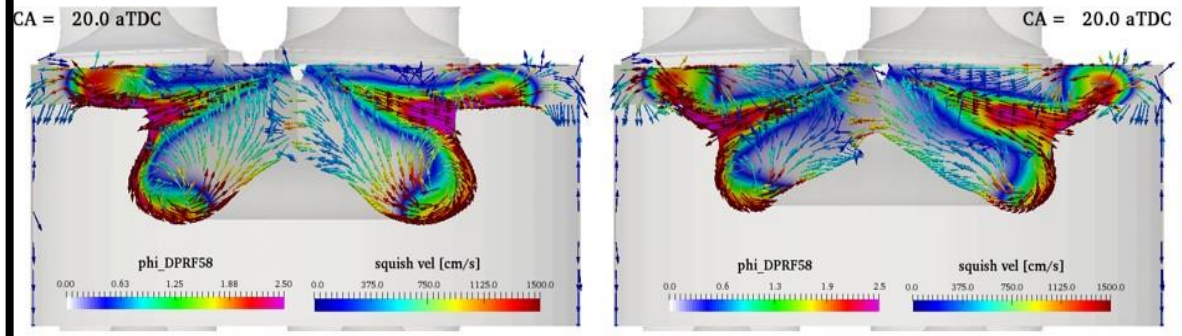
Combustion System



Cylinder Pulse Exhaust Manifold

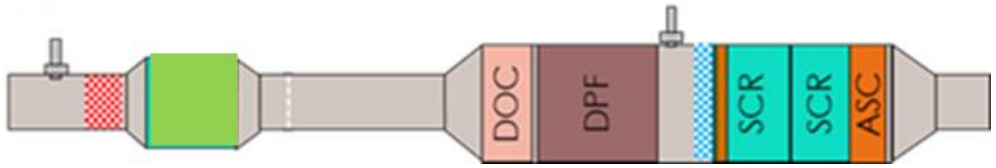
Crank Driven Fuel Pump

Ultra Low NOx



Gasoline Compression Ignition

- High BTE and ULN
- Experiments Completed
- Diesel is Prime Path



Close-Coupled EAS

- 48V e-Heater
- Carb ULN 2027 (FTP 0.02 g/bhp-hr)
- Included in Vehicle Demonstrator

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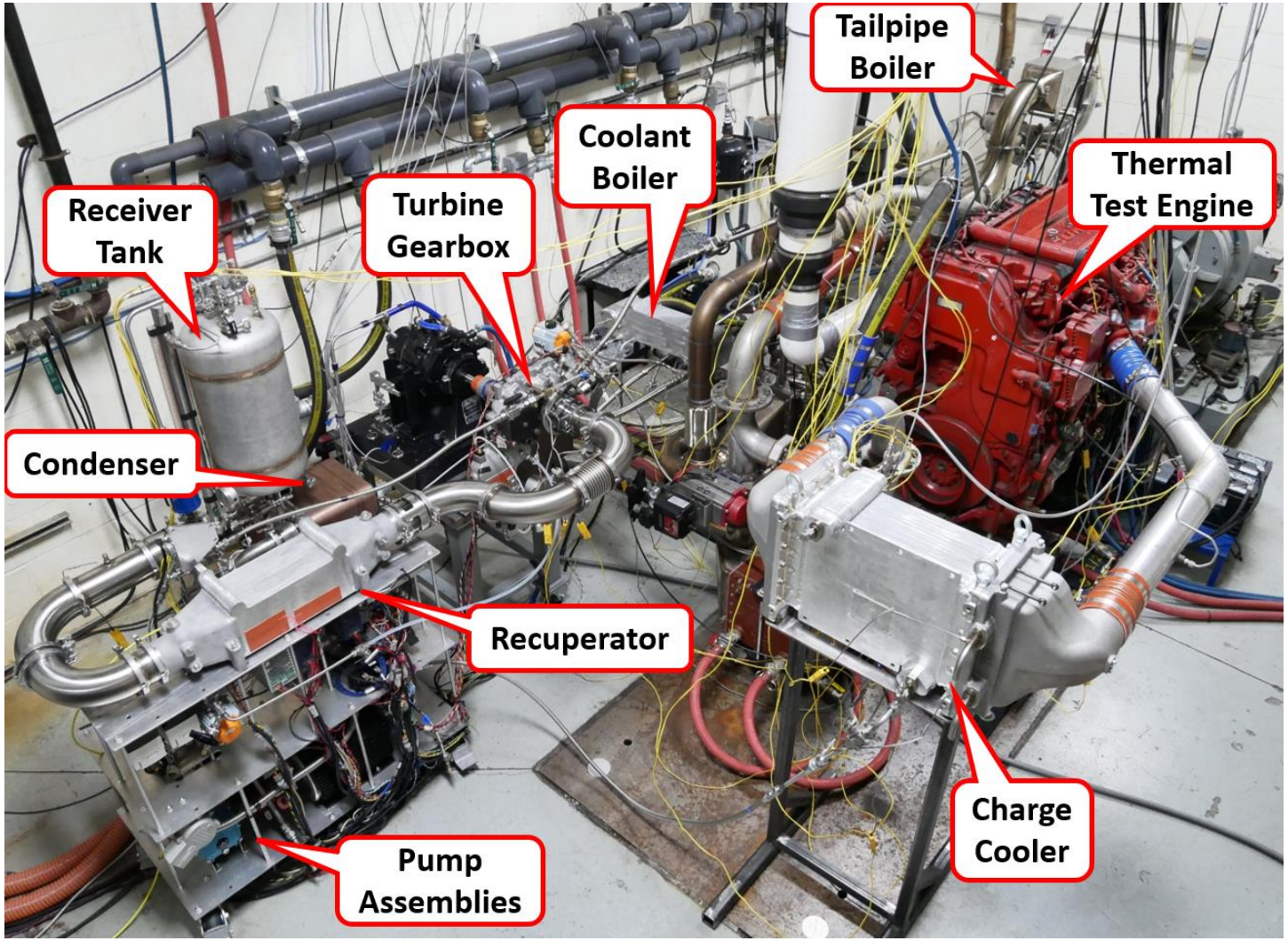
Waste Heat Recovery



- **Cummins WHR System, Tailored to PACCAR Engine**
- **Multiple Waste Heat Streams**
  - **Exhaust**
  - **Coolant**
  - **Charge Air Coolers**

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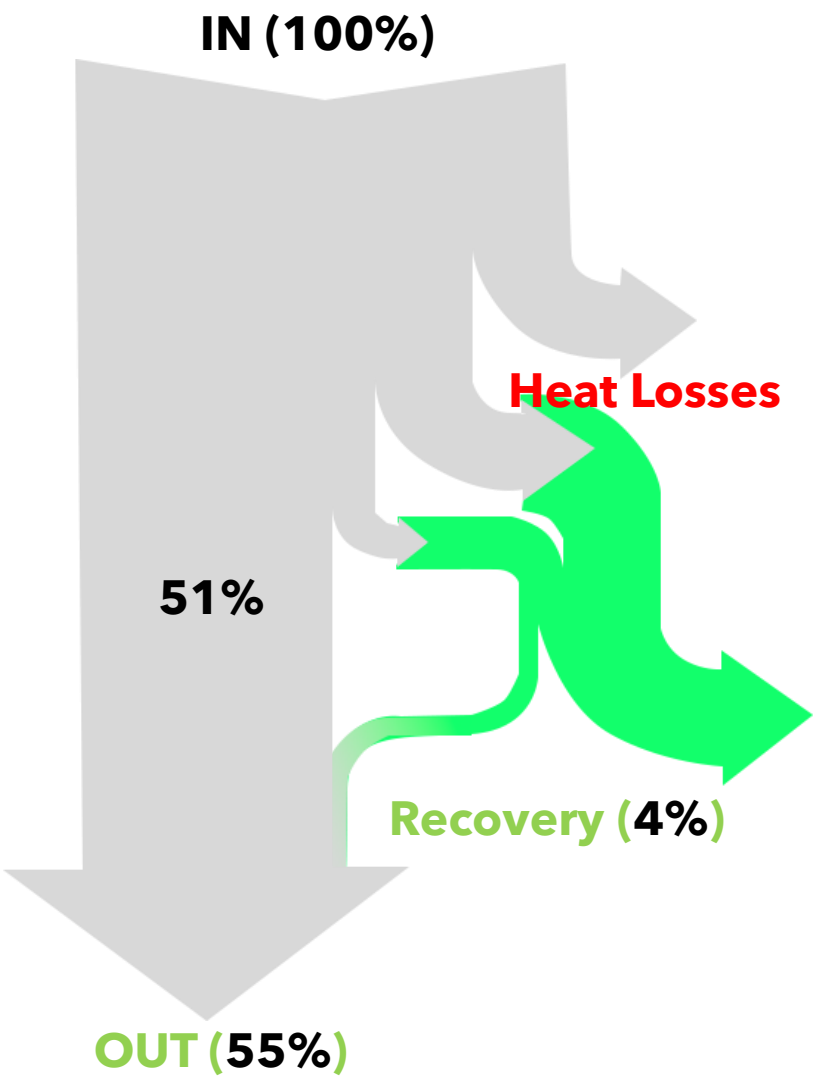
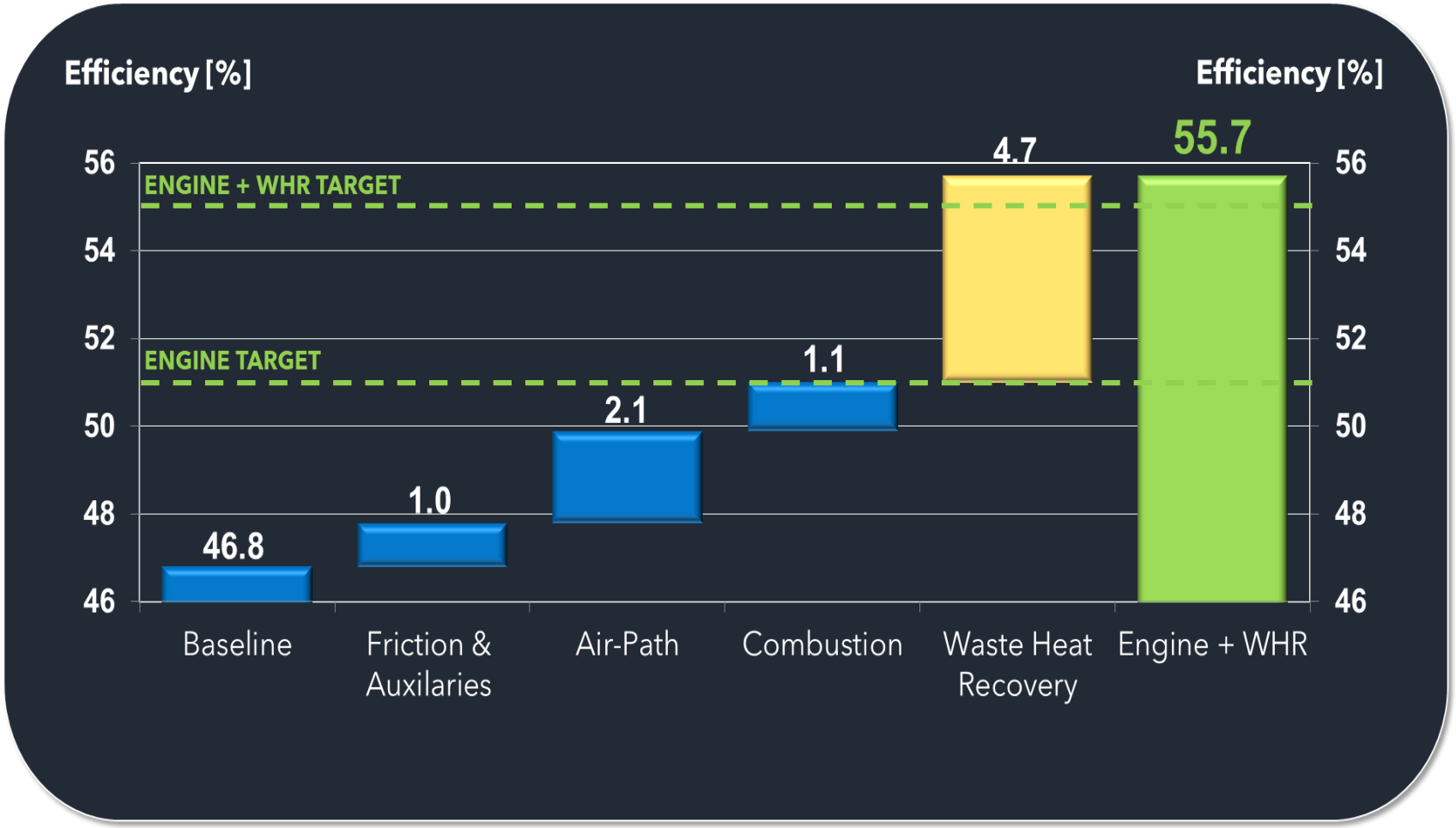
55% BTE Demonstrator Results

Design Targets:



Testbed Measurements:



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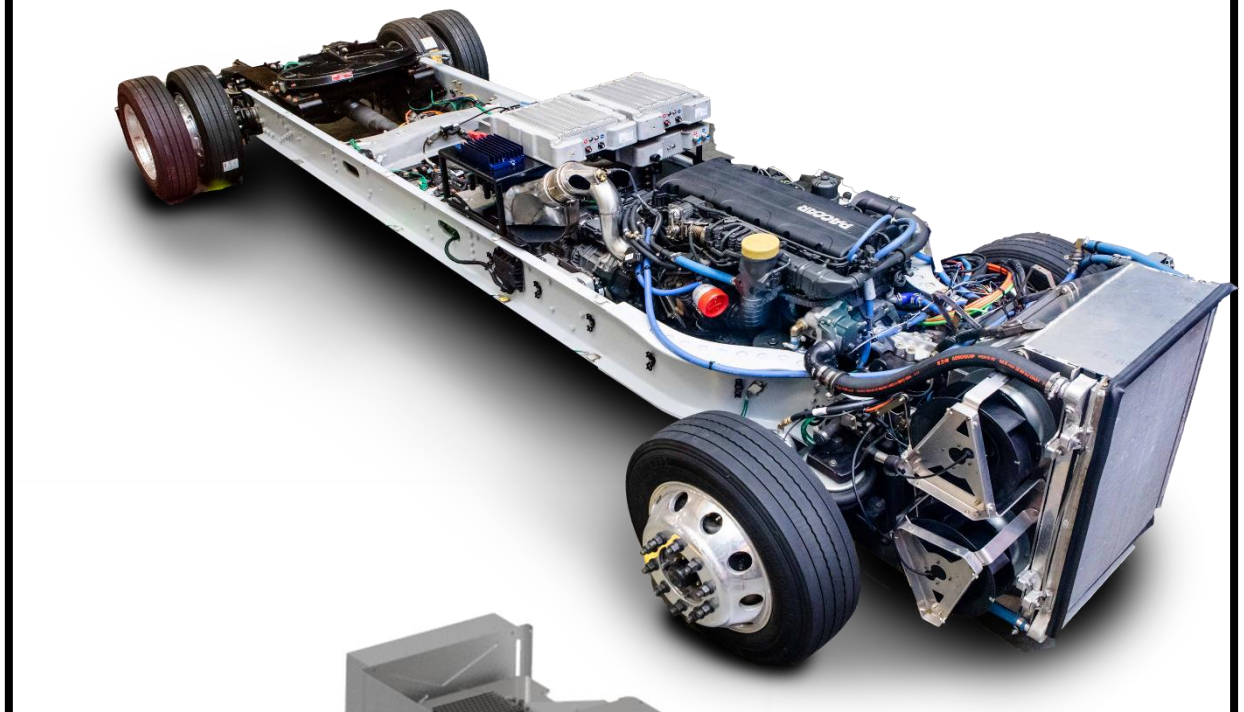
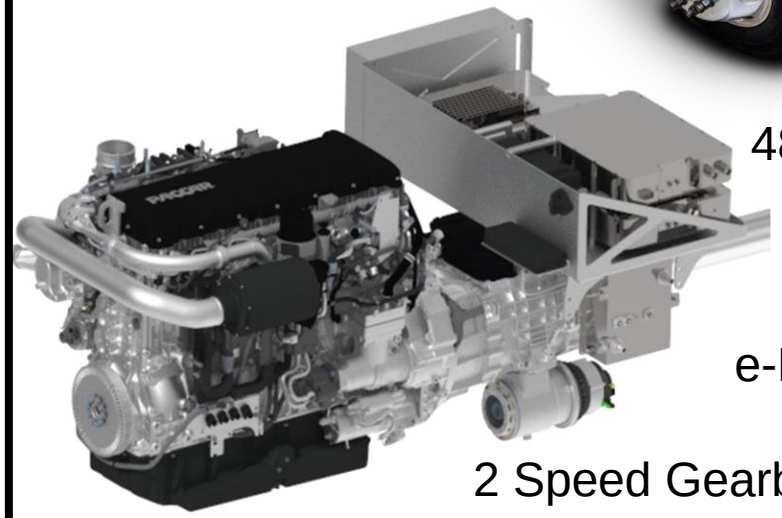
Powertrain

Powertrain Efficiency
40% Improvement

Base Powertrain	21%
Mild Hybrid / Electrification	13%
Low Rolling Resistance Tires	6%



48V Battery-Pack



e-Motor

2 Speed Gearbox

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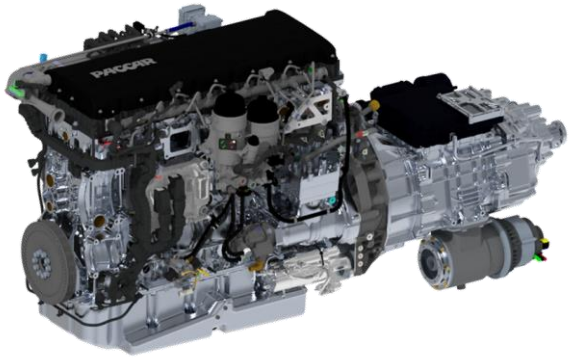
Vehicle Freight Efficiency

Powertrain Efficiency
40% Improvement



- Engine / Transmission / Axles
- Mild Hybrid / Electrification
- Low Rolling Resistance Tires

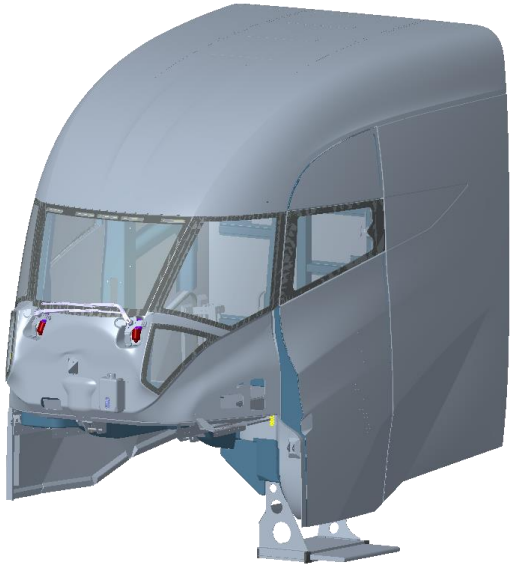
Weight Reduction
28% Reduction

- Systems Engineering
- Modular Integration
- Materials Application

Aerodynamics
63% Reduction

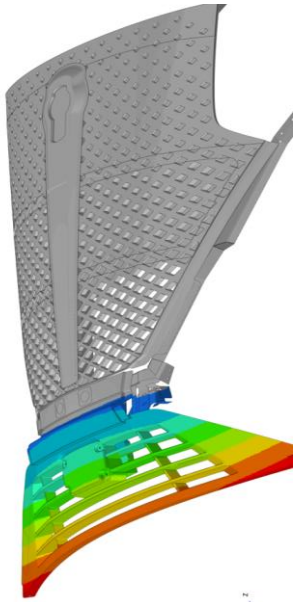
- Ideal Shape
- Enclosed Wheels
- Trailer Skirt & Pontoon

Cab Structure (BIW), Front End



BIW Design is complete and in process of being built by TPI Composites.

Roof Sub-Assembly



FEA Complete And Passed Stress And Modal Requirements

Sliding Fender Components Near Completion

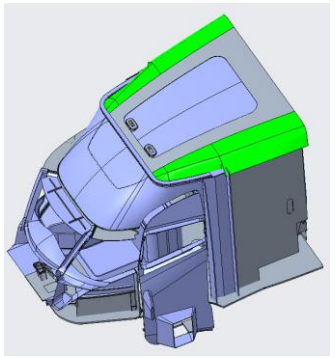
Floor Sub-Assembly

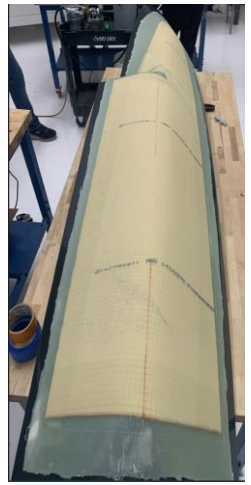
Front Wall

Headlights Are Completed And Pending Shipment

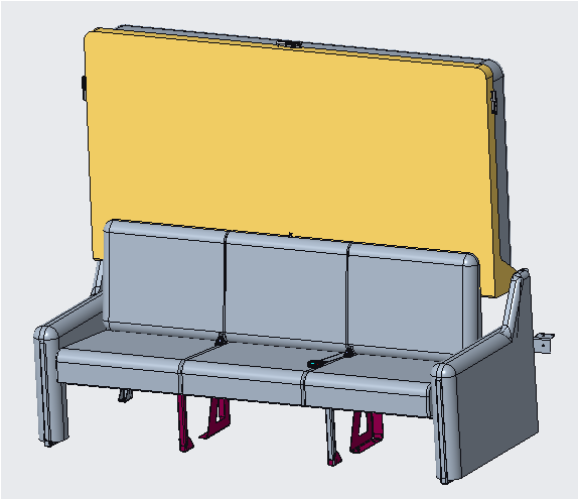
Interior Cabin and HVAC

Driver seat structure and belt system integration completed. Seat styling & Trim covers development on schedule



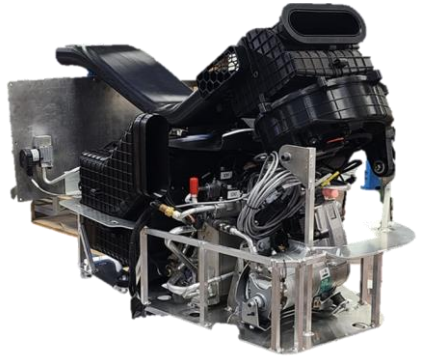


Interior panels fabrications in process. Tooled corner ceiling panels shown



Sofa and Bunk design & FEA completed.

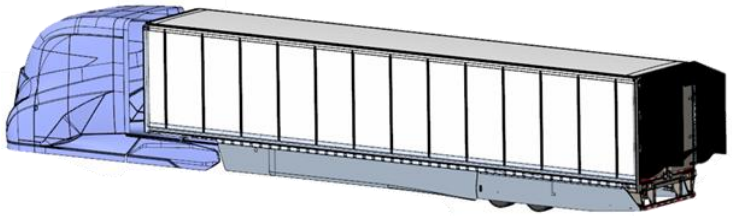
Interior Cabin Rendering

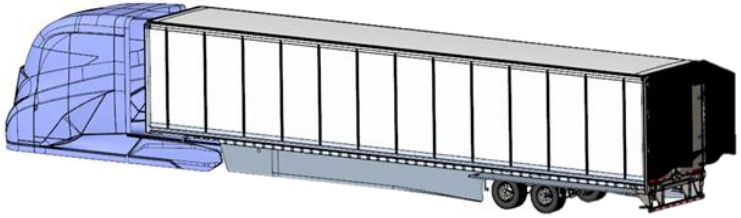


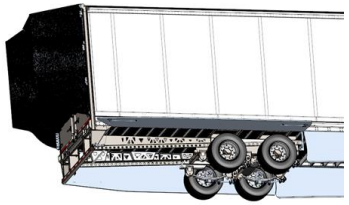
HVAC unit completed, tested, and on hand

Trailer Development

Trailer design completed and is being assembled at Stoughton



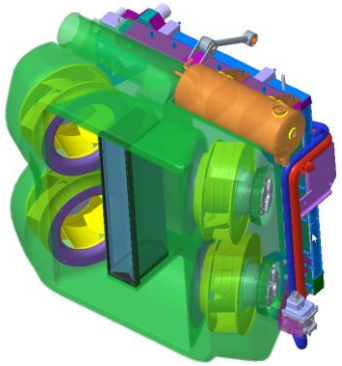




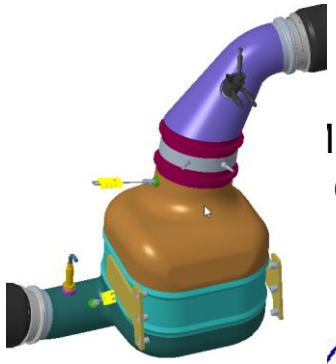
Trailer Skirt Design complete, and parts are currently being fabricated at Ridge

Trailer Suspension complete

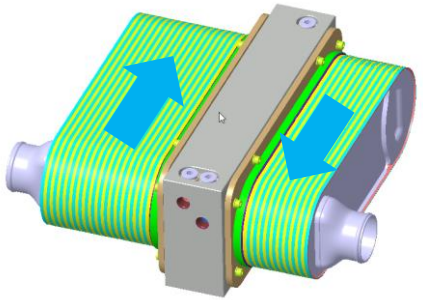
Chassis & Powertrain



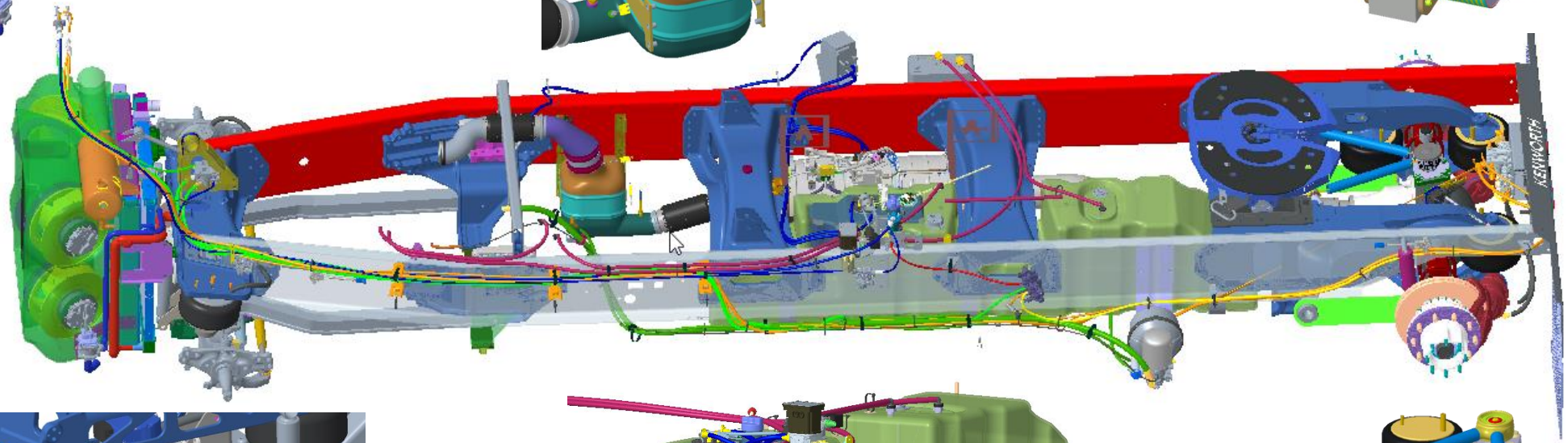
Two Circuit Cooling
Two-Stage iCAC
40% Frontal Open Area
Integrated Air Cleaner
Centrifugal 48V Pusher Fans

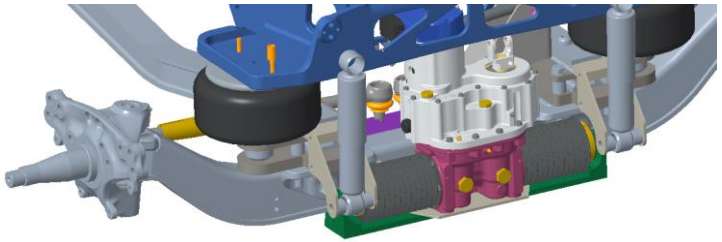


IY2027 Ultra-Low NOx
Close-Coupled SCR

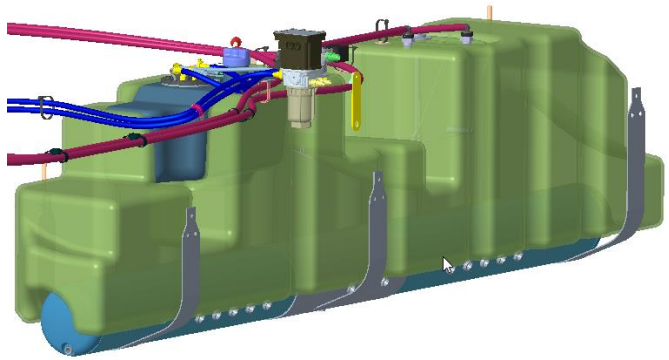


Two-Stage
iCAC
Integrated
coolant
distribution

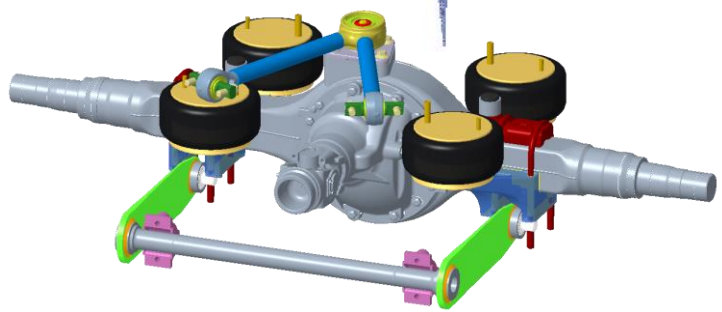




Narrow Track Axle - Aerodynamics
Reduced Scrub – Steering Power
Rack & Pinion – Weight / Ackerman



Combined Fuel / Air / Drier/ DEF Module



Lightweight Triangulated 3-Link
Suspension

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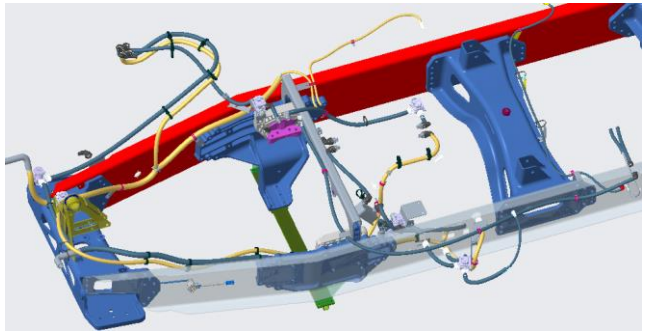
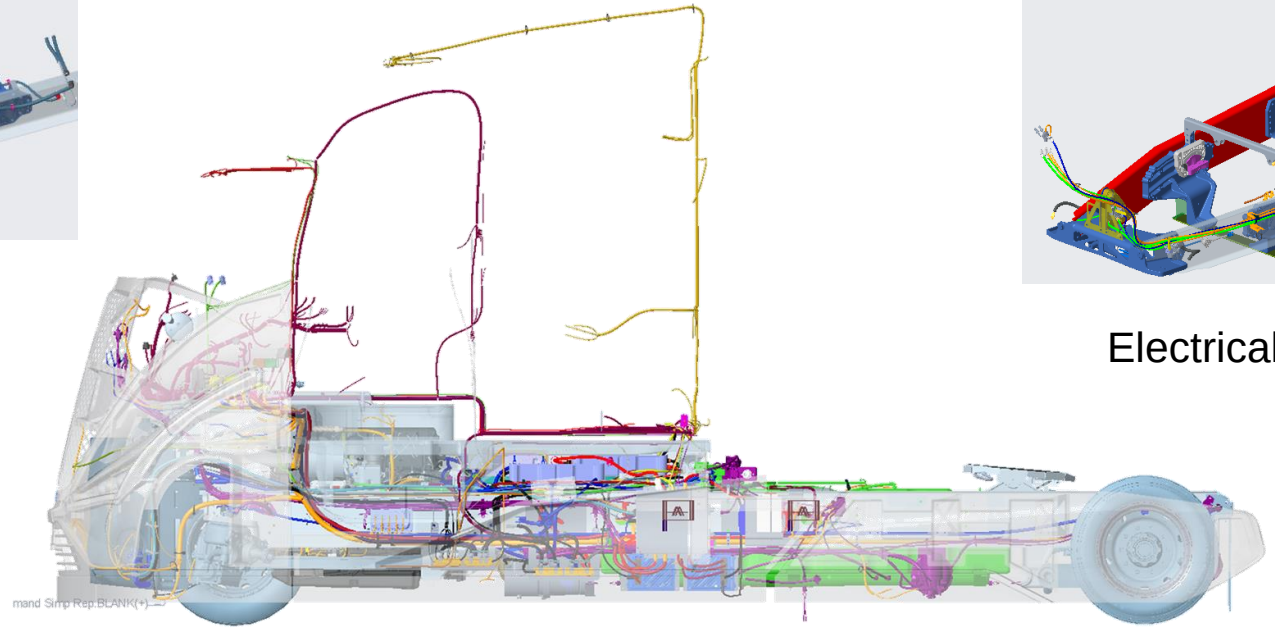
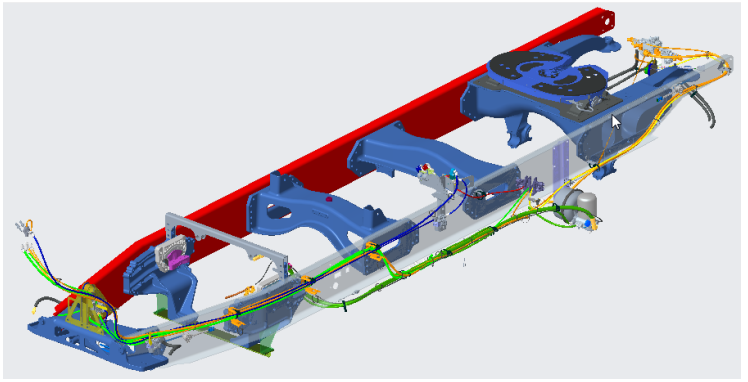
3D Routing



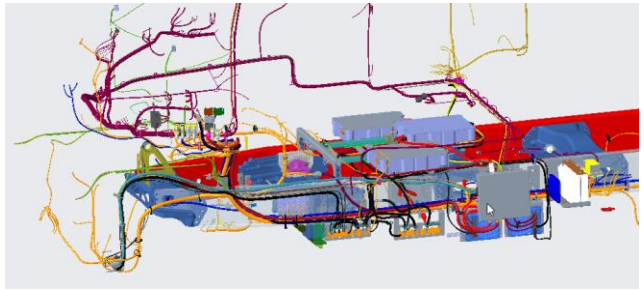
LT & HT Coolant System



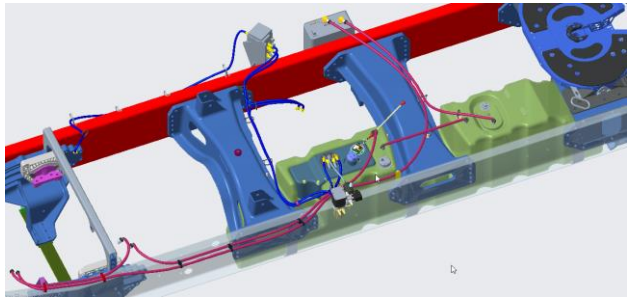
Vehicle Routing Strategy Complete



Electrical and Power Electronics



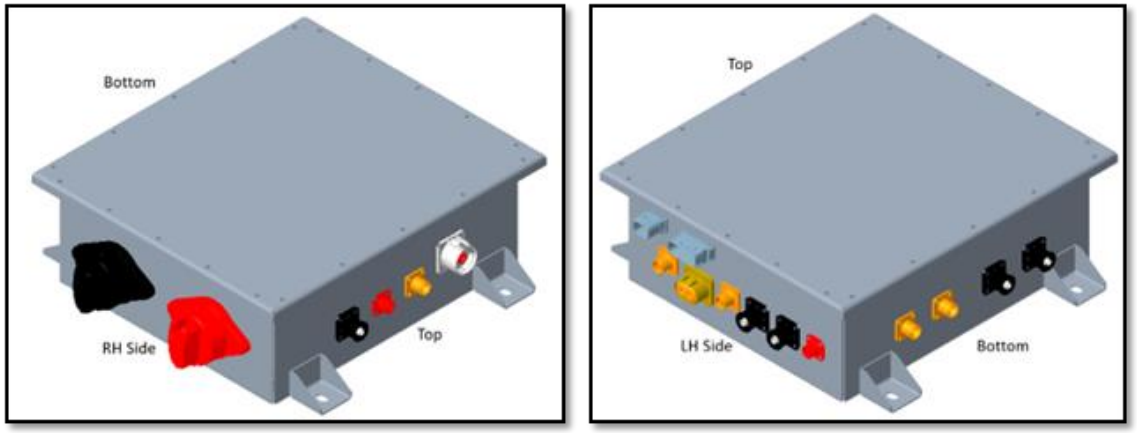
Air Brake System



DEF & Fuel System

Electrical & Controls

12V/ 48V Electrical



- High Current Power Distribution Complete
- Electrical Component Definition Complete
- Harness Requested to Suppliers

Controls & Architecture

GCM 196

RCM 112

MicroAutoBoxII

- CAN Architecture for Demonstrator - Finalized
- Controls Development - Complete
- Unit Testing of the Individual Subsystem - Complete
- Bench Testing of Component - Complete
- Fault Management Implementation - In Progress

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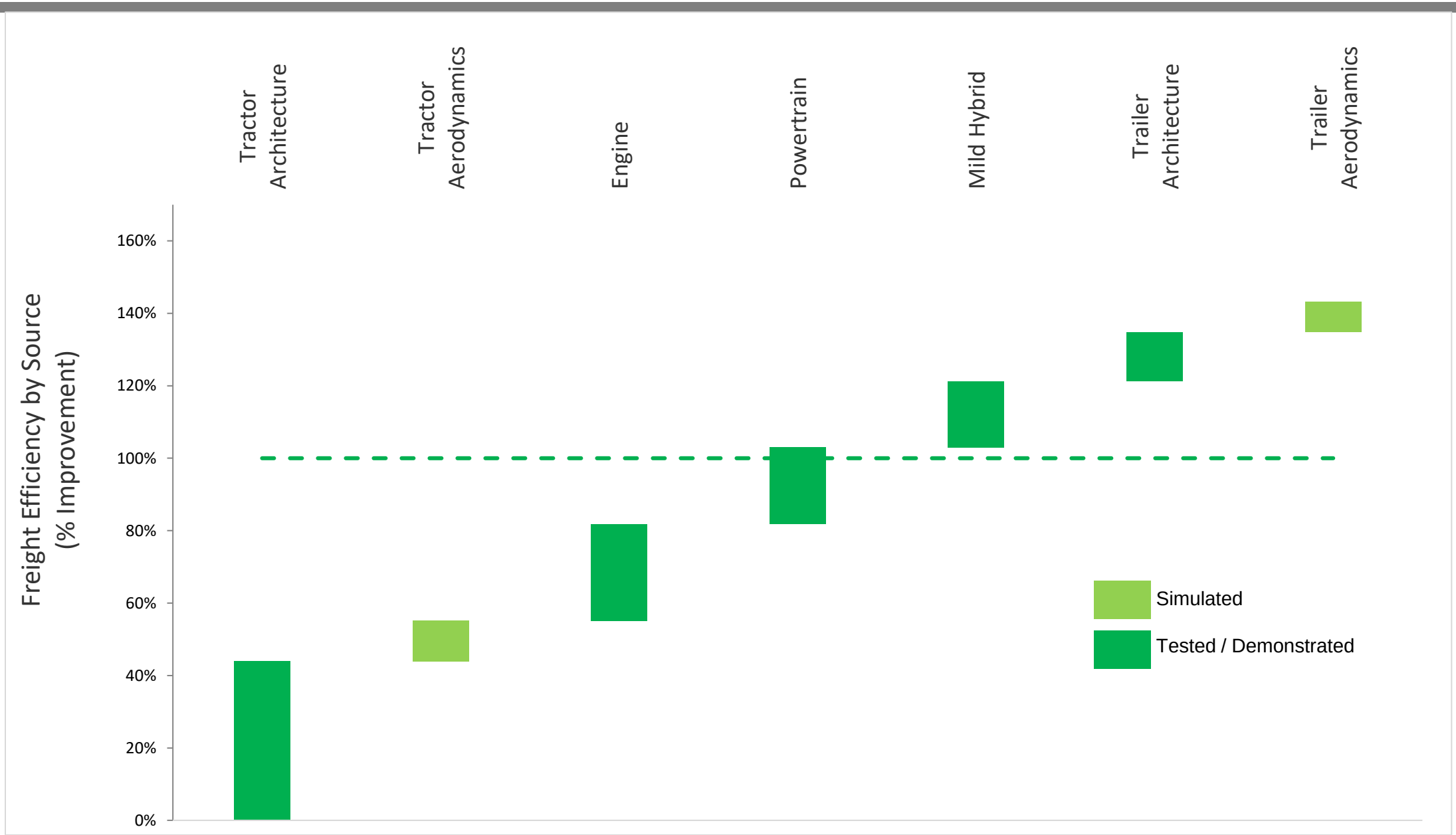
Freight Efficiency Contributions



Partnerships/Collaborations

KENWORTH	Vehicle Development, Vehicle Level Supervisory Controls
PACCAR TECHNICAL CENTER	Engine and Powertrain Development, Program Administration
EATON	Electrified Powertrain, Transmission, and Air Management Systems Development
AVL	Engine Development
NREL NATIONAL RENEWABLE ENERGY LABORATORY	Drive Cycle Development, and Thermal Management
Cummins	Waste Heat Recovery Integration
MERITOR	Axle Integration
Continental	Tire Development
THE OHIO STATE UNIVERSITY	Model Development for Cabin Hoteling Optimization

Remaining Challenges

- **Complete Vehicle Build**
- **Vehicle Demonstration:**

National Average Drive-Cycle Selected Using Specialized NREL Algorithm

Key metrics

- Road Grade
- Hill length
- Altitude
- Max. Speed
- Hotel Loads

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Summary

- **Program Completion on Time, Within Budget While Meeting Targets**

- **Engine**
  - 55.7% BTE Demonstrated
  - Tech Transfer for Commercialization

- **Powertrain**
  - Mild Hybrid Powertrain & 48V Battery System Validated & Integrated in Final Vehicle Demonstrator

- **Vehicle**
  - Updated Freight Efficiency Roadmap To 150% Improvement
  - Final Vehicle Demonstrator Build Ongoing
  - Freight Efficiency Demonstration Preparations Ongoing

TECHNICAL BACKUP SLIDES