2023 Annual Merit Review

PACCAR SUPERTRUCK 3

Development and Demonstration of Zero-Emission Technologies for Commercial Fleets (SuperTruck 3)

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PACCAR Inc.

June 15, 2023

Project ID: ELT285

Overview

PACCAR SUPERTRUCK 3

Timeline

Start Date: May 2022

End Date: April 2027

Completion: 20%

Budget

Total Project Funding

DOE: $33.0M.

Cost Share: $35.4M

FY 2023 DOE Funding: $9.7M

Barriers

Real World Deployment of Zero-Emission Vehicles and Infrastructure

ZEV Technology Development: Improved Freight-Efficiency, Reduced Cost, and Extended Applications

Infrastructure Development: Improved Infrastructure Including High-Power Charging, Micro-grid, and Integrated Charging Management

Partners

Challenges

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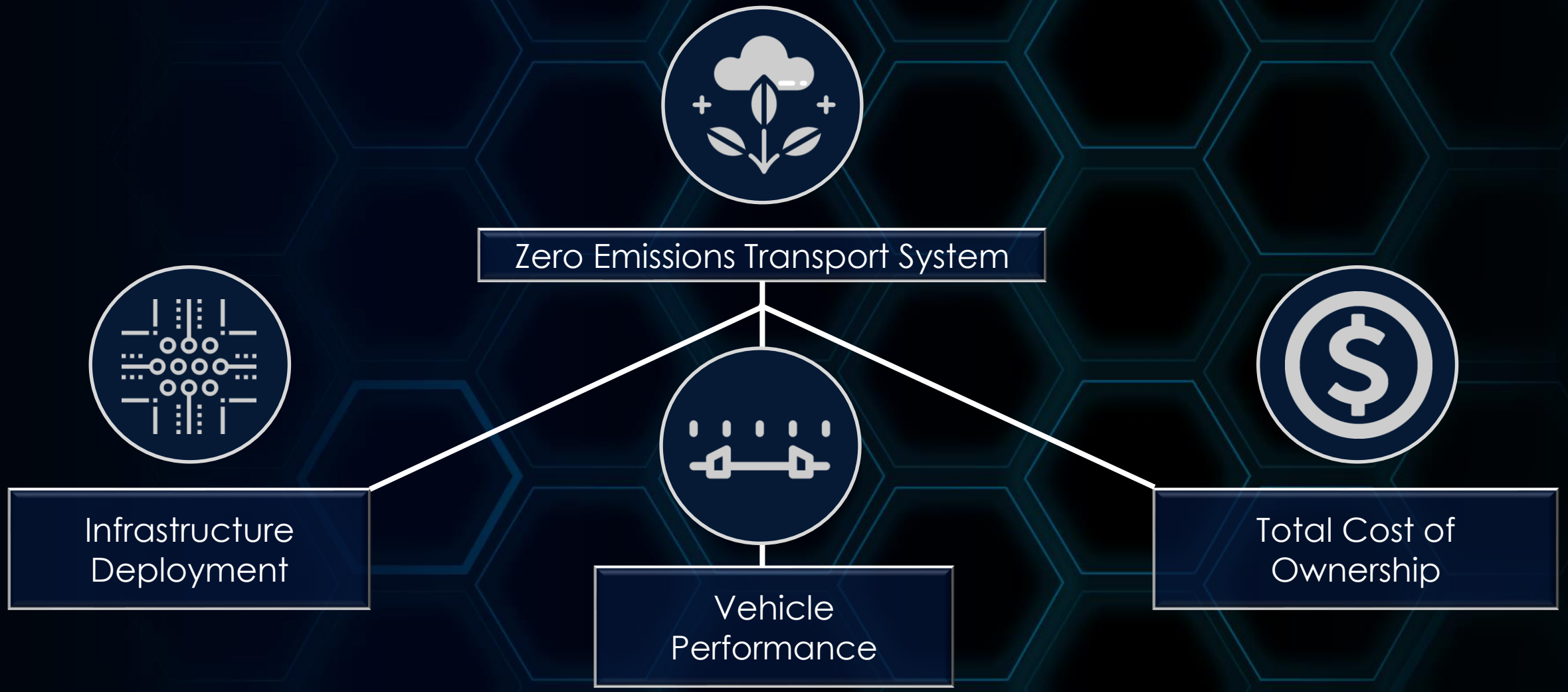

Relevance

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Overall Objectives	• ≥ 75% CO_2 Reduction (On Fleet Level, Compared to Diesel Baseline) • ≥ 30% Total Cost of Ownership Reduction (Compared to Current BEV Portfolio) • Environmental Equity and Justice
Objectives This Period	• Deployment of Gen 1 BEV & Charging Infrastructure • Definition of Gen 2 and Gen 3 BEV • Level 2 ADAS and Fleet-Connectivity Requirements • Definition of (High-Power) Charging Infrastructure
Impact	• Collaboration Across Industry to Decarbonize Commercial Vehicle Transportation • Learn From Fleet Deployment About Barriers to ZEV Adoption and Develop Targeted Technology Improvements • Evaluation of Higher Risk ZEV Technologies To Improve Efficiency & Cost

Environmental Equity and Justice

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- PACCAR Environmental Lifecycle Assessment Tool
- PACCAR Sponsored Programs
  - UW Electric Truck
  - Capstone Programs
- PACCAR Day Events
  - Historically Black Colleges and Universities (HBCUs)
  - Local Universities
- STEM Outreach

Key Technologies

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Vehicle

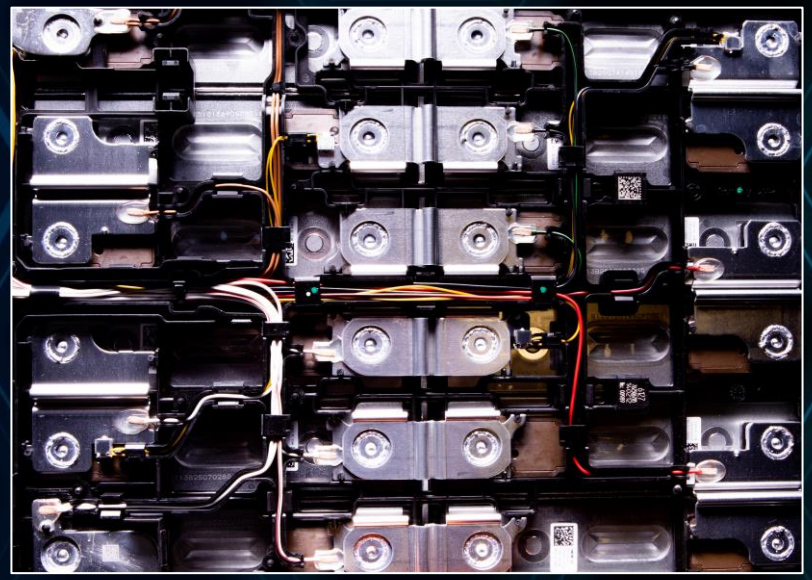
- BEV L2 ADAS
- Connected Spec'ing & TCO
- Cab & Chassis
- FCEV Analysis

Powertrain

- Increased Voltage
- Next Gen. Batteries & e-Axle
- Power Electronics & Auxiliaries
- Systems Integration

Infrastructure

- High Power Charging
- Route & Charging Optimization
- Micro-Grid Integration
- Utility Integration (V2X)



Vehicle Deployment Generations

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	Fleet Partner Deployment				Closed Track
	May 2022 – April 2023	May 2023 – April 2024	May 2024 – April 2025	May 2025 – April 2026	May 2026 – April 2027
	Gen 1 (4 Trucks) 	*Gen 2 & Gen2+ (10 Trucks)* 			*Gen 3 (2 Trucks)* 
Program Activities	BEV Baseline Definition, Concept Generation	Improved Product Deployment Select Technology Upfits Gen 3 Concept Generation			Build Development Units Evaluate Technology Maturity
Applications	Local	Gen1 + Vocational			Heavy Duty
CO_2 Reduction	Diesel to Current BEV	Increased Applications			Challenging Applications

Timing

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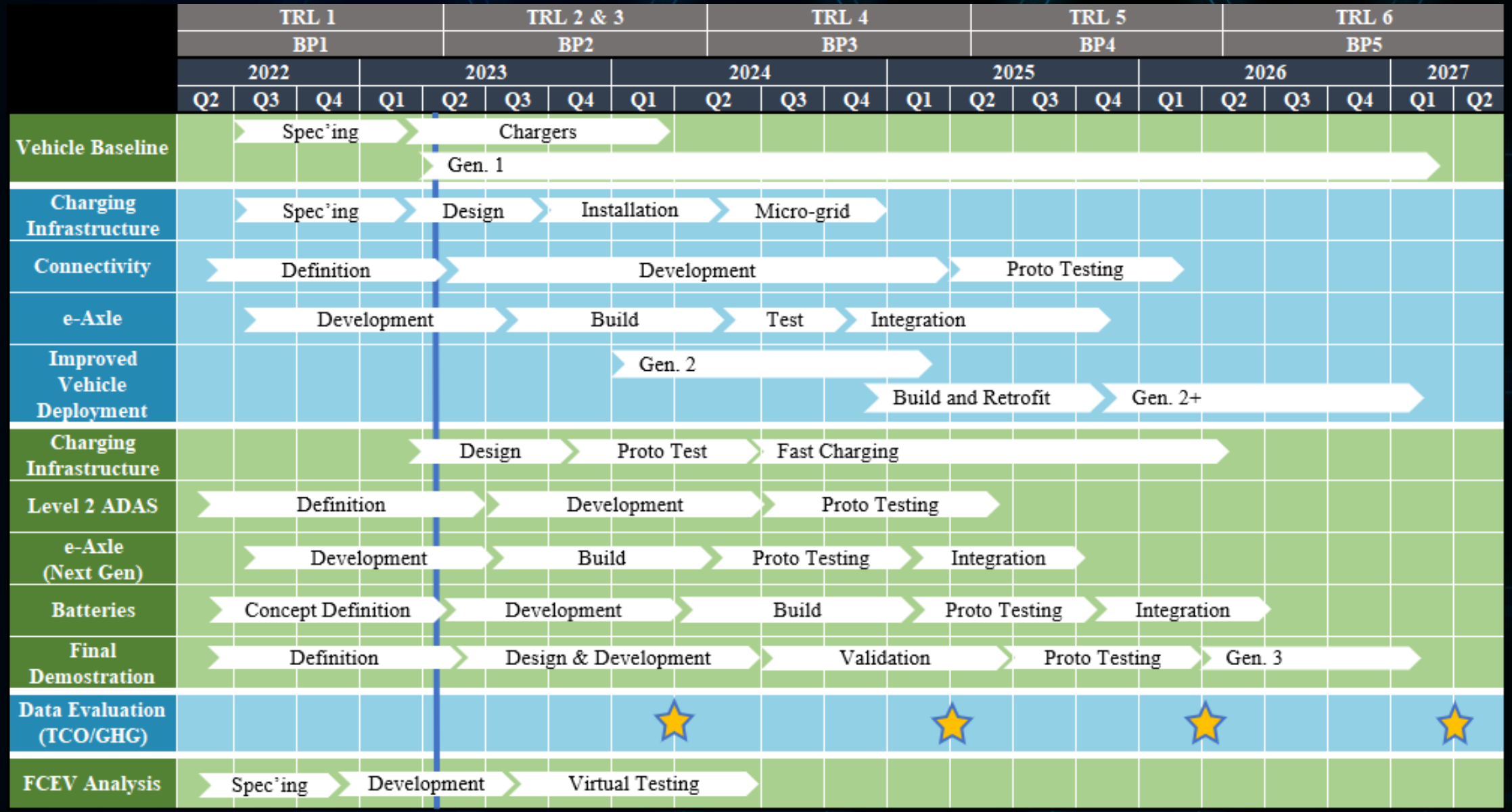

Fleet Vehicle Deployment

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Swift Transportation
- Jurupa Valley Terminal

Vehicle Deployment
- 2 – Peterbilt 579 EV
- 2 – Kenworth T680e
- Data Logging
- Driver Training

Infrastructure & Micro-Grid

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KNIGHT TRANSPORTATION | SWIFT TRANSPORTATION | Schneider Electric | PACCAR PARTS

Scope Included:

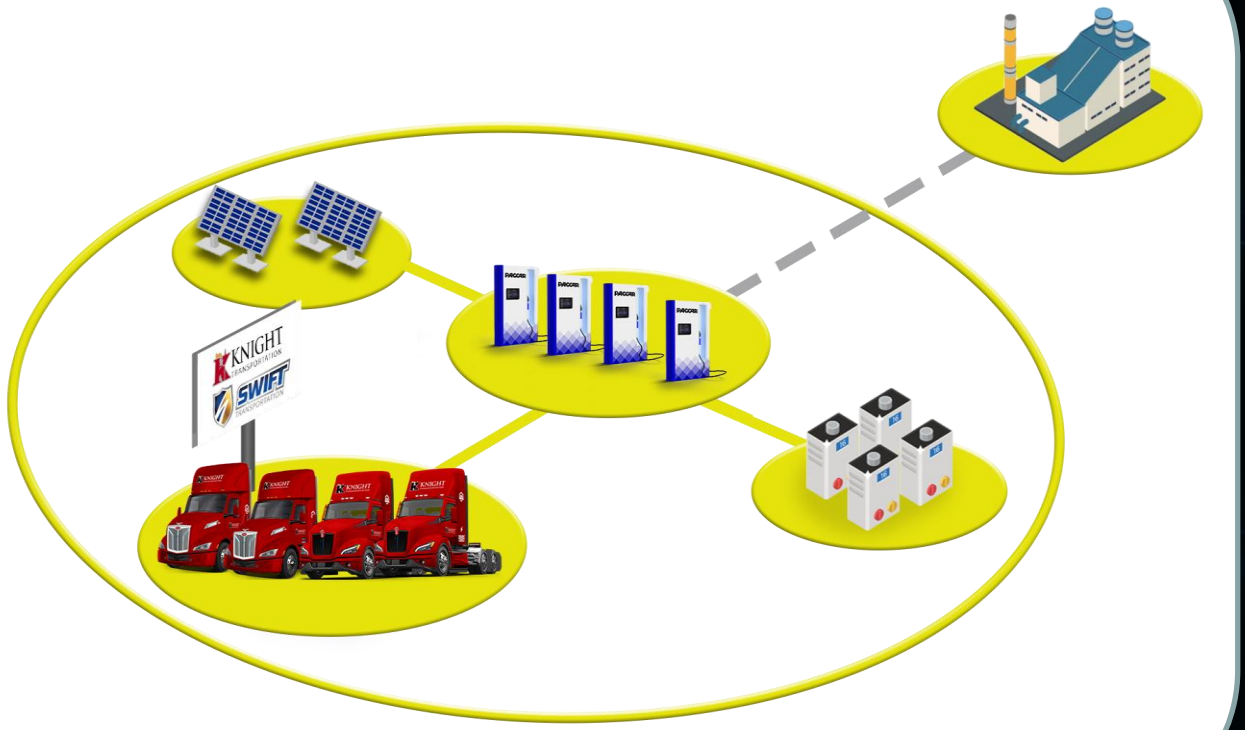
- 500 kWh Battery Energy Storage System (BESS)
- 500 kW Solar Charing Array
- 10 – 180kW DC Fast Chargers
- Q1 2023 Initial Deployment
- Q2 2024 Full Deployment

Status:

- Permits Granted
- Purchase Orders Submitted
- 2 of 10 Chargers Installed

Fast Charging Scope Removed:

- Reduced Incentives from Utility Supplier
- Support Engineering Vehicles (Closed Track)



BEV Gen2/2+ Scope Definition

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- Increased Range
- Increased Charging Rate
- Improved Vehicle Packaging & Layout
- Advanced Thermal Management Controls
- BEV Specific Fleet V2C Connectivity
- Expanded Vehicle Applications
- 30% Total Cost of Ownership Reduction

Connectivity

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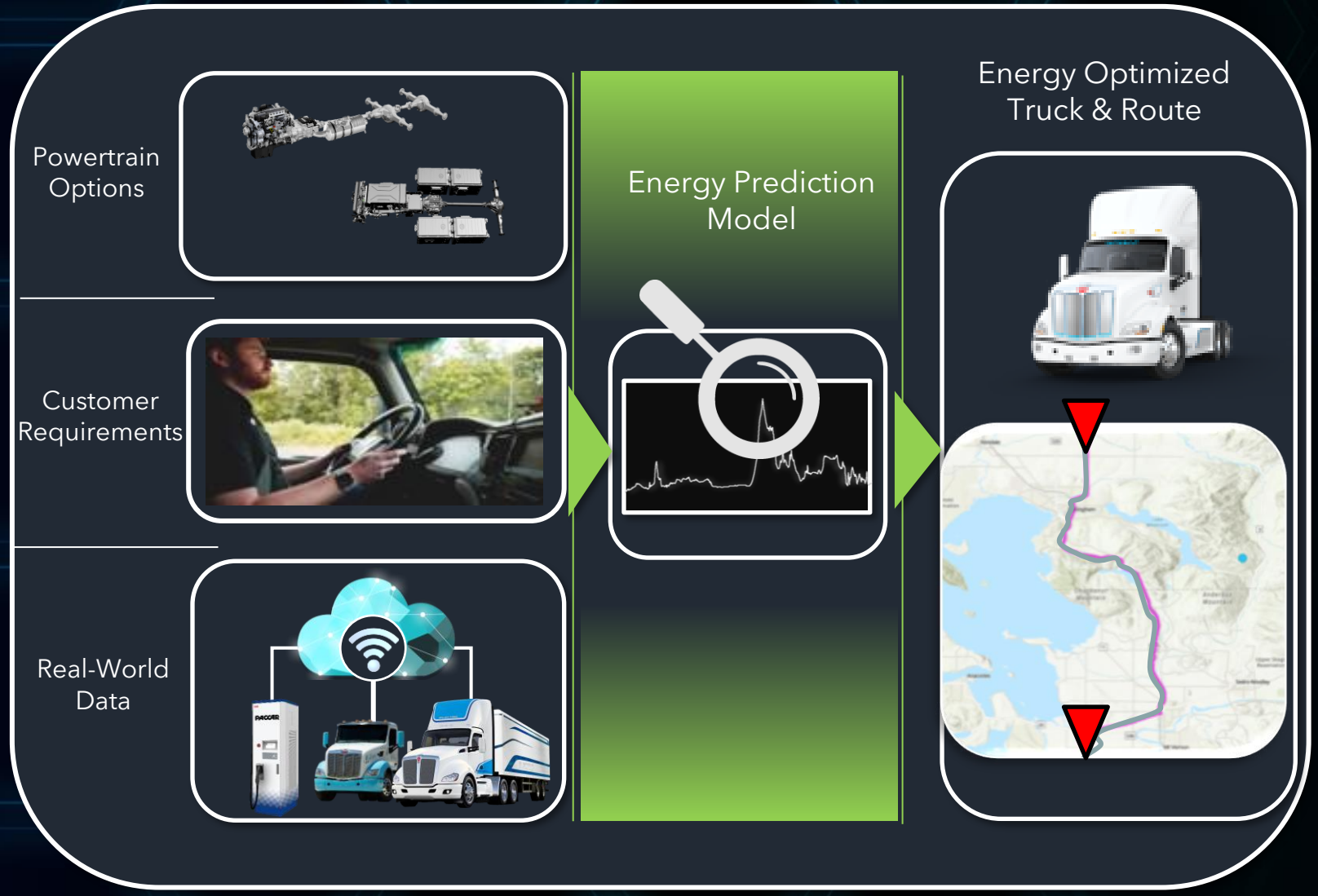
Scope:
- BEV Specific
- Include Charging Infrastructure
- Leverage: Co-Optimization of Vehicles and Routes (EEMS-108)

Features:
- Vehicle Range Prediction
- Diver Coaching & Eco-Score
- V2X Communication
- Truck Specification Optimization

Status:
- Requirements Completed
- Data Loggers on Baseline BEV's



Gen3 BEV Targets

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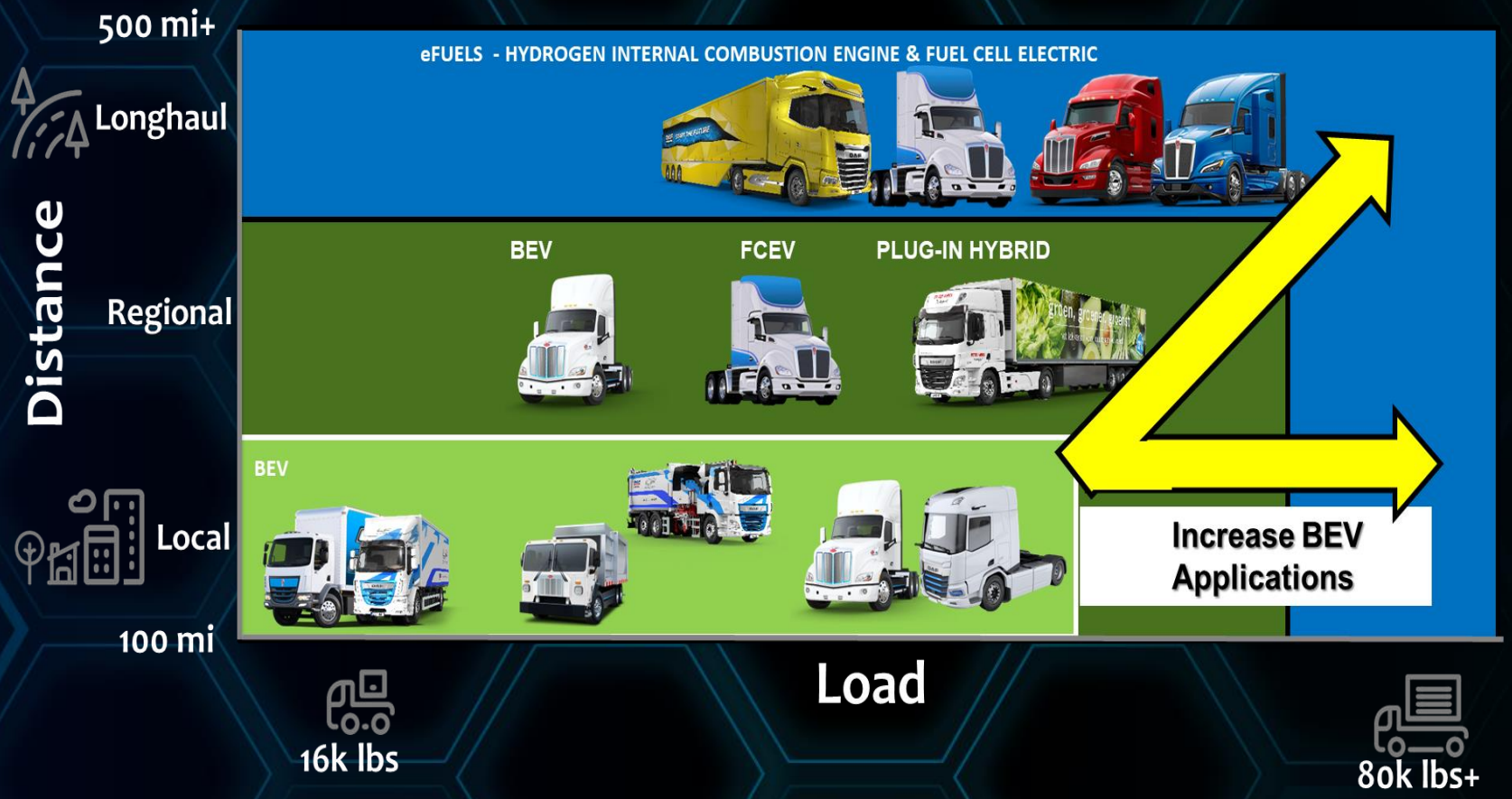
- Extend BEV Applications
  - Hard to De-Carbonize Sectors
  - Heavy-Duty Trucking
- High Energy Density
  - Range / Load



- Deliver 65k Equivalent Payload, Over 400-500 Miles, Under NA Highway Drive Cycle Conditions

BEV Gen3 Scope Definition

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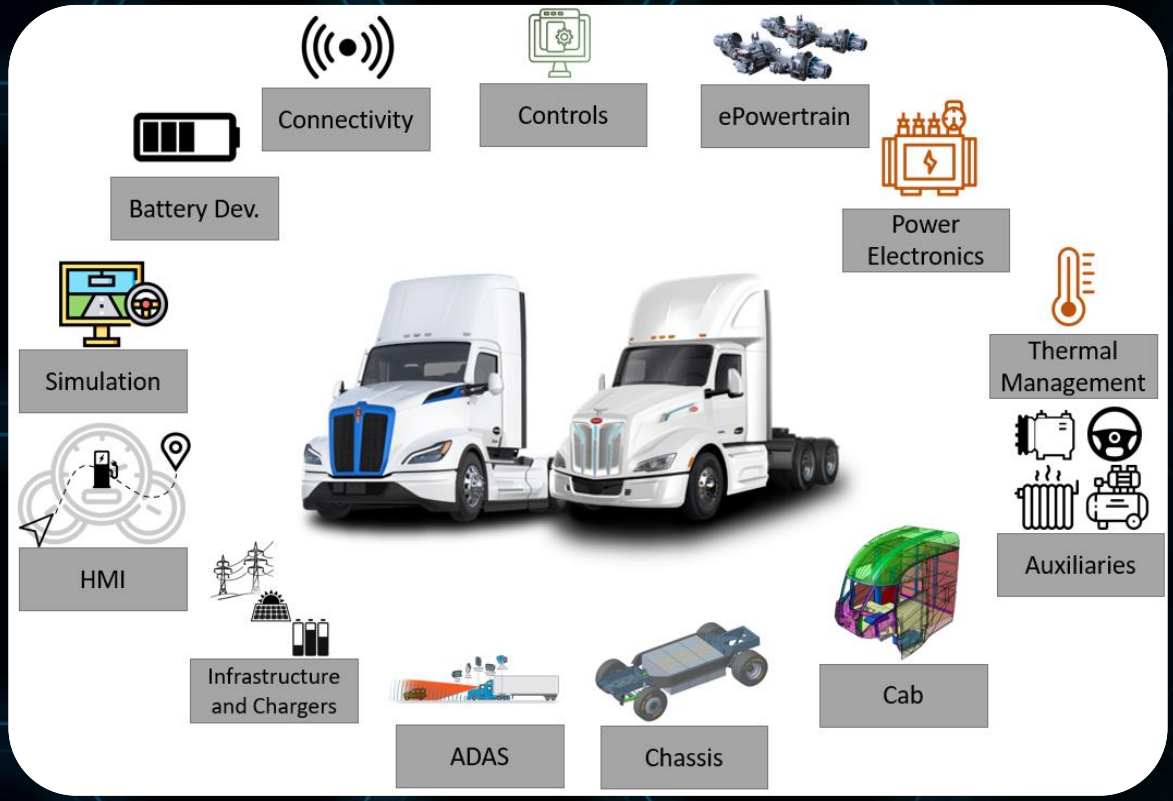
- Longer Range
- Faster Charging
- Improved Packaging, Weight Distribution, Payload
- Advanced BEV Specific L2 ADAS
- Enable Expanded EV Adoption Across Applications
- Stretch Goal: 40% Total Cost of Ownership Reduction



Battery Development

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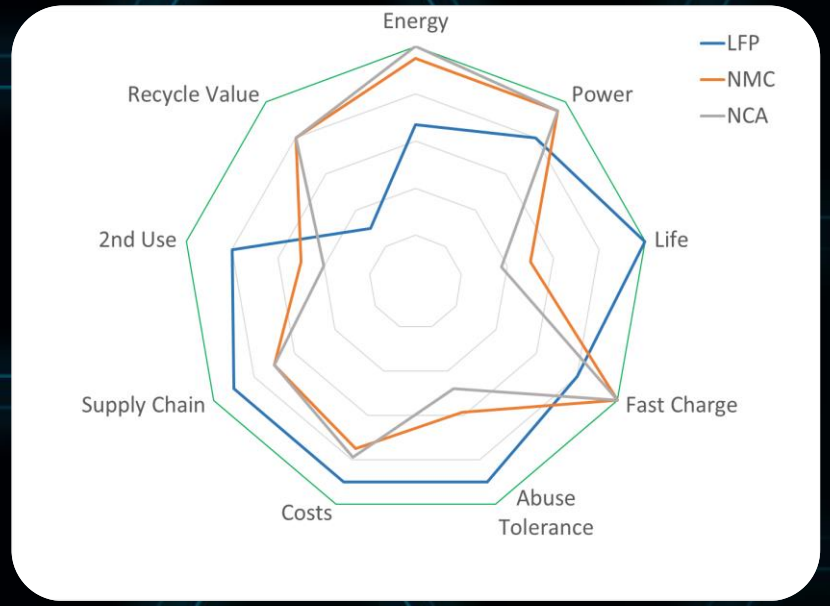
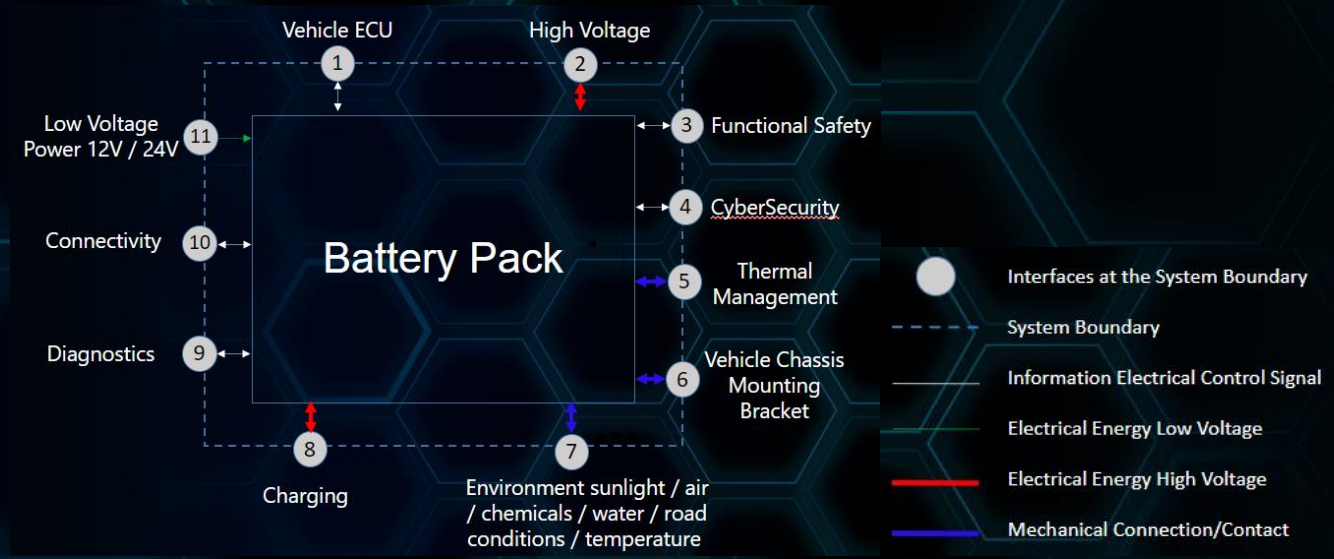
- **High Energy Density Collaboration with LGES**
  - Higher Energy Density
  - Better Fast Charging Performance
- **Requirements Target**
  - Pack Level Density: 210 Wh/kg
  - Charging Time: Preliminary 75 Mins (6-97%)
  - Voltage: 870V nominal and 1000V Peak
- **Vehicle Space Claim Evaluated**
- **System Boundary Interface Defined**





E-Powertrain

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- Next Generation e-Axles from accelera
- Increased Efficiency
  - Higher Operating Voltage
  - Twin Countershaft Transmission
  - 3 Speed Transmission
- Improved Packaging
  - Integrated Inverter, Shifter Controller

accelera by Cummins

Power Electronics

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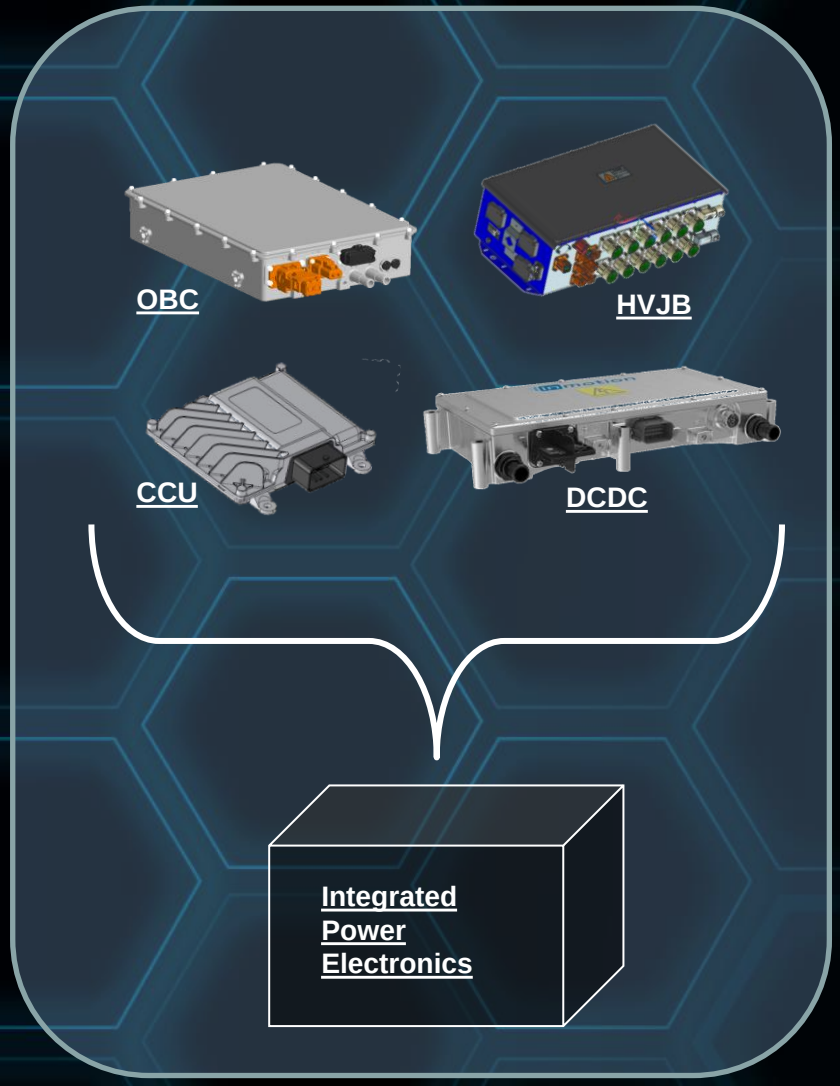
- Increased Efficiency
  - Higher Operating Voltage
  - Higher Operating Amperage
  - Improved Cooling Performance
- Reduced Total Cost of Ownership
  - Integrated Power Electronics
  - Reduced HV Connectors/Cabling



Auxiliaries

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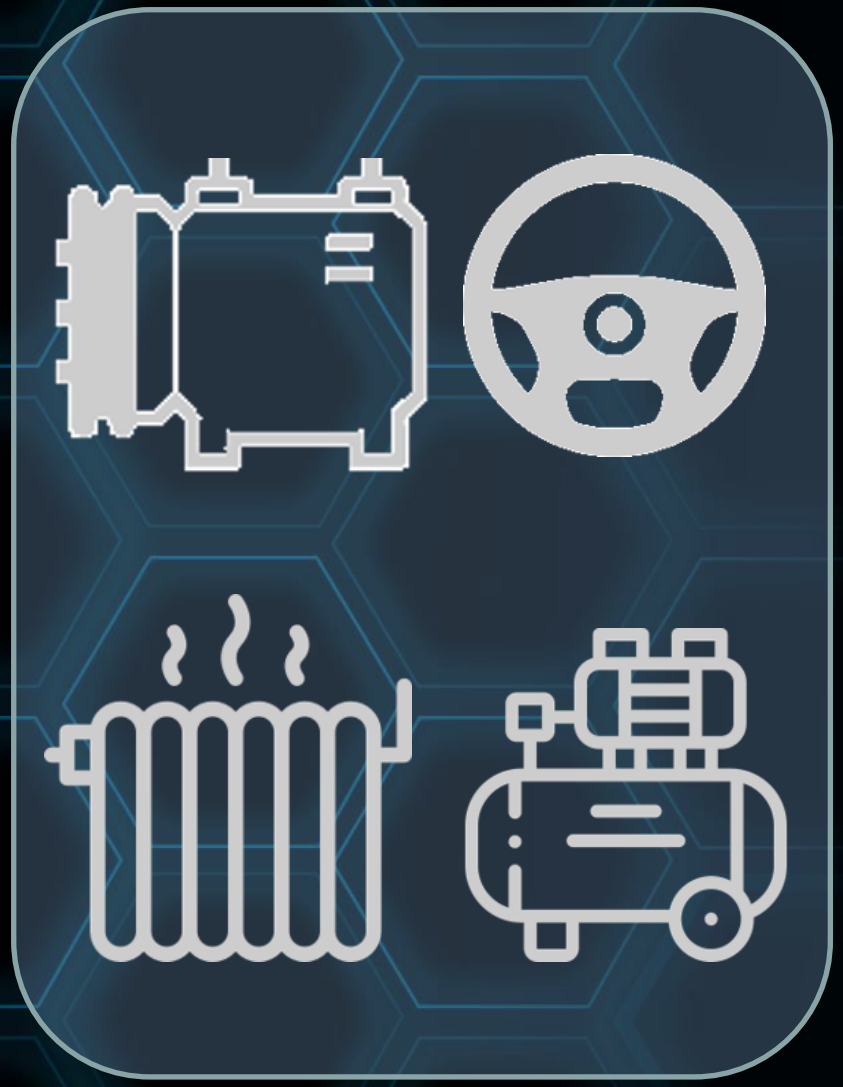
- Fully Electrified Power Steering
  - Elimination of Pump, Hoses
- Cabin Heat Pump
  - Increased HVAC Efficiency
  - Air Heater for Lower Ambient Temperature
- Air Compressor
  - Integrated Inverter & Controller
  - Improved Packaging of Air Dryer, Tanks



ADAS

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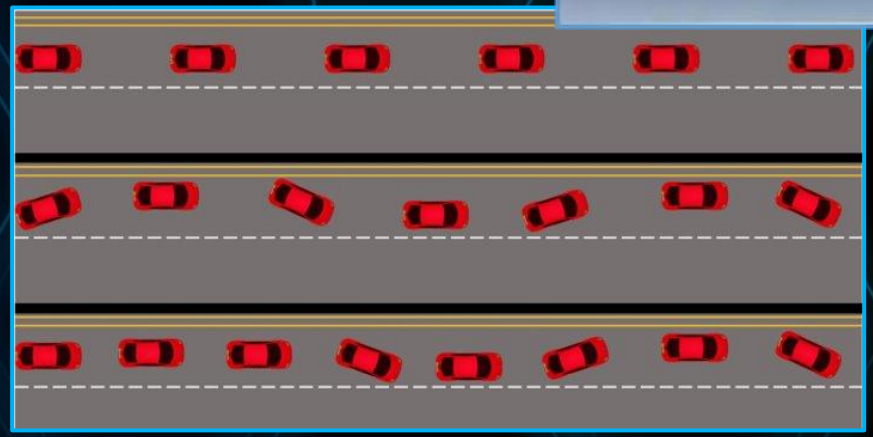
Scope:

- Adaptive Cruise Control (ACC)
- Active Lane Keeping (ALK)
- Enhanced Predictive Cruise Control (PCC)
  - Predefined Route
  - Road Curvature
  - Speed Limit Integration
  - Live Traffic, Accidents, Construction

Benefits:

- Driver Safety / Comfort
- Energy Efficiency Improvement



Response to Reviewers' Comments

- **First Year: No Reviewer Comments to Address**

Partnerships/Collaborations

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Peterbilt, Kenworth	PACCAR OEM Manufacturers
Schneider Electric	Infrastructure Energy Management & Microgrid Development
Knight Transportation, Swift Transportation	Fleet Partner and Featured Operator
LG Energy Solution Michigan, Inc.	Development of Commercial Vehicle High Energy Density Battery
accelera by Cummins	Development of High Efficiency e-Axle's
Argonne National Laboratory	GHG, TCO, Environmental Equity and Justice Modeling / Analysis
Ohio State University	Powertrain Recommender Tool / ADAS / V2X Simulation Tool Development
UNT	V2V Perception Technologies
chargepoint	High-Power Chargers Hardware Development

Remaining Challenges

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Vehicle

- Gen3 BEV Targets
- Analysis Cab / Chassis
- Analysis FCEV
- ADAS: Constrained Test Environment

Powertrain

- High Voltage Architecture
- Battery Performance / Life
- Component Integration

Infrastructure

- Supply Chain Constraints

Proposed Future Research

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Vehicle

- Finalize Cab and Chassis Design
- Generate ADAS & Connectivity Architecture Design
- Fuel Cell EV Concept Design

Powertrain

- Battery Cells Development Design
- Design Freeze for Technology Improvement Components
- Prototypes for Next Gen e-Axle

Infrastructure

- Lab Testing for High-Power Charging Sub-system Prototypes
- BEV Deployment with Charging Infrastructure

Any proposed future work is subject to change based on funding levels.

Summary

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PROGRAM ON TRACK TO MEET TARGETS:

Vehicle & Infrastructure Deployment	• Gen1 BEV and Chargers Deployed • Extensive Data-Logging Ongoing
BEV & Charger Development	• Gen2 and Gen3 BEV Scoped Definition • Battery & e-Axle Development Ongoing • Power Electronics & Aux. Development Ongoing
ADAS & Connectivity	• BEV Specific Scope and Requirements in Place • V2V and V2X Simulation Activities Ongoing

Technical Backup Slides

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14Xe e-Powertrain

- Axle configuration: 4x2, 6x2, 6x4
- GAWR range per axle: 15 – 23k lbs.
- **1 & 2-speed planetary & 2 & 3-speed twin-countershaft transmissions**
- High voltage range: 450-**900V,** Evaluating 1000-1200V
- Inverter Location: Chassis mounted
- FUSA (ISO-26262) / ASIL C: Yes
- **Cybersecurity (ISO-21434/R155): Yes**

V4.5 Enhancements

- **Voltage**
  - Future proofing voltage requirements @ 800V (750V Nominal)
- **Performance**
  - Higher continuous power capability
  - Achieve rated power across a broader motor speed band
  - Higher peak & continuous torques, while torque is available across a broader motor speed band
  - Improved drivability due to reduced power droop between gears
- **Efficiency**
  - Higher efficiency across a wider speed range
- **Vehicle integration**
  - Improved vehicle integration, manufacturability, and serviceably with high voltage (DC & AC) quick connectors
- **Design & Supply Chain Control**
  - Increased engineering control over the motor & inverter, while reducing supply chain complexity