Kenworth Electrified Powertrain

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Director, R&D
KENWORTH Electrification History

2008 – MD Parallel Hybrid Production

2008 – HD Parallel Hybrid Demonstration

2012 – MD Micro-Turbine Series Hybrid

2015 – HD Micro-Turbine Series Hybrid

2018 – Fuel Cell and Nat Gas Hybrid
Industry Outlook 2030 – Trucking Industry

**Urban Delivery**
- MD / Step Van / Pod
- Diesel Hybrid and BEV
- Autonomous Level 4-5

**Regional Haul**
- Day Cab
- Diesel Hybrid / BEV / Fuel Cell EV
- Autonomous Level 4+

**Line Haul**
- Advanced Aero Cab
- Diesel Mild Hybrid and Fuel Cell EV
- Autonomous Level 4+
Heavy Duty Tractors with Zero Emissions and Zero-Emission Capability

Market (2022-2025):
• 50-200 per year
• Tractors hauling on regional routes
• Localized markets based on infrastructure
• Regulatory and/or incentive driven

Performance Targets (2022-2025):
• 82,000 GVWR
• Capable of highway speed operation
• 30mph on 6% grade and startability on 20% grade
• Better than diesel acceleration 0 - 30mph
• 300+ mile range / 15 min refill
• B10 life of 500,000 miles
<table>
<thead>
<tr>
<th><strong>Kenworth Electrified Powertrain Projects</strong></th>
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</thead>
<tbody>
<tr>
<td><strong>Traction Motor Power</strong></td>
</tr>
<tr>
<td><strong>Battery Capacity</strong></td>
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<tr>
<td><strong>Range Extender Power Source</strong></td>
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<tr>
<td><strong>On-board fuel storage</strong></td>
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**Funded by DOE & SCAQMD**
<table>
<thead>
<tr>
<th></th>
<th>Battery Electric with CNG Range Extender</th>
<th>Battery-Electric with Hydrogen Fuel Cell Range Extender</th>
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<tbody>
<tr>
<td>Traction Motor Power</td>
<td>420 kW (560 hp)</td>
<td>420 kW (560 hp)</td>
</tr>
<tr>
<td>Battery Capacity</td>
<td>100 kW-h</td>
<td>12 kW-h</td>
</tr>
<tr>
<td>Range Extender Power</td>
<td>Cummins L9N Near Zero CNG Engine / Generator</td>
<td>2 x Toyota Mirai Fuel Cell</td>
</tr>
<tr>
<td>Source</td>
<td></td>
<td></td>
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<tr>
<td>Target Range</td>
<td>500+ miles</td>
<td>300+ miles</td>
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<tr>
<td>Target Zero Emission Range</td>
<td>30+ miles</td>
<td>300+ miles</td>
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Funded by ARB & SCAQMD Funded by ARB through POLA
Kenworth – Toyota

Partnership Responsibilities

• **Toyota**
  - Fuel Cells Stacks
  - Balance Of Plant
  - Power Delivery Controls
  - Hydrogen Fuel Storage
  - Batteries

• **Kenworth**
  - Chassis and Cab
  - Supervisory Controls
  - Motors and Transmission
  - Cooling Systems
  - Integration
Recent Award from DOE

**Battery Electric with Wireless Extreme Fast Charging**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Traction Motor Power</td>
<td>420 kW (560 hp)</td>
</tr>
<tr>
<td>Battery Capacity</td>
<td>600+ kW-h</td>
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<tr>
<td>Target Range</td>
<td>180+ miles</td>
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**Funded by DOE**
Recent Award from DOE

- Long-Range Battery-Electric Tractor-Trailer
- Local routes during day shift
- Night shift:
  - Seattle to Portland
  - Re-charge in Portland in 30 minutes
  - Return to Seattle
- Wireless charging at Megawatt rate
- Project start planned for 1 October 2019
- Commercial operation planned January 2021
Challenges for Adoption

- Developing Supply Base
- Complex Cooling and Electrical Architectures
- Driver Interface Needs Are Critical
- High Customer Interest at Limited Scale
- Need Continuous High Power Output for Long Grades
- Fueling Infrastructure
- Fuel Cell Cost