Medium-Duty Urban Range Extended Connected Powertrain

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Robert Bosch LLC

2017 DOE VTO Annual Merit Review

June 7th, 2017

Project ID #**GI190**

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GI190: MURECP Class 4 Delivery PHEV
Overview

Timeline

- Project start date = 8/19/2016
- Project end date = 11/30/2019
- Percent complete = 21%

Budget

- Total project funding
  - DOE share = $4,731,884
  - Contractor share = $1,984,907
- Funding received in FY 2016
  - $205,848
- Funding for FY 2017
  - $2,345,136

Barriers

- **Performance** – 50% Fuel Consumption Reduction for class 4 delivery truck
  - Baseline = 8.5 MPG, Target >17 MPG
  - Full performance capabilities meeting or exceeding baseline vehicle
- **Cost** - < 3 year payback period
- **EV Range** - > 35 miles all electric range

Partners

- Bosch – Project Lead
- Morgan Olson
- Voss
- University of Michigan
- NREL
- Ricardo (vendor)

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Relevance/Project Objectives

- Demonstrate 50% fuel consumption reduction on CSHVC* utilizing a PHEV powertrain with a dual-planetary gear transmission utilizing electric components based on high-volume light duty vehicles
  - Baseline vehicle: Class 4 Morgan Olson Route Star delivery van, built upon the Freightliner MT45 chassis with a 6.7 liter Cummins ISB and Allison 5-speed automatic transmission
- Targets for Aug ’16-April ‘17:
  - Developing simulation environments for evaluation and optimization
  - Down select dual-planetary gear transmission from >18 million to top 3 designs
  - Define PHEV Traction and Energy Storage Systems
  - Defined software and control architecture for power split within our existing product portfolio
- Evaluation against Project Barriers
  - **Performance:** current simulation modeling predicts >20 MPG (>50% fuel consumption reduction) on CSHVC* (Charge Sustaining Mode)
  - **Cost:** Still being evaluated, cost estimates expected in budget period 2
  - **EV Range:** ~35 miles of all-electric range achievable with existing battery packs on the CSHVC* (final energy storage to be defined by 6/30/2017)

*CSHVC=City Suburban Heavy Vehicle Cycle

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Milestones FY 2017

*CSHVC=City Suburban Heavy Vehicle Cycle

Milestone	Type	Description	Date	Result
Validated baseline simulation model	Technical	Simulation baseline model fuel consumption prediction within 10% of baseline vehicle measurement results	12/31/2016 ☑	GT Suite model predicted 8.2 MPG on CSHVC* compared to NREL's chassis dyno data of 8.5 MPG
Validation of dual planetary gear hybrid powertrain	Technical	Quantify superior benefits of the 2PG hybrid powertrain as compared to other architectures	2/25/2017 ☑	P2 Hybrid with downsized internal combustion engine achieved 39% fuel consumption reduction vs. 2PG Power-split hybrid achieving 60% fuel consumption reduction (CSHVC*, Charge Sustaining)
Defined hybrid powertrain topology and components	Technical	Component selection for the proposed solution to achieve the desired fuel consumption reduction and cost target	6/30/2017 ☐	Final topology selection ongoing. Top 3 dual-planetary-gear designs selected 2/28/2017.
Developed control oriented transmission models	Technical	The control-oriented models will be simple to implement while capturing the primary transmission dynamics	8/21/2017 ☐	Rule-based control development ongoing. Simulink models to be integrated with GT Suite vehicle model
Powertrain Architecture Defined	Go/No Go	Modeling results show the architecture can achieve a 50% reduction in fuel consumption	11/30/2017 ☐	TBD based on final dual-planetary-gear architecture selection and control-oriented algorithms

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Milestones FY 2018

Milestone	Type	Description
Validated supervisory controller with hybrid configuration	Technical	Supervisory controller validation in GT-SUITE is completed and produces preliminary fuel economy results
Completed 3D CAD model of the final design solution	Technical	Virtual packaging study completed in the vehicle space and installation locations for all new components defined
Finalized driveline design	Technical	The hybrid drive system design, integration, and optimization will include an optimum final drive ratio(s)
Pseudo vehicle certification achieved using powertrain map input	Technical	Powertrain mapping procedure completed with input maps used to generate a GEM vehicle certification CO2 /fuel consumption values
Rolling chassis operational under its own power	Go/No Go	Class 4 PHEV delivery truck is assembled and basic drive functionality is demonstrated

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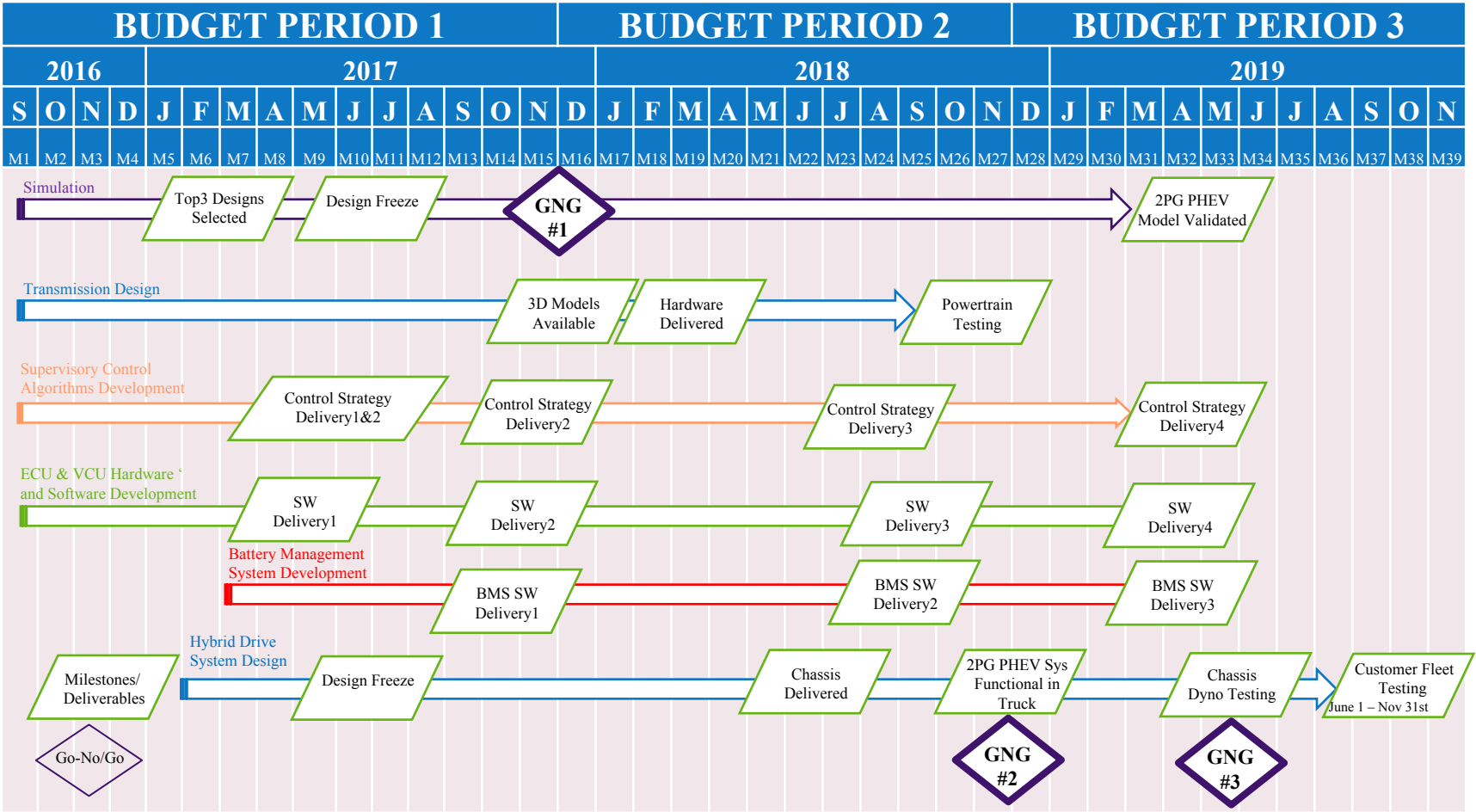
Approach- Overview (Full Project View)



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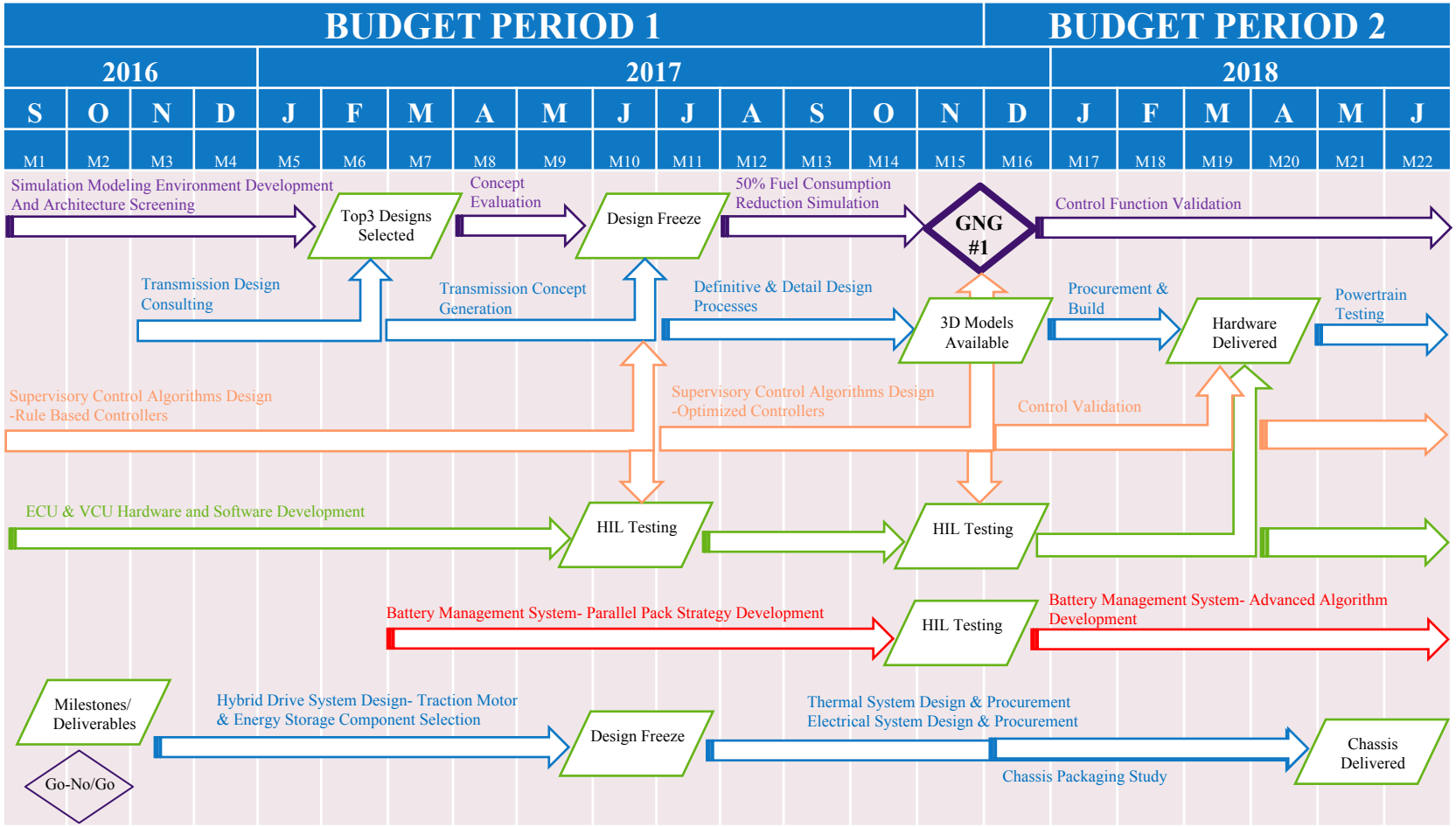
Approach- Detailed (12 Month View)



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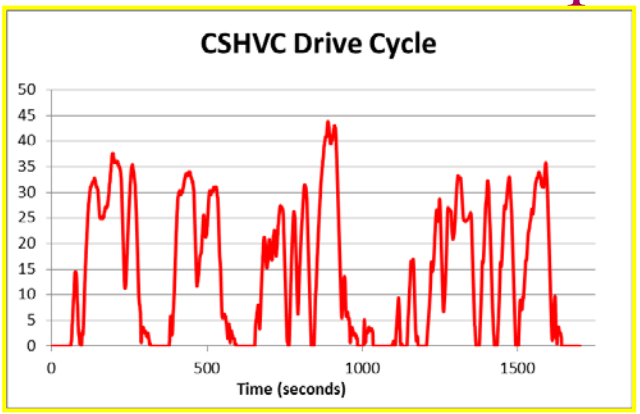
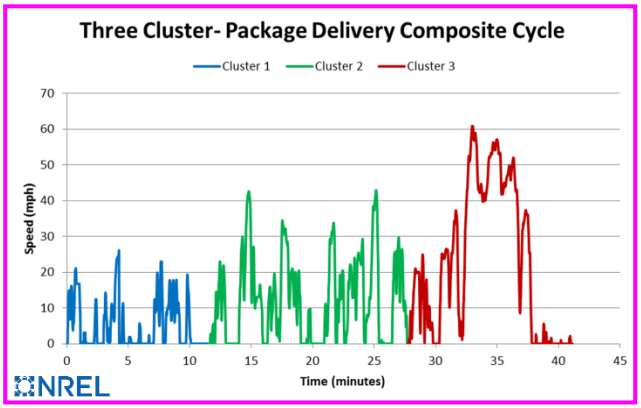
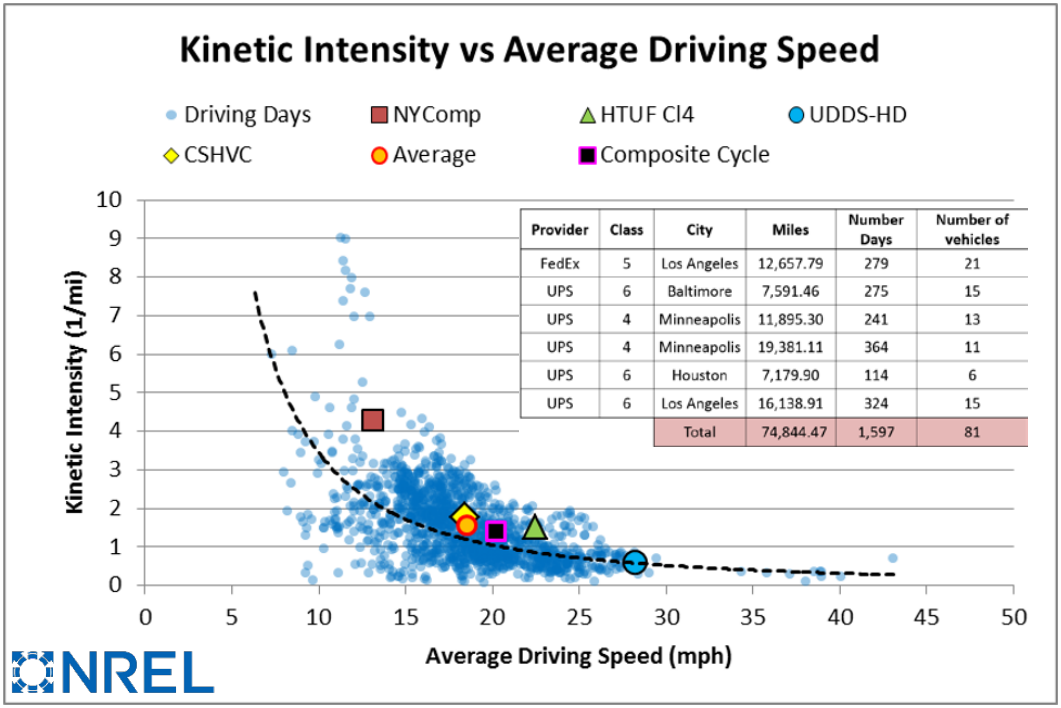
Technical Accomplishments and Progress







Provider	Class	City	Miles	Number Days	Number of vehicles
FedEx	5	Los Angeles	12,657.79	279	21
UPS	6	Baltimore	7,591.46	275	15
UPS	4	Minneapolis	11,895.30	241	13
UPS	4	Minneapolis	19,381.11	364	11
UPS	6	Houston	7,179.90	114	6
UPS	6	Los Angeles	16,138.91	324	15
		Total	74,844.47	1,597	81

Baseline vehicle data from NREL Fleet DNA database. Target drive cycle defined in collaboration with NREL and Morgan Olson

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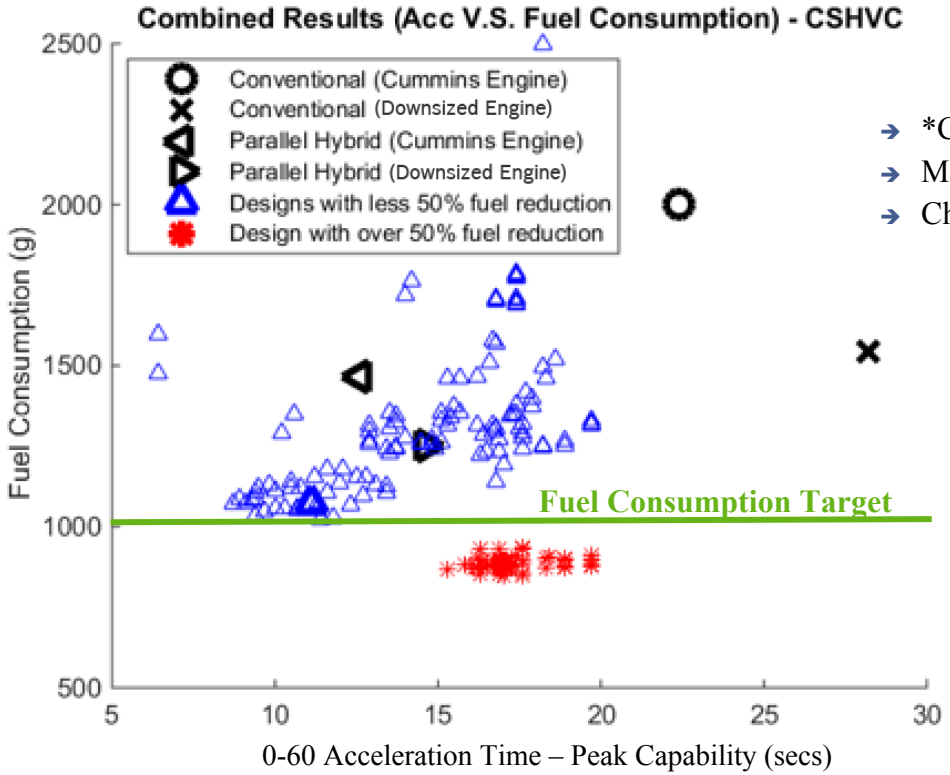
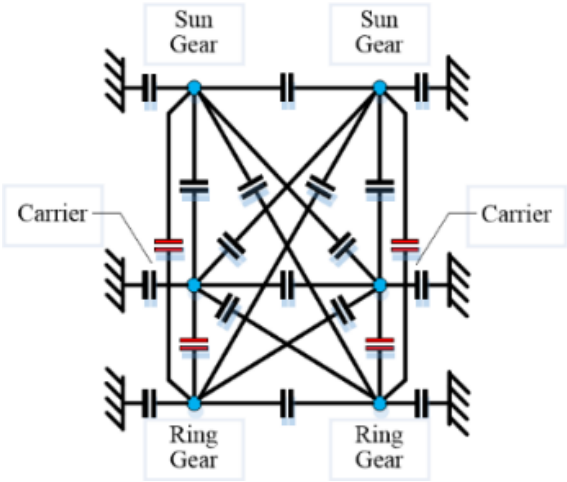
Technical Accomplishments and Progress



- *CSHVC = City Suburban Heavy Vehicle Cycle
- Model Basis: Matlab w/ Dynamic Programming
- Charge sustaining mode



Down selected dual planetary gear topologies from >18 million to 3. Performance is improved. Transmission includes 3-4 clutching elements

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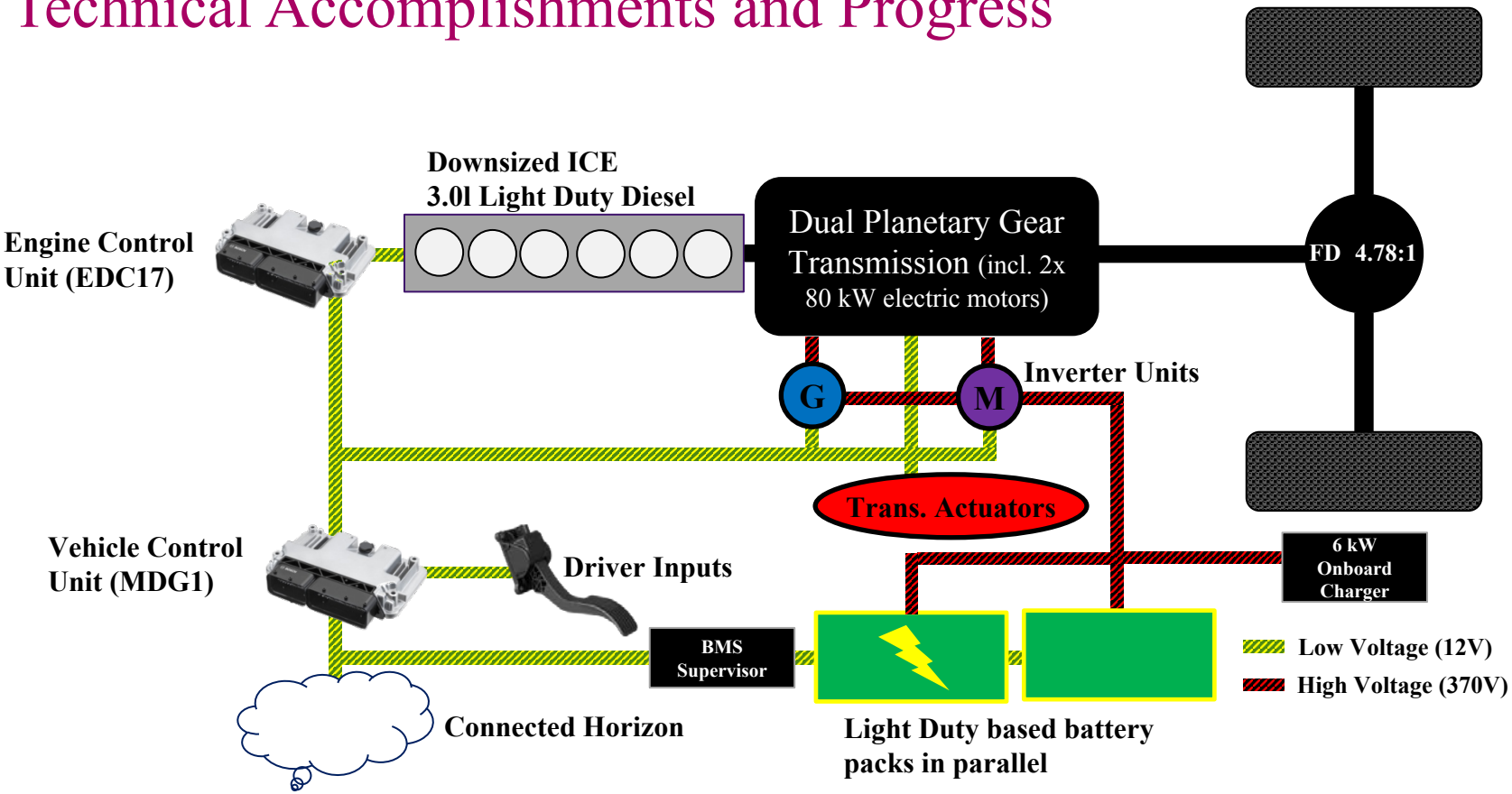
Technical Accomplishments and Progress



Dual-planetary gear PHEV system architecture defined

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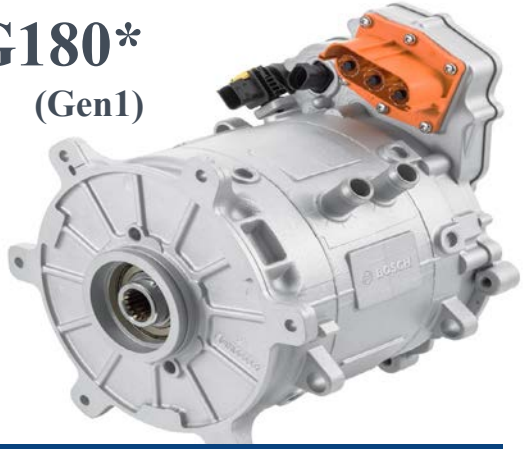
Technical Accomplishments and Progress

SMG180*
(Gen1)

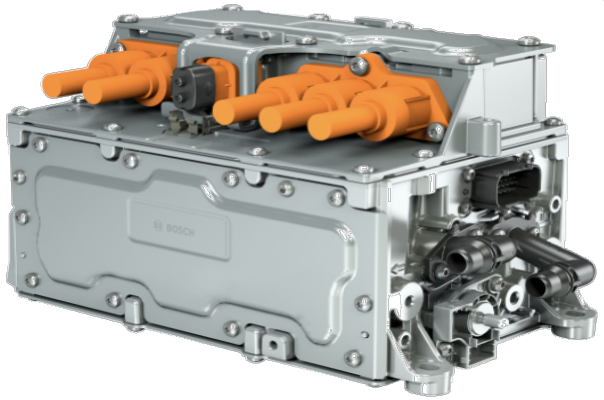


Bosch SMG* 180 Electric Motor
Winner of "Ward´s 10 Best Engines 2014"

Permanent Magnet Synchronous Motor (PSM)

- Peak $torque_{max}$ 200 Nm [@ 370V]
- Cont. $torque_{max}$ 95 Nm [@ 370V]
- Peak $power_{max}$ 80 kW
- Cont. $power_{max}$ 59 kW [@ 370V]
- $Motor\ Speed_{max}$ 12,800 rpm
- Cooling Coolant 8l/min, 85°C_{max}

INVCON**3.3
(Gen3)



*Separated Motor Generator
** Inverter Converter

Defined traction motor sizing → 2x SMG* 180/120 & INVCON3.3

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Responses to Reviewers' Comments

- Project was started in August 2016 and therefore not reviewed last year

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Collaboration with Other Institutions

Organization	Role	Responsibilities
Robert Bosch LLC	Project Lead	Technical project management, downsized engine calibration Vehicle calibration, monitoring strategy support DPF regen and SCR dosing strategy calibration Engine ECU SW modifications for PHEV Design, manufacturing, and interface support of electric motors and inverters Powertrain and controls simulation and calibration, electronic horizon calibration Battery management system, powertrain architecture optimization, controls R&D
University of Michigan	Partner	Powertrain architecture optimization, controls R&D, eHorizon evaluation @ Mcity
Morgan Olson	Partner	Vehicle integration, vehicle fleet testing, consulting
VOSS Automotive	Partner	Thermal management system design, build, integration
NREL	Partner	Vehicle fuel economy validation, drive-cycle definition, cost-benefit ratio analysis, chassis dynamometer testing, field evaluation
Ricardo	Vendor	Transmission design, manufacturing, and interface support
Freightliner Custom Chassis Corp.	Support	Base chassis information support, including CAD models and wiring diagrams

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Remaining Challenges and Future Research

Key Challenges

- Determine optimum battery sizing
  - ↑ Range/ ↓ Size, Weight, and Cost
- Developing and manufacturing a dual planetary gear transmission w/ plug-in electric motors (PC based) for class 4 CV trucks, which is scalable within classes 2b-5
- Achievement of system cost targets and payback period
- Packaging of PHEV system into existing chassis

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

Future Research

BP1 (April – November 2017)
- Optimized Control Strategy Development
- Transmission HW Design Freeze
- Simulation of 50% Fuel Consumption Reduction (Go/No-Go #1)
- Battery Management System- Parallel Pack Control Development

BP2 (December ’17 – November ’18)
- Advanced Battery Management System Control Algorithms
- Delivery of 2 Transmission Samples
- Powertrain Testing
- Chassis Packaging Study
- Thermal System Design
- Electrical System Design
- Chassis Build & Basic Drive Functionality
- Commercialization Plan

BP3 (December ’18 – November ’19)
- Vehicle calibration
- Chassis Dyno Test
- 6 Month Customer Fleet Testing

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Summary

Simulation activities to-date indicate that our PHEV architecture w/ a dual planetary gear transmission will meet the project objective of >50% fuel consumption reduction on the City Suburban Heavy Vehicle Cycle (CSHVC*), even in charge sustaining mode

Features	Fuel Consumption % Improvement
Baseline Vehicle	--
Downsized Engine	22%
Parallel Hybrid w/ downsized engine	39%
HEV w/ Dual-Planetary Gear Transmission and 3 Clutches	61%
PHEV w/ Dual-Planetary Gear Trans. and 3 Clutches (EV only)	100% (58 MPGe**)

*CSHVC = City Suburban Heavy Vehicle Cycle
Model Basis: Matlab w/ Dynamic Programming

**6.68 miles on CSHVC
37.656 kW-h/gallon diesel fuel

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THANK YOU! QUESTIONS?

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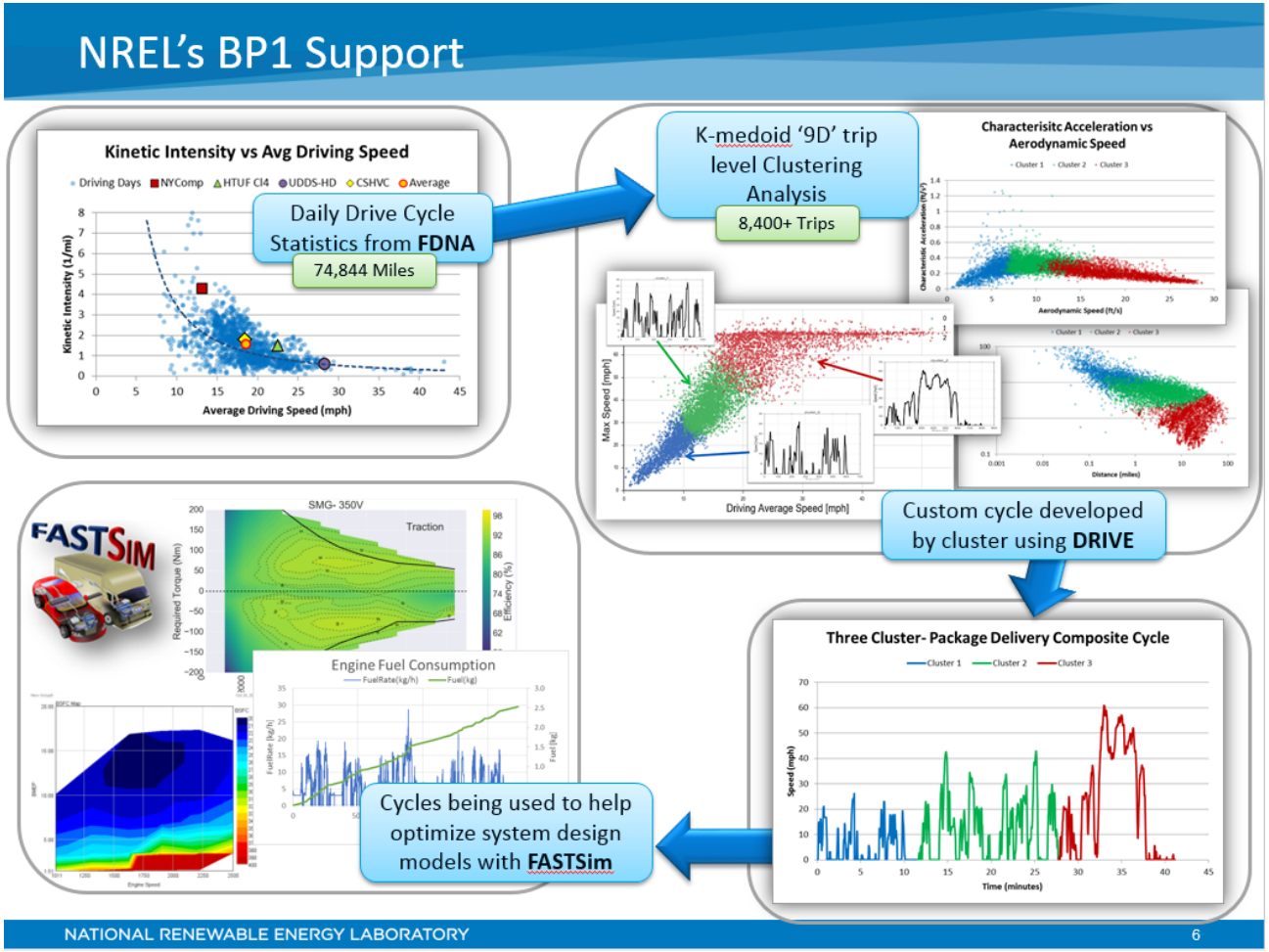
Technical Back-Up Slides

GI190: MURECP Class 4 Delivery PHEV
Technical Backup



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