GI191
Medium Duty Vehicle Powertrain Electrification and Demonstration

DoE VTP Annual Merit Review

PI - Mr. Wiley McCoy

McLaren Engineering

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Medium Duty Vehicle Powertrain Electrification and Demonstration - Overview

DOE Project EE0007513

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Medium Duty Vehicle Powertrain Electrification and Demonstration - Overview

DOE Project EE0007513

Timeline

- Project start date – June ‘16
- Project end date – Nov ‘19
- Percent complete – 30%

Budget

- Total project funding $ 3.65M -
- DOE share - $ 2.64M -
- Contractor share $ 1.01M -
- Funding FY ’16 $ 61K -
- Funding FY ’17 $ 2.37M -

Barriers

(Addressing technical barriers from VT Program Multi-Year Program Plan)

- Acceptance of electric drive as Medium Duty vehicle choice.
- Reduce the carbon footprint of transportation (FE Improvement)
- Cost of hybridization (medium duty TCO)

Partners /Collaborators

- AVL - Technical Partner
- UPS
- Electric Solutions
- Dana

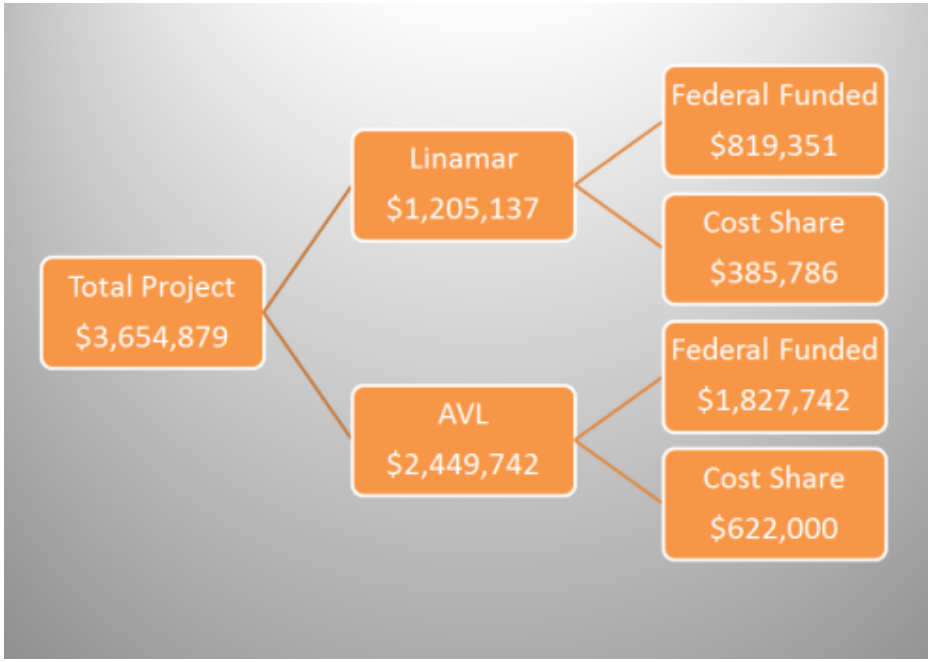
Medium Duty Vehicle Powertrain Electrification and Demonstration - Overview

DOE Project EE0007513

Timing and Budget

- **Total Project Timing is 29 months**

- **Project is divided into three - (3) phases spanning two (2) budget periods.**
  - **Phases 1 & 2 are in BP 1 (14 Months) ends Sept '17**
  - **Phase 3 is in BP 2. (15 Months) ends Dec '18**



Medium Duty Vehicle Powertrain Electrification and Demonstration - Overview

DOE Project EE0007513

Project Overview:

- **Project Objective / Expected Outcome - to attain a 100% improvement in Fuel Economy over real world drive cycles for medium duty package delivery vehicles & achieve a system at project conclusion that can be commercialized.**

- **Project Approach - Team will design and develop a plug-in hybrid powertrain, build 4 demonstration vehicles and run a demonstration of performance, cost and reliability for a period of 12 Months.**

Medium Duty Vehicle Powertrain Electrification and Demonstration – Project Team Resources

DOE Project EE0007513

Overview - Project Team: (Responsibilities & Resources) -

- McLaren Engineering / Linamar – PI, E Axle System engineering, build and development. Prime commercialization agent to OE and Retrofit Markets
- AVL – Plug-in hybrid system, simulation, design, development and vehicle integration; Test program data collection and analysis
- Electric Solutions – Manufacturing advisor for retrofit strategy
- UPS – Demonstration partner
- Dana – Key Supplier for Axle Components

Medium Duty Vehicle Powertrain Electrification and Demonstration – Project Phase 1 Complete

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- **Phase 1 – Power Train Development – Major Tasks**
  - Confirm Vehicle Requirements
  - System Analysis, Drive Cycle Modeling, Fuel Economy Simulation *"Build The System In The Virtual World"*
  - Preliminary Design Package; All System Concepts Complete
  - CORE Reviews and Revisions
  - Vehicle Test Plan Established
- **Key Milestones were Completed on Sept 29, 2016**

- **Phase 1 – Achieved Outcomes**
  - UPS contributed Vehicle Requirements that were integrated into the concept design
  - Analysis and Modeling showed system achieving 100% FE Improvement
  - E-Axle, Range Extender & Battery Design Concepts Completed,
  - Plan for Vehicle Demonstration established with UPS
- **Formal Gate Review was conducted Oct 2016**
- **Approved to proceed to Phase II**

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Medium Duty Vehicle Powertrain Electrification and Demonstration – Phase 1 Concept Design

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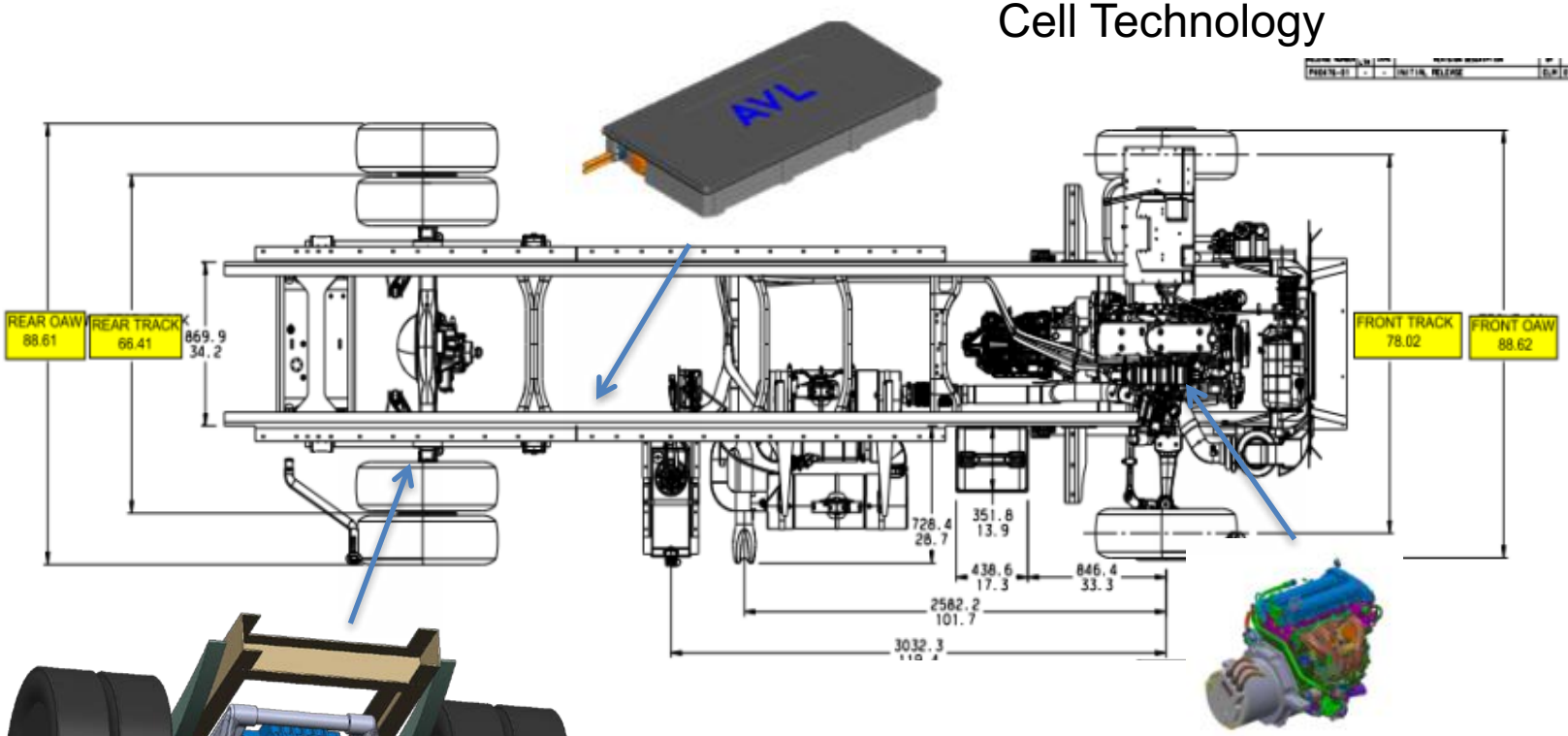
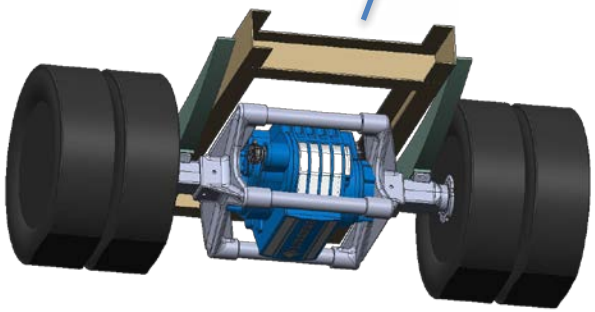
38 kWh Battery

Cell Technology





220 kW eAxle Module
- Independent 2-speed gearboxes

50 kW Auxiliary Power Unit
- Integrated ancillary drive
- LPG Fuel Adaptation

Medium Duty Vehicle Powertrain Electrification and Demonstration – Phase 1 – E Axle System

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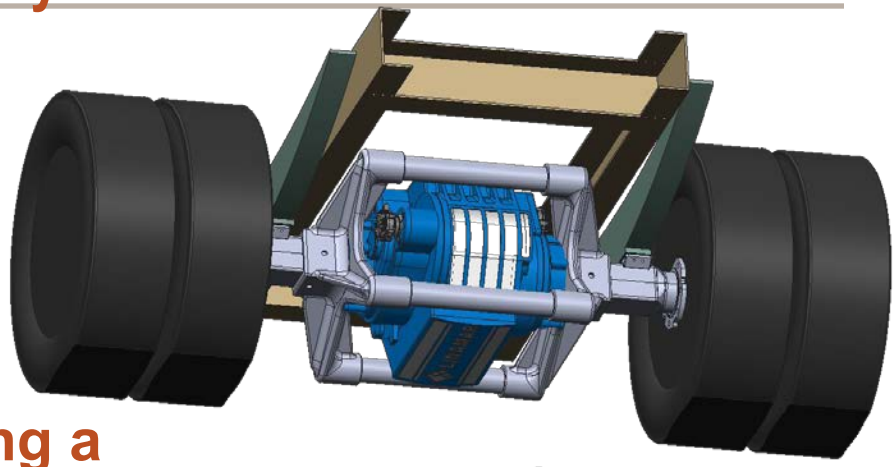
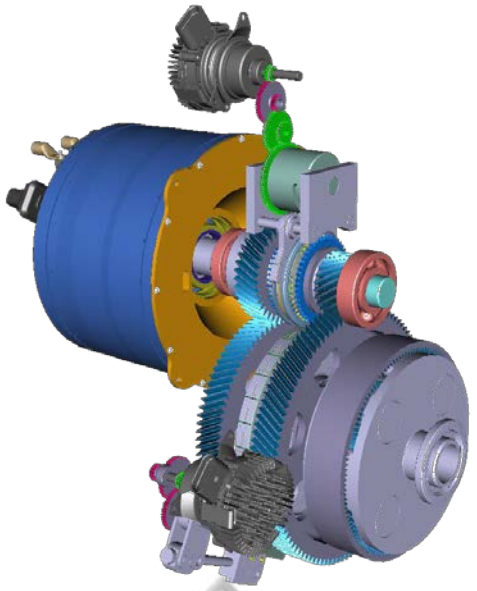


Technical approach – eAxle

System Description:

- All electric drive system using a battery pack for initial zero emissions operation and a range extender system to complete daily routes & eliminate range issues.
- 2 Drive motors integrated into a new medium duty axle design that is based on previous developments w/ 2 spd gearbox.
- Axle design will use Dana components & conform to industry standards for medium duty truck use.



Medium Duty Vehicle Powertrain Electrification and Demonstration – Phase 1 Technical Challenges

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Significant Technical Challenges exist for the final Design Release

- **Technical Challenges - Axle:**
  - **Integration of the Linamar eAxle into a beam axle architecture**
  - **Vehicle Park System Integration**
- **Technical Challenges - Controls**
  - **Synchronization of shift between the left and right drive units**
  - **System optimization to achieve > 100% FE improvements and > 50% CO2 reduction**
- **Technical Challenges - High Voltage**
  - **Battery packaging in modular format to accommodate UPS application and other typical commercial vehicle applications**
- **Technical Challenges - APU**
  - **Engine-off Front End Accessory Drive (FEAD)**
  - **Alternative Fuel - LPG**
- **Technical Challenges - System Integration**
  - **Interaction between foundation & re-gen braking**

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AVL Phase 1 Simulation Summary

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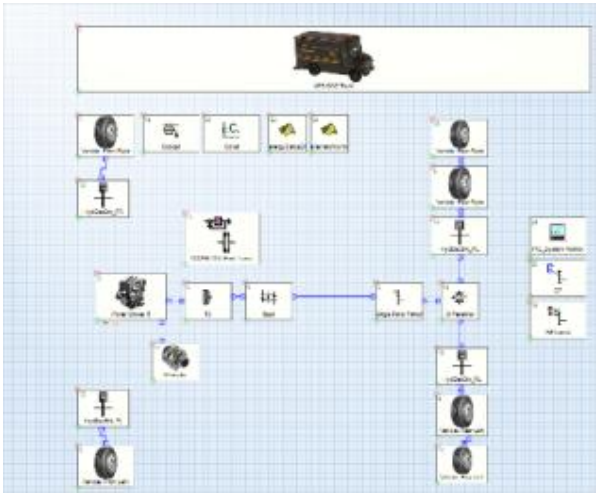
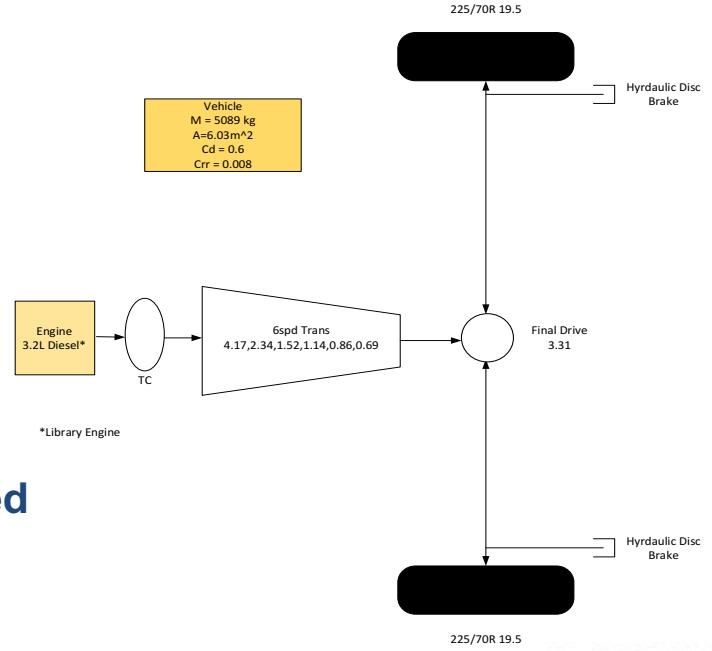
Conventional Vehicle Model (for Baseline FE)

- AVL Cruise used to model vehicle with goals of:
  - Model Baseline vehicle similar to one used in field tests.
  - The same basic vehicle parameters were used
- Vehicle Definition
  - Test Weight: 11220/19719[lbs.]
    - Frontal Area:6.03[m^2]
    - Drag Coeff:0.606
    - Tire Coeff: 0.008 (P225/70R 19.5)
  - Engine:
    - Generic Diesel 3.2L (from library)
  - Transmission
    - 6 Speed Automatic (from library)
- Development notes:
  - Library engine and transmission substituted because no application specific engine or transmission data was available.





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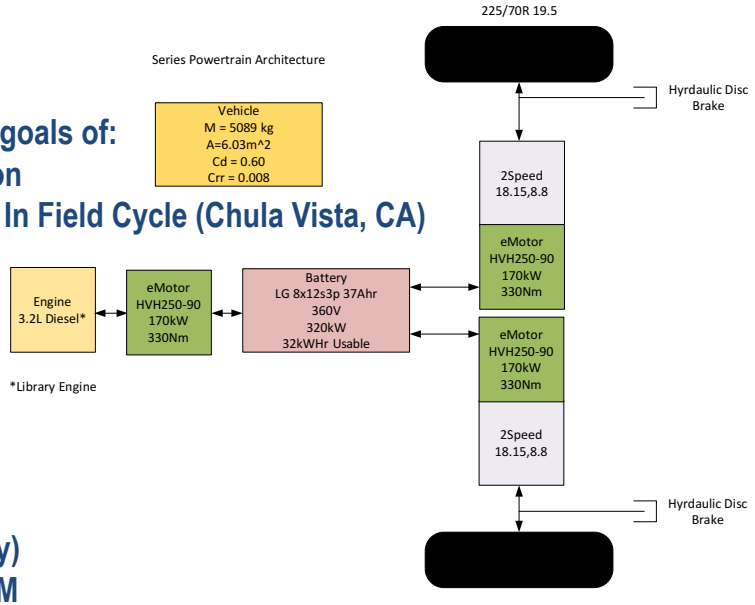
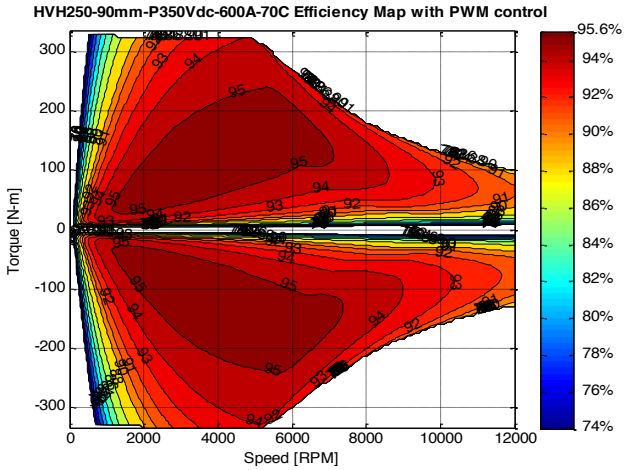
Hybrid Vehicle model

- AVL Cruise used to Model vehicle with goals of:
  - 2spd Gear selection / Optimization
  - Range Estimation based on UPS In Field Cycle (Chula Vista, CA)
  - Estimation Vehicle Performance
- Vehicle (Freightliner MT)
  - Test Weight: 11220/19719[lbs.]
  - Frontal Area:6.03[m^2]
  - Drag Coeff:0.606
  - Tire Coeff: 0.008 (P225/70R 19.5)
- Engine/APU:
  - Generic Diesel 3.2L (From Library)
  - Generator: Remy HVH250-90-DOM
- Battery
  - LG 8x 12s3p x 37 Ahr
  - Nominal Voltage: 360[V]
  - Energy(total/usable): 39/30[kWHr]
  - Power:320[kW]
- 2spd eAxle Direct Drive
  - 2 x eMachines Remy HVH250-90-DOM
    - Peak Torque 332[Nm] per motor
    - Peak Power 172 [kW] @5600[rpm] per motor
  - 2 x 2 Spd gear boxes (optimized gear ratio)
    - 1st gear: 18.15:1
    - 2nd gear: 8.8:1
- All electric range estimated:~40miles





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Fuel Economy Analysis

- Cycle data was obtained from UPS Facility in Chula Vista, CA.
  - Fuel Economy = Distance Traveled (mi.) / Fuel Used (gal.)
  - Electricity is discounted.
- Based on electrical throughput of the hybrid system an All Electric Range estimate could be made.
  - Energy Economy = Energy Through / Distance [kWHr/mi].
- Hybrid and Conventional vehicle models were run at curb weight plus 1500lbs and curb weight plus 10000lbs.
- Distance, Energy and fuel use was accumulated to develop fuel economy estimates.
- The base fuel was diesel and the convert to fuel was propane. The convert to fuel usage was converted based on energy content and fuel density.
- Start Signal Info (i.e. did the operator shutoff the vehicle) was collected to determine idle and auxiliary loading.

All Electric Range Curb + 1500lbs			
	Energy Economy	All Electric Range	Usable Energy
Cycle	[kWHr/mi]	[mi]	[kWHr]
VBS008 Day1	0.758	39.9	30
VBS010 Day2	0.801	37.7	
VBS001 Day4	0.670	45.2	
Average	**0.780**	**38.8**	**30**

All Electric Range Curb + 10000lbs			
	Energy Economy	All Electric Range	Usable Energy
Cycle	[kWHr/mi]	[mi]	[kWHr]
VBS008 Day1	1.040	29.1	29
VBS010 Day2	1.121	27.0	
VBS001 Day4	0.998	30.3	
Average	**1.081**	**28.0**	**29**

Diesel Curb + 1500lbs			
	Conventional	Hybrid	Improvement
Cycle	[mpg]*	[mpg]*	[%]
VBS001 Day4	9.4	20.6	119%

Diesel Curb + 10000lbs			
	Conventional	Hybrid	Improvement
Cycle	[mpg]*	[mpg]*	[%]
VBS001 Day4	6.0	17.8	196%

*0.8 reduction factor applied to simulated FE's

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Hybrid Vehicle Performance

- Predicted Vehicle performance vs. initial requirements.
- Observations:
  - Significantly improved acceleration times
  - Improved Peak Stall
  - Comparable Continuous Stall torque
  - Significantly improved fuel economy.

	Requirement	HDEAXLE HVH250-90mm-DOM		Unit
Mass *All Hybrid values at Test weight unless otherwise stated.*	Curb:4408 Test:5089 GVW:13154	Test:5089		[kg]
Gear1		18.15		[-]
Gear2		8.8		[-]
Final Drive		1		[-]
Total Gear1		18.15		[-]
Total Gear2		8.80		[-]
Peak Power Mechanical		344		[kW]
Continuous Power Mechanical		246		[kW]
Motor Peak Power Time Const.		1		Min
Acceleration 0-100kph	23	10.12		[sec]
Acceleration 60-100kph	15	6.29		[sec]
Acceleration 0-60kph	8	3.83		[sec]
Peak Traction Effort Stall	27	32		[KN]
Continuos Traction Effort Stall		22		[KN]
Top Speed	113	155		[kph]
Maximum Launch Grade @GVW	20	20		[%]
		Pk [30 sec.]	Cnt	
Grade Speed 20%	38	102	50	[kph]
Grade Speed 17%	40	109	88	[kph]
Grade Speed 10%	70	130	120	[kph]
Grade Speed 5%	90	149	135	[kph]
Grade Speed 2%	110	155	150	[kph]
Grade Speed 0%	115	155	155	[kph]
Fuel Economy HDUDDS:(Diesel)	11.4	23		[mpg]
Fuel Economy HDUDDS:(Propane)	7.4	15		[mpg]
All Electric Range	35	38		[mi]
Fuel Capacity (Propane)	45	45		[gal]
Total Range	369	500-600		[mi]

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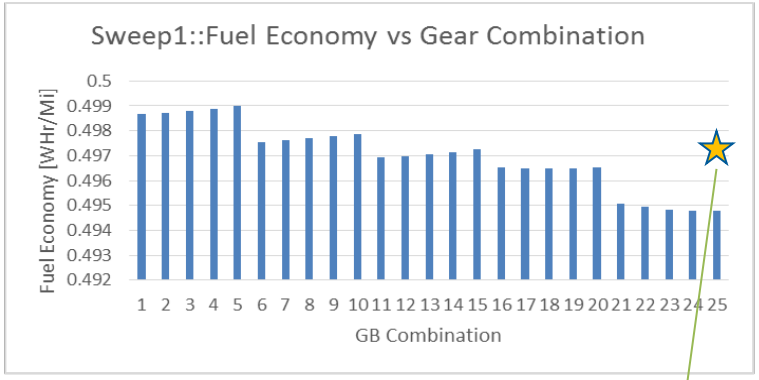
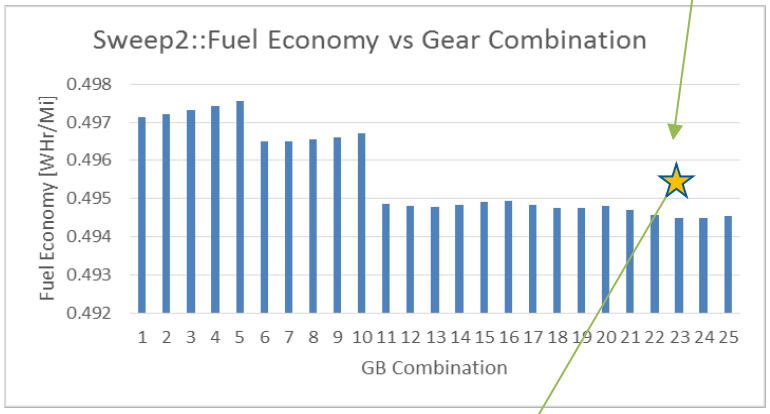
Gear sweep results

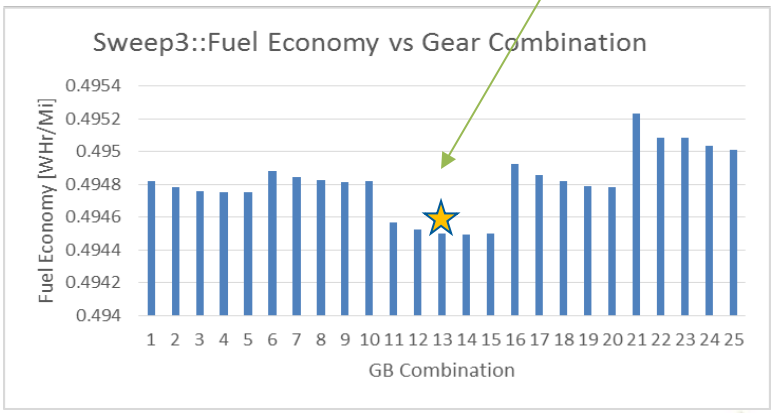
Sweep1		
Var	Case	FE
[-]	[-]	[kWHr/mi]
gb_11	1	0.498660997
gb_12	2	0.498725965
gb_13	3	0.498803317
gb_14	4	0.498888651
gb_15	5	0.498980506
gb_21	6	0.497540605
gb_22	7	0.497606054
gb_23	8	0.497682573
gb_24	9	0.497769237
gb_25	10	0.497859735
gb_31	11	0.496922056
gb_32	12	0.496986957
gb_33	13	0.497062828
gb_34	14	0.497147884
gb_35	15	0.49724031
gb_41	16	0.49653923
gb_42	17	0.496497741
gb_43	18	0.496482128
gb_44	19	0.496491558
gb_45	20	0.496523263
gb_51	21	0.49508642
gb_52	22	0.494935445
gb_53	23	0.494839836
gb_54	24	0.494794349
gb_55	25	0.494792204
	Min	0.494792204

Sweep2		
Var	Case	FE
[-]	[-]	[kWHr/mi]
gb_11	1	0.497132
gb_12	2	0.497224
gb_13	3	0.497325
gb_14	4	0.497434
gb_15	5	0.497553
gb_21	6	0.496508
gb_22	7	0.496514
gb_23	8	0.496548
gb_24	9	0.496615
gb_25	10	0.496701
gb_31	11	0.494856
gb_32	12	0.494797
gb_33	13	0.494792
gb_34	14	0.494837
gb_35	15	0.494916
gb_41	16	0.494951
gb_42	17	0.494825
gb_43	18	0.494761
gb_44	19	0.49476
gb_45	20	0.494797
gb_51	21	0.494699
gb_52	22	0.494566
gb_53	23	0.494498
gb_54	24	0.4945
gb_55	25	0.494546
	Min	0.494498

Sweep3		
Var	Case	FE
[-]	[-]	[kWHr/mi]
gb_11	1	0.49482
gb_12	2	0.49478
gb_13	3	0.494757
gb_14	4	0.494751
gb_15	5	0.494754
gb_21	6	0.494884
gb_22	7	0.494844
gb_23	8	0.494823
gb_24	9	0.494814
gb_25	10	0.494821
gb_31	11	0.494566
gb_32	12	0.494522
gb_33	13	0.494498
gb_34	14	0.494497
gb_35	15	0.4945
gb_41	16	0.494923
gb_42	17	0.494858
gb_43	18	0.494822
gb_44	19	0.494792
gb_45	20	0.494782
gb_51	21	0.495232
gb_52	22	0.495082
gb_53	23	0.495082
gb_54	24	0.495038
gb_55	25	0.495009
	Min	0.494497







Sweep1::Gear Ratio Variations[sw1]					
	1	2	3	4	5
	0.9	0.95	1	1.05	1.1
Gear 1	13.500	14.250	**15.000**	15.750	16.5
Gear 2	7.200	7.600	**8.000**	8.400	8.8
Overall					
Gear 1	13.500	14.250	15.000	15.750	16.500
Gear 2	7.200	7.600	8.000	8.400	8.800

Sweep2::Gear Ratio Variations[sw2]					
	1	2	3	4	5
	0.9	0.95	1	1.05	1.1
Gear 1	14.850	15.675	**16.500**	17.325	18.150
Gear 2	7.920	8.360	8.800	9.240	9.680
Overall					
Gear 1	14.850	15.675	16.500	17.325	18.150
Gear 2	7.920	8.360	8.800	9.240	9.680

Convergence on:
Gear1: 18.150 Gear2: 8.8
FE=.4945 [kWHr/Mi] ** using Crr = 0.004

Sweep3::Gear Ratio Variations[sw3]					
	1	2	3	4	5
	0.95	0.975	1	1.025	1.05
Gear 1	17.243	17.696	**18.150**	18.604	19.058
Gear 2	8.360	8.580	**8.800**	9.020	9.240
Overall					
Gear 1	14.850	15.675	16.500	17.325	18.150
Gear 2	7.920	8.360	8.800	9.240	9.680

Medium Duty Vehicle Powertrain Electrification and Demonstration – Phase 2 - Current Work

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- Phase 2 – ***Power Train Integration into a Vehicle – In Progress Ends Sept '17***
  - Module Design, Release, Sourcing & 1st Vehicle Build
  - Material Procurement - E-Axle, Battery Pack, Range Extender & Auxiliary Systems
  - Module Build and Test
  - Vehicle Controls Development
  - 1st Vehicle Build and Test, Veh 2-4 assembled
  - Controls Testing and Calibration
  - Project Manufacturing Plan – 1st Level
- Phase 2 – ***Expected Outcomes***
  - 1st Vehicle Fulfills UPS Operational Requirements
  - Vehicle Achieves 100% Fuel Economy Improvement in 'Real World'

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Medium Duty Vehicle Powertrain Electrification and Demonstration – Phase 3 - Future Work Tasks

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- Phase 3 – ***Vehicle Build Test and Demonstration – Starts Oct 17, Ends Nov '18***
  - 2nd – 4th Vehicle Builds Completed
  - UPS Demonstration Site Preparation
  - Demonstration conducted – 1 year duration
  - Data Collection and Analysis – All Sub-Systems
  - Project Manufacturing Plan
- Phase 3 – ***Expected Outcomes***
  - 4 Vehicle Test Fleet meets UPS OP Requirements
  - Vehicle Fleet Achieves 100% FE Improvement in 'Real World'
  - Commercialization Plan Finalized

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Medium Duty Vehicle Powertrain Electrification and Demonstration – Phase 3 Future Work

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- **Demonstration Location – UPS Depot, Chula Vista, CA. (near San Diego)**
- **UPS plans to use 4 trial units on normal delivery runs**
- **Data collection system will verify performance**

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Medium Duty Vehicle Powertrain Electrification and Demonstration – Commercialization

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- **Commercialization Strategy**
  - **Commercialization targeted at fleet partner usage**
  - **Volumes will be based on TCO benefits to users**
  - **Collaborations with:**
    - **OEM chassis builder through the fleet partner**
    - **Electric Solutions on retrofits**
  - **Linamar will leverage its $6+ billion components & systems manufacturing business to commercialize medium / heavy duty electric drive systems.**
  - **Linamar can build retrofit kits & OEM systems in its new low volume assembly facility in Livonia, MI.**

Medium Duty Vehicle Powertrain Electrification and Demonstration Summary Slide

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- **Summary**
  - **Phase One was successfully completed**
  - **100% Fuel Economy Improvement demonstrated in a simulation environment**
  - **Phase Two is in process where final designs will be completed, systems sourced, and vehicles built to demonstrate FE objectives.**
  - **Phase Three will be a four vehicle fleet demonstration in the 'Real World'. TCO and commercialization plan will be developed.**

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- **QUESTIONS???**

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