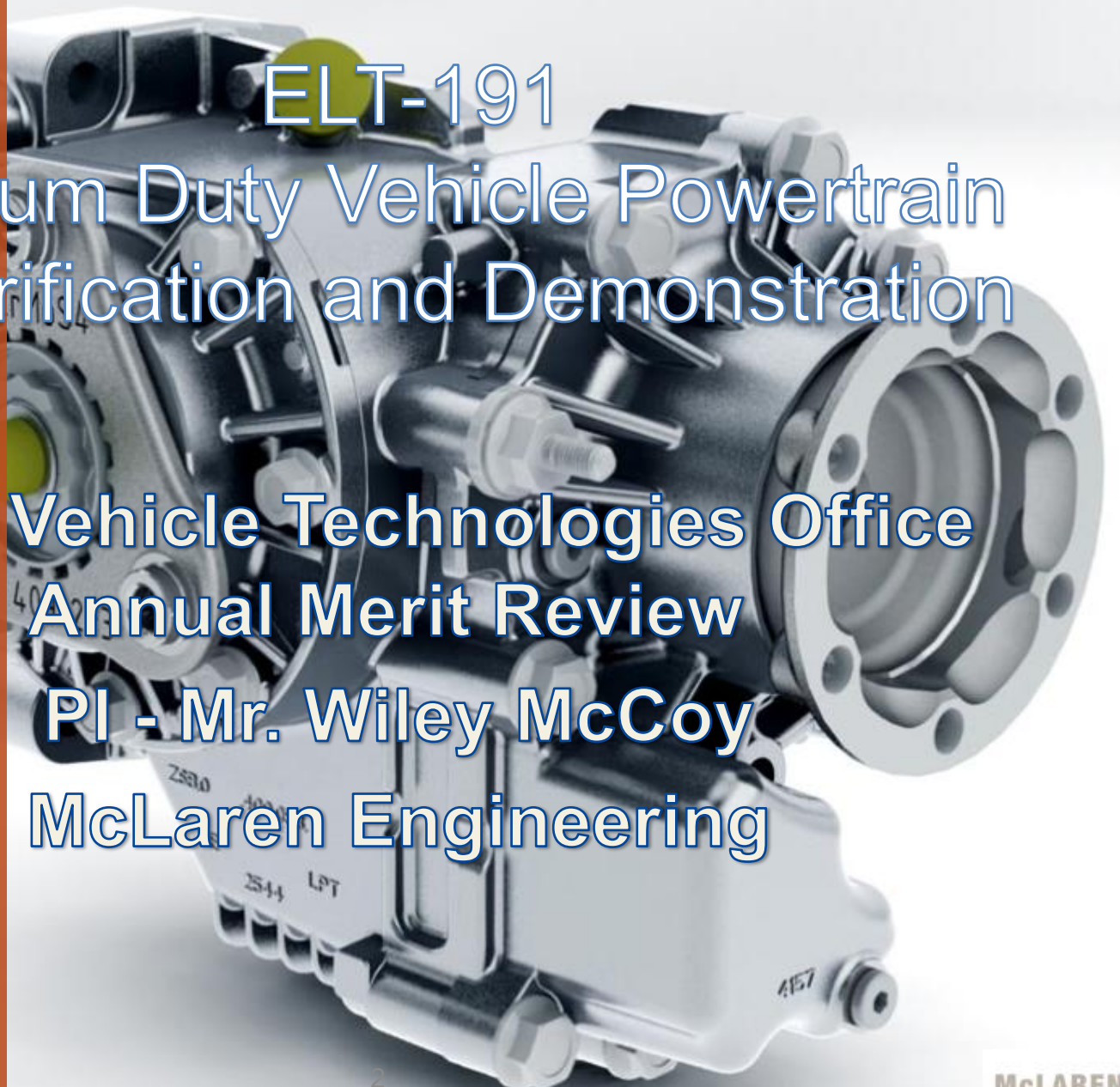
US DoE AMR Review 2020

ELT 191

27 April 2020

ELT-191
Medium Duty Vehicle Powertrain Electrification and Demonstration



DoE Vehicle Technologies Office Annual Merit Review

PI - Mr. Wiley McCoy
McLaren Engineering

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27 April 2020

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 – TBD
Percent complete – 80 %

Budget

Original project budget	**$ 3.65 M**
DOE share	**$ 2.64 M**
Actual Spend to Date	**$ 5.16 M**
Contractor Share	**$ 2.61 M**
Fed Funds Spent	**$ 2.55 M**
Fed Funds Remaining	**$ 0.10 M**

BP2 will end TBD

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 MD hybridization (TCO)

Partners /Collaborators

UPS – Demo Partner
Ford - Commercial Chassis
N-Fab - New Build Supplier
AVL - Tech Partner thru Ph. 2

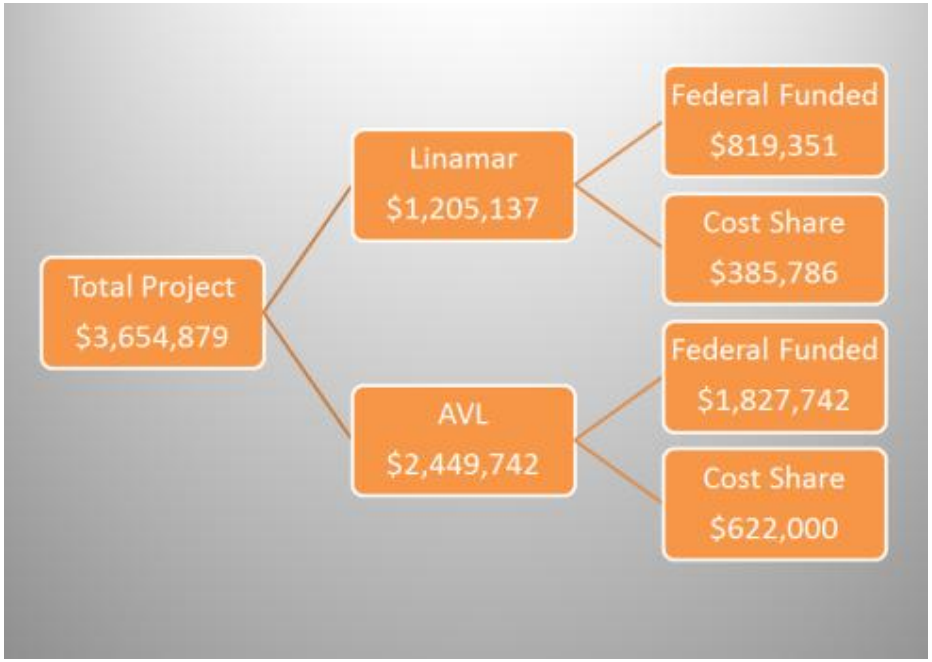
Medium Duty Vehicle Powertrain Electrification and Demonstration - Overview

DOE Project EE0007513

Timing and Budget

- Total Project Timing is now extended to TBD (Interruption by COVID 19 Shutdown)

- Project is divided into three (3) phases spanning two (2) budget periods.
  - Phases 1 & 2 are in BP 1 (23 Months) ended April '18
  - Phase 3 is in BP 2. (16 Months) ends TBD



Original Project Budgets

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, eAxle System engineering, build and development. Test program data collection and analysis. Prime commercialization agent to OE and Retrofit Markets.
- AVL – Plug-in hybrid system, simulation, design, development and 1st vehicle integration.
- N-Fab – Build completion & development support of Demonstration Vehicles.
- Ford – OEM for New e-Chassis, Range Extender powertrain support.
- UPS – Demonstration Partner

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

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- Phase 1 – Power Train Development – Completed 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 Vehicle Test Plan Completed
- 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 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

Medium Duty Vehicle Powertrain Electrification and Demonstration – Project Phase 2 Complete Apr '18

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- Phase 2 – Power Train Design and Build – Completed Tasks
  - Design, Analysis and release of all systems' components
  - Source and procure all systems' components
  - Build, fitting and commissioning of initial full vehicle
  - Commissioning and calibration of full vehicle
  - Confirmation of 100% FE improvement as predicted.
- Key Milestone was completed on April 30, 2018

- Phase 2 – Final Outcomes
  - Systems were built, pre-tested and assembled into Vehicle 1.
  - Initial Testing shows system achieving 100% FE Improvement
  - E-Axle, Range Extender & Battery first builds were completed,
  - Plan for Vehicle Demonstration finalized with UPS
- Formal Gate Review was conducted May 3, 2018
- Approval Granted to proceed to Phase III & BP2

Medium Duty Vehicle Powertrain Electrification and Demonstration – Phase 3 Technical Challenges

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New technical challenges arose during continuous functional system testing. The following sequence of system issues and updates from the Q3 and Q4 2019 time period is presented below:

- **The remote oil supply and scavenge system required modifications to increase oil flow and return. Increased capacity and de-areation capability were added & tested in a tech cell environment.**
- **E-Motor resolver failures were addressed**
- **An active positive ventilation system was developed**
- **Various 2 speed shifting strategies were developed in a cell environment for further on-road dynamic testing.**
- **On-road testing resumed in Q4. After several hundred miles of "ghost" duty cycles, a catastrophic failure of the 2-speed occurred. (See Side Bar – Page 11)**
- **A recovery program was instituted, continued into Q1 2020.**

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Side Bar

- Functional Testing in a dynamic test cell environment continued thru the Summer, 2019. By August, a unit was ready for in-vehicle on-road testing.
- One package car was prepared, instrumented for data acquisition and a McLaren Team, in Sept, operated the unit on a local Orange County roads.
- A Ballast system was developed using water filled barrels.
- Several hundred miles were completed before a failure developed in the 2-speed shifting mechanism.
- The e-axle was removed and sent back to McLaren Detroit for analysis and modifications.

Medium Duty Vehicle Powertrain Electrification and Demonstration – Phase 3 Technical Challenges

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Timeline of issues and actions - *April 2019 to April 2020*

- Cell testing in *April 2019* found inadequate oil flow VS de-aeration capability
  - Modifications required to oil pump sizing/capacity and an active positive ventilation system created.
  - Invertor overheating in vehicle system solved with coolant flow modifications.
  - E-Motor resolver failure required adjustments made with E-motor supplier
- The series of issues addressed during *3rd Quarter 2019*.
  - Modified E-axle system returned to California location and one vehicle returned to road testing – *Sept. 2019* (See Side Bar Page 11)
  - E-Axle return to McLaren, Detroit for 2 speed failure Assessment – *October 19*
  - Teardown/failure analysis completed *October/November 2019*
  - Mid *December 2019* 2 speed recovery plan developed
- *Activities in 1st Quarter 2020*
  - 2 speed recovery plan initiated.
  - Involved redesign & manufacture of certain parts, bench test of same, followed by dynamic cell testing.
  - Control software updates were developed in parallel.
  - March 30, 2020 - last iteration ready for dyno test. Not completed due to COVID 19 shut down.

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

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DOE Project EE0007513 Any proposed future work is subject to change based on COVID 19 Shutdown

- **Phase 3 – *Vehicle Build, Test and Demonstration***
  - ***Tasks Completed To Date:***
    - ***3 vehicles are complete mechanically and hi-voltage components are complete & ready for installation***
    - ***A 4th vehicle has all systems completed but not installed. May become 'spares' for a 3-vehicle test fleet – TBD***
  - ***Tasks due to be Completed:***
    - ***Vehicles will re-start the simulated UPS route schedule and run to meet UPS reality criteria. Exact goals & Milestones to be determined in collaboration with UPS/DOE.***
    - ***Primary DOE requirements of 100% FE improvement in "Real World" conditions is still primary target to verify.***

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Medium Duty Vehicle Powertrain Electrification and Demonstration

- *DOE Project EE0007513 Any proposed future work is subject to change based on COVID 19 Shutdown*

Commercialization Strategy

- ***Commercialization of this full design iteration is not economically feasible for this duty cycle / vocation.***
- ***Linamar is committed to applying the learnings of this program to the development of future 2 speed systems for electric powered commercial trucks in alternative weight classes that will potentially be Zero Emissions.***
- ***Linamar is proceeding with development of an updated design for commercialization of this duty cycle for medium/heavy duty electric drive systems.***

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- **Prior Year Reviewer Comments**
  - ***A reviewer commented last year regarding delays in the program that required redesign of different components. I was further commented that the DOE funds had been almost spent and that if phase 3 was extended, perhaps specific milestones & metrics should be re-set to evaluate success.***

- ***Answer:***
  - **As the current reports shows, another year has brought to light various new shortcomings that have kept the vehicles out of full UPS service. The DOE funds have been depleted, except for a minor amount that is designated for support once the vehicles are in UPS hands. Linamar recognizes that new issues have arisen that change the intermediate goals. A "Phase 2.5" has been instituted that is an extension of development. New goals/metrics are still being formulated.**

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- **Prior Year Reviewer Comments**
  - ***Various reviewers commented on a shortfall of technical accomplishments and progress toward goals and proposed future research. A comment was made that the program had shifted focus onto vehicle testing, demonstration and calibration.***

- ***Answer:***
  - **Progress towards goals in previous time scales have all changed, but the primary focus of the program has always been to develop and demonstrate a commercially capable and available E-axle system that meets the primary DOE requirements of 100% FE improvement. Linamar has employed its ability and capability to continue to test and develop this system & has reached a conclusion: The system as presently configured will not be commercially feasible. A second-generation system that is commercially viable is being deployed. That said, this GEN1, 2 speed project will continue thru to a 12-month, "Real World" demo period with UPS. The operational knowledge gained will be invaluable to all the partners.**

Forward Looking Information, Risk and Uncertainties

Certain information regarding Linamar set forth in this presentation and oral summary, including managements assessment of the Company's future plans and operations may constitute forward-looking statements. This information is based on current expectations that are subject to significant risks and uncertainties that are difficult to predict. Actual results may differ materially from these anticipated in the forward-looking statements due to factors such as customer demand and timing of buying decisions, product mix, competitive products and pricing pressure. In addition, uncertainties and difficulties in domestic and foreign financial markets and economies could adversely affect demand from customers. These factors, as well as general economic and political conditions, may in turn have a material adverse effect on the Company's financial results. The Company assumes no obligation to update the forward-looking statements, or to update the reasons why actual results could differ from those reflected in the forward-looking statements.

- **QUESTIONS???**