US DoE AMR Review 2019

ELT 191

12 June 2019

ELT-191
Medium Duty Vehicle Powertrain Electrification and Demonstration

DoE Vehicle Technologies Office Annual Merit Review

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McLaren Engineering

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12 June 2019

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 – Aug 2020
Percent complete – 75 %

Budget

Original project budget	$ 3.65 M
DOE share	$ 2.64 M
Actual Spend to Date	$ 4.74 M
Contractor Share	$ 2.35 M
Fed Funds Spent	$ 2.39 M
Fed Funds Remaining	$ 0.25 M

BP2 will end Aug 2020

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

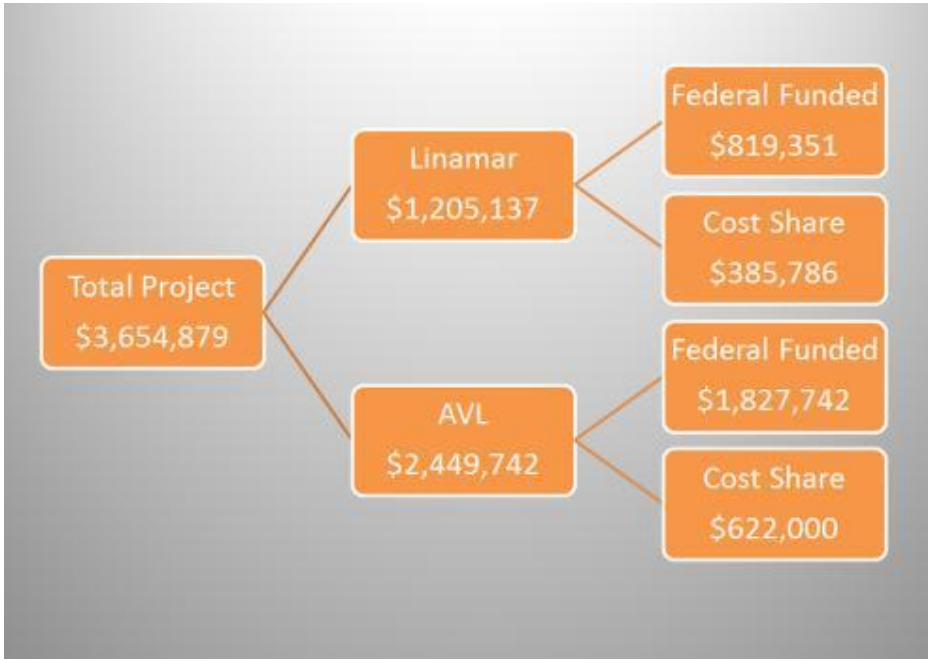
Medium Duty Vehicle Powertrain Electrification and Demonstration - Overview

DOE Project EE0007513

Timing and Budget

- Total Project Timing is now extended to 48 months

- Project is divided into three (3) phases spanning two (2) budget periods.
  - Phases 1 & 2 are in BP 1 (23 Months) ends April ‘18
  - Phase 3 is in BP 2. (16 Months) ends Aug ’20



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**

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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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During the functional systems testing and commissioning of the vehicles, new Technical Challenges arose in Ph 3 . The time to solve all of them was much greater than anticipated because they arose at different times in the commissioning process. McLaren and UPS agreed that a well developed, reliable system was the priority.

Specific Technical Challenges – eAxle & Charge System

- **Lubrication issues,**
- **Park lock engagement issues,**
- **Inverter communication issue,**
- **Wiring issues,**
- **Sealing issues,**
- **Bearing specification and procurement issue,**
- **Charge system communication issue**

Medium Duty Vehicle Powertrain Electrification and Demonstration – Phase 2 Build (Ford Chassis shown)

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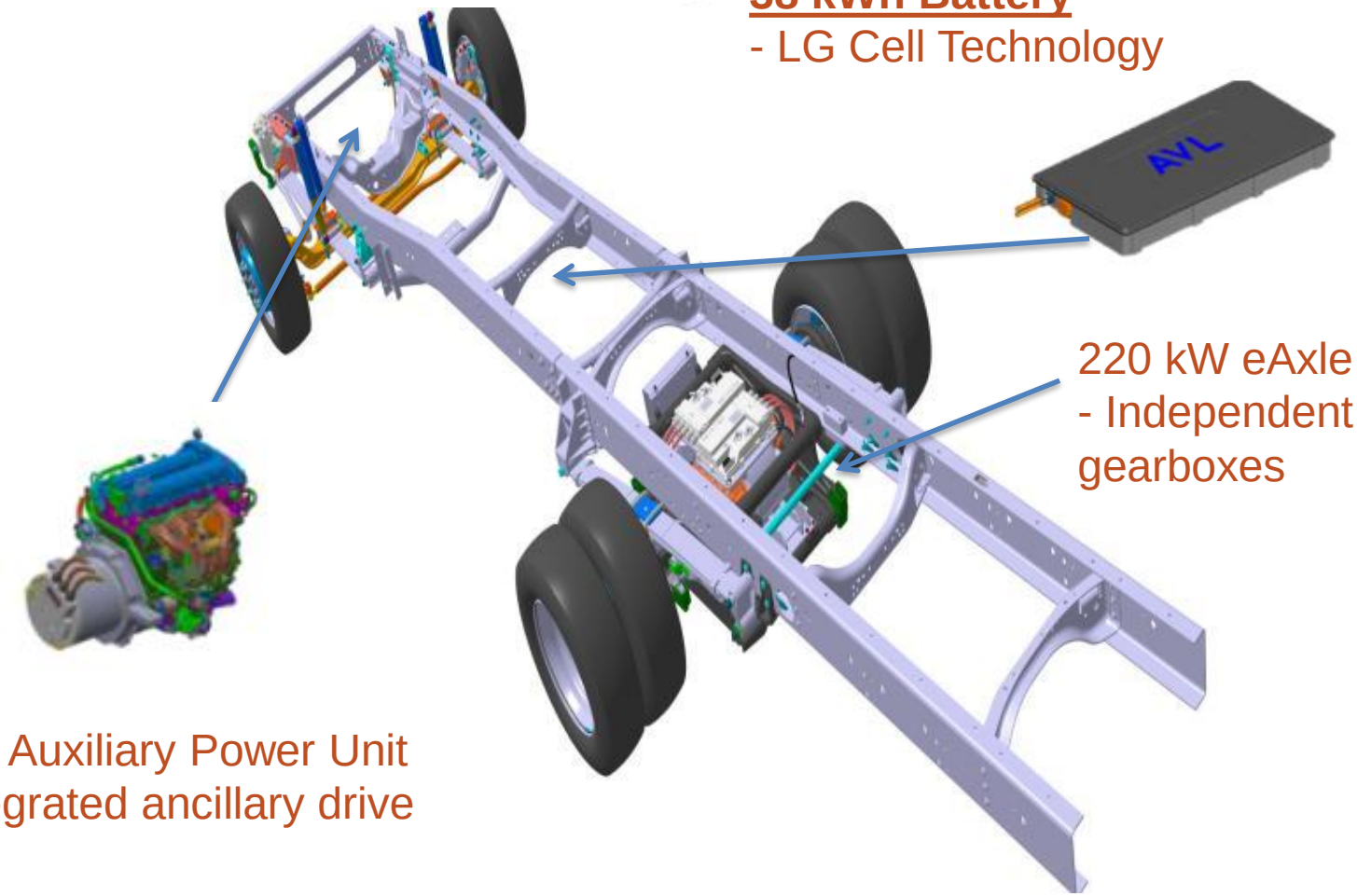
38 kWh Battery
- LG Cell Technology



220 kW eAxle Module
- Independent 2-speed gearboxes

50 kW Auxiliary Power Unit
- Integrated ancillary drive

Class 6 Commercial Truck Dual Motor eAxle w/Gearbox

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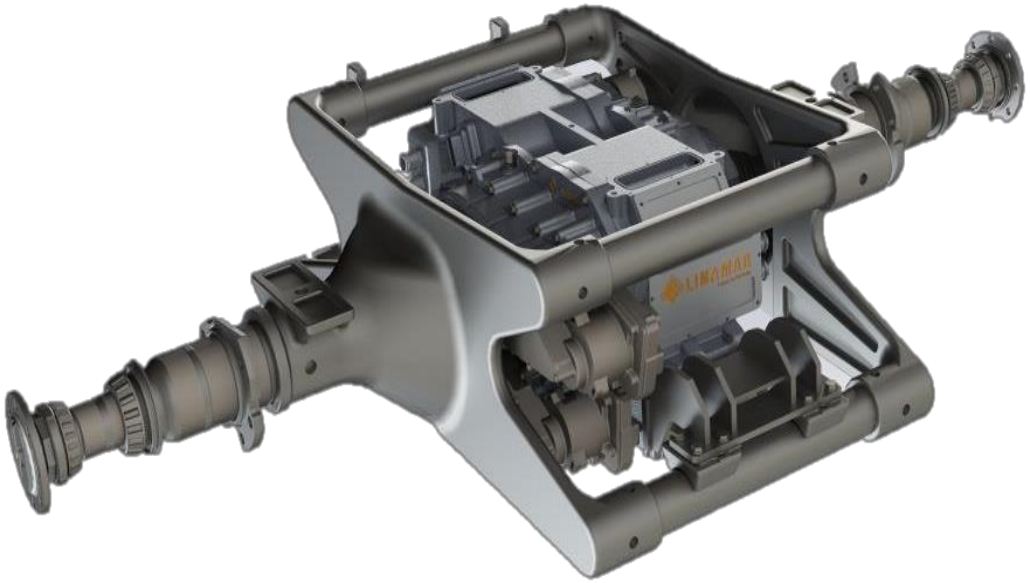
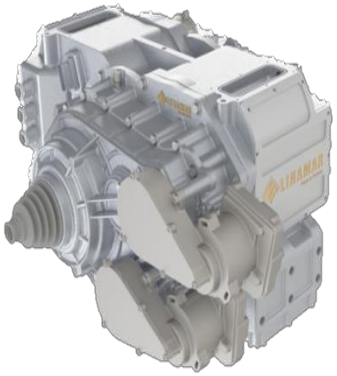
Medium Duty Plug-In Hybrid Electric Electrified Axle Module



Features

- eAxle Assembly for Class 6 Truck
- 1 year Fleet Study in 2018
- Dual Independent motors
- 2-Speed Synchronized Gearbox
- Integrated Park Lock



System Specifications

Total Rated Input Torque	664 Nm
Rated Input Speed	10,600 RPM
Max Output Torque	11,900 Nm
Max Output Speed	1,200 RPM
Transmission Layout	Parallel Axis
Parklock	Yes
Disconnect	Neutral Shift Position
Lubrication	Electric Forced Lube
Package Space	825x700x420 mm
# of Forward Ratios	2
1st Gear Ratio	17.9
2nd Gear Ratio	8.8
Peak Power	276 kW
Output Shafts	Splined Axle Shafts

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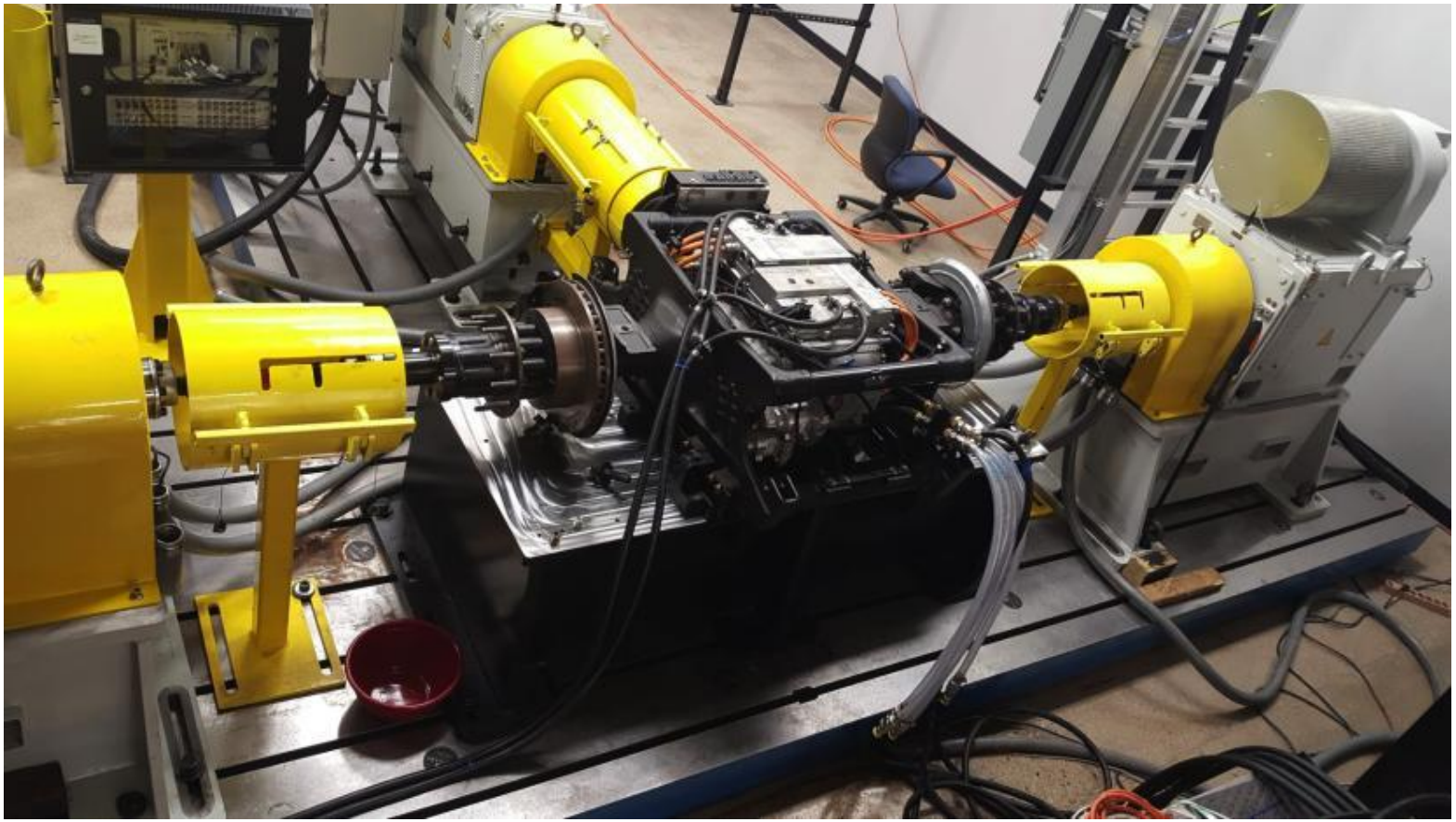
Class 6 Dual Motor eAxle Test on Linamar/McLaren Dyno

Medium Duty Plug-In Hybrid Electric Vehicle Electrified Axle on Test Dyno



Class 6 Demonstration Vehicle

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Medium Duty Plug-In Hybrid Electric Vehicle Utilizing an Electrified Axle

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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 – Tasks Started May '18***
  - System Updates and Vehicle Build Completion
  - UPS Demonstration Site Preparation – May '19
  - Demonstration Conducted – 1 yr starting Jul '19
  - Data Collection and Analysis – Jul '19 – Jun' 20
  - Final Report & Manufacturing Plan – Aug '20
- **Phase 3 – *Expected Outcomes***
  - 4 Vehicle Test Fleet will Achieve UPS OP Req'ts
  - 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 electrified package cars (2 new & 2 retrofits) on normal delivery runs**
- **Data collection system will verify performance**

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 after product costing is completed.**
  - **Collaborations with:**

    Ford chassis builder through the fleet partner
  - **Linamar is proceeding with development of an updated design for commercialization of medium / heavy duty electric drive systems.**
  - **Advances in eDrive motor technology has facilitated this updated design.**

Medium Duty Vehicle Powertrain Electrification and Demonstration Summary Slide

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- **Summary**
  - **Phase 2 was successfully completed but timing was extended by 7 months.**
  - **Phase 3 had an extended lead-in due to a number of technical and business issues.**
  - **Phase 3 timing has been extended because McLaren is committed to complete the demo and gain knowledge for future commercialization.**
  - **Added project costs are being borne by Linamar. To date, no Fed funds increase requested.**
  - **Phase 3 remains a four unit, 1 Year long fleet demonstration in the 'Real World'. TCO and commercialization plan will be developed.**

- **Prior Year Reviewer Comments**

Most comments were positive citing the team composition and the process.

One reviewer commented that the process used for selecting the electrification architecture was unclear, and that the authors should provide more details, to better assess whether the optimal solution was achieved, prior to the detailed design phase of the project.

Ans: The selection of the architecture to be demonstrated was a subject of the proposal phase of the program. It was a DoE decision to award grants to three different architectures. The data from the three programs will establish which architecture may be best suited for specific types of drive cycles.

- **Prior Year Reviewer Comments**

One reviewer stated that the fact that the project team is taking the time to refine the design and incorporate feedback from the manufacturing team may be a good sign of the long-term impact of this project.

Ans: The team has gained enormous knowledge from this program. Current and future production designs will use this knowledge as well as the rapid advances in technology in eDrives since the start of the program. i.e. Drive motors have advanced to allow a lower cost single motor/single speed design which will be built for a new test program funded by CARB.

Prior Year Reviewer Comments

In one reviewer's opinion, the project should better discuss the overall project objectives of a retrofitable design, or how easily it could be designed into other chassis; this was not discussed in enough detail.

Ans: It may not have been clearly stated that there are four vehicles in the demonstration program. Two are new vehicles and two are retrofits of used vehicles. The systems are essentially the same except for mounting brackets. These older chassis are quite common in the delivery vehicle fleets in the USA.

Prior Year Reviewer Comments

One reviewer stated that the planned testing period will likely be shortened, due to slippage in the delivery schedule, and the reduced testing time may reduce some of the information value from the project. Although it is not the end of the world; if the technology gets a commercial foothold, then reliability data will be developed later.

Ans. It has been decided that the demonstration testing period will NOT be shortened and that the prime contractor is intending to support the demonstration through to conclusion to gain the maximum knowledge possible.

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???**