FINAL REPORT

For Contract Ending June 30, 2014

DOE Award: DE-EE0001814
Recipient: Workhorse Sales Corp.
Project Title: Commercial Electric Vehicle (EV) Development and Manufacturing Program
Principal Investigator: Dion van Leeve

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A. Executive Summary

Navistar with the Department of Energy's assistance undertook this effort to achieve the project objectives as listed in the next section. A wholly owned subsidiary of Navistar, Workhorse Sales Corporation was the original grant awardee and upon their discontinuation as a standalone business entity, Navistar assumed the role of principal investigator. The intent of the effort, as part of the American Recovery and Reinvestment Act (ARRA) was to produce zero emission vehicles that could meet the needs of the marketplace while reducing carbon emissions to zero. This effort was predicated upon the assumption that concurrent development activities in the lithium ion battery industry investigations would significantly increase their production volumes thus leading to substantial reductions in their manufacturing costs. As a result of this development effort much was learned about the overall system compatibility between the electric motor, battery pack, and charging capabilities. The original system was significantly revised and improved during the execution of this development effort. The overall approach that was chosen was to utilize a British zero emissions, class 2 truck that had been developed for their market, homologate it and modify it to meet the product requirements as specified in the grant details. All of these specific goals were achieved. During the course of marketing and selling the product valuable information was obtained as relates to customer expectations, price points, and product performance expectations, specifically those customer expectations about range requirements in urban delivery situations. While the grant requirements specified a range of 100 miles on a single charge, actual customer usage logs indicate a range of 40 miles or less is typical for their applications. The price point, primarily due to battery pack costs, was significantly higher than the mass market could bear. From Navistar's and the overall industry's perspective, valuable insights and lessons into this all-electric vehicle propulsion were gained during the performance of this effort and can be revisited when battery chemistry and technology advance to the point of more suitable economic viability. Additionally, another goal of the ARRA act and this specific grant was to manufacture the product in the, at that time, economically depressed Northwest Indiana area. Navistar chose a location in Wakarusa, Indiana which fulfilled this requirement. Navistar was and continues to be committed to alternative fuel and propulsion options as an industry leader in the medium and heavy duty truck industry.

B. Project Objectives

The objective of this project was to manufacture and distribute zero tailpipe emission, light/medium duty commercial electric vehicles (EV) in the United States. Navistar was to develop and demonstrate at least 950 EVs (Class 2c through Class 5 trucks) in the U.S. market. Specific objectives of this project included demonstrating the applicability of EV technology for commercial transportation applications, demonstrating reliability in geographically and climatically diverse locations, demonstrating a reduction in carbon emissions, while using no fossil fuels. Additionally it addressed the needs of the customers while enhancing the EV attributes to achieve mass market penetration in the future. Navistar applied its affiliates' in-house engineering, product development, manufacturing, marketing, and distribution expertise in preparing the vehicles for market introduction. This preparation required, among other activities, ensuring full compliance with Federal Motor Vehicle Safety Standards (FMVSS) and tailoring the functionality of the vehicle to customer requirements. Navistar demonstrated in-service functionality and accelerated the initial adoption of electric vehicles.

C. Project Scope

During PHASE 1, Navistar focused on preparing its on-road commercial EV for distribution in the commercial market. PHASE 1 included the integration of EV technology into existing conventional vehicle platform displacing the traditional internal combustion powertrain. Navistar utilized its engineering and design expertise in preparing the vehicles to comply with FMVSS. Navistar and its supply partners began developing component technologies and subsystems that facilitated the rapid acceleration of manufacturing capability within the U.S. Navistar prepared full scale marketing and distribution plans and engaged regularly with its dealers in preparing the service and support network. Navistar began manufacturing and assembling the vehicles at selected Navistar Elkhart County, Indiana manufacturing facility, created and maintained jobs and boosted the local economy. Navistar initially planned to deliver at least 950 vehicles to a variety of customers. Also during this phase, a thorough review of the vehicles' performance continued and data gathered on in-use performance was received and assimilated into the product development process. Early EV experience was used to investigate an electric powertrain and create a broader range of more efficient and cost effective electric vehicles based on existing vehicle platforms. Phase 2 began, while still completing Phase 1 along with the deployment of vehicles during which Navistar gathered in-service vehicle operating data in order to understand vehicle and component performance in real world situations. This data was used for further testing and development work. In parallel, Navistar began to execute its technology and cost reduction strategies. This was intended to lead to significant job creation in the United States and throughout the electric vehicle value chain.

D. Tasks that were to be performed during the course of the project

Phase I: In Phase 1 of the program, Navistar would manufacture and deploy demonstration vehicles to U.S. customers. Specific tasks performed during Phase 1 include:

Task 1 – Project management and planning:

Navistar developed comprehensive budget, timeline and workplans for the EV program, identified risks and developed mitigation plans. Navistar Identified and appointed a dedicated EV program team.

Task 2 – Develop initial EV deployment plan:

Navistar identified potential customers for vehicles in target geographies and engaged them in negotiations about future deliveries, custom specifications and data collection requirements. Also, Navistar conducted outreach campaigns to showcase demonstration vehicles to potential customers and generated publicity necessary for success of the initial deployment. A thorough market analysis was conducted for EVs and comparable conventional vehicles (incl. total cost of ownership analysis, conjoint pricing analysis, etc.) and determined a pricing strategy for successful deployment of initial demonstration and ramp-up in volumes. Contractual relationships with critical suppliers of EV parts and components were secured. Detailed launch plans for the initial three diverse geographic markets where vehicles were deployed were developed.

Task 3 – Make necessary improvements to the EV to make it fully compliant with United States transportation and emissions regulations:

Vehicle testing, development and validation to ensure compliance with U.S. regulations was accomplished via U.S. Homologation – development, prototyping, certification and manufacturing implementation of EV components requiring adaptation to U.S. safety and manufacturing standards.

Task 4 – Begin and ramp up production of the vehicles:

Initial pilot units were built. Next a steady state manufacturing process for volume production was established. Upon completion, a regular volume production of the vehicles commenced with associated training and hiring of new assembly workers to meet production levels.

Task 5 – Establish EV aftermarket support network:

A dealer and service network was established and training was completed on the new product line. Aftermarket parts distribution logistics and processes were established. Charging infrastructure partners were identified via the Electrification Leadership Council and established relationships to support future EV deployment in the target markets.

Task 6 - Establish infrastructure for data collection on demonstration EVs:

Requirements were identified for the data collection program (reference Appendix I.3 for representative information). A suitable data collection provider was selected. The unit was integrated into the vehicle and tested data collection hardware into EV. The data collection methodology was established and monthly reporting of the collected data was occurring to NREL.

Task 7 – Initiate EV deployment with U.S. customers:

EVs were deployed with customers in at least three markets, (Portland OR, Los Angeles CA, and New York NY) and the data collection program was initiated. The collected data from the vehicles deployed in the initial markets was analyzed and applied the findings to further product development.

Task 8 – This task would cover Product Development of Advanced EVs:

A customer optional air conditioning (HVAC) system was integrated and offered on the vehicle. Designs were completed to offer various battery pack sizes to offer potential customers various range choices. An intelligent parking brake “hill hold” solution was achieved which improved the vehicle’s operational safety and minimized the inefficient use of electric power.

Task 9 – Creation of an Electrification Leadership Council including representatives from other electric vehicle OEMs, suppliers, potential customers, finance companies, etc., to promote and encourage the overall development of electric vehicle technology and the U.S. electric vehicle market as a whole.

The council was established and met several times in various geographic areas.

Task 10 – **Development of the next generation of EV propulsion systems:**

This effort had not yet begun.

Task 11 - **Include development of features driven by customer and market requirements.**

This effort had not yet begun.

Phase 2: **During Phase 2, Navistar would undertake a comprehensive data collection and analysis program to provide a detailed understanding of vehicle in-use performance. This phase will overlap with Phase 1 activities. Specific tasks to be performed in Phase 2 include:**

Task 12 – Conduct data collection and analysis program:

Comprehensive performance, climatic and operating data on the units deployed for a period of at least 2 years. It was intended to integrate results of data collection into further Product Development programs.

Task 13 – Implement cost reduction initiatives:

This effort had not yet begun.

Task 14 – **Conduct Canadian homologation - Development, prototyping, certification and manufacturing of components requiring adaptation to Canadian safety and customer standards thus increasing U.S. production and job creation.**

This effort was completed and resulted in units being shipped to Canada and put in service in various locations.

Task 15 – **Ongoing evaluation of technology advancements to improve EV's performance, range, efficiency, customer appeal and while reducing manufacturing and operating costs.**

This effort had not yet begun.

Task 16 – **Continue integration of EV technologies into other existing conventional vehicle platforms to improve fuel economy. It is the intention of Navistar to use whatever knowledge is gained from this program to develop improvements to current and/or future vehicle platforms.**

This effort had not yet begun.

E. Briefings/Technical Presentations/Marketing Activities

Several technical briefings were given by Navistar to the DOE to explain the status, technical results, and near-term plans of the project efforts at the time.

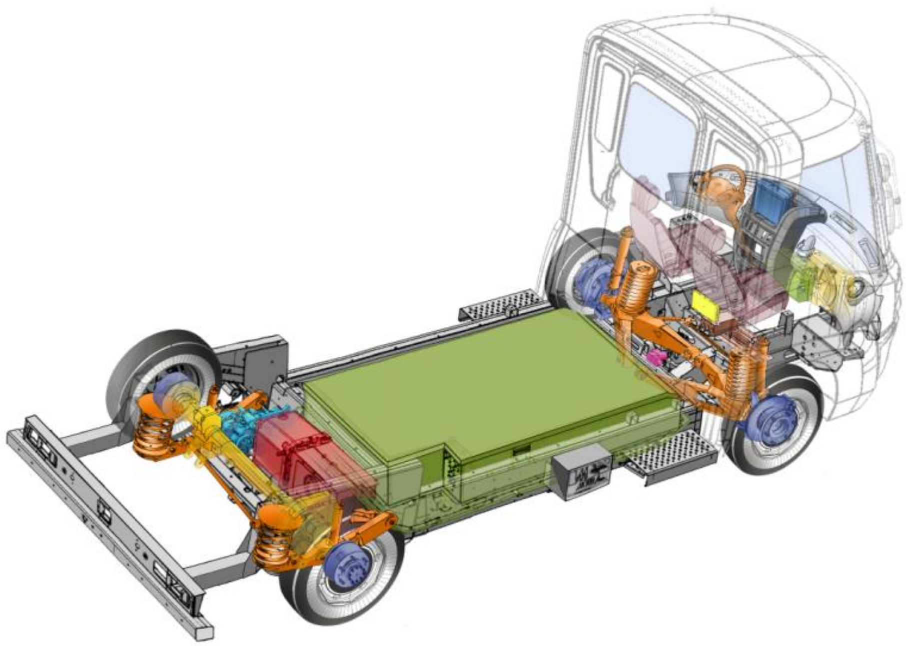
In addition, a technical presentation would be required at the annual DOE Program Merit Review. The project presented at the following DOE Annual Merit Reviews:

1. June 7th, 2010
2. May 11th, 2011
3. May 17th, 2012.

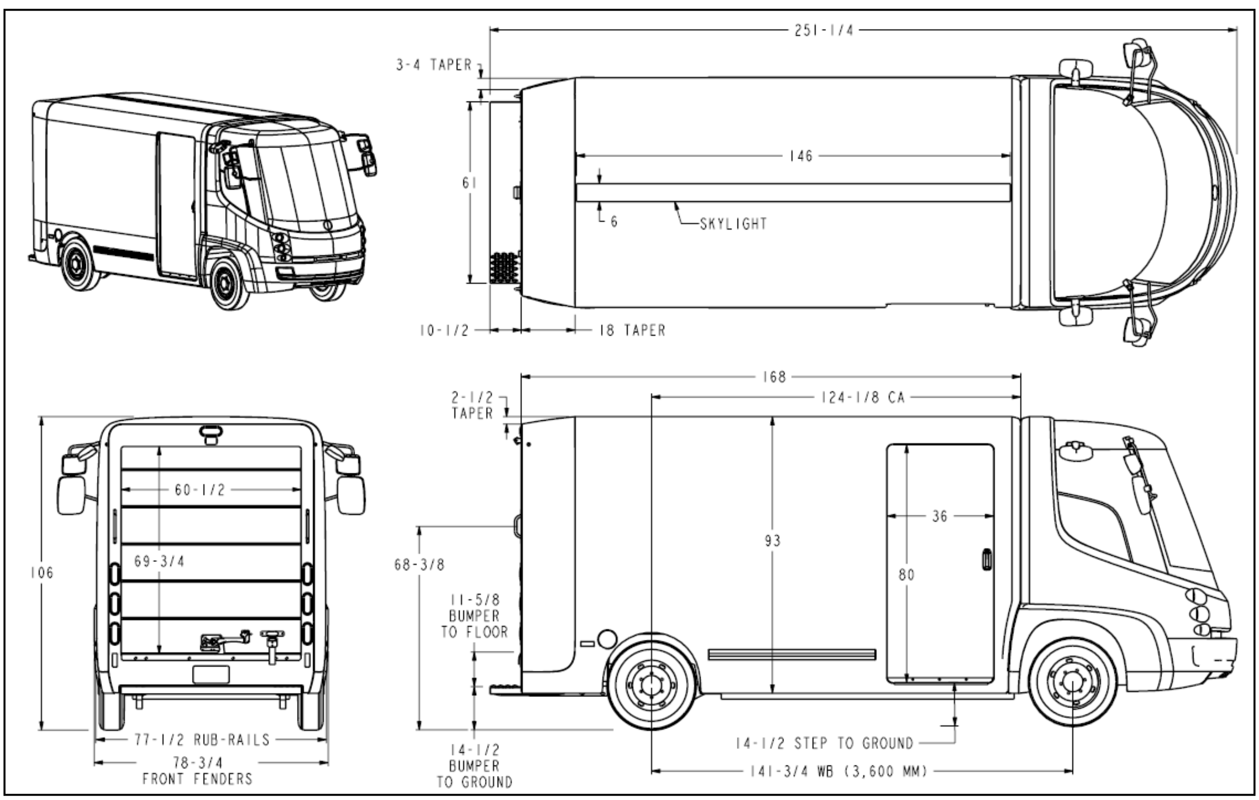
The eStar vehicle was featured in the GE EV experience tour. The nationwide tour educated different industry segments and stakeholders on the emergence of electric vehicles (EV) and the benefits they could provide to businesses, governments and communities. The eStar was among a variety of EV manufacturers showcased during the tour. The tour began in March 2011 and stopped in six U.S. cities: San Francisco, Seattle, Los Angeles, San Diego, New York and Washington, D.C.

An industry and user council was formed to promote and develop synergies in interested participants to increase market acceptance for electric vehicles as required by the grant. This Electrification Leadership Council's website was http://www.elcouncil.com/index.html.

F. EV Product Information



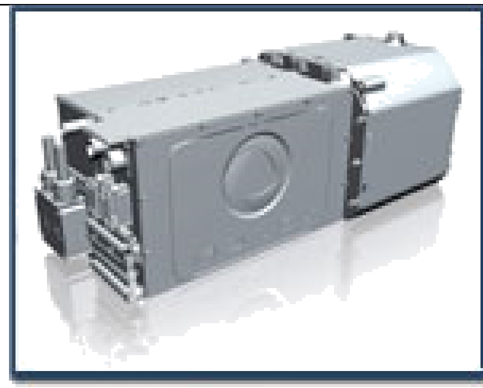
Dimension Drawings



A tall, open cab layout allowed the driver to walk-in and slide into the seat with ease and speed. The command driving position (cab-over layout) and large 180 degree glass area gives excellent visibility. The cab structure itself consisted of GRP (Glass Reinforced Plastic) RTM (Resin Transfer Molded) monocoque bonded construction using high-strength adhesives.

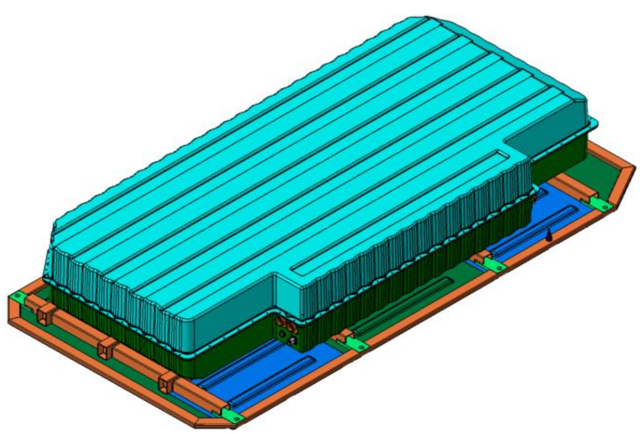
The high strength (90,000 PSI) ladder frame chassis had been purposely designed for the EV. Designed from the ground up as an electric vehicle, the battery sits snuggly within the frame and does not occupy valuable cargo space. This battery configuration also lowers the vehicle center of gravity to improve handling characteristics. The chassis is a non-standard width with approximately a 49 inch (1240 mm) centerline.

The 79 kWh electric motor provides a peak rating of 106 HP and 212 ft. lbs. of torque--available the second the driver presses the accelerator. This power is supplied with zero tailpipe emissions (i.e. no CO, CO2, NOx or particulate matter). The electric motor was controlled by a simple PRND clutch-less transmission and the advanced inverter systems also provided additional charge to the battery while coasting or braking. Full acceleration was to 50 mph, economy operation– 2/3 acceleration to 40 mph.



The gearbox was packaged together with the motor and axle behind the battery cassette in a space-saving "Z" shaped layout (driveshaft lies across the vehicle). The 180 degree single speed gearbox allowed 50mph and 16% gradability at GVW. A 2-speed version was under development to give 33% gradability capability.

At the core of the EV was the uniquely designed removable 79kWh battery cassette, securely packaged inside the custom designed chassis. This design provided the flexibility to easily adapt the battery to the vehicle, enable optimum performance for an urban delivery vehicle and meet specific customer requirements. The design of the battery pack and the FRP chassis was also "future proof", meaning that, if battery technology had continued to evolve, the existing pack could have been upgraded quite easily without making significant vehicle modifications.



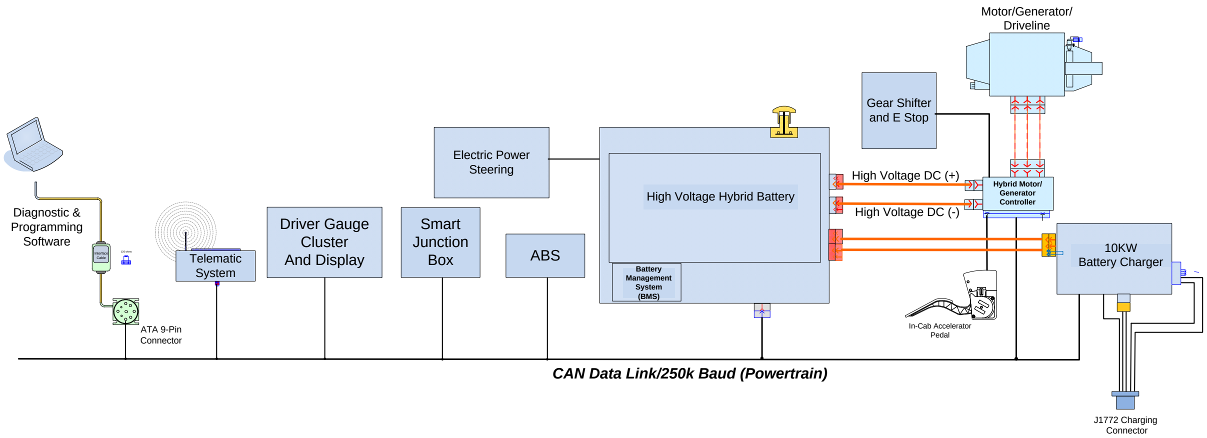
Front disc /rear drum brakes and standard anti-lock braking systems (ABS) were standard on the EV together with electronic braking distribution-- which ensured optimal power was distributed to each of the vehicles wheels, which allowed the driver to maintain control on poor roads or during adverse weather conditions. In addition, the vehicle's regenerative system captured the kinetic energy produced in the coasting the vehicle to a stop and feeds that energy back to the battery**.**

Battery charging was accomplished via the Clipper Creek CS-40 EVSE or compatible system and was accomplished as follows. Push down the mechanical latch on the charger lead and insert into the charge port while aligning the lower groove and the upper tab. Push in completely then lock in place by releasing the mechanical latch. The vehicle would then begin charging.

Electrical Systems

The electrical system was implemented using a distributed architecture of intelligent components to provide vehicle controls and propulsion that was compatible with driver expectations as well as safe to operate with multiple fail safe interlock controls. Software based power management schemes enabled the vehicle to achieve up to one hundred miles of driving with a full payload on one battery charge cycle.

The eStar electrical system was developed with highly integrated electrical sub-systems to lower vehicle cost and maintain electrical system simplicity. See the following block diagram:



The main elements of the system were the integrated motor/generator with a high voltage controller, a high voltage Lithium battery pack, a smart junction box (body controller), ABS unit, a telematics system and an on board high voltage battery charger.

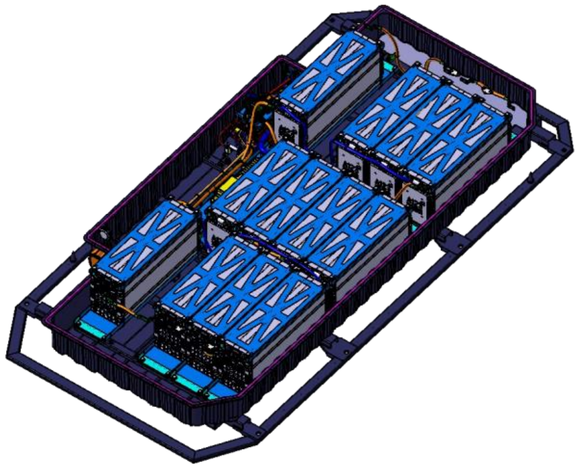
Safety interlocks were required for all elements of the system. Every high voltage connector employs a safety shutdown high voltage interlock loop (HVIL) so that power was turned off as soon as any connector is disconnected. An emergency stop switch was positioned near the driver seat to enable immediate shutdown of the system by the driver. The system was also interlocked with a switch located in the driver seat such that once the driver left the seated position; the system would shut down within a programmable length of time. The vehicle couldn't be driven if the 240 volt AC charger was connected to a shore power charging station. Thus every aspect of the electrical system was built around safe operation for the driver.

The electrical system network backbone was based upon a CAN data link operating at 250K baud. Programming, configuration and diagnostic reporting was performed across this data link. Each intelligent node performs independent functions in a peer to peer relationship. Fail safe strategies were employed to drive the system components into a shut down or safe condition if communication was lost between any of the system components.

The eStar employed a high resolution color display as the main driver interface for displaying road speed, state of charge for the high voltage battery and many other required warning light indications. The display was interfaced to the main vehicle CAN data link and provided a means to display a wealth of information. In addition, it provided a visual indication if any of the cargo body doors had been left open.

eStar Driver Electronic Information Display

The battery pack for the eStar was a 79kWh Lithium Ion based battery pack operating at a maximum of 346 volts. The battery pack was integrated with both the motor/generator controller and an on board high voltage 10 kilowatt charger for charging the vehicle while parked. The charger was powered from a charging station at 240 volts AC, single phase, through an SAE standard J1772 connection system.



The eStar could be recharged at any public J1772 charging station delivering up to 10 kilowatts of power between 208 to 240 volts of single phase 60 Hz AC power.

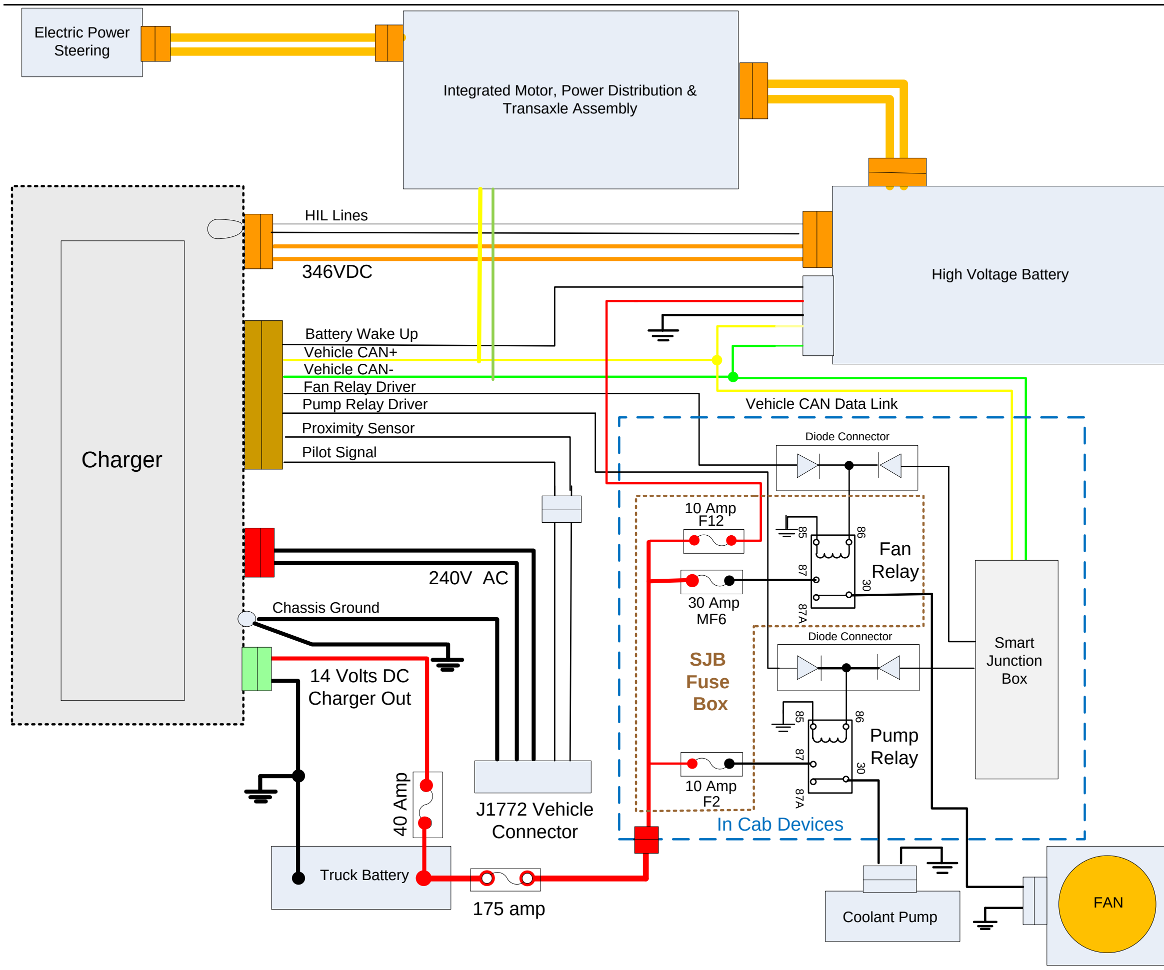


Diagram of High Voltage Battery, High Voltage Charger and the Motor/ Generator Controller.

G. Additional Grant Requirements

It was a requirement to produce units in the Elkhart, Indiana area as part of the ARRA grant. The plant was established and ramped up production at the Wakarusa, Indiana location.

During the performance of this project, all FMVSS requirements were achieved to successfully homologate this vehicle for introduction to the US market. The following details changes required, if any.

FMVSS101 - Controls telematics and Indicators

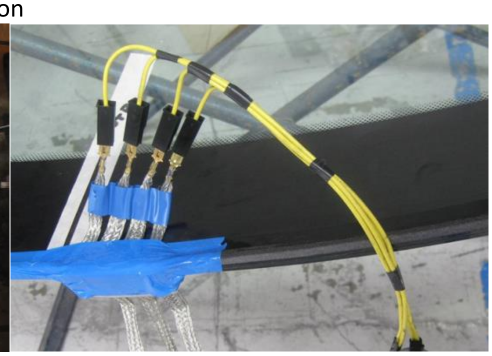
- Telltails update – new silkscreen required
- Software update to cluster
- Shifter illumination added
- Heater System Controls illumination update

FMVSS102 – Transmission shift lever sequence, starter interlock & braking effect

- Park Pawl integrity for US Market
- Hardware - Navistar lead the redesign of park pawl
- Software – Implemented park Pawl re-try strategy

FMVSS103 - Windshield defrosting & defogging

- 2.5 kW EU heater attained FMVSS requirements
- Implemented heated windshield
- Improved window ducting routing and insulation

FMVSS104 - Windshield wiping and washing

- Wiper motor change required

FMVSS105 - Hydraulic & electrical brake system
- No changes required in this area

FMVSS106 - Brake hoses
- Articulation studies completed; new jounce lines required

FMVSS108 - Headlamp Module (lamps & reflectors)
- Low and High beam reflector and bulb assembly replaced
- Turn signal position and size had to change

FMVSS111 – Review Mirror
- EU mirror layout changed for US application
- Passenger mirror surface shape had to be altered

FMVSS113 – Hood latch
- No Design Change required

FMVSS119 - New pneumatic tires for vehicles other than passenger cars
- Goodyear America selected as tire supplier

FMVSS120 - Tire selection & rims for motor vehicles other than passenger cars
- No design changes required

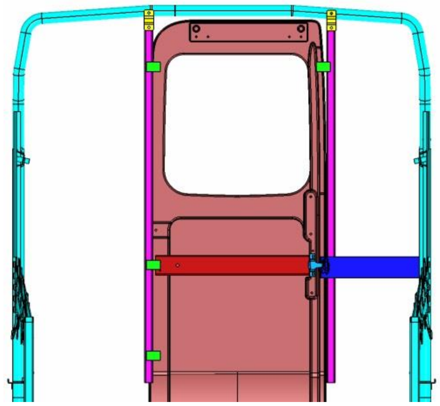
FMVSS124 and IAC-005 - Accelerator control systems
- All compliance had to be evaluated after any Software and/or calibration updates

FMVSS206 – Door locks &retention components
- Restricted sales into cargo van applications due to entry and egress requirements

FMVSS207 and IAC 002 - Seating systems
- Seat structure design changes required
    - Improve ergonomics
    - Added seat belt cab retention straps

FMVSS208 - Occupant crash protection
FMVSS209 - Seat belt assemblies
FMVSS210 and IAC 002 - Seat belt assembly anchorages

- Cabin Roll hoop upgrade
- Seat belt straps with additional retainers included into hoop structure
- Seat belt retainers attached to chassis frame



FMVSS302 - Flammability of interior materials

- Certified that every cabin part complies

Additionally the following product improvements were accomplished to improve the overall reliability and performance of the vehicle.

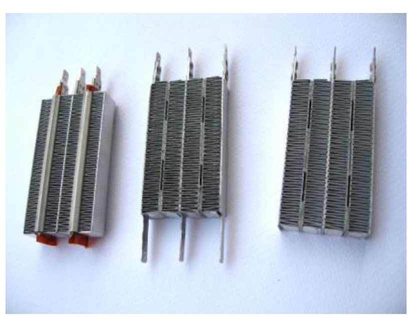
- A new body was styled and designed to achieve a 7% drag improvement over it's off shore version.

- An optional 12V air-conditioning unit was introduced to meet customer demand.

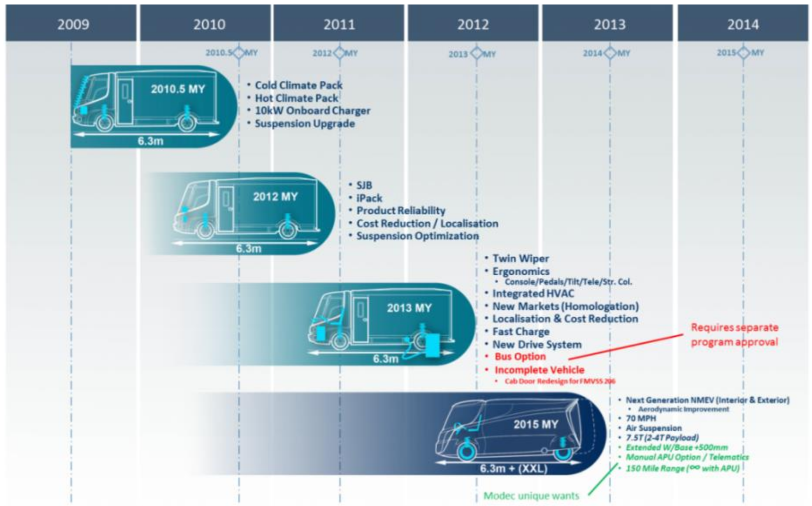
- In all, 6 different EVSE's were validated to work with this vehicle. Two of those validation documents are included in the Appendix J.3 to demonstrate the testing methodology.
    - Coulomb Chargepoint CT-500
    - Eaton 30A
    - Clippercreek CS-60
    - AeroViroment – Wall Mount and Pedestal
    - GE Wattstation (required software updates from GE)
    - Ecotality – Blink 30A and 48A

- The internal to the battery pack 6.6kW charger was replaced with an external 10kW charger to improve charging time and significantly improve reliability.

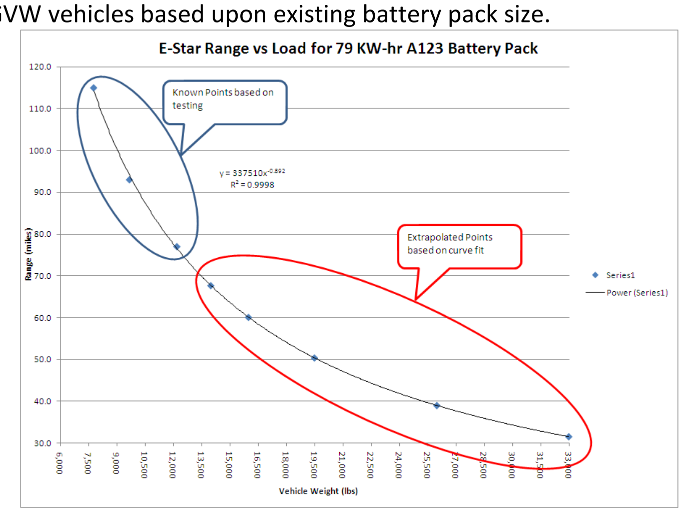
- A 5kW heater was developed and introduced for increased driver comfort, faster heating to desired temperature, improved efficiency with electronic controls and improved reliability.



Another requirement was for Navistar to continue to refine and upgrade the original vehicle and introduce the EV technology onto other platforms across multiple GVWs. Packaging studies were completed on the Workhorse W62 chassis, including extensive analysis and design on battery pack configurations to integrate into the chassis. Navistar did plan to introduce future versions of the product, but these plans were stopped after the MY2012 upgrades when it was mutually agreed with the DOE to stop work on the grant.



Range analysis for other GVW vehicles based upon existing battery pack size.



H. Summary and Conclusions

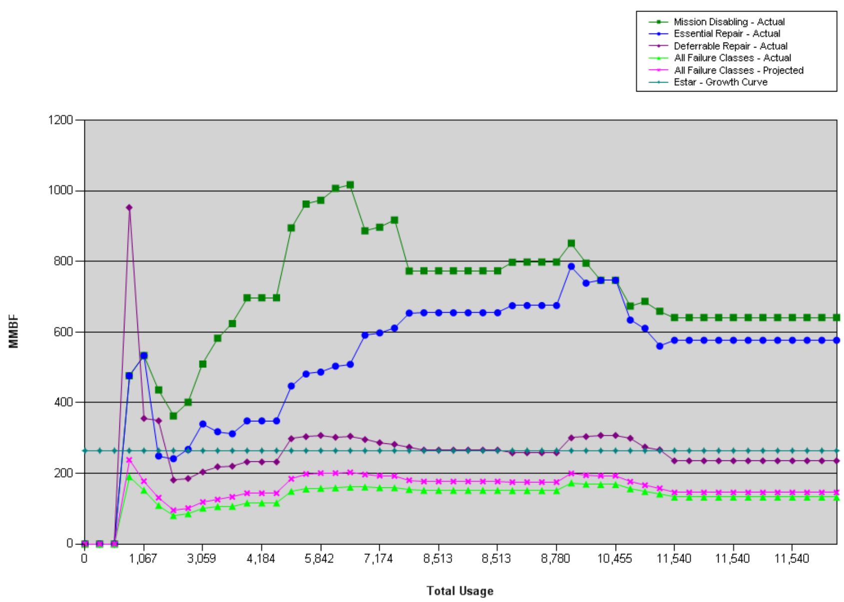
The projects fundamental intent was to develop and manufacture an all-electric drive vehicle, with a range on one charge of 100+ miles, and introduce the product both domestically and in Canada. The result was the homologation of a British developed all electric vehicle that Navistar introduced to the market as the eStar truck, a Class 3 product with a GVW of 12,100 lbs. with a 4,000 lb. payload capacity. These overarching tasks were accomplished. More than a hundred units were fielded domestically and in Canada and the data loggers recorded performance information for over two years.

During the performance of this project, all FMVSS requirements were achieved to successfully homologate this vehicle for introduction to the US market. The battery pack was redesigned with a FRP enclosure to decrease

overall weight.
During the performance of this project it was assumed that the highest cost component, the battery pack's costs would significantly reduce, either via technological improvements in the lithium Ion pack or the replacement with pack chemistry, or both. However, the cost curve did not bend down at the necessary rate to bring the product's market acceptance up for the unit cost of this type of urban delivery vehicle. As such, the number of customers entering the market at, or near the original price point was limited to just over a 100 units.
Customer user data seems to indicate that for this duty cycle, urban package delivery routes, that 40 miles is the typical duty cycle for a day's deliveries. As such, it's possible that the overall vehicle cost could be decreased by reducing the overall battery pack size. The following table reflects range vs battery size studies.

Current A123 Battery				Theoretical Battery Size Requirement KW-hr for Mile Range and Curb Weight								
Weight	Miles	KW-hr	KW-hr/mile	50 mi	60 mi	70 mi	80 mi	90 mi	100 mi	110 mi	120 mi	140 mi
7,780	115.0	79	0.6870	34	41	48	55	62	69	76	82	96
9,680	93.0	79	0.8495	42	51	59	68	76	85	93	102	119
12,200	77.0	79	1.0260	51	62	72	82	92	103	113	123	144
14,000	67.7	79	1.1676	58	70	82	93	105	117	128	140	163
16,000	60.1	79	1.3151	66	79	92	105	118	132	145	158	184
19,500	50.4	79	1.5686	78	94	110	125	141	157	173	188	220
26,000	39.0	79	2.0270	101	122	142	162	182	203	223	243	284
33,000	31.5	79	2.5067	125	150	175	201	226	251	276	301	351

Concurrently, reliability issues with the charger, the electric motor, and the initially designed suspension components of the off shore vehicles road worthiness made vehicle uptime and continued support too unreliable for continued operation of the vehicles already fielded.



As a result it was mutually agreed to modify the terms of the grant between the Department of Energy and Navistar. It was decided to continue reporting on the units already fielded for the next year.


Coca-Cola all-electric vehicle
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