Boulder Electric Vehicle Field Validation Project 2012

Task 4 & Final Deliverable Report

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Abstract/Executive Summary

Boulder Electric Vehicle (BEV) will produce, deploy and field validate 18 all electric, zero NO_x, advanced zero emissions new vehicle 11,500 gross vehicle weight rating (GVWR) delivery trucks with a patent pending ultra-light-weight aluminum honeycomb composite vehicle frames, a top speed of 65 miles per hour (mph) and a range of 120 miles. BEV will deploy them in three metropolitan non-attainment areas in Texas for a full calendar year. FedEx and UPS will deploy and test a combined total of nine trucks in the cities of Dallas, Houston, and San Antonio. The Cities of Dallas, Galveston, and San Antonio will deploy and test three vehicles each. The validation of the top speed, range, and carrying capacity as well as the heating and cooling of the battery pack will all be validated under real world conditions and duty cycles. BEV has reduced the curb weight of a standard delivery truck from 9,000 pounds (lbs) down to near 5,000 lbs by incorporating patent pending composite aluminum frame technology. Due to the reductions in weight, the size of the battery pack is also greatly reduced, thus lowering the cost of the vehicles and increasing economic viability. Because the ultra-light-weight aluminum honeycomb composite vehicle frames are a departure from the standard steel frame rails, field validations will greatly accelerate the market acceptance and commercialization of this new technology, thereby reducing the NO_x in Texas metropolitan non-attainment areas. The data logged and published from this field validation project will greatly accelerate the market adaptation of this zero emissions vehicle technology as well as validate the potential for great pollution reduction in Texas non-attainment cities.

Introduction/Background

There are three major issues with the performance (and therefore market acceptance) of large format electric vehicles.

- The vehicles weigh too much and therefore require very large and expensive battery packs.
- The batteries will not perform as well when it is cold (noticeable degradation of range starts at 40 degrees Fahrenheit (F)), and when the temperature goes over 120 degrees F the pack starts to "bake" drastically reducing cycle life. The later issue has been greatly publicized by a major original engine manufacturer (OEM) having their range reduced in their first offering of electric cars deployed in Phoenix, Arizona.
- No one is making a commercially available electric truck that goes faster than 50 mph.

BEV has addressed all of these issues in our first prototype 11,500 lbs GVWR vehicle.

Vehicle Weight

BEV has filed patents on the ultra-lightweight composite aluminum frame which we think will be a key component in the automotive industry for making vehicles lighter while retaining strength.

Aluminum honeycomb composite is well known in the aerospace industry but has never been used in the automotive industry until now. Our primary invention is the placement of key stringers of tubing inside the honeycomb core in order to stiffen and spread out the load inside the vehicle frame and where it attaches to key suspension points. There are three primary advantages in our frame design over the typical steel frame rail truck design.

First is lightness of the vehicle. Batteries for electric vehicles have such a high cost, that a gain in the efficiency of the vehicle pays for itself through a smaller battery pack and less initial costs. On smaller vehicles such as the Nissan Leaf or the GM Volt the batteries might be 20-30% of the price of the vehicle. On larger trucks the battery pack can be fully 50% or more of the costs of materials in the manufacturing of the vehicle. Especially in the delivery market where there is a great deal of stop and go driving, the reduction in weight offers a tremendous increase in efficiency.

Second is safety. By bringing the battery pack to the center of the vehicle it protects the battery pack from accidents, thus protecting the investment in the high cost battery packs and increasing the factor of safety. This also places the weight of the battery pack (1,400 lbs or over) in the center of the vehicle, increasing the stability and drivability of the vehicle.

Third is the reduced energy needed to manufacture the frame itself. Costs, energy, and ease to manufacture the frame are all better than a typical steel frame rail truck. The process is vacuum bagging six parts instead of plasma cutting, welding and bolting 30 parts or more. Thus costs and energy to manufacture is dramatically decreased.

Battery Thermal Management System (BTMS)

This is different from the usual Battery Management System (BMS) in that the usual BMS is involved in managing the battery cells during charge and discharge in order to keep track of any over or under voltage conditions outside of normal parameters. Our Battery Thermal Management System (BTMS) allows us to use the same heating and cooling system that we use on the cab of the truck and heat and cool the battery pack. We have spent the last 18 months in Colorado testing the system in the summer and winter. At 40 F the range of the battery pack is already being reduced without heating the pack. In minus 20 F conditions the range is reduced by 80% without heating the pack. Although it is a much more difficult parameter for a customer to quickly quantify, cooling the pack in the heat of the summer is equally important by keeping cycle life in line with manufacturer's spec. Over 102 F the pack is being baked. The cycle life can be reduced by up to 80% just by a few weeks of operations at this higher temperature. The problem is compounded by the necessary placement of the battery pack about one foot above the black pavement. Therefore we cool the battery pack. No one else has implemented this in electric trucks.

Highway Capable Electric Trucks

BEV's top speed is 71 mph. We are the only electric truck OEM that offers this speed. From a department of transportation legal perspective any vehicle that gets on an interstate highway *must* be capable of going at least 10 mph less than the posted speed limit. Since many states have speed limits of 75 mph this dictates a 65 mph speed. For large format electric vehicles this means either a motor/controller with a greater amount of torque and power, or a transmission. This is not hard to do. but the market dictates that this *must* be done. The only reason we can speculate as to why neither Smith nor Navistar has done this is that both of their designs were finalized in England where this is not a market driven necessity. We have also observed through our own extensive testing of our prototype truck that higher speeds will decrease range and therefore make the trucks either more expensive to produce or lower in range.

Project Objectives/Technical Approach

The objectives for this project are:

1. Build all electric, zero-NO_x delivery trucks with a top speed of 65 mph and a range of 120 miles.
2. Demonstrate for a period of up to one year the 18 electric delivery trucks in the Dallas, Houston-Galveston, and San Antonio areas with both public and private entities, collecting data on vehicle durability and performance and customer acceptance.
3. Evaluate the durability of vehicle components and battery packs in three of the demonstration vehicles after demonstration is complete.

Tasks

The tasks for this entire project are as follows:

- Task 1: Demonstration preparation and vehicle design adjustments;
- Task 2: Vehicle production;
- Task 3: Vehicle deployment;

- Task 4: Vehicle demonstration;
- Task 5: Post-demonstration vehicle durability analysis (cancelled by amendment); and
- Task 6: Reporting.

This specific report is the report for *Task 4 – Vehicle Demonstration* and will address actual performance and data logged and our methodology.

Task 4 – Vehicle Demonstration

Task 2.4 Vehicle Demonstration

From the Grant Activities (Scope of Work):

> *"Task 4: Vehicle demonstration*
>
> *2.4. Task Statement: The PERFORMING PARTY will oversee and assist with the demonstration of the electric trucks at the demonstration partner sites for a period of one year."*

Task 2.4.1 Operate the Vehicles

From the Grant Activities (Scope of Work):

> *"2.4.1. The PERFORMING PARTY will ensure that demonstration partners operate the demonstration vehicles in a normal manner as part of their daily fleet operations for a period of approximately one year."*

The city fleet validation partners have been able to run the vehicles for a longer period of time than the commercial fleet validation partners. This is largely due to the speed at which city fleet operators can deploy vehicles on the ground. It is also due to the speed with which a city can install charge stations in their own facilities. The city fleets control the permitting process, they control the facility, and they control the end users, so it is really a perfect vertical integration. The corporate fleets must permit the charge stations to a city building department, sub-contract the install to an electrician on the ground, and deal with physical plant departments in a corporate headquarters a thousand miles away; theirs is a slower process.

The result of this is that we have been able to gather much greater quantities of data from the city fleet vehicles than the private commercial fleets. This is exactly the opposite of what we thought would happen when we proposed the work in this grant. The interesting part about the city fleets is the different uses for which each fleet has put the exact same vehicle. For instance, the City of Dallas is using their delivery van in their code enforcement department, whereas the City of San Antonio consistently takes their vehicle off road, which, although not recommended by us, is proving out the durability of the mechanical toughness of the vehicle.

The driver training provided by us was crucial in actually getting the drivers to use the vehicles every day during their normal operations. The additional customization for each specific fleet was also crucial to that objective.

Task 2.4.1.1 Monthly Safety Inspections

From the Grant Activities (Scope of Work):

> *"2.4.1.1. During the demonstration period the PERFORMING PARTY will perform monthly safety inspections and stress analysis on all of the vehicles in operation."*

Monthly safety inspections and vehicle checks were a great way of making sure the vehicles are holding up and that the drivers are actually using them. The flaws we found on the initial three vehicles were able to be corrected before the subsequent 15 vehicles left the factory floor. These were all minor things such as the front shock absorber needing a tighter bushing so that there would be less road noise. These visits also allowed us to help the city fleets do additional customization of the vehicles such as adding strobe lights for specific end users' needs. Another great piece of information gleaned was that the regenerative braking was helping the brakes of the vehicles perform even better than expected. The brake inspections of the vehicles which have been on the road for *over* a year have shown that the brake pads look as if they are brand new; they literally do not yet have all their fuzziness worn off.

Our monthly safety inspection sheets are very similar to our final electrical and final mechanical inspection sheets which were previously provided in Task 2. They included inspections of:

- general functionality,
- appearance,
- door locks,
- doors operation,
- window operation,
- seat adjustment operation,
- seat belts,
- washer fluid,
- brake fluid,
- power steering fluid,
- heater fluid,
- mirrors,
- tire pressure,
- coolant level,
- odometer accuracy,
- speedo accuracy,
- zerks greased,
- coolant leaks,
- abs operation,
- park brake adjustment,
- backup alarm,
- key sets BEV fob,
- remotes (optional),
- lug nut key,
- differential oil forward,
- reverse,

- steering wheel aligned,
- parking brake,
- backup camera alignment,
- regenerative braking,
- lights,
- main driver display indicators,
- dash auxiliary display,
- dash controls,
- high voltage cabinet visual check,
- rear running lights,
- front running lights,
- high beams,
- low beam alignment,
- high beam alignment,
- rear flashers,
- front flashers,
- left turn,
- right turn,
- backup lights,
- license plate light,
- rear clearance,
- front clearance,
- brake lights,
- dome in cab, and
- dash light emitting diodes (LEDs).

Under Main Driver Display Main Indicators we have line items as follows:

- odometer,
- speedometer,
- charging,
- anti lock brake system (ABS),
- drive,
- neutral,
- reverse,
- park/brake,
- turn flasher,
- state of charge (SOC),
- fuel gage,
- regenerative braking, and
- latest software version.

Under Dash Controls we have line items as follows:

- headlights,
- LED dimmer,
- wiper speed,
- windshield washer,
- shift control,
- heat/air-conditioning,
- vent/defrost,
- fan speed,
- horn,
- high/low beam,
- turn,
- radio/speaker operation,
- ignition switch,
- dome light,
- park alarm with key off, and
- cab fan (optional).

Task 2.4.2 Driver Feedback

From the Grant Activities (Scope of Work):

> *"2.4.2. The PERFORMING PARTY will collect driver feedback by providing an in-truck comment log for the demonstration vehicle drivers to record their comments on the performance of the vehicles. The PERFORMING PARTY will collect and analyze this feedback."*

Drivers, we have found, are under immense pressure to complete their daily delivery routes or service work and thus writing down daily feedback on the vehicle's performance was often neglected. In general we would only hear about a vehicle if a driver had left the vehicle unplugged and allowed the 12 volt battery to run down. This actually happened enough to where we started putting on discharge preventers so that if a driver did not plug the vehicle in the 12 volt battery could only go down to 11.5 volts before being shut off, thus protecting the 12 volt battery from permanent damage. The high voltage battery pack already had battery discharge damage protection built in.

That being said we got driver feedback verbally throughout the project at the monthly safety inspections. In general the feedback on the performance was that it was quiet and not smelly like their other vehicles in the fleet. For some drivers range anxiety, the worry about whether the vehicle would run out of electricity in the battery, was initially an issue. After drivers learned to trust the "estimated range" gauge on the dashboard that was generally relieved.

Additional feedback would often go into the realm of requiring additional build out so that the assigned driver could more effectively or more safely perform their tasks. This was sometimes as simple as asking us to provide bungee cords as the city procurement process was so cumbersome that it would take six months. However it was often a build out need such as adding strobe lights that we were required to perform during a safety and maintenance visit.

Task 2.4.3 Onboard Data Collection

Task 2.4.3.1 Data Logging

From the Grant Activities (Scope of Work):

> *"2.4.3.1 The PERFORMING PARTY provide on board data logging for the performance of the battery thermal management system and the charge-discharge cycles of the electric trucks. The PERFORMING PARTY will document the data logging procedure for the PERFORMING PARTY's service technicians to capture monthly data in regards to operational use of the vehicles."*

The amount of data logged on the controller area network (CAN) bus network was immense. The early issue of drivers not plugging the vehicles into charge and the batteries running down resulted in several corrupted files, which gave us little, poor, and sometimes no results over the first few months. Once the battery discharge and driver habits were corrected the data stream became more consistent. The logging procedure was automatic and the infield service technician had merely to swap out thumb drives and label them according to vehicle identification number (VIN).

The challenge of this task was not logging the data but making sense out of it. The winter time use of electricity in the vehicles was somewhat higher which was what we expected. This is largely due not to the heating of the driver in the cab, but of heating the battery pack so that it is warm in the mornings thus allowing the vehicle to perform its full route. The results from this data is presented in the following *Task 2.4.3.2 Metering Functions.*

Task 2.4.3.2 Metering Function

From the Grant Activities (Scope of Work):

> *"2.4.3.2 The PERFORMING PARTY will provide a metering function to calculate vehicle energy usage and will display this information in a prominent location for both the driver and the fleet manager. The PERFORMING PARTY will also capture the metering data for analysis."*

We designed our driver dash display so that the driver could always view an "estimate range" gauge which would reduce in miles as the driver drove their route throughout the day. We also designed our driver dash display to show total pack voltage as well as amperage draw during actual driving so as to have instant feedback as to how hard the driver was pushing the electrical usage of the vehicle. Making this information available to the driver was very easy however making it available to the fleet manager was only able to be accomplished through logging it with an onboard control unit and downloading the date during monthly safety inspections. This resulted in an immense amount of raw CAN bus data which was able to be sifted out for an overall electrical use calculation. Unfortunately this was not able to be analyzed in real time for a fleet manager but only after the fact of usage and even then with enormously time consuming data crunching.

After analyzing the data we did not find any significant difference between the different models of our vehicles and we did not find any significant difference in driver results. The end calculations were for watt-hours per mile (wh/mi). This is the electric vehicle equivalent of miles per gallon. On average the electric vehicle usage was about 620 watt hours per mile. In general this meant the cost to run one of our

vehicles one mile was roughly 7 cents with electricity costing about 11 cents per kilowatt-hour. This compares favorably with a similar vehicle which might get 20 miles per gallon at a cost of $4 per gallon costing 20 cents per mile. If the end fleet user is replacing a vehicle which gets only 10 miles per gallon then the comparable is 40 cents per mile.

The following figures detail the monthly average miles driven daily and calculated (wh/mi) for each vehicle as listed by VIN number.

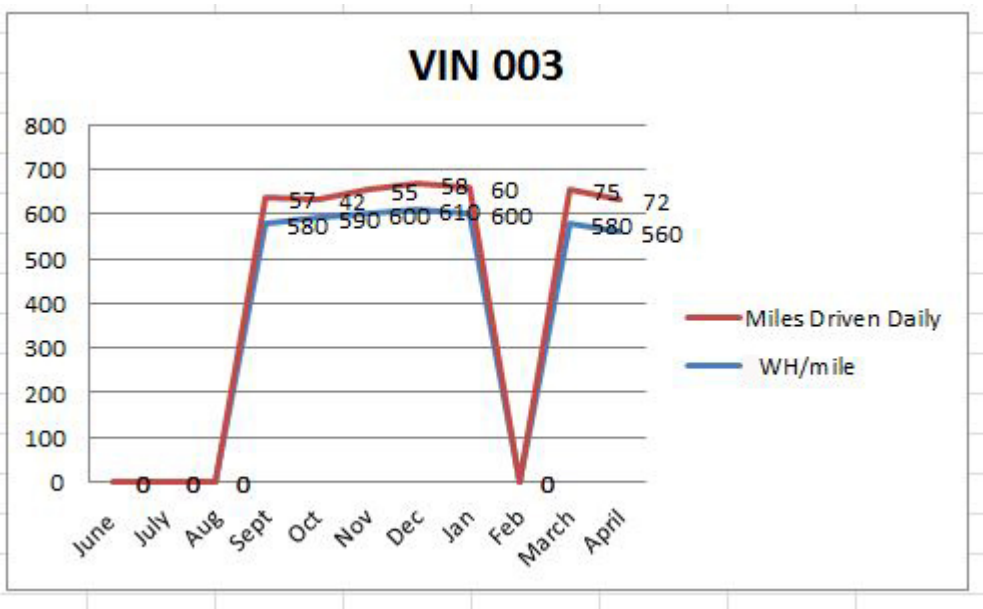

Figure 1: VIN 003 monthly wh/mi averages

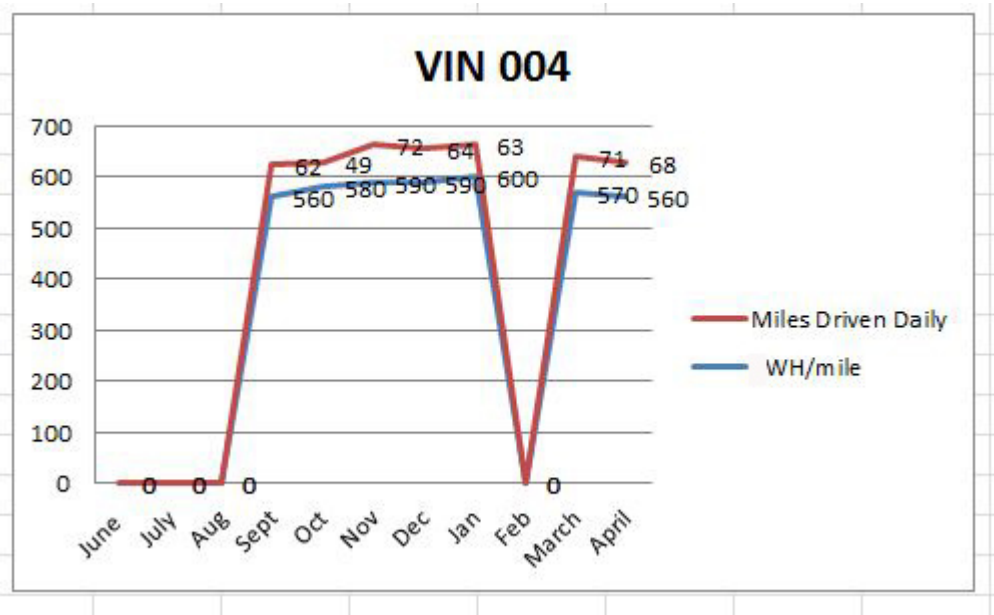

Figure 2: VIN 004 monthly wh/mi averages

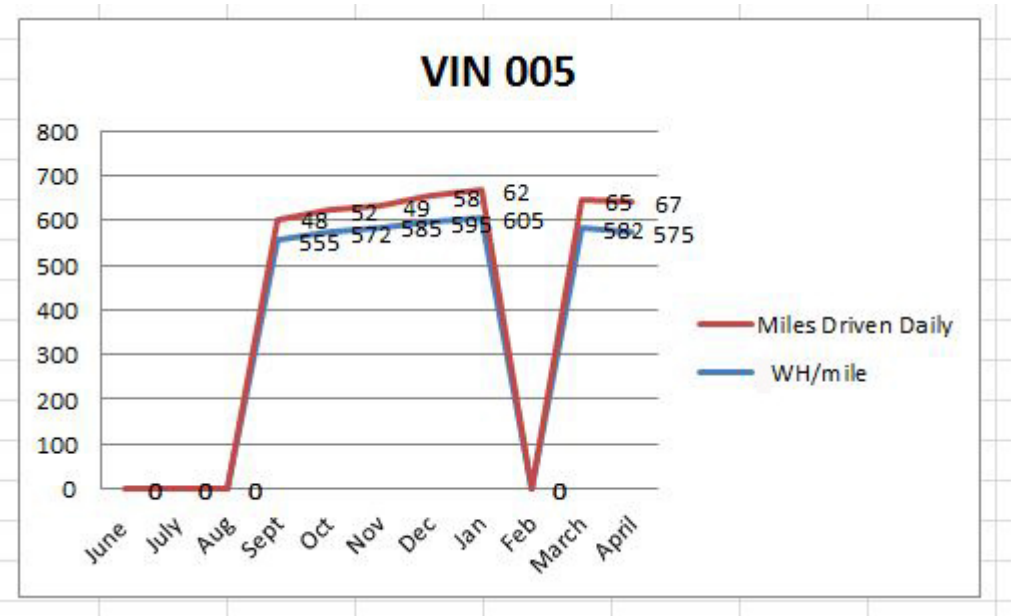

Figure 3: VIN 005 monthly wh/mi averages

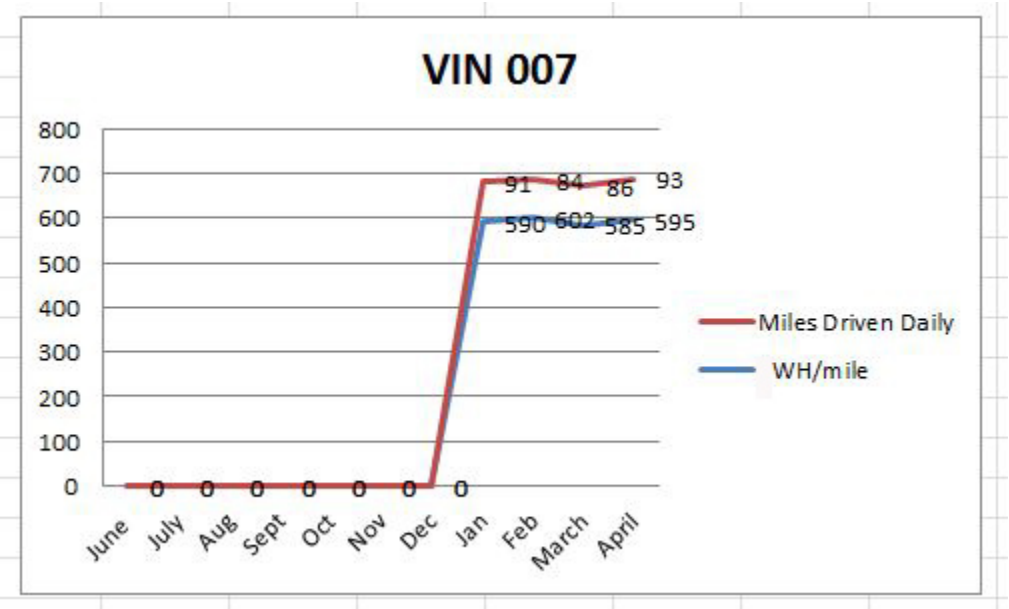

Figure 4: VIN 007 monthly wh/mi averages

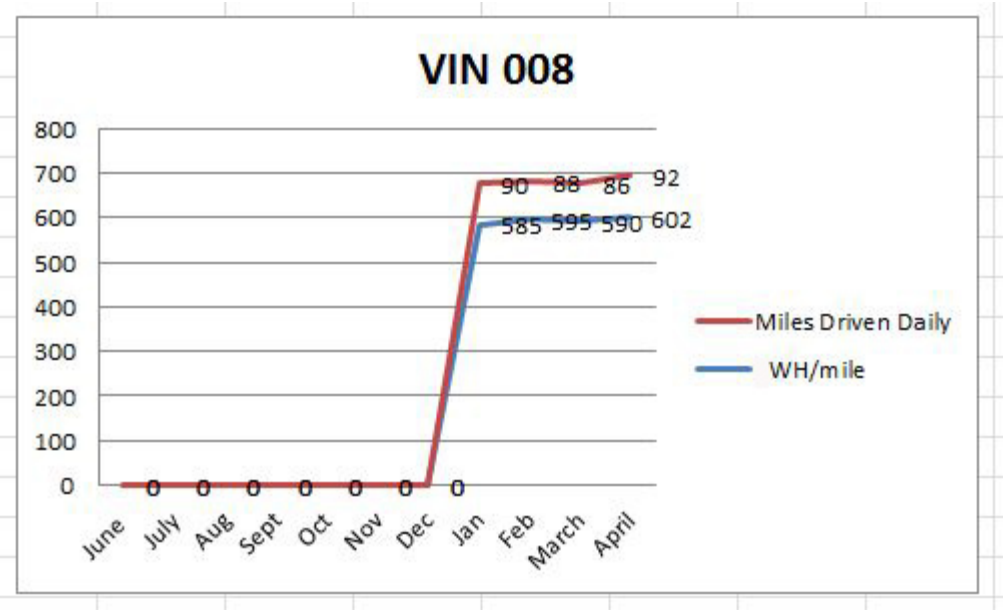

Figure 5: VIN 008 monthly wh/mi averages

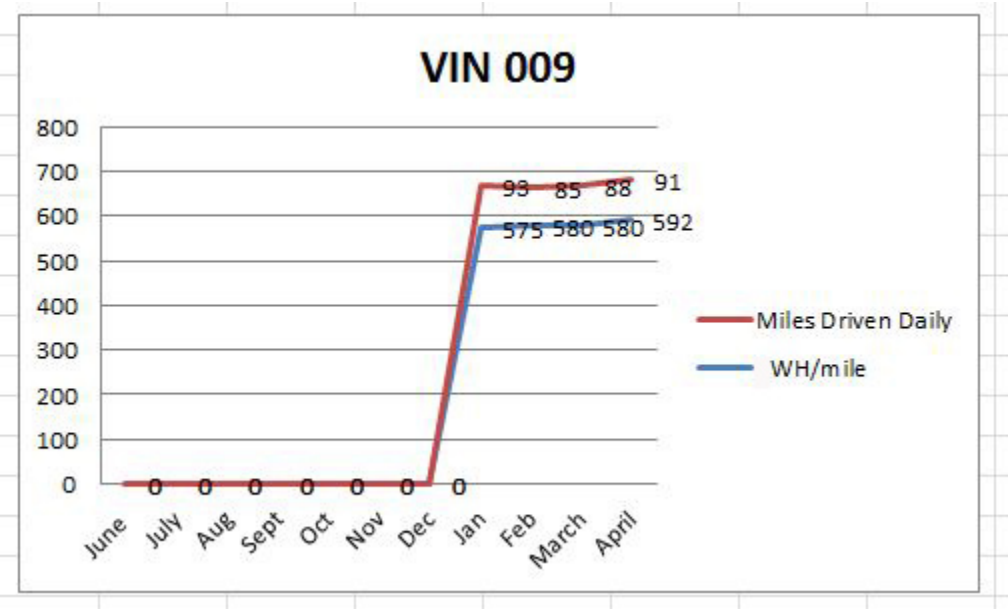

Figure 6: VIN 009 monthly wh/mi averages

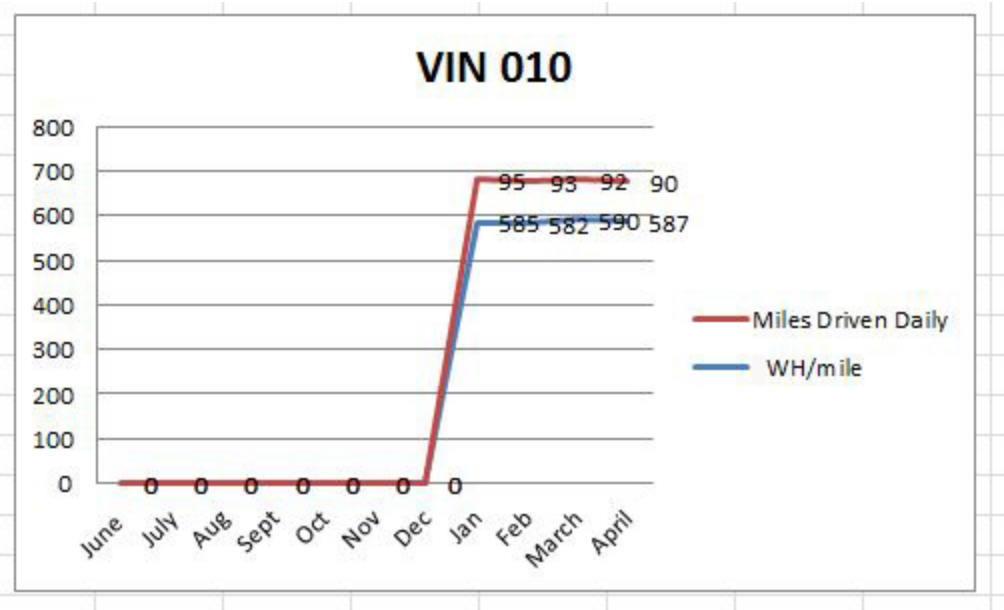

Figure 7: VIN 010 monthly wh/mi averages

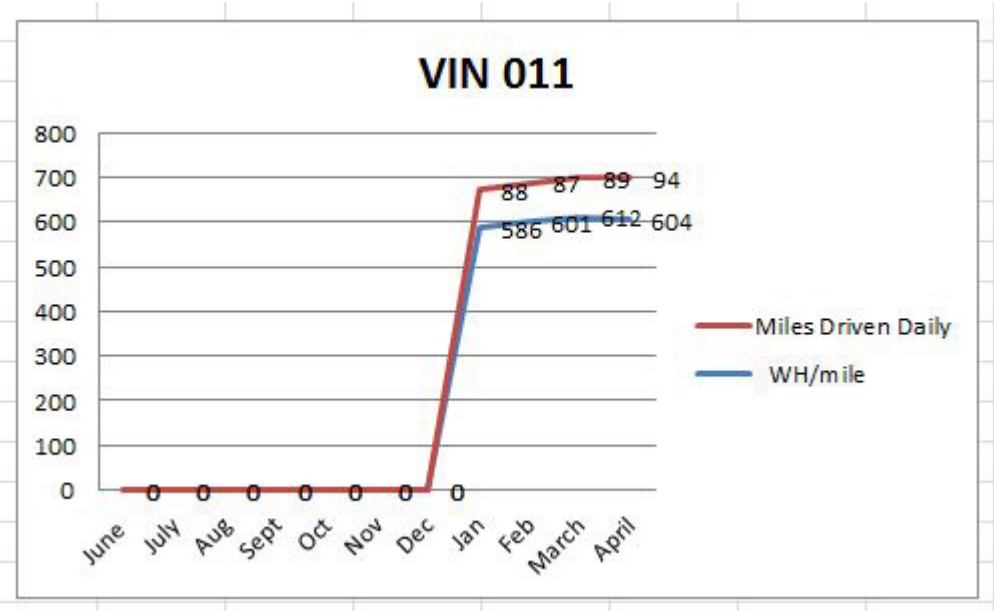

Figure 8: VIN 011 monthly wh/mi averages

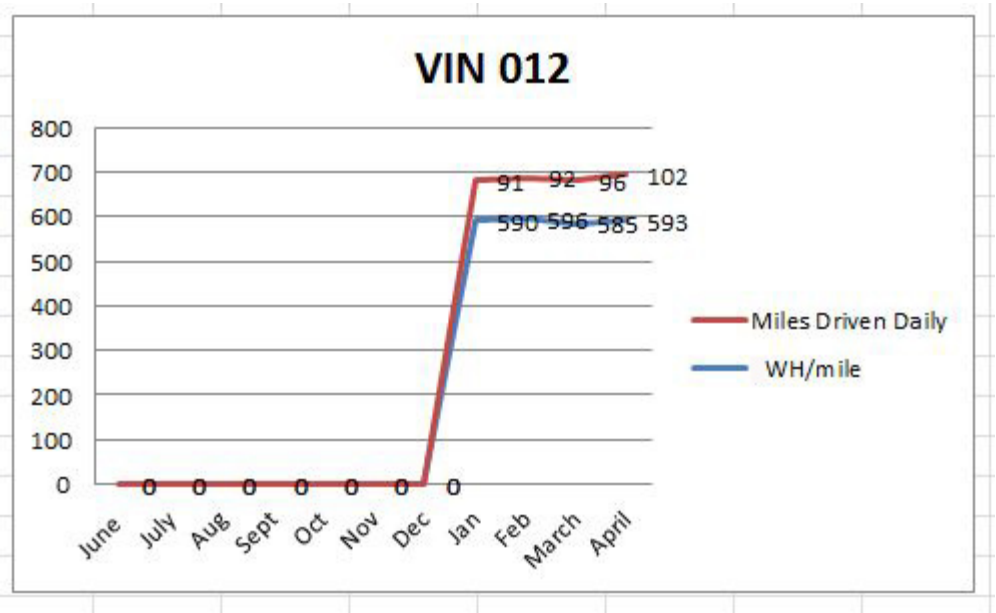

Figure 9: VIN 012 monthly wh/mi averages

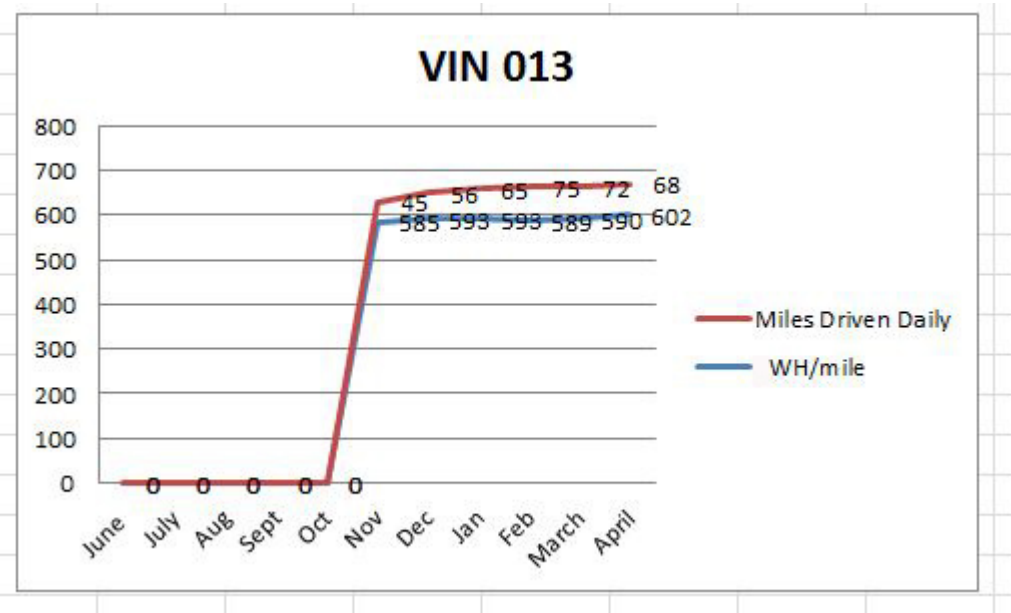

Figure 210: VIN 013 monthly wh/mi averages

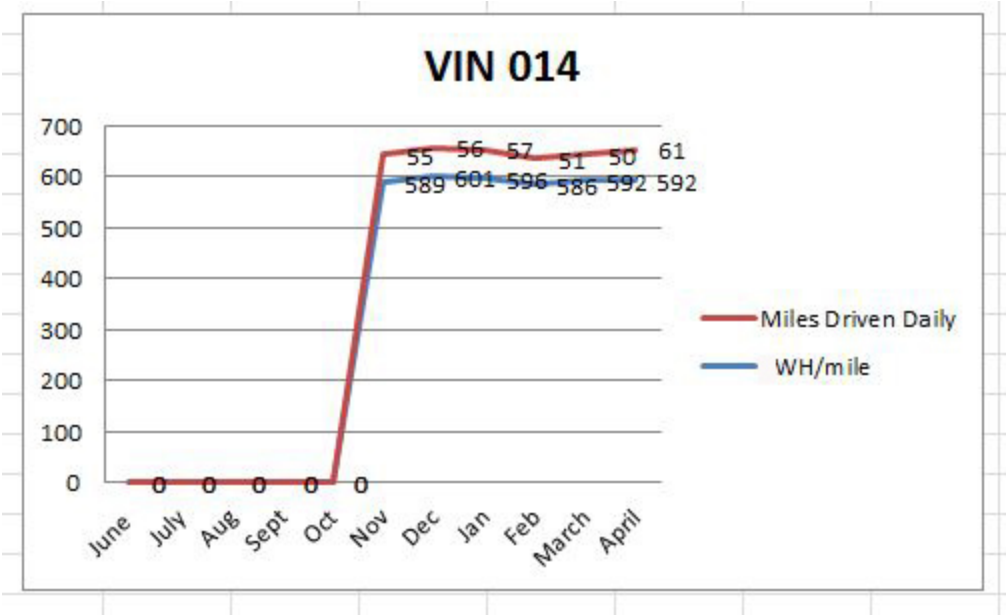

Figure 311: VIN 014 monthly wh/mi averages

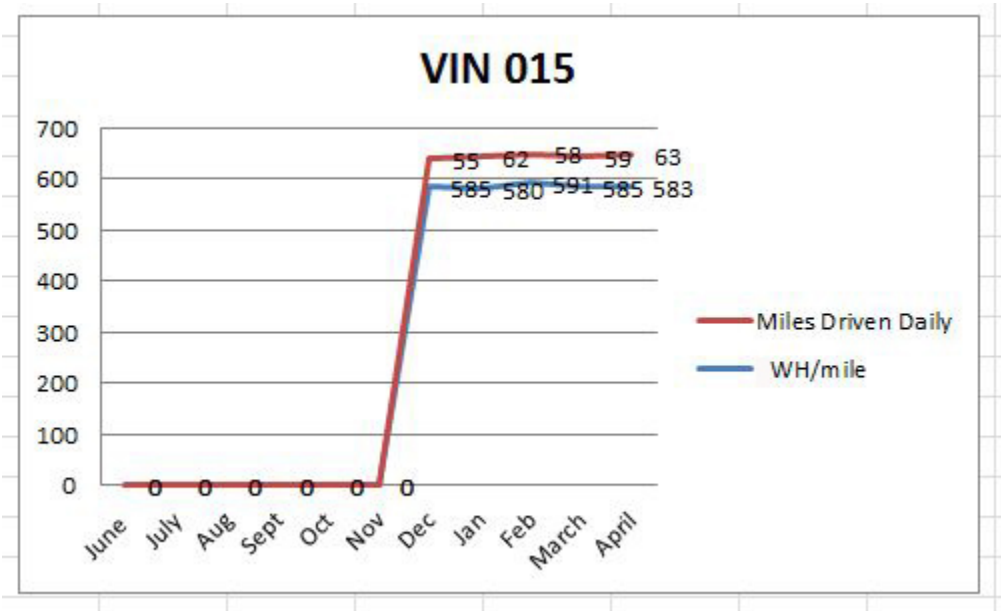

Figure 412: VIN 015 monthly wh/mi averages

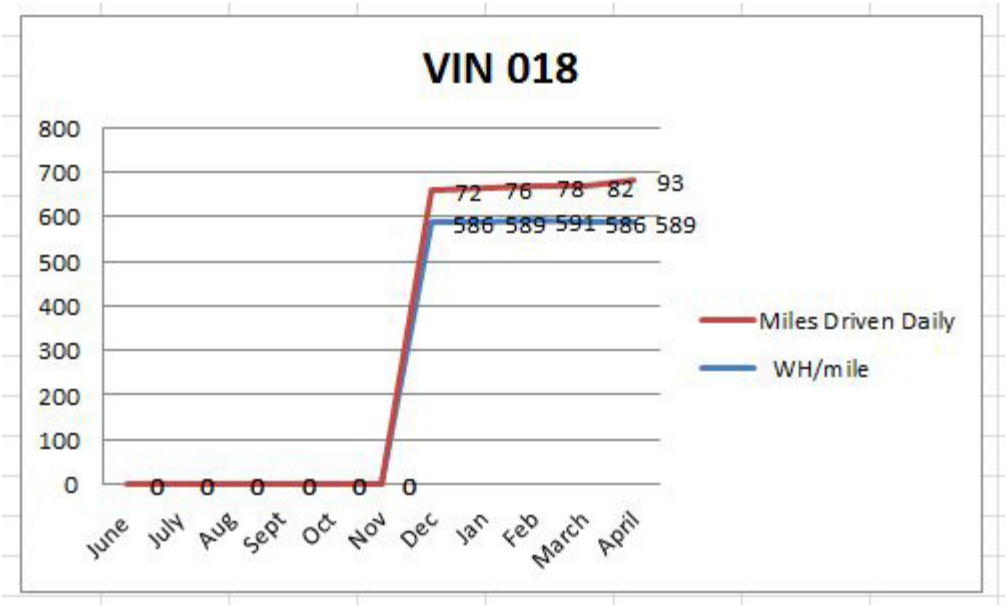

Figure 513: VIN 018 monthly wh/mi averages

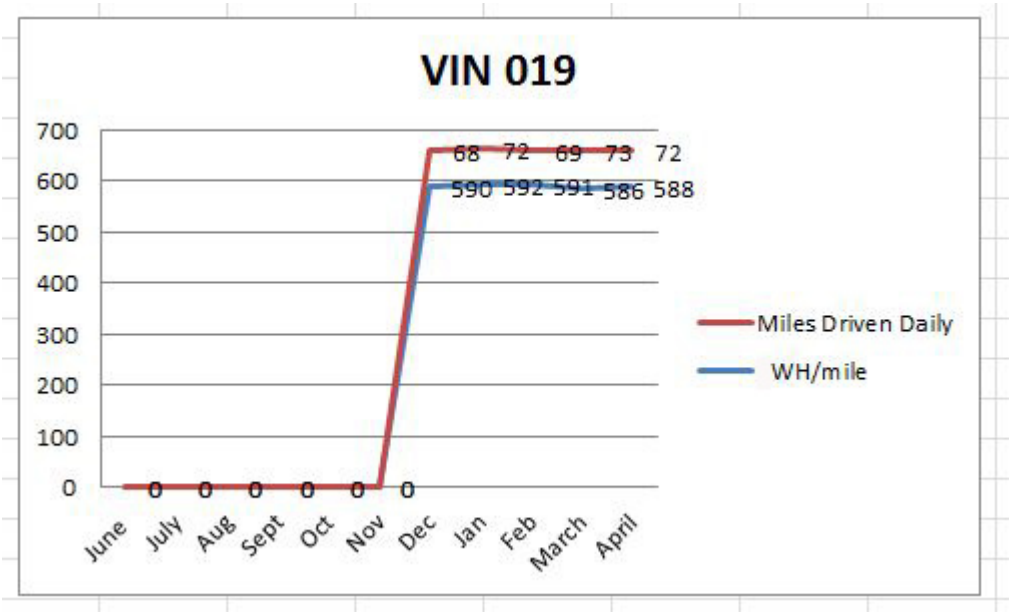

Figure 6~~1~~4: VIN 019 monthly wh/mi averages

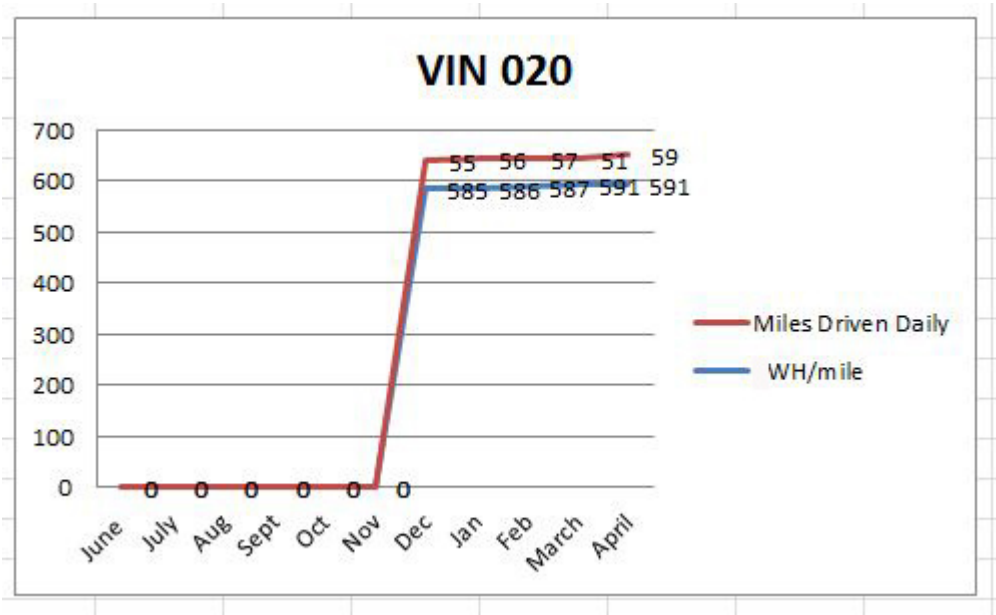

Figure 7~~1~~5: VIN 020 monthly wh/mi averages

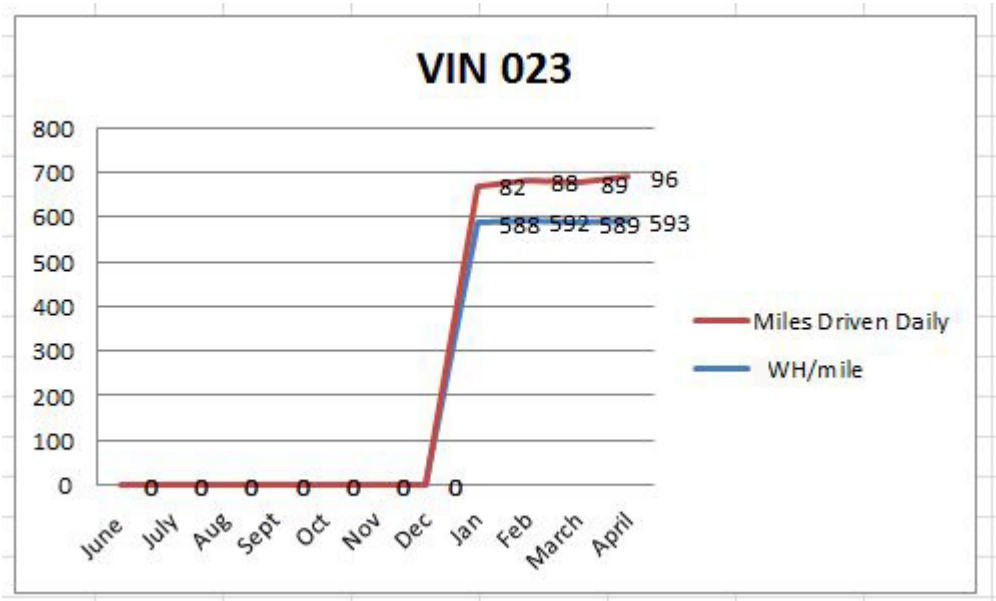

Figure 8~~1~~6: VIN 023 monthly wh/mi averages

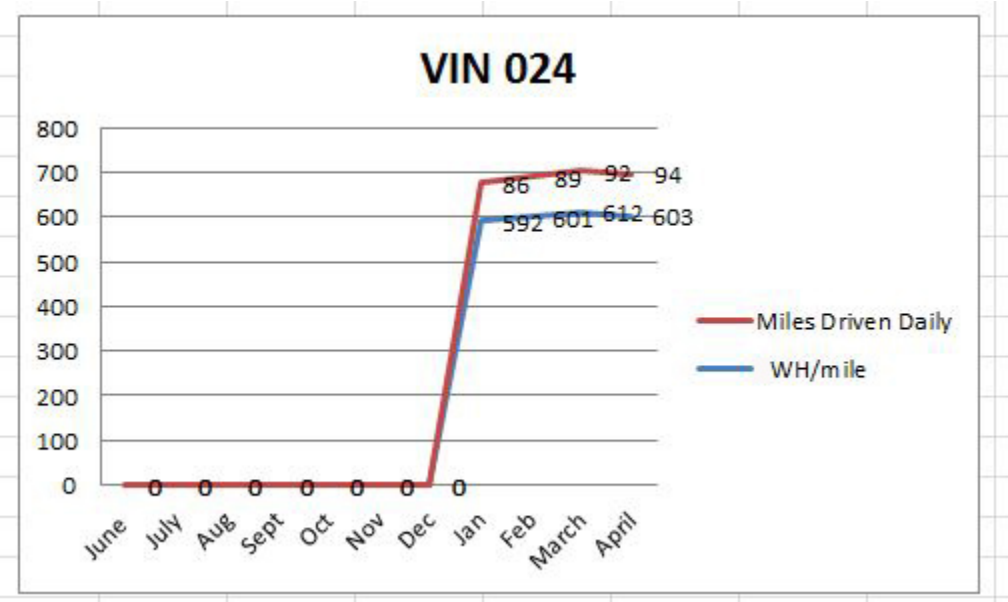

Figure 9~~1~~7: VIN 024 monthly wh/mi averages

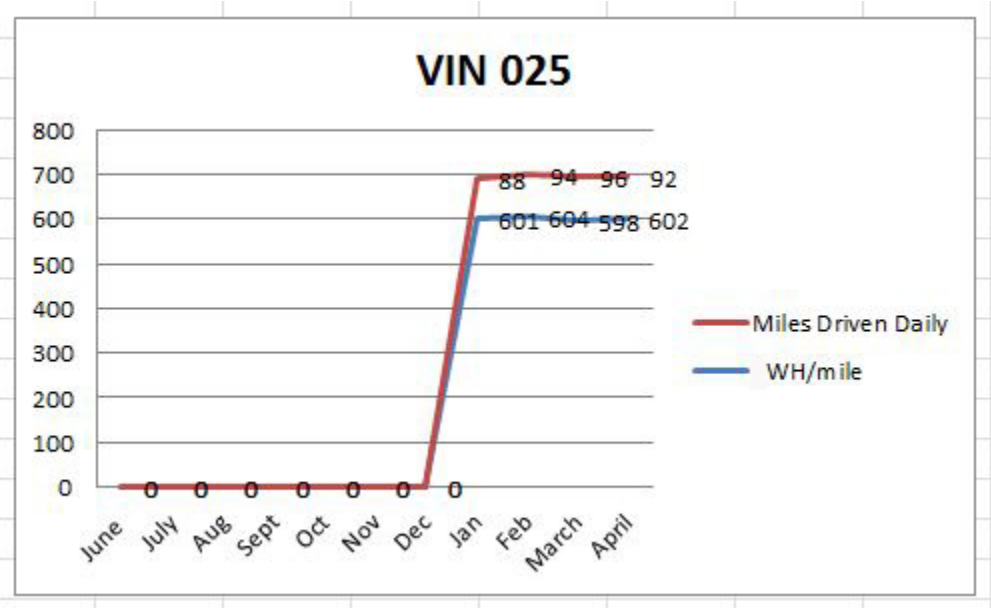

Figure 10~~1~~8: VIN 025 monthly wh/mi averages

Task 2.4.4 Schedule

From the Grant Activities (Scope of Work):

> *"2.4.4. The PERFORMING PARTY shall complete this task within 19 months of the signed Notice to Proceed Date as issued by TCEQ."*

Because of delays in Tasks 2 and 3, largely due to third party vendor bankruptcies, this task was not actually completed until 22 months after the signed Notice to Proceed Date.

Task 2.4.5 Deliverables

From the Grant Activities (Scope of Work):

> *"2.4.5. The PERFORMING PARTY shall submit a report to the TCEQ upon completion of this task. This report will include but is not limited to the monthly safety inspection and stress analysis log, demonstration partner driver feedback logs, battery thermal management system and charge-discharge cycle logs, and energy usage metering log."*

This report stands as the deliverable for this task.

Discussion/Observations

Objectives vs. Results

The objective of this task was to monitor the deployed vehicles for up to one year and to log data in reference to performance of the vehicles. The results were adequate to meeting the objectives. Some fleets had delayed deployment and so results could have been produced with greater quantities of data. It is difficult for a driver who is under a high pressure delivery schedule to take the time on a daily basis for feedback on each particular day. Therefore driver feedback was obtained from interviews during the monthly maintenance and safety check visits instead of through quantifiable daily data.

The driver satisfaction however is tremendous as the acceleration is better than any diesel delivery vehicle on the market. The regenerative braking creates less wear and tear not only on the brake pads but also on the driver's lower back as they do not have to constantly step hard on the brake pedal thousands of times a day. The driver acceptance has been one of our successes in the overall results.

We have had two critical component failures throughout the vehicle trials. Our battery management system, which keeps the battery cells in equal balance has had repeated failures early on in the field validation demonstration. This was realized on the first three vehicles deployed and was corrected in subsequent vehicles. However this did result in each of those first three vehicles being brought back to Colorado to have a new system from a different vendor installed into each of our vehicles. This resulted in a months' worth of drive time being lost for each of those first three vehicles in the field. The second critical component failure was the internal computer behind the dashboard display. The vendor provided us with units that had faulty hard drives and would start "crashing" after three to six months of use. This resulted in field repairs and frustration from the maintenance departments of the fleets.

However the fact that we addressed these issues in a timely manner gave us a wonderful "service on the spot" reputation with the fleet validation partners.

The objective of this grant was to successfully deploy 18 electric vehicles into the hands of fleets which would be end users of the vehicles on a successful basis. The specific criteria we had goals of measuring were watt hours used per mile over a wide range of vehicle usage and over various fleets both city owned and privately owned. Another objective was to determine what if any of our componentry would have issues due to the higher humidity of Texas as well as in the cold of winter and the heat of summer.

The overall results were that all of these objectives were met to varying degrees of success. We deployed the vehicles successfully although some were late on arrival due to the bankruptcy of our motor controller supplier and the need to source, engineer and integrate a new supplier's product. We were able to log the watt hours per mile which was the crucial data we were after as it provides real world fuel costs for operations of an electric truck. We found no components failing over the winter however during the heat of the late spring and early summer we have found that our display computer is inadequate to the operating temperatures demanded of it. This may also be a vendor quality control issue as some units are operating with no issues and others have to be reset every few hours. The result is that the operators have to power cycle the display computer by turning a switch off for 15 seconds and turning it back on after which the display computer takes about 3 minutes to reboot. This varies in frequency as to how often the

driver must reset this, sometimes it is once a week and sometimes it can be 3-6 times a day. Part of our future work involves replacing this unit with a more reliable and temperature tested unit.

Critical issues

One of the hardships of the field validation data logging was that we could not do this from a remote location but rather had to physically download a memory stick of data from each vehicle each month. Any effort that could be made to log and report this data remotely would be of great benefit to future projects. The other difficulty was sifting the data for the crucial matrices of performance when the entire CAN bus of data was being logged so that any internal system issues could be trouble shot.

One of the great things we implemented from a customer satisfaction point of view was to actually have the same person on the ground each month for the maintenance and safety inspections as well as the data harvest. This gave a great deal of continuity to our relations with the drivers as well as the fleet operators.

Technical and commercial viability of the proposed approach

The technical approach of rolling out the vehicles with testing of the charge stations as well as driver training is somewhat expensive for the roll out of a new vehicle. However the customer relations and satisfaction gained from such a detailed approach is invaluable in the long run. The onsite data harvest must absolutely be changed to a remote access feature. This also needs to be a remote panel that a fleet manager can pull up to see the performance and analyze competitive acceptance of electric vehicles.

In large scale production there are some ways that the verification of the charge stations and the driver training can be outsourced to a company that would also be responsible for the maintenance and repair of the vehicle, thus starting that relationship with delivery and not with the first repair needed. This we think would be to great advantage.

Scope for future work

We intend to keep the 18 vehicles in the Fleet Validation Partner’s fleets in operation as long as possible and hopefully for up to 20 years. We also intend to use them somewhat as a rolling test bed for implementing new componentry for field tests before placing a component into production use. We may at times have to bring the vehicles back to our Colorado plant for significant upgrades that cannot be accomplished easily in the field. We have already done this for the newer Battery Management System as well as the newer drive train componentry we switched over to halfway through the build process of the 18 vehicles.

We will continue to monitor driving range as well as energy use of the vehicles, both through driver logs and on board data logging. One driver in one city fleet continues to take their vehicle off road even though we have said numerous times that this is not advisable. However this does give us a higher level of stress on the vehicle componentry itself. Therefore we monitor this particular vehicle exceptionally closely. We suspect this will be the first vehicle to show signs of mechanical wear and tear.

Immediate next steps include implementing a different data logger which can send the data to us via a cell phone connection rather than having to physically download the data from a memory stick. This same upgraded data logging system will also be able to send error messages when the vehicle is having a problem as well as track the vehicle via GPS.

Another near term change will to be to replace the dash display units with units that are less subject to failure from high temperatures than the ones presently in the vehicle.

We plan on continuing our monthly inspections for at least the next year after which we plan on reducing the frequency to quarterly. We are also planning on implementing a data logging system which can report to us in Colorado via a cellular connection therefore eliminating the need of a physical removal of a thumb drive to retrieve the data.

We would like to develop an online driver training as well as maintenance training course. The Federal General Services Administration (GSA) schedule has an online training course which forces the end user to read sections and answer questions before being able to move on to the next section, verifying that the student is learning and comprehending the subject matter. We think this approach might be valuable for development. We think that developing both an electric school bus and an electric port tractor offer significant fuel and environmental pollution reduction. We think that for both of these applications that developing the vehicle to grid capabilities would in theory offer significant economic payback for vehicles sitting idle and being charged or discharged.

As part of our commercialization strategy in Texas we are starting to develop contacts for dealers as well as repair facilities throughout the State's metropolitan areas. Part of our commercialization strategy also depends on developing relationships with leasing companies. So far we have two lease companies who are extremely interested in leasing these vehicles in the State of Texas. Solidifying this should rapidly accelerate our commercialization efforts.

Long term technology projects with electric vehicles include the demonstration of vehicle to grid technologies which are currently being implemented by Boulder Electric Vehicle for the Federal SPIDERS project in conjunction with the Department of Energy, the Army Corp of Engineers, TARDEC, Southwest Research Institute and Coritech Services. Vehicle to grid will lead to frequency regulation, peak shaving and energy storage opportunities which will present a significant payback for the owners of large scale electric vehicles.

We also think that the vehicle to grid work we are doing and the DC fast charging work we are doing will carry over to both all electric school busses as well as all electric port tractors. School busses provide a vehicle with a potentially very large battery pack if they were electric and they are used only 6 hours per day, five days per week and only during the school year. They are available all night long to absorb extra energy from wind farms and they are available during the sunniest part of the day to take energy from solar PV arrays. In addition they are parked all summer long during the highest use months of the year for air conditioning units. If each school district with 100 busses could deliver 150 Kilowatts each that would be 15 Megawatts of energy for each 100 busses. That represents a substantial amount of "spinning reserve" which would otherwise be provided by a coal fired power plant.

We also think that Port Tractors that remain idle and in line for a container much of the time represent a great opportunity for electrification and that the DC fast charging work we are doing will carry over to that market niche with great success. These vehicles sit in line most of the day waiting for a load to carry about 5 miles maximum and while they are sitting in line the drivers have the air conditioning on high. The vehicles are often in one spot for 10 minutes before the line moves and that presents a great chance for a DC fast charger to bring a battery pack to full. This would present the chance to “right size” the battery pack thus reducing the cost of the vehicles.

Intellectual Properties (IP)/Publications/Presentations

There was no IP developed, disclosed or filed during this task or grant execution.

Summary/Conclusions

We have found that through the two years of executing this grant that there are two over reaching issues that must be addressed before the successful roll out of electric trucks can be accomplished. The first issue is quality control in the vendor supply chain and the second issue is driver acceptance coupled with human behavior, they are really one in the same. We have found that with the implementation of leasing that the initial price barrier is no longer an issue. The price of the lease if stretched out over five or seven years is usually just a bit more than what customers pay for diesel. The monthly payment is often less than what a customer pays for diesel and maintenance combined. So even in the early years we thought price was the major hurdle to overcome in the path to commercializing the technology we have found a way around that.

Quality control in the vendor supply chain is a serious issue and a part of this is the financial stability of the vendors themselves. About six months into this grant one of our key vendors who was providing the motors and controllers for the vehicles went bankrupt. This caused an approximate 6-12 month delay in selecting a new drive train motor and controller and doing the engineering to accommodate the different attachment points as well as different electrical routing and cooling for the unit. This is the main reason some of the trucks were running for less than a full year. The company that went bankrupt was a publicly traded company that had at least $10 M in inventory sitting on their shelves, unfortunately none of it was the parts that we needed. Some other electric vehicle companies have had serious trouble when their battery supplier, A123 systems, went bankrupt and was no longer able to supply them. A123 had a Billion dollar IPO and still went bankrupt within 3 years of that IPO. That being said the world economy in general has been in sad shape during the time frame of this grant and it is not surprising that many companies have gone under, whether related to the electric vehicle industry or not. We do not think that the problem of financial stability exists only in the electric vehicle supply chain as just before this grant GM, Chrysler and the US Postal Service were all in major financial trouble.

Quality control within the vendor supply chain is another issue closely tied to the financial stability of the vendor themselves. If the vendor is not large enough to have quality control procedures then there is no incoming inspection of components, no final testing before shipping and possibly no shipping verification

that the actual components shipped are the correct ones. We have run into this from our vendors on several fronts. The solution that we have not yet been able to implement is to have multiple sources for the same item.

In all of this we are referring to the electric vehicle specific components such as battery cells, battery management systems, high voltage heater and air conditioning units, vehicle battery chargers, J1772 connectors and other high voltage wiring components specific to the electric vehicle build.

The second major barrier to acceptance and use of large electric trucks is driver acceptance and human behavior. The most simple thing is that the vehicles have to be plugged in every night. As well as serving the function of the vehicle being available with full range for driving the next day, plugging the vehicles in also keeps the battery pack fully charged and healthy. Plugging the vehicle in every night serves as a maintenance procedure. In an electric vehicle there is no oil to change, no valves to adjust, no fuel filters to change, no belts to adjust and/or replace but keeping the battery pack healthy means plugging it in whenever the vehicle is at rest for more than a few hours. So educating the fleet manager and the drivers as to this facet is crucial. This was one of the key benefits of developing a driver training course.

We accomplished a high level of driver acceptance of electric trucks in the field. We developed a repair and replace procedure on the fly which was basically outside the scope of the grant but none the less necessary to its successful completion. We conclude that human behavior in the way vehicles are maintained and driven is the hardest single barrier in the acceptance of electric vehicles.

Electric motors and electric vehicles have been proven to have a much greater efficiency curve over any Internal Combustion Engine, whether powered by gas, diesel, bio diesel or compressed natural gas. Long term the operating costs are a magnitude less than the above mentioned fuels so we think the adaption of electric vehicles is almost inevitable. The looming question is whether American manufacturers will be leading the way or trying to catch up with China once they start importing these vehicles into our country.

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