

# Heavy-duty Hybrid Utility Trucks – HTUF Deployment Experiences and Results

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## Abstract

The growth of hybrid drive trains in the medium- and heavy-duty vehicles has been rapidly increasing. To speed this commercialization effort WestStart-Calstart has organized qualifying fleets within the Hybrid Truck Users Forum (HTUF) and launched a large field deployment effort. The project is the largest deployment of this class of vehicles in terms of scope and number of vehicles. A total of twenty-four hybrid and twenty baseline vehicles are being tested in this field deployment lasting over twelve months. The trucks are being evaluated for overall performance, fuel economy, reliability and availability, and user acceptance. The results have been very positive with 99% availability and a range of fuel consumption improvements of the hybrids over baseline trucks on the order of 14-54%. The range is very likely due to differences in duty cycles in this application indicating that it is very important to match the hybrid truck with the duty cycles it was designed for.

**Keywords:** heavy-duty vehicles, hybrids, hybrid-electric.

## 1. Introduction

Hybrid technology for medium- and heavy-duty vehicles is at a stage of significant growth and potential expansion. Medium and heavy-duty hybrids are rapidly moving from the prototype stage to the pre-production and early market deployment stage. Use of hybrid drivelines in the medium- and heavy-duty applications has the potential to provide improved fuel economy, extend engine service life due to decreased engine hours, and to reduce brake wear due to regenerative braking. Applications that involve mixed duty-cycles with stop-and-go and idling modes have the greatest benefit from hybrid systems. This is why the first applications of hybrids have been in vocational work trucks and urban transit buses. The utility bucket truck has been identified as a promising application having stop-and-go driving modes and relatively longer idling modes at work sites. This paper reports on the experiences and results of a large field deployment effort of pre-production utility hybrid-electric trucks. This project is the first of its kind in deploying this class of hybrid trucks and is the largest to date in terms of scope and number of vehicles.

## 2. Objectives of the Field Deployment

To speed commercialization of heavy-duty hybrids and to assess hybrid driveline capabilities, WestStart-Calstart has organized qualifying user fleets within the Hybrid Truck Users Forum (HTUF) program for a field deployment effort<sup>1</sup>. Twenty-four (24) pre-production hybrid-electric trucks are deployed among fourteen (14) fleets in geographically diverse locations throughout North America. The locations cover

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<sup>1</sup> For more information on the HTUF program and the different working groups organized under HTUF see the paper by Van Amburg (EVS-23, 2007).

different terrain and climate conditions to ensure that the truck is tested under different operating environments (see Figure 1).

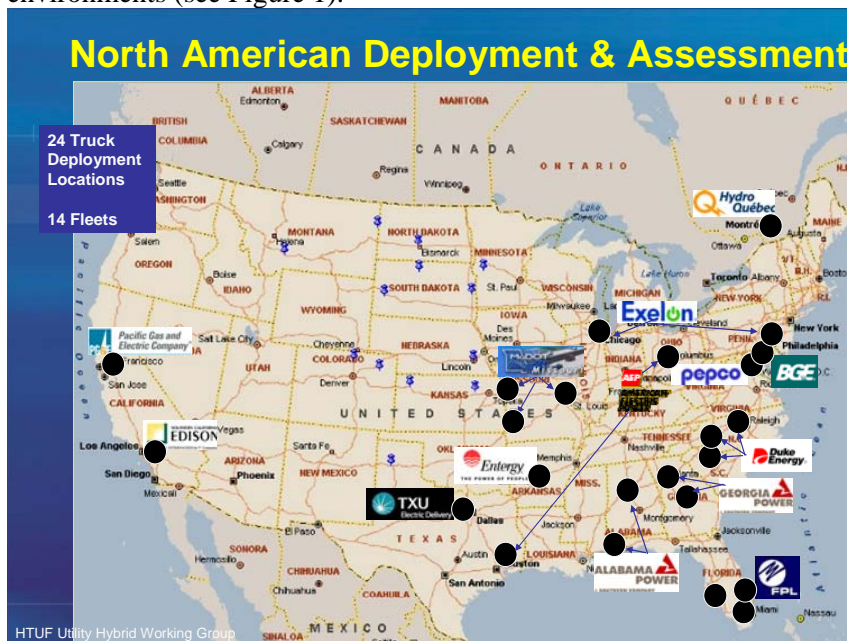


Figure 1: Locations of the field deployment.

The main objective of the field deployment effort is to evaluate the overall performance of the hybrid trucks during a testing period of one-year. To achieve this, it is necessary to collect reliable and uniform data across the participating fleets. The two major overall elements of the project are a) deployment of the vehicles for a statistically significant, geographically diverse test, and b) one year data collection, analysis and assessment. The focus of the data collection process is to obtain data on 1) fuel economy, 2) reliability and availability, and 3) user acceptance.

## 2.1 Design and operation of the hybrid electric utility truck

The truck is a medium heavy-duty commercial Class 6/7 (24,000 – 33,000 GVW) International 4300 work truck built on a standard commercial chassis and utilizing a DT466 diesel engine with 225 horsepower. The hybrid system is a parallel, “mild” hybrid system by Eaton Corporation, inserted in the space of the existing transmission. The transmission on the trucks is automated manual transmission also by Eaton Corporation. The hybrid system is battery electric (energy storage of the battery pack is 1.8 kWh) with a 44 kW electric motor. The trucks are equipped with a 42 ft aerial device and a hydraulic system (supplied by Altec Industries in most of the units and in one case by Posi-Plus) connected to the power-take off device (PTO). The PTO can be driven either by the engine or the electric motor, with seamless transition from one to the other (see Figure 2). This type of truck is common in the commercial market segment used by electric utilities, cable operators, telecom and state and public agencies nationwide.



Figure 2: Hybrid-electric utility truck used in the HTUF deployment.

The hybrid control system on the units was optimized to decrease or eliminate engine idling at work site operations. When the truck comes to a designated work site in order to use the PTO, the operator must enable the ePTO which by default powers the PTO from the hybrid system. During this time the engine is in the off position. The engine will come on when the state of charge of the battery is low to recharge the battery to a pre-determined state of charge. In addition to this, the hybrid system assists in the launch of the vehicle and captures the energy through regenerative braking. Therefore, while the system has been specifically designed to save fuel by replacing engine idling, fuel savings during driving also contribute to the overall fuel economy.

## **2.2 Data collection**

### **2.2.1 Performance data**

To collect consistent, reliable data across all fleets, an on-board data collection system was put in place. The system is Aware™ Vehicle Intelligence, a product of International Truck Company. Each hybrid truck and a comparison baseline truck is equipped with a data tracking module and wired appropriately to record the data during the deployment. The data is then sent to a central computer via the wireless internet network. The system was designed to track data in real-time and in monthly summary reports. The main parameters being tracked are listed in Table 1. In each of the operation modes, the fuel consumed and the time spent in each mode are being measured. In addition, the location of the trucks is tracked via GPS.

Table 1: Main parameter (or operation modes) tracked.

| No. | Configuration modes   |
|-----|-----------------------|
| 1   | Driving               |
| 2   | Idle                  |
| 3   | PTO with engine       |
| 4   | PTO no engine only    |
| 5   | Electric drive only   |
| 6   | Hours of operation    |
| 7   | Electric Drive Assist |
| 8   | Regeneration          |
| 9   | Service Brake Applied |

While this is a well set up system with automated data collection, it did require design of parameters for tracking data specifically for this deployment. There also were some communication and routing problems through the internet that needed to be addressed along the way. The main benefit of the on-board tracking system is that it provides uniform and automated reporting from all the units.

### 2.2.2 Reliability and availability

The reliability and availability of the trucks is tracked by the supplier team (Eaton, Altec, International) and reported each month. The data is tracked according to service calls that the team receives as well as by tracking the fault codes available via Aware<sup>TM</sup>. Reliability tracks all the parts and components that were reported during the field deployment. Availability is an industry measure of vehicle being available for revenue service and for the hybrid electric trucks it is defined as the time that the hybrid system was not preventing the truck from being used.

### 2.2.3 User acceptance

We also tracked user acceptance of the units via surveys that were sent out to the users at the beginning of the field deployment as well as the end. The users were asked to rate the truck in comparison to the baseline trucks they normally use in terms of overall performance of the units as well as rate the special features of the hybrids (e.g. switch from electric to engine on). The list of the questions is provided below:

- Starting- initial launch
- Braking
- Low speed maneuverability
- Acceleration
- Deceleration
- Grade pulling
- Transmission –shift quality
- Boom operations electric mode (engine off)
- Boom operation mechanical mode (engine on)
- Boom operations - smoothness of switch from electric to engine on
- Hydraulic power for tools
- Power generation
- Noise level
- In-cab ergonomics (controls, switches, etc.)
- Overall rating

### 3. Results

The first trucks were deployed in May/June 2006 and have been in the field for over 12 months. The deployment of the units was staggered, with roughly a couple of trucks being deployed each month and the final units were deployed in September 2007. The total number of truck in the field deployment is 24 hybrid units and 20 baseline units, same or comparable engine and chassis model. The hybrid trucks have accumulated over 400,000 miles to date.

#### 3.1 Fuel performance

As described earlier, the fuel performance was measured on the hybrid and the baseline units. In order to compare the performance of the baseline and hybrid units it is important to capture the gallons consumed and also the total hours of operation, which includes the engine-on as well as the engine-off operation hours. We thus compare the data in terms of gallons per hour of total operation (gallons/hour). Note that parameter 6 listed in Table 1 records the total hours of operation defined as the time with the key in the ignition. Figure 3 shows the comparison of fuel consumption in gallons/hour for the baseline and the hybrid trucks for selected fleets.

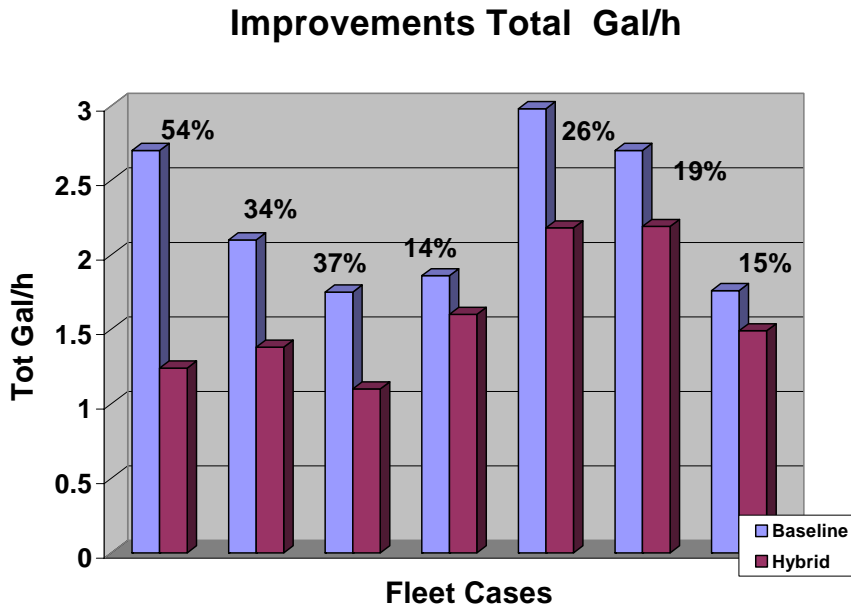


Figure 3: Comparison of baseline and hybrid trucks for different fleets in terms of total gallons/hour.

The hybrids show a decrease in fuel consumption over their baseline vehicles consistently. The percent improvement is calculated as the difference in gal/h of the hybrid and the baseline over the baseline. The lowest value is 14% and the highest is 54% indicating the differences between the fleets. These differences are due to different baseline vehicles but mostly due to different duty cycle characteristics for each fleet. In terms of gallons of fuel used per day, which is a number that fleets can more readily compare to their own fuel use, if both the hybrid and the baseline truck operate 7 hours in a day, the baseline would consume 14.7 gallons that day and the hybrid would consume 9.8 gallons (difference is 34% or second pair of bars in the chart above). This is in agreement with the values measured in lab testing where the hybrid consumed 40% less fuel than the baseline vehicle.

We also evaluated specifically the fuel performance for the driving portion of the duty cycle. This was calculated by comparing the gallons measured in the driving mode and the miles that the trucks drove to

give the mpg value for driving. The comparison of the baseline and the hybrids is shown in Figure 4 for the same units as in Figure 3.

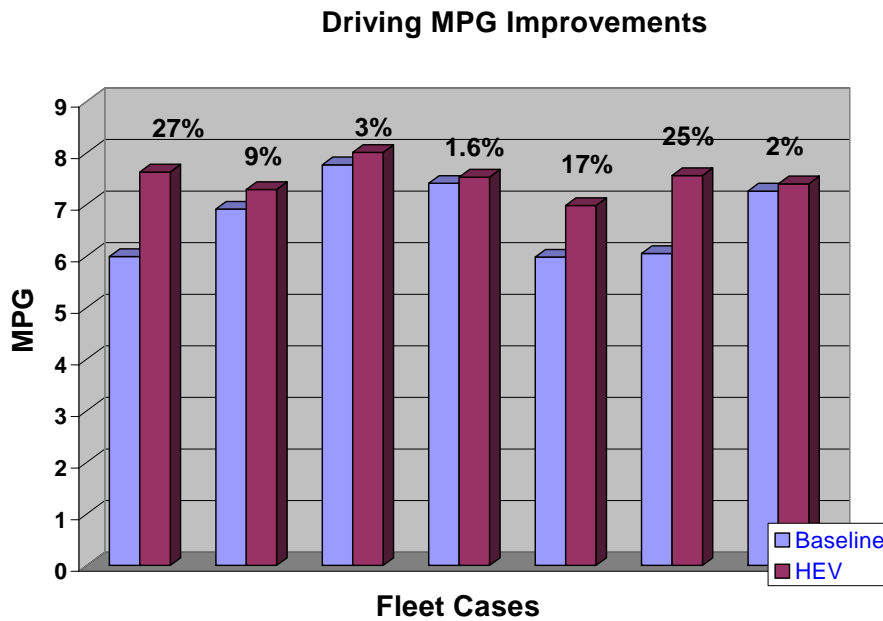


Figure 4: Comparison of baseline and hybrid vehicles in terms of mpg during driving.

In the driving mode the hybrids showed improvements over the comparison baseline vehicles ranging from 2 - 27% depending on the specific fleet. These improvements once again underline the importance of specific duty cycle that the truck is experiencing. The mpg can be affected by speed, terrain, acceleration which should be examined in more detail for better interpretation of the range measured here. We also found that majority of the fuel is used for driving, about 80%, and that most of the trucks drive 70 mi/day.

### 3.2 Reliability and availability

Reliability of the units is being tracked during the entire field deployment. To date the team has recorded a total of 130 issues from May 2006 through August 2007. The issues are grouped according to type in hybrid issues, body issues, and chassis issues.

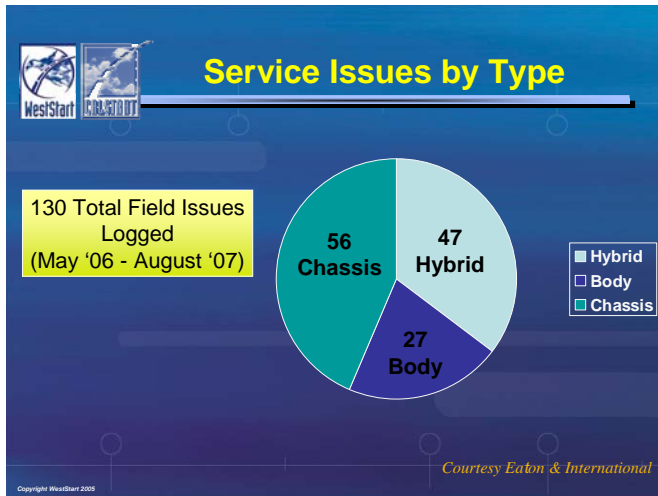


Figure 5: Service issues by type.

The other important part is that the number of issues during the deployment has steadily been decreasing over time. This can be seen on the chart in Figure 6. This is a result of the continuous improvements in the components of the truck and learnings from the deployment experiences.

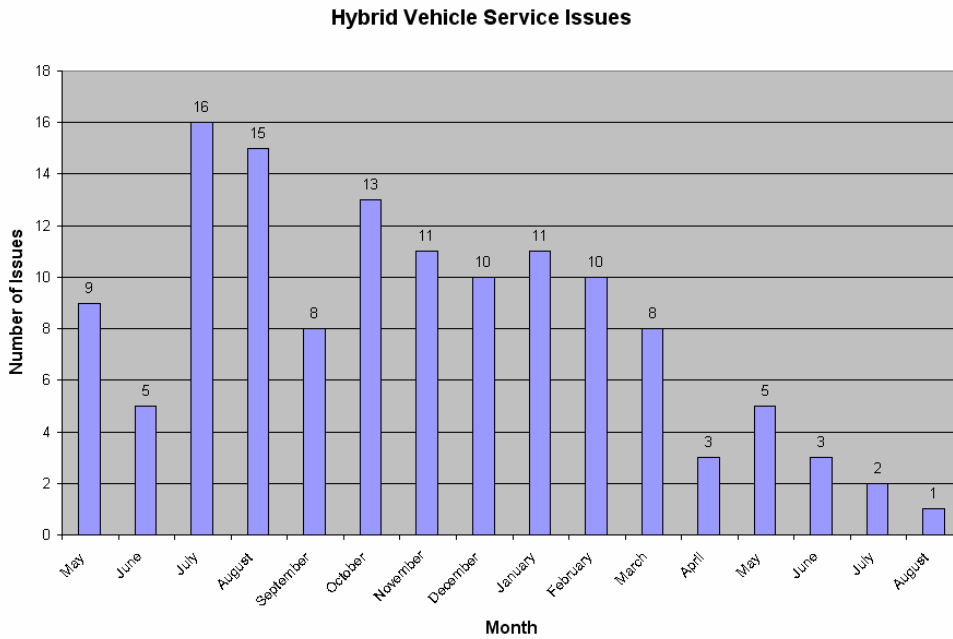


Figure 6: Service issues per month.

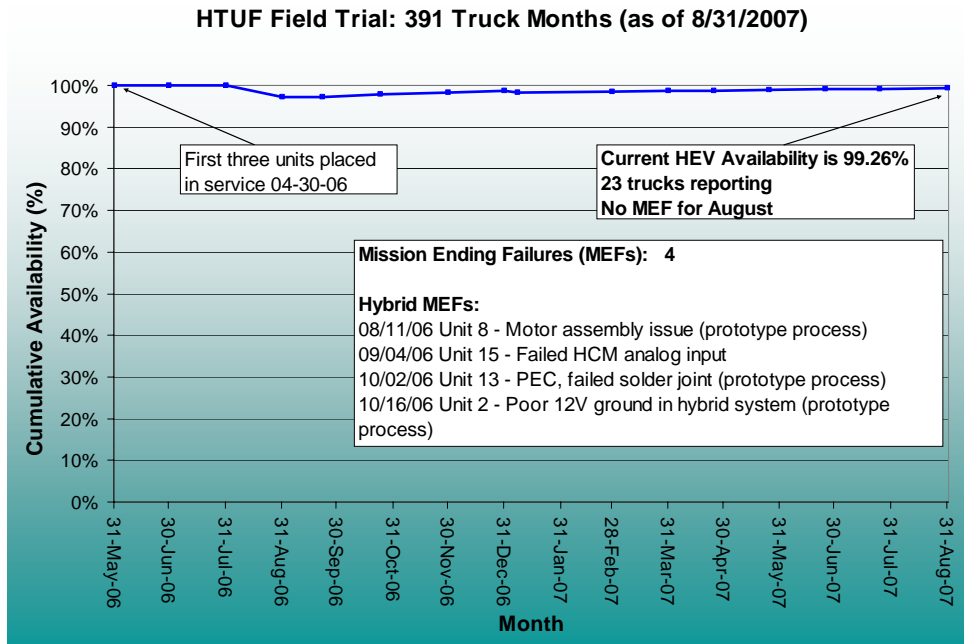


Figure 7: Availability of the hybrid trucks during the field deployment.

Availability is defined on the basis of the hybrid system being available for revenue service of the truck. The availability for all the units overall is very high, over 99%. The dip in the curve at the beginning indicates that the problems usually occurred at the start of placing the units into service but once resolved, the availability continued to stay high.

### 3.3 User acceptance

The users filled out surveys at the beginning of the field deployment, usually a month or two after starting to use the units, and again 12 months later. The users rated the performance of the vehicles on a scale from 1 to 5 in comparison to the baseline vehicles. A rating of 1 is equal to “much worse than” and a rating of 5 is equal to “much better than.” Figure 8 has shows plots of the mean values for each of the performance questions in 2006 (chart on top) and in 2007 (chart below). It should be noted that the data for 2007 is not fully complete as we are still receiving surveys.

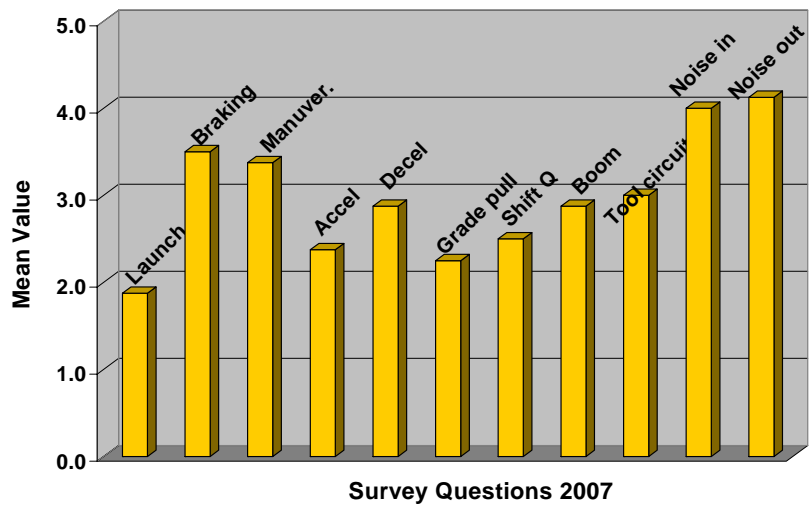
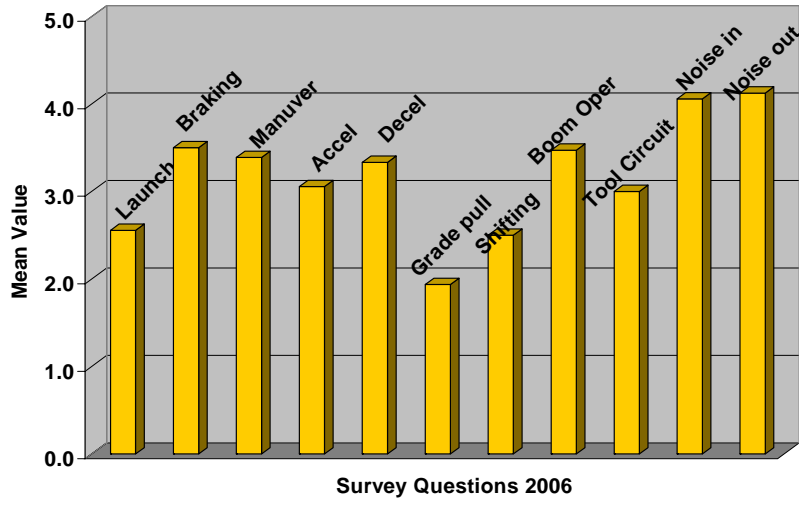
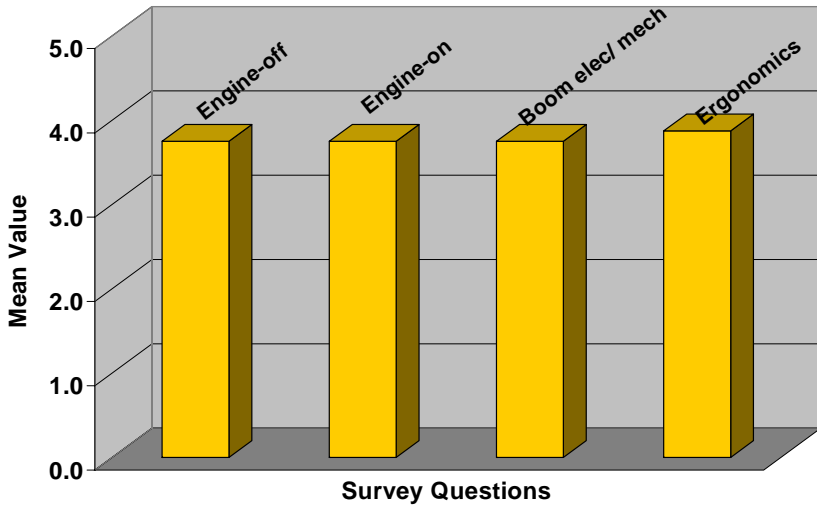


Figure 8: Results of acceptance surveys on the performance of the hybrid trucks in comparison the baseline vehicles.

Most of the ratings have a mean value greater than 3 indicating that the vehicle is as good as the baseline. A few ratings are lower, in particular launching, acceleration, and grade pulling. It should be noted that all the hybrid vehicles have 225 horsepower while some of the baseline vehicles have higher horsepower. This may explain the differences in performance reported by some users. In addition, a few of the vehicles are much heavier, or close to 33,000 lb GVW which is the upper limit for this class size, and may be the reason these units are reporting lower satisfaction with grade pulling and launching performance for example. High ratings were given for noise both in and outside of the trucks as well as braking.

We separately asked the users to rank the special hybrid features – these results are shown in Figure 9. We show only one set of results as the chart is similar for both 2006 and 2007 surveys in this case.



The mean values of the responses are around 4 indicating that the users were very satisfied with operations of the boom with engine-on and engine-off as well as the switching from electrical to mechanical.

#### 4. Conclusions and Lessons Learned

This is the largest deployment of hybrid vehicles in this class size to date. The twenty-four hybrids and twenty baseline vehicles are located across North America with fourteen participating fleets. While this large deployment provides an excellent test in different regions, it did present challenges in terms of deploying the vehicles as well as servicing and monitoring them. The deployment was staggered and instead of six months, it took longer than a year to put all the vehicles in service.

The hybrid trucks have been performing very well. The availability of the trucks for service based on the hybrid system has been very high, 99%. The reliability of the units has been steadily improving during the field deployment also with many improvements to components that have been permanently added to the production intent trucks. Most importantly, the fuel consumption for the hybrids shows improvement over the baselines in a range from 14 – 54% depending on the specific fleet, or duty cycle. We plan to investigate and understand the duty cycles in greater detail and identify best and worst duty cycles for the utility hybrid trucks. It is very important to put the hybrids in duty cycles they were designed for in order to capture the greatest benefits.

#### 5. Acknowledgments

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Jasna Tomic is Fuels Program Manager at WestStart – Calstart. The two main areas that she is presently working in are the Hybrid Truck Users Forum (HTUF), bringing hybrid trucks to the marketplace, and use of alternative fuels in transportation. Within HTUF, she leads the deployment and field testing of twenty-four pre-production hybrid trucks and investigates best pathways and uses for plug-in hybrid trucks. Dr. Tomic’s expertise includes research in vehicles-to-grid power (V2G) – innovative use of electric-drive vehicles for transportation and power generation. She holds a Ph.D. in Fuel Science from Pennsylvania State University and has published extensively on energy conversion processes as well as use of electric-drive vehicles.



Bill Van Amburg is Senior Vice President of WestStart - Calstart. As such he oversees the Hybrid Truck Users Forum (HTUF) program, which he helped create, together with overseeing teams in four other program areas: New fuels; Technology commercialization; Fleet analysis and consulting; and industry services. Van Amburg brings more than 25 years of experience in marketing and market development, technology commercialization, communications and environmental markets, including emission credit trading. He has a bachelor’s degree in Anthropology from the University of California, Berkeley, a Brand Management certificate from Stanford and is a graduate of the UCLA Anderson School of Management’s Executive Management Program.