HTUF Hybrid Refuse Truck Working Group

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White Paper

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This white paper is a product of the High-Efficiency Truck Users Forum (HTUF) and the Hybrid Refuse Truck Working Group of HTUF. The purpose of this white paper is to illustrate how a lifecycle cost analysis can better assess the benefits of advanced technology, rather than looking at the simple payback period.

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HTUF
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1. Introduction

In conversations with fleet managers, CALSTART has found that a large percentage of refuse fleets rely primarily on a Simple Payback Period (SPP) analysis. A Lifecycle Cost Analysis (LCA) can provide a far better understanding of the total value of the investment, but it requires that the fleet manager has fairly specific data on the performance of his conventional vehicles, as well as good information on the advanced technology against which to compare. CALSTART has at times found large gaps in the technology, desire, and ability of some fleets to gather accurate quantitative data.

The purpose of this case study analysis is to illustrate how the initial purchase price, fuel economy improvements, maintenance cost reduction, and possible productivity improvements figure into the overall equation for defining the benefits of investing in a more efficient technology to accomplish the same job as a conventional diesel refuse vehicle. LCA takes these factors into consideration over the life of the refuse vehicle and, using the projected cost of money, fuel inflation rate, and other factors, determines the effective cost savings over the life of the vehicle. The benefits of advanced technology are better assessed when looking at the costs across the vehicle's lifetime rather than looking at the simple payback period, so that optimal long-term investment decisions can be made.

Rolling stock purchases are expensive and fleets need to be able to justify these large outlays of funding for their vehicle acquisitions. Using LCA, refuse fleets will have a better understanding of the true costs of the vehicle from an economic standpoint and the benefits of this investment over the longer time period.

2. The HTUF Hybrid Refuse Truck Working Group, Phase I

Figure 1: DSNY's Crane Carrier hybrid-electric refuse truck

In March of 2007, the CALSTART Hybrid Truck Users Forum (now known as the "High Efficiency Truck Users Forum" commonly referred to simply as "HTUF") Hybrid Refuse Working Group released a Request for Proposal for a Class 8 hybrid refuse truck able to meet the specifications set by members of the group. These members included the City of New York Department of Sanitation (DSNY), the City of Houston, and the City of Chicago, who were all poised to make a purchase of a hybrid refuse truck, pending the demonstration of favorable performance characteristics and reasonable cost effectiveness. Crane Carrier, whose LET2 vehicle is shown in Figure 1, won that solicitation and subsequently provided three hydraulic hybrids using a Bosch-Rexroth drive system (including one vehicle powered by compressed natural gas and three electric hybrids using an ISE drive system to DSNY. DSNY was able to purchase the vehicles for deployment and testing by using funds that covered a portion of the cost of the hybrid drive systems. These funds were provided by the U.S. Army TARDEC/National Automotive Center through the HTUF program. The vehicles underwent field testing in New York City's five boroughs, as well as chassis dynamometer testing to quantify emissions and fuel efficiency in comparison to a conventional diesel vehicle.

The Crane Carrier test results were provided in an internal report to the team members of the first phase of the working group. These test results have not been made public due to some operational concerns with the vehicles, which were demonstration vehicles. However, results of the HTUF testing were positive enough to encourage DSNY to move forward with a solicitation for over fifty hydraulic hybrid refuse trucks. The electric hybrid variant was determined to be insufficiently developed at that time. The Crane Carrier/Bosch Rexroth vehicles did not enter production due to a lack of industry interest at the time, but the Bosch Rexroth hydraulic system is expected to enter production in Mack Trucks in 2013. The City of Chicago also purchased another hydraulic hybrid from Crane Carrier—this one with an Eaton system—to test the technology in their application. Unfortunately, Hurricane Ike in September 2008 curtailed the ability of the third fleet, the City of Houston, to move into the new technology, but the city's fleet managers subsequently invested in the technology on their own volition, based on the results of the working group deployment.

Phase I of the HTUF Hybrid Refuse Truck Group established the performance criteria for these new types of vehicles, developed test plans for evaluating the vehicles, and deployed seven vehicles between New York and Chicago for evaluation and testing. Results of the testing motivated DSNY to go out with a solicitation for hybrid refuse trucks, with Mack/Bosch Rexroth being selected as the provider.

3. The HTUF Hybrid Refuse Truck Working Group, Phase II

In the last two years, 2010-2012, the market has seen an increasing growth of hydraulic hybrid refuse truck purchases, so CALSTART's HTUF program re-invigorated the Hybrid Refuse Working Group to bring in those fleets that had direct experience with hybrid technology. The objective was to document the fleets' experiences with this new technology and quantify the benefits each has identified. Since we were relying on data provided by the fleets, we did not expect to quantify as many aspects of performance as could be done if a more in-depth data acquisition had been accomplished.

A number of fleets were willing to share their experiences with the vehicles, but we discovered that many fleets were not tracking the operating characteristics of their vehicles, either conventional or hybrid, as well as we thought they might. Therefore, it was difficult to gather enough quantitative data from the fleets to be able to coherently compare the performance of various hybrid technologies that were currently available. However, we were able to gather enough qualitative information that serve to illustrate the benefits of considering Lifecycle Cost Analysis when making capital equipment purchases, rather than relying solely on Simple Payback Period analysis.

As shown in Figure 2, the hydraulic hybrid refuse trucks that are currently deployed by various fleets represent the Eaton Hydraulic Launch Assist (HLA) on a Peterbilt platform, the Bosch-Rexroth parallel Hydrostatic Regenerative Braking system (HRB) on a Mack Truck chassis, and the Parker Hannifin RunWise® Advanced Series Hybrid Drive on an Autocar platform. BAE is proposing to bring a hybrid-electric refuse truck to the commercial market in a Crane Carrier platform, but as of October, 2012, they had yet to fully launch that product. Bosch is also about to introduce a hybrid-electric on a Mack platform into the DSNY fleet; projected to be in the 2013 timeframe.

Peterbilt 320
Eaton HLA

Mack LEU613
Bosch Rexroth HRB

Autocar Xpeditor E3
Parker RunWise

Figure 2: Currently available hybrid refuse trucks

CALSTART was able to collect sufficient information on two of the hybrid systems in service and moved forward with case studies to evaluate how the two different vehicles might compare in terms of their LCA and SPP economics. In order to compare the different vehicles and systems without causing any issues concerning market-sensitive information, we've chosen to identify the systems simply as Applications A and B. Lacking detailed technical information about the performance of the vehicles, we utilized a mix of qualitative and quantitative inputs from the fleet representatives to develop life cycle cost analysis models to portray the varying costs and operational characteristics of the vehicles in their different applications. These inputs ranged from detailed fuel mileage, maintenance, and duty cycle information, to indications of approximate fuel economy improvements based on manual fuel records. There are a number of reasons this data should NOT be used to compare or evaluate technologies or supplier offerings:

- Field test results included a variety of qualitative and quantitative data
- The two hybrid vehicles were tested under significantly different operating conditions
- Statistical significance of the data was very low (at times using only one test vehicle per new technology)

Despite these limitations with the data set, we believe there is sufficient information to enable an important discussion on the merits of incorporating LCA as a supplement (or alternative) to SPP economic analyses. In fact, the intention of this analysis is to demonstrate the merits of accomplishing an LCA on advanced technology refuse vehicles to better understand the full economic benefits. Application A represents a rather high incremental cost technology that provides a significant fuel economy improvement, while Application B is a lower incremental cost technology with a lower fuel economy improvement. The CALSTART team chose to incorporate field data to illustrate two ends of the spectrum in terms of cost and fuel economy improvement. Real applications may be better or worse depending upon the specifics of a fleet's operation, its drive cycle, and the technology it's evaluating. So, this case study should NOT be used for purposes of estimating hybrid refuse life cycle cost assumptions. The actual inputs that any given fleet should use for their own calculations will depend on baseline vehicle specifications, operating conditions (grade, congestion, drive cycle intensity, average speed, etc.). Table I below lists the parameters of the case study for the reader to compare the two ends of the spectrum used for illustration.

4. Case Study Illustration

Table 1: Parameters

Parameters	Application A	Application B
Vehicle Life	10 years	10 years
Hybrid Incremental Cost	$100,000	$60,000
Maintenance Costs • *Conventional Maintenance Costs (newer models)* • *Hybrid Maintenance Costs*	 *$4.00 per mile* *$2.50 per mile*	 *$2.00 per mile* *$1.50 per mile*
Vehicle Daily Range	40 miles per day	100 miles per day
Average Number of Lifts Per Day	1,100	950
Vehicle Usage	5 days per week / 50 weeks per year	
Diesel Prices	$4.1 per gallon	
Diesel Fuel Escalation Rate	3% per year	
Conventional Diesel MPG	1.6 MPG	2.5 MPG
Hybrid Fuel Consumption Improvement	40%	8%
Cost of Capital (discount rate)	4% public fleet	
Productivity Improvement (hours saved per shift)	See sensitivity analysis (tables 3-5)	
Labor Costs (for productivity improvement)	$50 per hour	

Although Applications A and B represent rather hypothetical cases based on information collected from the working group, they are interesting case studies to analyze the performance of hydraulic hybrid vehicles on two very different duty cycles. Application A has a very dense route (about 28 stops per mile compared to 10 stops per mile for Application B), with more stops and less distance covered between stops than the route for Application B. As a result, the fuel economy for Application A was lower than for Application B, indicating a lower average speed.

Although better fuel consumption improvements were observed in some cases (up to 54%) for Application A, we decided to use the lower end of the range (40%) to represent the improvement as an average over a variety of drive cycles. We feel that this conservative value is a more realistic number for the broad variety of duty cycles and road grades that a hybrid truck would run on. The higher fuel economy value (54%) occurred in one of the most ideal duty cycles for this technology in the entire country – a route with a flat topography and dense suburban population, which was ideal for the high ratio of stops to distance driven for the vehicle.

Table 2: Estimated Savings over the life of the vehicle:

Parameters	Application A	Application B
Diesel Fuel Savings (gallons)	25,000	8,000
WTW GHG (metric tons of CO2e)	320	100
Fuel Cost Savings (dollars)	$117,505	$37,602
Maintenance Savings	$150,000	$125,000
Total Lifecycle Savings	$267,505	$162,602
Net Present Value (in 2012 US Dollars)	$116,064	$71,594
Simple Payback Period	4.0 years	4.0 years

As shown in Table 2, there are considerable differences between the two applications in the initial costs of the systems, the way they are operated, the relative maintenance costs and savings, and the conventional vehicle fuel economy and hybrid fuel savings. So, it is important to look at these two hybrid refuse vehicle applications to understand how their overall economics are depicted when using LCA versus SPP.

The analysis demonstrates that the different operational characteristics result in equivalent SPPs of four years. However, the real and relatively large difference between the applications is identified in the savings over the life of the vehicles, as shown in Table 2 and Figure 3, which shows a lifecycle difference of almost $45,000 in Net Present Value (NPV). This comparative analysis illustrates that although simple payback calculations are easy to make, they do not tell the whole story about the full economic benefits to be realized.

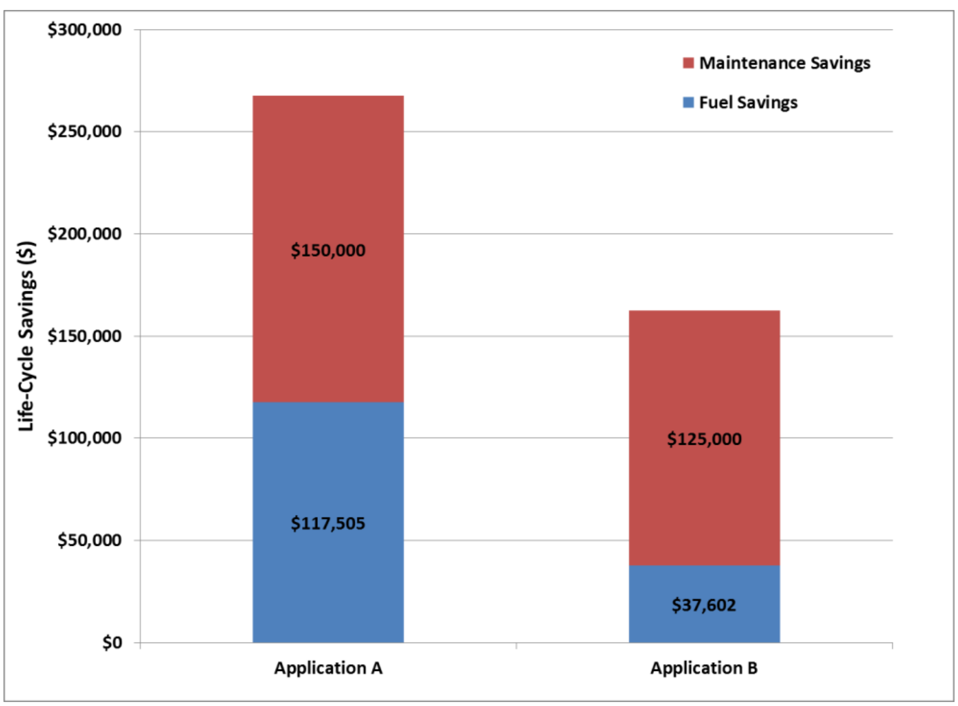

Figure 3: Lifecycle savings for maintenance and fuel

5. Maintenance Savings & Productivity Improvements

Even though hybrid vehicles are typically selected by a fleet manager for their improvement in fuel use, it is important to consider and prioritize other criteria to gain a greater understanding of the benefits of this technology. For instance, maintenance savings (i.e.: fewer brake changes) are relatively easy to recognize and take advantage of. The working group fleets observed that the brake wear on the hybrid vehicles was considerably lower than on the conventional vehicles, resulting in a large decrease in the frequency of brake changes.

Another criterion is productivity. One of the most interesting inputs received during the meetings of the working group was that there were possible savings to be realized in productivity enhancements resulting from the operational characteristics of the hybrid refuse vehicles. The improved acceleration and stopping capabilities of the hybrid vehicles allowed routes to be completed quicker than with the conventional vehicles. To be clear, although the potential for productivity savings are great, they may be challenging to realize for public fleets, depending on the fleets' labor arrangements.

Because of the increased productivity, a driver may finish their daily route an hour early, which was not uncommon among the fleets tested. Even with the reduced time worked, standard salary compensation structures might not reduce the labor costs. That is, the driver would likely still receive a full day's work, even if they finished an hour early. Thus, it is possible that in some cases, overtime may be avoided by increased productivity. Productivity improvements over a large fleet of hybrid vehicles may even result in reducing the number of vehicles required to complete the day's tasks. For instance, with a 10 percent productivity increase, a fleet of 10 or so vehicles might be able to decrease its size by one vehicle. However the fleets approach these possible savings, the monetizing of labor savings can be complex issues to manage.

Therefore, the fleet manager and his management would have to be creative in taking advantage of these potential productivity improvements by possibly changing routes or using their personnel for other productive tasks.

The LCA evaluated these estimated (or potential) savings in comparison to fuel economy improvements to determine if they were of significant value. In fact, the potential productivity and maintenance savings were substantial benefits in both cases. This finding highlights that there are important supplemental criteria that need to be considered by fleet managers when they're evaluating the purchase of hybrid or advanced technology vehicles. Tables 3, 4, and 5 below lay out a simple range from 15 minutes per day to 1 hour per day of productivity savings per vehicle. Figures 4 and 5 illustrate the savings graphically. The fleets that were finding productivity savings were doing so on average of one hour per day. To be conservative, we laid out a few smaller daily savings in fifteen minute increments.

Table 3: Estimated Operational savings with 15 min per day labor savings:

Parameters	Application A	Application B
Fuel savings	$117,505	$37,602
Maintenance Savings	$150,000	$125,000
Productivity Savings	$31,250	$31,250
Net Present Value (in 2012 US Dollars)	$141,411	$96,940
Simple Payback Period	3.5 years	3.2 years

Table 4: Estimated Operational savings with 30 min per day -labor savings:

Parameters	Application A	Application B
Fuel Savings	$117,505	$37,602
Maintenance Savings	$150,000	$125,000
Productivity Savings	$62,500	$62,500
Net Present Value (in 2012 US Dollars)	$166,757	$122,290
Simple Payback Period	3.2 years	2.7 years

Table 5: Estimated Operational savings with 1 hour per day labor savings:

Parameters	Application A	Application B
Fuel Savings	$117,505	$37,602
Maintenance Savings	$150,000	$125,000
Productivity Savings	$125,000	$125,000
Net Present Value (in 2012 US Dollars)	$217,450	$172,980
Simple Payback Period	2.6 years	2.1 years

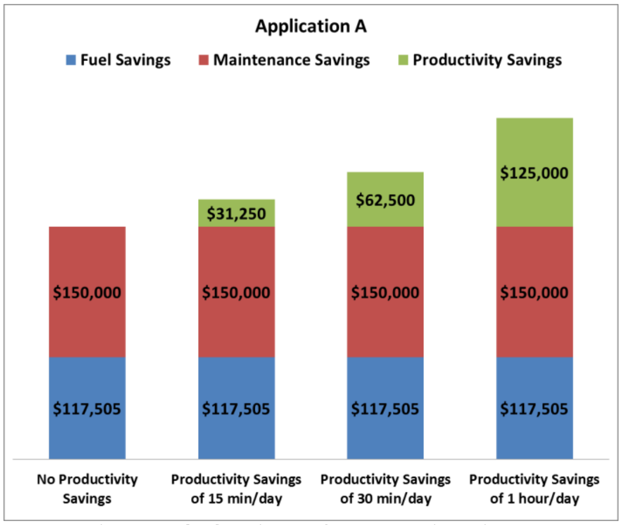

Figure 4: Savings for Application A

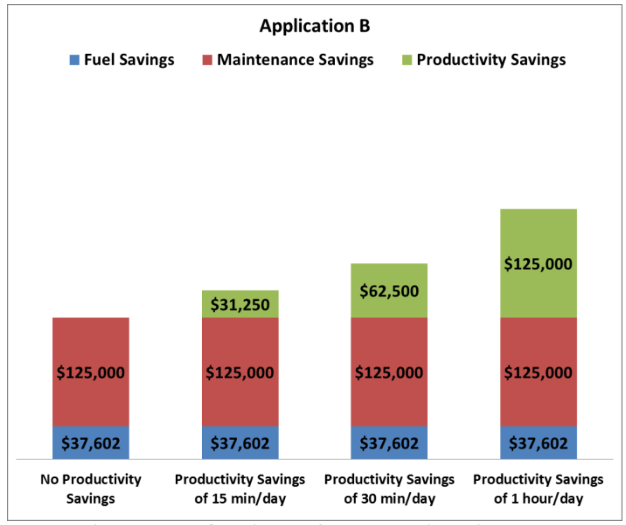

Figure 5: Savings for Application B

Several working group fleets reported productivity improvements of up to one hour per shift. As Figure 5 and 6 illustrate, monetizing these productivity savings can represent significant lifecycle savings equal or better than fuel and maintenance lifecycle savings.

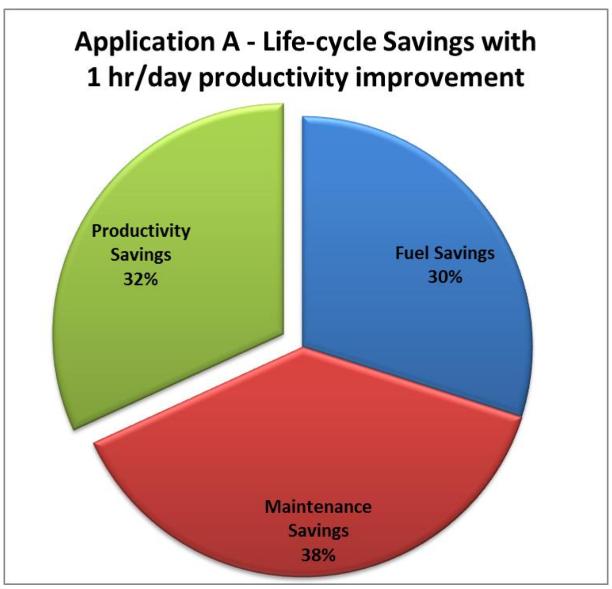

Figure 5: Savings breakout for Application A

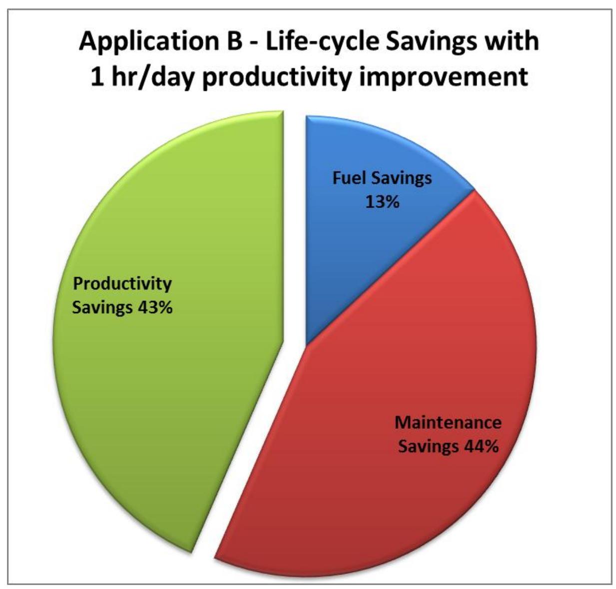

Figure 6: Savings breakout for Application B

6. Next Steps in Commercialization

As a whole, hybrid refuse technology is still in the early commercialization phase. There is a range of maturity in this technology space. While some of the technologies are now ready for full implementation in a variety of duty cycles, topographies, and climates, some are not. Those technologies that are still in their early production and demonstration phases will need more development and testing before they are ready for fleet utilization. For those technologies that are ready, the next steps are for the fleets to continue to deploy the vehicles in broader testing conditions, and to share the results publicly for the benefit of the industry.

A large number of fleets are unaware of the true value of advanced vehicles they have deployed. There are potentially large savings that are being unrecognized in some refuse fleets that have deployed advanced technology due to a lack of tracking capability, manpower, willingness to gather the data, or ability to perform lifecycle cost evaluations. Assistance is available to fleets through the CALSTART/HTUF organization to help resolve some of these issues. Interested fleets can contact the authors using the information at the end of this paper.

7. Summary / Recommendations

Analyzing two hydraulic hybrid vehicle technologies that are currently commercially available, the HTUF Refuse Working Group found that there appears to be a favorable business case for both technologies if deployed in the appropriate conditions. More importantly, this study highlights the importance of incorporating Lifecycle Cost Analysis (LCA) as a supplement or alternative to traditional Simple Payback Period (SPP) techniques. By incorporating hybrid drive technologies into a refuse fleet, significant savings can be realized over the life cycle of the vehicle's performance and these long-term financial benefits should be considered in addition to or instead of simple payback. Thus, when considering hybrid vehicles in the medium- and heavy-duty weight classes, we recommend the following:

- When evaluating hybrid technology, lifecycle cost analysis should be used to go beyond simple payback period and assess economic performance over the full life of the vehicle.
- Better fleet tracking should be implemented to carry out more accurate lifecycle cost analyses and help fleets identify opportunities for further reductions in costs. Sharing this type of data should help additional fleets adopt these new technologies, thereby driving increased scale and improved economics for the entire industry.
- Route selection is crucial to maximize fuel savings. It is important for a fleet manager to select routes that have the density of stops and the distance between stops that are appropriate for each specific technology. GPS tracking of vehicle routes can help in this selection.
- Driver training offered by OEMs and system suppliers (as well as others) is imperative to adjust driving pattern (top speed, acceleration, and deceleration rates between stops) to maximize the specific characteristics of hydraulic hybrid technology.
- Maintenance savings (mainly through reduce brake wear) typically represents the greatest benefit from implementing hybrid technology in refuse application (based on data provided in this report).
- If they can be captured, productivity savings (through the ability to cover routes quicker) can represent a substantial benefit from implementing hybrid technology in refuse application.
- Fleet managers should interact with other fleets to determine their experiences with these technologies, especially considering issues such as vehicle durability and effectiveness. The HTUF program provides excellent opportunities for information sharing.

The above suggestions can help fleets achieve the optimum return on investment by better tracking vehicle operating characteristics (such as fuel consumed and miles driven), characterizing duty cycles, and helping with accurately quantifying operation savings improvement.