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16. Abstract

This study evaluated the power consumption of traditional and LED-based exterior lighting systems on passenger vehicles, examining nominal consumption as well as realistic consumption based on real-world usage patterns of various lighting equipment. The results indicate that an all-LED system employing the current generation of LEDs would result in general power savings of about 50% (nighttime) to about 75% (daytime) over a traditional system. The effect on long-term savings for the LED system depends upon the type of vehicle in use (gasoline-powered vs. electric). While the long-term fuel-cost savings (dollars) were higher for the gasoline-powered vehicle, long-term distance savings (range) favored the electric vehicle. Also presented are calculations of potential savings for two different scenarios of future improvements in LED power consumption.

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CONTENTS

INTRODUCTION

In a recent study, we documented the increasing use of light-emitting diode (LED) light sources for various external lighting functions on light vehicles sold in the U.S. (Schoettle, Sivak, and Takenobu, 2008). In that study, we surveyed 97% of all currently sold light-vehicle models, and provided sales-weighted information about the frequencies of LEDs. Although the results showed that overall penetration of LEDs for most external functions is still low, advances in technology have recently enabled vehicle manufacturers to offer completely LED-based exterior lighting systems for the first time.

One of several advantages that LED lighting offers over traditional lighting systems is the reduction in power required to perform the same functions. Recent studies (DOE, 2003; Erion, 2006) have examined the power savings in automotive applications using LEDs. The critical factor in such calculations is the frequency of use of various functions. Previous work has relied on either estimates (DOE, 2003) or frequency of use by employees of a vehicle manufacturer (Erion, 2006).

There are two main contributions of the present study. First, we used recent data on the usage of different lighting functions that were obtained in a naturalistic study employing a large, random sample of drivers. Second, we extended the focus of implications beyond gasoline-powered passenger vehicles to electric vehicles as well. Consequently, savings with LED lighting were expressed not only in terms of power and cost reductions, but also in terms of increases in range on an individual charge for current electric vehicles.

APPROACH

Lamp usage data

The usage data for various lamps and lighting functions on U.S. passenger vehicles came from Buonarosa, Sayer, and Flannagan (2008). In turn, those data were obtained in a field operational test at UMTRI of crash-warning systems, with 87 drivers using 11 instrumented vehicles. Each driver used one instrumented vehicle as a personal vehicle for between 13 and 27 days, with data collection occurring each time the vehicle was driven. Table 1 shows the summary data that were used in the present study.

Table 1
Average usage rates for each function.

Function	Average usage rate	
	Minutes per 100 km	Hours per year
DRL	116.5†	382.0
Low beam	97.6*	97.3
High beam	9.8*	9.8
Parking/position	107.4*	107.1
Turn signal, left	5.8	24.9
Turn signal, right	4.6	19.5
Side markers	107.4*	107.1
Stop	18.9	80.7
Tail	107.4*	107.1
CHMSL	18.9	80.7
Backup/reverse	0.9	3.8
License plate	107.4*	107.1

† Daytime driving only.
* Nighttime driving only.

Lighting systems examined

Two lighting systems were considered in this study: a traditional system using 100% incandescent and halogen light sources, and a 100% LED system. To simplify the comparisons, it was assumed that both systems used separate lamps for all functions (i.e., no functions were combined, though this is frequently done on actual production vehicles). A typical number of lamps currently employed were used in the calculations for both systems.

Baseline power

Traditional system

The baseline power requirements for the traditional lighting system were based on the measured wattages of the actual light sources installed on the instrumented test vehicle used in the field operational test that produced the usage data (a 2003 Nissan Altima), with the following exceptions:

- For low- and high-beam headlamps: Market-weighted, measured wattages for the high- and low-beam headlamps were used (based on the information in Schoettle et al., 2008).
- For DRLs: Two DRL implementations were used—no DRLs and dedicated DRLs.

As indicated above, all functions were treated as having separate light sources (although several functions were combined on the actual test vehicle). Table 2 includes the list of the traditional system's baseline wattages used in this study.

LED system

We computed average wattages for the various functions in the LED system based on measured and reported data for LED lamps currently available on production vehicles. These data were provided by vehicle manufacturers and lighting suppliers. The list of the LED system's average baseline wattages used in this study is included in Table 2.

Table 2
Baseline wattages for each function in the two systems.

Function	Power per lamp (W)	
	Traditional system	LED system
DRL, dedicated	22.9	11.4
Low beam	56.2	54.0
High beam	63.9	34.4
Parking/position	7.4	1.7
Turn signal, front	26.8	6.9
Side marker, front	4.8	1.7
Stop	26.5	5.6
Tail	7.2	1.4
CHMSL	17.7	3.0
Turn signal, rear	26.8	6.9
Side marker, rear	4.8	1.7
Backup/reverse	17.7	5.2
License plate	4.8	0.5

Values used in the power consumption and savings calculations

Vehicle efficiency (kW·h/km)

Table 3 shows the efficiency values that were used in the calculations of long-term consumption and potential power savings of each lighting system.

Table 3
Efficiency values used in the consumption and power-savings calculations.

Variable	Value used
Alternator efficiency[1]	45%
Engine efficiency[1]	40%
Energy content of gasoline[1]	8.9 kW·h/L (33.7 kW·h/gal)
Electrical output, gasoline engine[1]	1.6 kW·h/L
Fuel efficiency, gasoline engine[2]	8.5 km/L (20 mpg) = 0.19 kW·h/km (0.30 kW·h/mile)
Fuel efficiency, electric vehicle[3]	0.10 kW·h/km (0.17 kW·h/mile)

[1] Kassakian, Wolf, Miller, and Hurton (1996).
[2] Typical efficiency for U.S. vehicles (DOE, 2008).
[3] Average of efficiency values from Tesla (2008) and Edmunds (2008).

Fuel costs ($/kW·h)

For gasoline, a range of possible gasoline prices was used. Translating from $/gal to $/kW·h yields the following values:

- $3.00/gal = $0.50/kW·h
- $4.00/gal = $0.66/kW·h
- $5.00/gal = $0.83/kW·h

Equations 1 and 2 were used to convert from $/gal to $/kW·h for gasoline:

$$\frac{\$/\text{gal}}{3.785\ \text{L}/\text{gal}} = \$/\text{L} \qquad (1)$$

$$\frac{\$/\text{L}}{1.6\ \text{kW·h}/\text{L}} = \$/\text{kW·h} \qquad (2)$$

For electricity, the minimum, maximum, and average current (April, 2008) residential electricity prices in the U.S. were used (EIA, 2008).

- Minimum: $0.07/kW·h
- Average: $0.11/kW·h
- Maximum: $0.30/kW·h

RESULTS

General power requirements

Daytime functions

Table 4 presents the daytime power requirements for each function using both lighting systems. Each system's total is shown for two DRL implementations—no DRLs and dedicated DRLs.

Table 4
Daytime power requirements of the traditional and LED-based exterior lighting systems.

Daytime functions	Number of lamps	Total power (W)		LED percent of traditional system
		Traditional system	LED system	
DRL, dedicated	2	45.8	22.8	49.8
Turn signal, front	2	53.6	13.8	25.7
Stop	2	53.0	11.2	21.1
CHMSL	1	17.7	3.0	16.9
Turn signal, rear	2	53.6	13.8	25.7
Backup/reverse	2	35.4	10.4	29.4
Total (no DRLs)		213.3	52.2	24.5
Total (with dedicated DRLs)		259.1	75.0	28.9

When using dedicated DRLs, the traditional system requires about 20% more power than when using no DRLs at all, while the LED system requires about 45% more power when using dedicated DRLs, compared to using no DRLs at all. A comparison between systems shows that the traditional system uses about three and a half times the power of the LED system when they both use dedicated DRLs, and about four times the power without DRLs.

Nighttime functions

Table 5 presents the nighttime power requirements for each function using both lighting systems. The traditional system requires about two times the power of a comparable LED system.

Table 5
Nighttime power requirements of the traditional and LED-based exterior lighting systems.

Nighttime functions	Number of lamps	Total power requirement (W)		LED percent of traditional system
		Traditional system	LED system	
Low beam	2	112.4	108.0	96.1
High beam	2	127.8	68.8	53.8
Parking/position	2	14.8	3.3	22.6
Turn signal, front	2	53.6	13.8	25.7
Side marker, front	2	9.6	3.4	35.4
Stop	2	53.0	11.2	21.1
Tail	2	14.4	2.8	19.4
CHMSL	1	17.7	3.0	16.9
Turn signal, rear	2	53.6	13.8	25.7
Side marker, rear	2	9.6	3.4	35.4
Backup/reverse	2	35.4	10.4	29.4
License plate	2	9.6	1.0	10.4
	Total	511.5	242.9	47.5

Long-term power consumption and savings

Using the per-distance and annual usage data in Table 1, the average power consumption and savings per 100 km are shown in Tables 6 and 7, and the average annual power consumption and savings in Tables 8 and 9.

Table 6
Total average power consumption of each system per 100 km.

DRL type	Power consumption per 100 km (W·h)			
	Traditional system		LED system	
	Day	Night	Day	Night
None	21.0	313.9	4.5	213.2
Dedicated DRLs	110.0		48.7	

Table 7
Power savings of LEDs over traditional lighting per 100 km (LED consumption minus traditional consumption).

DRL type	LED power savings per 100 km (W·h)	
	Day	Night
None	16.5	100.7
Dedicated DRLs	61.3	

Table 8
Total average power consumption of each system annually.

DRL type	Power consumption per year (W·h)					
	Traditional system			LED system		
	Day	Night	*Total*	Day	Night	*Total*
None	5,391	20,040	*25,431*	1,144	13,023	*14,167*
Dedicated DRLs	22,887		*42,927*	9,854		*22,877*

Table 9
Power savings of LEDs over traditional lighting per year (LED consumption minus traditional consumption).

DRL type	LED power savings per year (W·h)		
	Day	Night	*Total*
None	4,247	7,017	*11,264*
Dedicated DRLs	13,033		*20,050*

Potential long-term power savings

In this section, calculations of potential power savings were performed, both for conventional gasoline-powered passenger vehicles and current examples of electric passenger vehicles. These savings represent the power and cost (of fuel) that could be saved by completely switching from traditional lighting systems to systems that are completely LED-based. These power savings were calculated for each vehicle type for the following three conditions:

- No DRL use by either system (minimum required lighting for the U.S.). This condition represents the *lowest* daytime power consumption for both systems.
- Daytime LED system savings over the traditional system using dedicated DRLs.
- Nighttime LED system savings over the traditional system.

Summaries of these results were produced for all daytime and nighttime conditions, as a function of distance driven (km and dollars saved per 100 km) and savings per year (km and dollars saved per year). Each set of results is presented for various fuel costs for each vehicle type. Potential distance savings per 100 km are shown in Figure 1, while the potential fuel-cost savings in dollars are shown in Figure 2.

Daytime savings per 100 km: No DRLs

Potential distance savings per 100 km for daytime driving are relatively low for this condition, with the electric and gasoline-powered vehicles saving 0.2 km and 0.1 km, respectively. The fuel-cost savings amount to $0.01 or less for the electric vehicle, and $0.01 for the gasoline vehicle.

Daytime savings per 100 km: Dedicated DRLs

Potential daytime distance savings per 100 km are slightly higher for this condition, with the electric and gasoline-powered vehicles saving 0.6 km and 0.3 km, respectively. The fuel-cost savings amount to $0.02 or less for the electric vehicle, and from $0.03 to $0.05 for the gasoline vehicle.

Nighttime savings per 100 km

For nighttime use, the overall distance savings per 100 km is greater for the electric vehicle than for the gasoline-powered vehicle (0.96 km vs. 0.53 km). These savings amount to approximately 1% of the total distance driven for the electric vehicle, and 0.5% for the gasoline-powered vehicle. However, the higher cost (per kW·h) of operating a gasoline-powered vehicle leads to greater overall potential fuel-cost savings for that vehicle type ($0.05 to $0.08 per 100 km for gasoline vs. $0.01 to $0.03 per 100 km for electric).

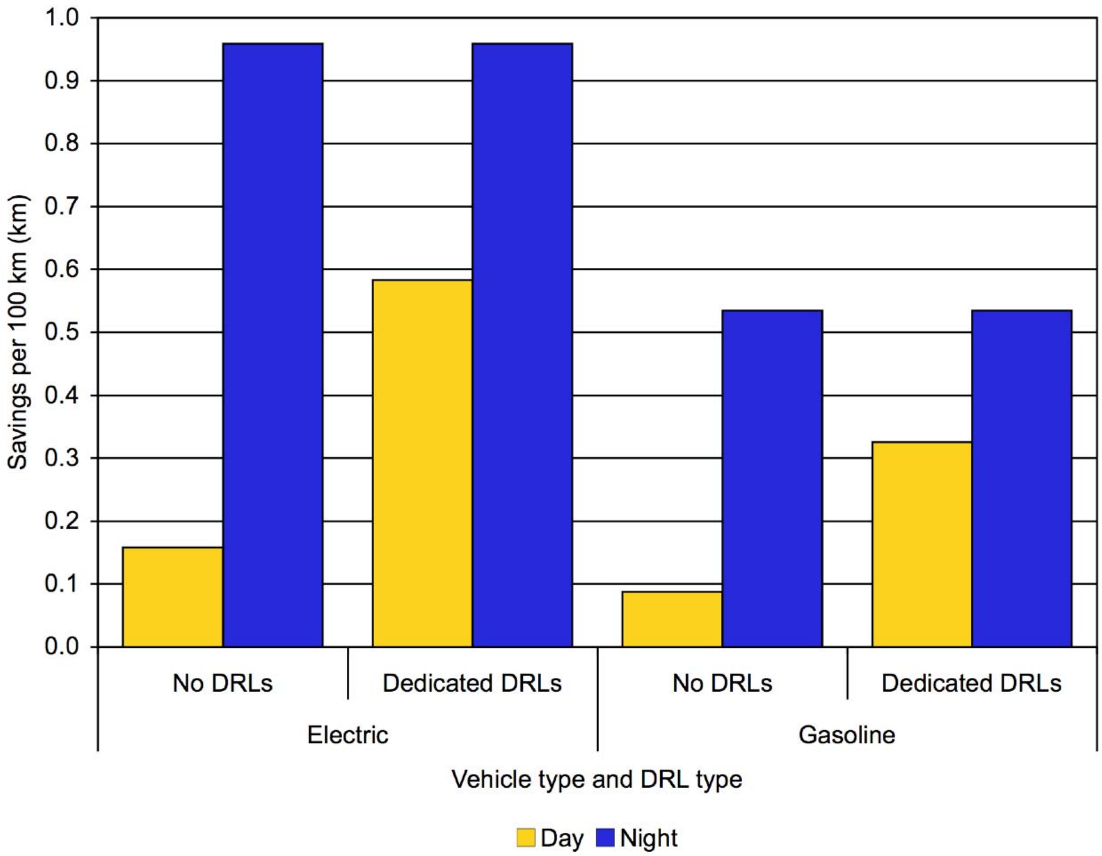

Figure 1. Potential distance savings (km) per 100 km for vehicles equipped with LED lighting vs. traditional lighting, both with and without DRLs.

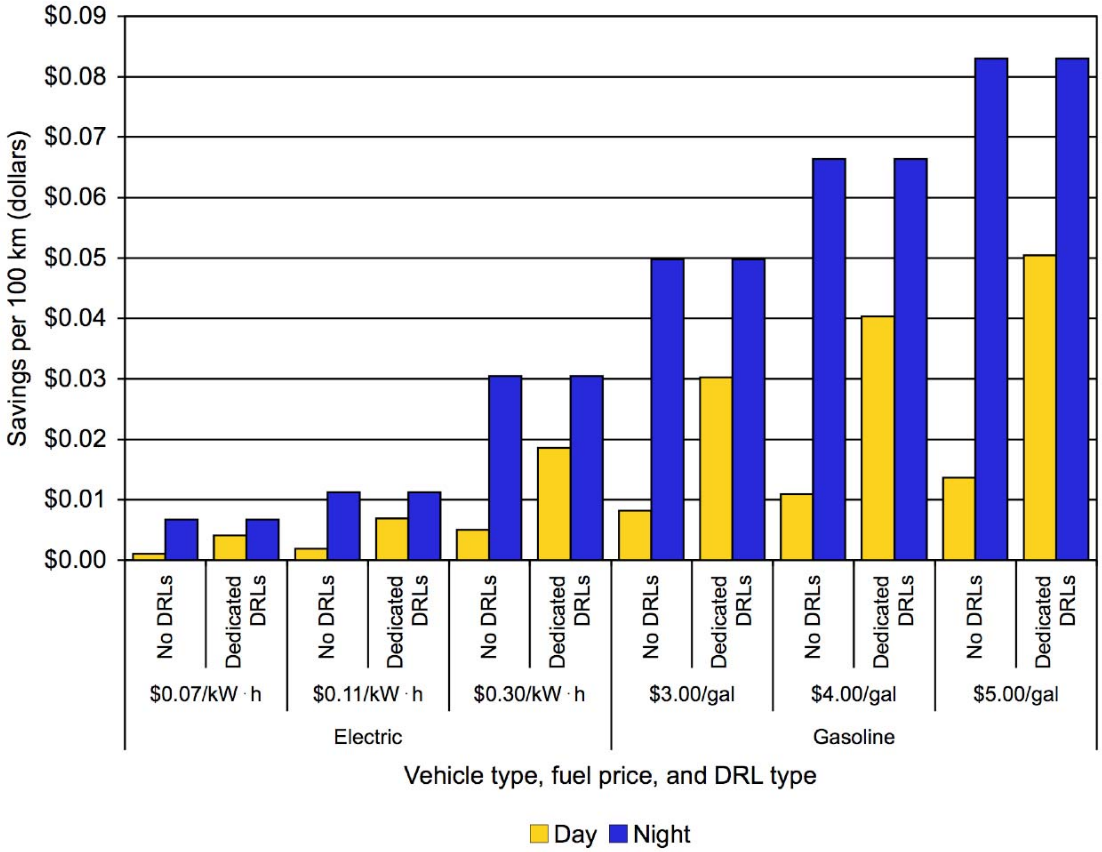

Figure 2. Potential fuel-cost savings (in dollars) per 100 km for vehicles equipped with LED lighting vs. traditional lighting, both with and without DRLs.

Total annual savings

Potential total annual distance savings are presented in Figure 3, and potential annual fuel-cost savings are shown in Figure 4. Annual distance savings for the electric vehicle are approximately 80% higher for both day and night driving for all conditions. (This is due to the electric vehicle in our calculations being 80% more efficient in terms of kW·h/km.) These savings ranged from 60 km to 106 km for the gasoline-powered vehicle and from 107 km to 191 km for the electric vehicle. Monetary savings, however, are significantly higher for the gasoline vehicle for all conditions. For the dedicated DRL condition, total annual savings ranged from \$9.92 to \$16.53 per year for the gasoline-powered vehicle, compared to \$1.34 to \$6.08 for the electric vehicle. When using no DRLs, the gasoline-power vehicle saves between \$5.57 and \$9.28 per year, compared to \$0.75 to \$3.41 for the electric vehicle.

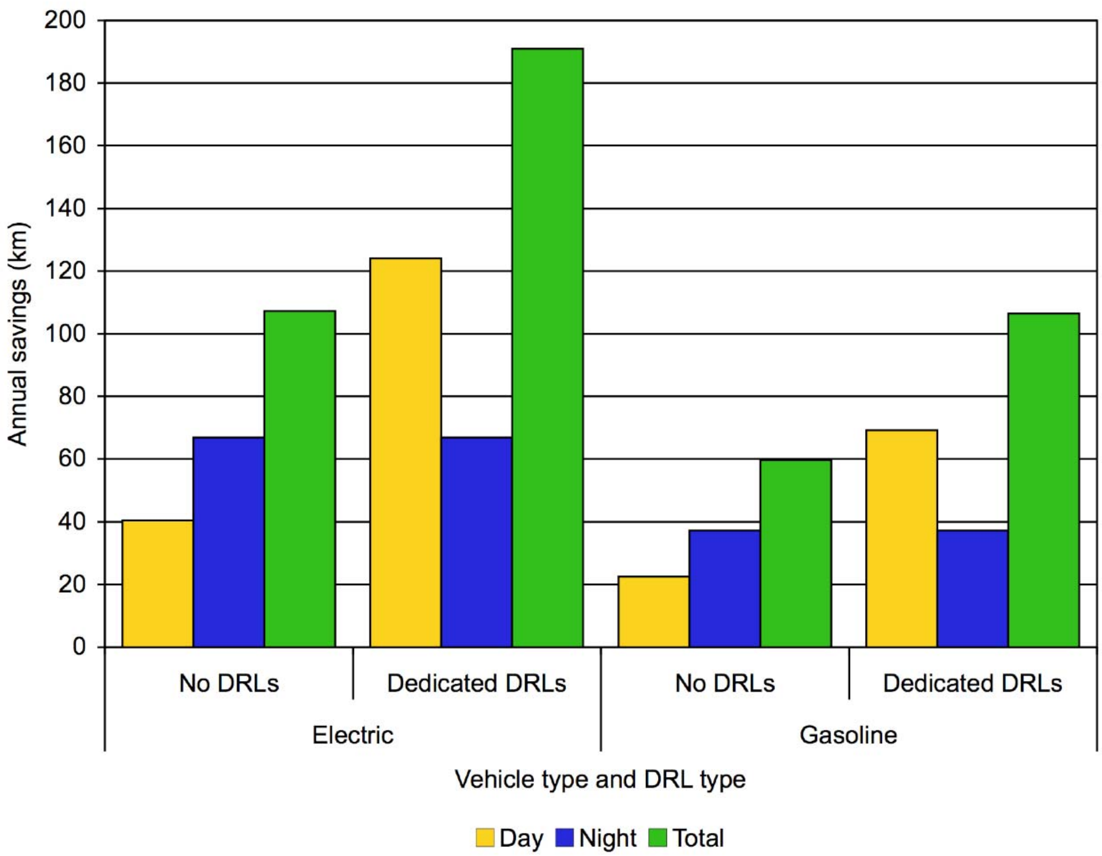

Figure 3. Potential annual distance savings (km) for vehicles equipped with LED lighting vs. traditional lighting, both with and without DRLs.

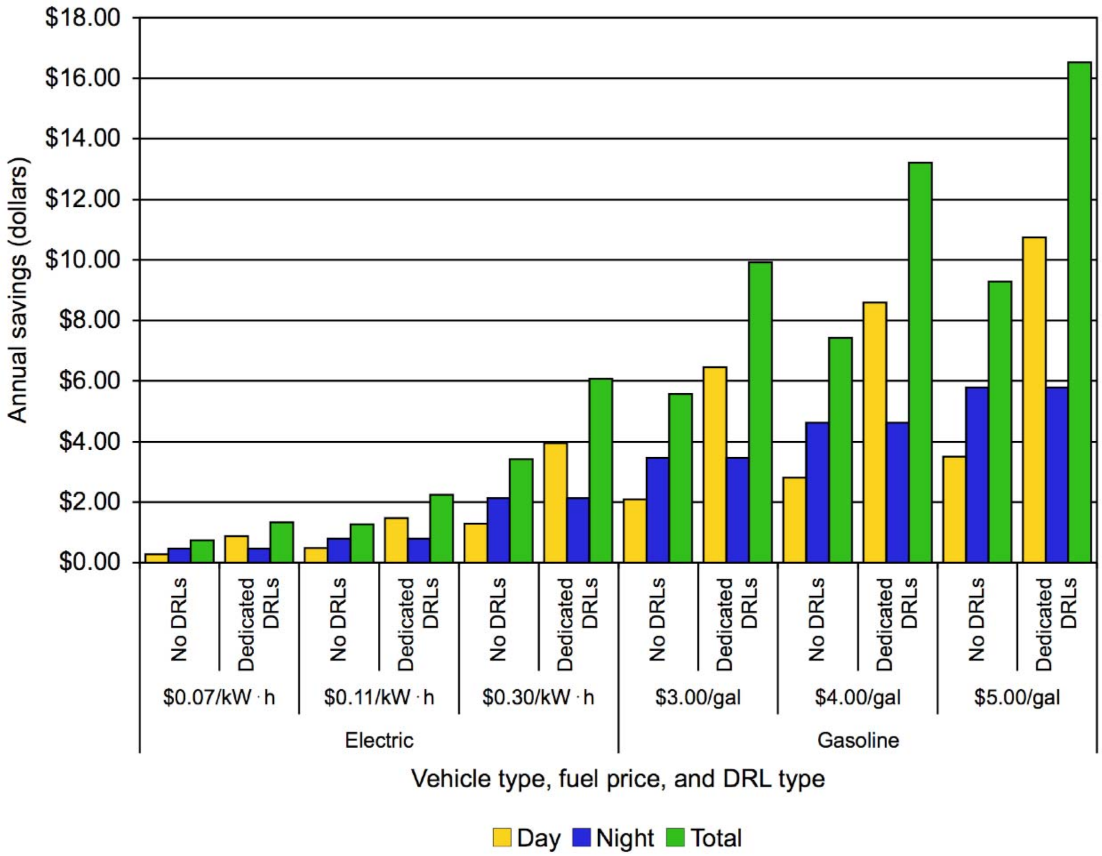

Figure 4. Potential annual fuel-cost savings (in dollars) for vehicles equipped with LED lighting vs. traditional lighting, both with and without DRLs.

Potential savings with future reductions in LED power consumption

In the preceding sections we analyzed potential savings using the current generation of LEDs. In this section, we made analogous calculations using projected future reductions in LED power consumption. We considered two scenarios: (1) a 25% reduction in LED power consumption for all functions and LED types, and (2) a 50% reduction for all functions employing white LEDs, with the remaining functions achieving a 25% reduction. Results for both scenarios are shown for conditions employing dedicated DRLs and the highest of the fuel-cost values considered earlier. The potential savings are shown in Tables 10 and 11.

Table 10
Potential savings resulting from an additional 25% reduction in power consumption for all LED types. (These results are for the use of dedicated DRLs.)

Vehicle type	Fuel cost	Distance savings (km) per 100 km		Annual savings	
		Day	Night	Fuel cost	Distance
Electric	$0.30/kW·h	0.70	1.47	$7.81	245 km
Gasoline	$5.00/gal	0.39	0.82	$21.23	136 km

Table 11
Potential savings resulting from a 50% reduction in power consumption for white LEDs and a 25% reduction for all other LED types.
(These results are for the use of dedicated DRLs.)

Vehicle type	Fuel cost	Distance savings (km) per 100 km		Annual savings	
		Day	Night	Fuel cost	Distance
Electric	$0.30/kW·h	0.80	1.92	$9.33	293 km
Gasoline	$5.00/gal	0.45	1.07	$25.36	163 km

DISCUSSION

This study evaluated the power consumption of traditional and LED-based exterior lighting systems on passenger vehicles, examining nominal consumption as well as realistic consumption based on real-world usage patterns of various lighting equipment. The results indicate that an all-LED system employing the current generation of LEDs would result in general power savings of about 50% (nighttime) to about 75% (daytime) over a traditional system. The effect on long-term savings for the LED system depends upon the type of vehicle in use (gasoline-powered vs. electric).

Though the consumption (in terms of W·h) does not vary between vehicle types, the difference in electrical load for the two lighting systems affects each vehicle type differently. The electric vehicle, with a relatively low fuel cost ($/kW·h), is more substantially affected in terms of overall vehicle range. The total savings in overall range amount to approximately 1% per distance driven for current generation electric vehicles. Another way to express this is that the savings with LED lighting extend the range on each battery charge by up to 1%. Alternatively, this adds up to as much as one full battery charge per year (from 107 km to 191 km). This effect becomes even more pronounced as an electric vehicle's overall efficiency (kW·h/km) improves.

The gasoline-powered vehicle, as a result of its lower fuel efficiency, does not experience the same effect in terms of overall range. However, because of much higher fuel costs (relative to electricity), the effect of the differing electrical loads is felt mostly in overall dollars spent on fuel. These reductions in total fuel costs due to LED lighting resulted in savings between $5 and $17 per year for the conditions modeled in this report. Due to the influence of fuel efficiency (kW·h/km) and cost of fuel ($/kW·h) on cost per distance ($/km), this effect is approximately constant over the range of fuel efficiencies for gasoline-powered vehicles in the U.S.—10 to 32 mpg (4.2 to 13.5 km/L, or 23.5 to 7.3 L/100 km) (DOE, 2008).

As the calculations and results presented here are based on two extreme examples (a 100% incandescent/halogen system and a 100% LED system), the ultimate benefit from LED lighting will vary with each application. Furthermore, the presented calculations are based on the efficiency of the current generation of LED systems. Future

LED systems are generally expected to substantially reduce the power requirements, especially for headlamp applications. With the current LED headlamps being approximately on par with the high power requirements of their traditional counterparts, further improvements in LED efficiency for these functions (and others) will only serve to increase the power saving advantages of LED systems over incandescent/halogen systems. Potential savings could reach as high as $25 per year in fuel costs for the gasoline-powered vehicle, and about 300 km per year for the electric vehicle. This would amount to 1% (daytime) to 2% (nighttime) of the total distance driven, or approximately one to two full battery charges for the current generation of electric vehicles.

REFERENCES

Buonarosa, M. L., Sayer, J. R., and Flannagan, M. J. (2008). *Real-world frequency of use of lighting equipment* (Technical Report No. UMTRI-2008-14). Ann Arbor: University of Michigan Transportation Research Institute.

DOE [U.S. Department of Energy]. (2003). *Energy savings estimates of light emitting diodes in niche lighting applications*. Washington, D.C.: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Building Technologies Program.

DOE [U.S. Department of Energy]. (2008). *Fuel economy guide: Model year 2008* (Document No. DOE/EE-0321). Washington, D.C.: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, U.S. Environmental Protection Agency.

Edmunds. (2008). *First drive: 2010 Mitsubishi i MIEV plug-in electric*. Retrieved September 9, 2008 from http://www.edmunds.com/insideline/do/Drives/FirstDrives/articleId=124867

EIA [Energy Information Administration]. (2008). *Average retail price of electricity to ultimate customers by end-use sector, by state*. Retrieved September 9, 2008 from http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html

Erion, J. (2006). LEDs in exterior vehicle lighting. *Photonics Spectra, 40*(12), 50-52.

Kassakian, J. G., Wolf, H.-C., Miller, J. M., and Hurton, C. J. (1996). Automotive electrical systems circa 2005. *IEEE Spectrum, 33*(8), 22-27.

Schoettle, B., Sivak, M., and Takenobu, N. (2008). *Prevalence of LED light sources on vehicles sold in the U.S.* (Technical Report No. UMTRI-2008-12). Ann Arbor: University of Michigan Transportation Research Institute.

Takenobu, N., Schoettle, B., and Sivak, M. (2008). *Availability and implementation of Daytime Running Lights in the U.S.* (Technical Report No. UMTRI-2007-33). Ann Arbor: University of Michigan Transportation Research Institute.

Tesla. (2008). *Well-to-wheel energy efficiency*. Retrieved September 9, 2008 from http://www.teslamotors.com/efficiency/well_to_wheel.php