

# **AN ANALYSIS OF HYBRID AND ELECTRIC VEHICLE CRASHES IN THE U.S.**

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## **ABSTRACT**

The growing popularity of hybrids and electric vehicles in the U.S. has raised questions about whether they might pose a different crash risk than conventional vehicles. In particular, there have been anecdotal reports of fires associated with the battery system in these advanced fuel vehicles. The objective of the study was to characterize the factors that influence the risk of serious to fatal injury in U.S. hybrid and electric passenger vehicle crashes.

Our approach in this study was to compare the crash performance of the conventional passenger vehicle fleet with hybrid/electric passenger vehicles in the U.S. The study was based upon the analysis of three U.S. crash databases: the Fatal Analysis Reporting System (FARS), the National Automotive Sampling System / Crashworthiness Data System (NASS/CDS), and the National Automotive Sampling System / General Estimates System (NASS/GES). Cases recorded by the databases between the years 1999 and 2013, and involving passenger vehicles model year 2000 and newer were extracted from all three databases.

Hybrid vehicles constituted less than 1% of the total vehicle population in all three databases. FARS contained no fatalities in electric vehicles, and less than 0.01 % of cases in NASS/CDS and NASS/GES involved electric vehicles.

The incidence of fire was lower for hybrid vehicles than the conventional fleet in all three databases. Fatal crashes involving fire constituted 2.6% of hybrid vehicle cases and 4.4% of conventional vehicle cases. No cases of fire or electric shock injury associated with hybrid vehicles were found in NASS/CDS. Only 1 case of a hybrid fire was found in NASS/GES and 5 cases of hybrid fire were found in FARS. No fires involving electric vehicles were found in any of the three databases.

Similar crash characteristics were found for both hybrid and conventional vehicle populations. Median longitudinal delta-V was 18 km/hr for hybrid vehicles and 14 km/hr for conventional vehicles. Hybrid vehicle occupants were found to have higher risk of AIS2+ upper extremity injury but lower risk of AIS2+ lower extremity injury than conventional vehicle occupants. Similar risk of AIS2+ head and chest injury was observed between the two groups.

The most notable difference between hybrid vehicles and conventional passenger-vehicles was that occupants of hybrid vehicle were more likely to be older than occupants of conventional vehicles. In FARS, the median age of fatally injured hybrid vehicle occupants was 59 years versus 36 years for conventional vehicle occupants. In NASS/CDS, the median age of hybrid vehicle occupants was 42 years and the median age of conventional vehicle occupants was 29 yrs. In NASS/GES, the median age of hybrid/electric vehicle occupants was 44 years, as compared to the median age of 32 years for conventional vehicle occupants.

The present study characterized the crash and occupants of hybrid and electric vehicles. The comparison between hybrid and conventional vehicle crashes showed little difference in the crash performance and injury outcome between the two groups. The incidence of fire was actually lower in hybrid vehicles than in the rest of the fleet.

## INTRODUCTION

Hybrid and electric vehicles have been gaining popularity in the U.S. market since their introduction. Nearly 500,000 hybrid vehicles and 100,000 electric vehicles were sold in the U.S. market in the year 2013 [1]. Although the improved fuel economy offered by hybrid and electric vehicles have made them very attractive to consumers, the advanced battery systems utilized by these vehicles have raised questions whether they pose a different crash risk than conventional fuel vehicles. It is still unknown whether hybrid and electric vehicles' reliance on heavy battery packs lead to different crash outcomes as compared to similar size conventional vehicles.

Several instances of battery fire associated with hybrid and electric vehicles have been reported. In 2011, The National Highway Traffic Safety Administration (NHTSA) reported that a Chevrolet Volt, which had undergone the side impact pole test as part of the New Car Assessment Program (NCAP), had sustained damage to the lithium-ion battery during the crash test and subsequently experienced a fire [2]. In March 2013, Mitsubishi Motors reported two instances of battery fire associated with the Mitsubishi i-MiEV and Mitsubishi Outlander P-HEV. Both fires occurred at Mitsubishi's battery pack assembly plant during testing [3]. Although these fires occurred in unusual conditions, the concern remains that a real world crash of sufficient severity could trigger a fire event.

The objective of this study is to characterize the factors which influence the risk of serious to fatal injury in U.S. hybrid and electric passenger vehicle crashes. Specifically, we would like to answer the following three questions:

1. What is the frequency of fire in these crashes?
2. What are the characteristics of the occupants in these crashes?
3. What types of crashes and injury outcomes are associated with each vehicle fleet?

## METHOD

Our approach in this study was to compare the crash performance of the conventional passenger vehicle fleet with the crash performance of hybrid and electric passenger vehicles in the U.S. The study was based upon the analysis of three U.S. crash databases: (1) the Fatal Analysis Reporting System (FARS), (2) the National Automotive Sampling System / Crashworthiness Data System (NASS/CDS), and (3) the National Automotive Sampling System / General Estimates System (NASS/GES).

FARS is a census of all traffic fatalities in the U.S. and was used in this study to determine the characteristics of fatal crashes. NASS/CDS is a sample of 4000-5000 in-depth crash investigations collected each year at 24 sites nationally. NASS/CDS provides exhaustive detail on injuries suffered in these crashes and, in this study, was used to explore the factors associated with injury. To be included in NASS/CDS, cases must involve at least one passenger car or truck and be of sufficient severity that one vehicle was towed from the scene. NASS/GES is a database of approximately 60,000 crashes/year sampled from U.S. police reported crashes, and was used for computation of exposure in this study. Both NASS/CDS and NASS/GES are weighted to be representative of crashes nationally.

Cases were extracted from all three databases using the criteria listed below.

- Case Year 1999-2013
- Model Year (MY) 2000+
- Cars, light trucks, and vans only
- Hybrids identified by Make/Model codes and Fuel Code Variable (hybrid)

These criteria were chosen to include only vehicles with the latest safety technologies. All MY 2000+ passenger vehicles would have been equipped with both driver and right front passenger airbags.

NASS/CDS describes the severity of these injuries based on the Abbreviated Injury Scale (AIS). AIS ranks injuries on a scale of 1-6 based on the threat to the life of the occupant, AIS 1 is a minor injury and AIS 6 is an unsurvivable injury. Here we focused on AIS2+ injured occupants – those occupants with moderate (AIS2) to unsurvivable (AIS6) injuries. Our analysis classified injury severity by the maximum AIS (MAIS) level injury sustained by an occupant. In the analysis which follows, weighted values based on NASS sample weight were used in order to better represent the larger population.

Hybrid and electric vehicles were identified in two ways. For most cases in FARS and NASS/CDS, hybrid and electric cars were identified by using the NASS and FARS FUELCODE variable, which denotes the type of fuel

used in the vehicle. In the event of a missing FUELCODE, the make-model codes of known hybrid and electric vehicles models, e.g. the Toyota Prius and the Chevrolet Volt, were used to identify hybrid and electric vehicles. NASS/GES does not contain a similar FUELCODE variable which describe the type of fuel used in the vehicle. For cases in NASS/GES, make-model codes of known hybrid and electric vehicle models were used to identify hybrid and electric vehicles.

## RESULTS

### Dataset Composition

Table 1 shows the composition of vehicles in all three databases used in the study. Hybrid vehicles made up approximately 0.3% of the fatal crashes in FARS, 0.7% of the weighted cases in NASS/CDS, and 0.3% of the weighted cases in NASS/GES. No fatalities associated with electric vehicles were found in the FARS databases. Only 2 electric vehicles were found in the NASS/CDS database, representing approximately 0.002% of the weighted vehicle sample, and 18 electric vehicles were found in the NASS/GES database, representing approximately 0.003% of the weighted vehicle sample in NASS/GES. Given the small proportions of electric vehicles in the databases, the following analysis only focuses on the comparison between hybrid and conventional vehicles.

**Table 1.**  
**Dataset Composition of Vehicles in All Databases (Case Year 1999-2013)**

Database	Hybrid Vehicles (%)	Electric Vehicles (%)	Conventional Vehicles (%)	Total Vehicles (%)
<b>FARS</b>	421 (0.3%)	-	128,119 (99.7%)	128,540 (100%)
<b>NASS/CDS (Unweighted)</b>	377 (0.7%)	2 (0.004%)	55,696 (99.3%)	56,075 (100%)
<b>NASS/CDS (Weighted)</b>	165,932 (0.7%)	553 (0.002%)	25,308,829 (99.3%)	25,475,314 (100%)
<b>NASS/GES (Unweighted)</b>	1,863 (0.3%)	18 (0.003%)	561,812 (99.7%)	563,693 (100%)
<b>NASS/GES (Weighted)</b>	233,796 (0.3%)	2,310 (0.003%)	68,280,880 (99.7%)	68,516,986 (100%)

### Dataset Composition

Table 2 shows the distribution of body types for vehicles in the databases. Weighted percentages are shown for NASS/CDS and NASS/GES databases. As shown by the table, conventional vehicles contains approximately equal percentage of cars and LTV, while hybrid vehicles are predominantly passenger cars.

**Table 2.**  
**Distribution of Vehicle Body Type in All Databases (Case Year 1999-2013)**

Database	Hybrid Vehicles		Conventional Vehicles	
	Cars (%)	LTV (%)	Cars (%)	LTV (%)
<b>FARS</b>	94%	6%	55%	45%
<b>NASS/CDS (Weighted)</b>	87%	13%	57%	43%
<b>NASS/GES (Weighted)</b>	100%	0%	57%	43%

### Incidence of Fire in Vehicles

Table 3 shows the number of vehicles involved in crashes with fire in all three databases. In fatal vehicle crashes extracted from FARS, incidence of fire was found in 11 of the 421 hybrid vehicles (2.6%). In comparison, 5,619 of 128,119 conventional vehicles (4.4%) involved in fatal crashes had fire occurrence.

Similar to the FARS analysis, Table 3 shows that vehicle fire was also rare for cases included in NASS/CDS. No hybrid vehicles in the sample experienced a vehicle fire and only 330 of 56,075 conventional vehicles had a fire. Using weighted numbers, this comprised approximately 0.1% of all conventional vehicles in crashes.

The incidence of fire was similarly rare in NASS/GES. Only 1 hybrid vehicle was reported to be involved in a fire, while 974 conventional vehicles were involved in crashes with fire incidences in NASS/GES. Using the NASS/GES weighting factor, fire occurred in 0.03% of all hybrid vehicles and 0.07% of all conventional vehicles.

**Table 3.**  
**Vehicles in Crashes Involving Fire in All Databases (Case Year 1999-2013)**

<b>Database</b>	<b>Hybrid Vehicles (% of All Hybrid)</b>	<b>Electric Vehicles (% of All Electric)</b>	<b>Conventional Vehicles (% of All Conventional)</b>
<b>FARS</b>	11 (2.6%)	-	5,619 (4.4%)
<b>NASS/CDS (Unweighted)</b>	-	-	330 (0.6%)
<b>NASS/CDS (Weighted)</b>	-	-	37216 (0.1%)
<b>NASS/GES (Unweighted)</b>	1 (0.05%)	-	974 (0.2%)
<b>NASS/GES (Weighted)</b>	61 (0.03%)	-	48,685 (0.07%)

#### **Incidence of Electric Shock**

In addition to the incidence of fire, we also searched for any reports of electric shock. Using the sample of crashes from NASS/CDS, AIS codes for all occupants were searched for cases of electric shock. However, no such cases were found in our dataset for either hybrid, electric, or conventional vehicles. Note however, that NASS/CDS only contains vehicles involved in towaway crashes. These results should not be generalized to non-towaway crashes on other non-crash situations.

#### **Occupant Characteristics**

**Occupant Composition and Gender** Table 4 shows the occupant distribution by gender in all three databases. Only weighted gender percentages are shown from both NASS/CDS and NASS/GES datasets. A total of 465 fatally injured hybrid vehicle occupants and 142,821 fatally injured conventional vehicle occupants were found in the FARS data set. Of all fatally injured hybrid vehicle occupants, 58% were male and 42% were female. On the other hand, 62% of all fatally injured conventional vehicle occupants were male and 38% were female.

In NASS/CDS, the distribution of gender between all exposed occupants was almost equal. 43% of hybrid vehicle occupants and 51% of conventional vehicle occupants in NASS/CDS were male. However, only 11% of all MAIS2+ injured hybrid occupants were male, while 47% of all MAIS2+ injured conventional vehicle occupants were male and 53% were female.

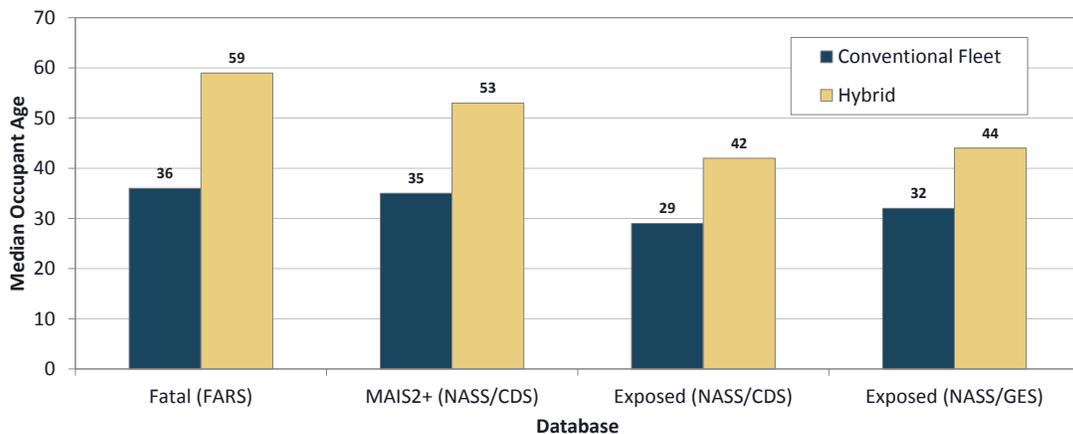
Similar to occupants in NASS/CDS, the distribution of gender in NASS/GES was found to be fairly equal. 50% of conventional vehicle occupants were male, while 47% of hybrid occupants were male.

**Table 4.**  
**Occupant Count and Gender Distribution in All Databases (Case Year 1999-2013)**

Database	Hybrid Vehicle Occupants			Conventional Vehicle Occupants		
	Occ. Count	% Male	% Female	Occ. Count	% Male	% Female
FARS	465	58%	42%	142,821	62%	38%
NASS/CDS (All Occ. Unweighted)	407	-	-	66,037	-	-
NASS/CDS (MAIS2+ Unweighted)	62	-	-	11,430	-	-
NASS/CDS (All Occ. Weighted)	165,070	43%	57%	25,029,076	51%	49%
NASS/CDS (MAIS2+ Weighted)	24,821	11%	89%	1,306,918	47%	53%
NASS/GES (All Occupants Unweighted)	2,523	-	-	802,523	-	-
NASS/GES (All Occupants Weighted)	301,992	47%	53%	94,734,122	50%	50%

**Occupant Age** The following subsection presents the distribution of occupant age in the three databases. Only occupants with known age are shown in the distributions. Occupants less than one year old are listed as having an age of 0.

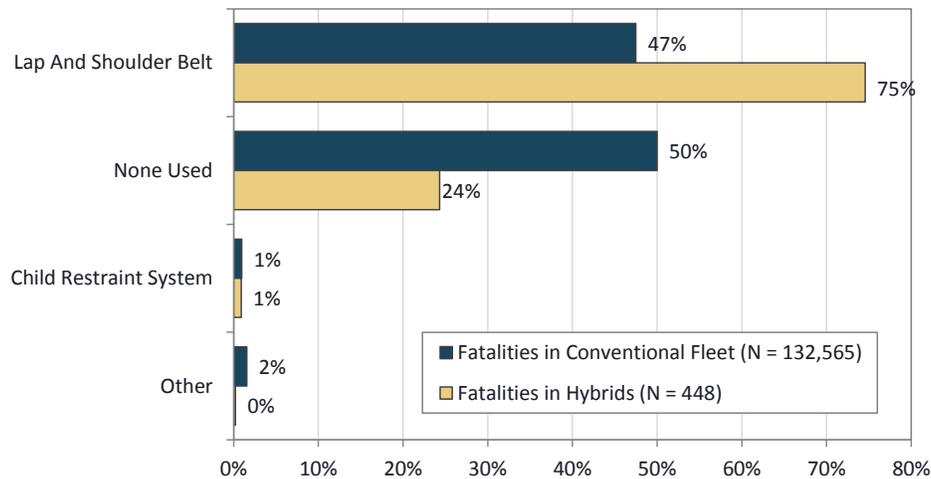
Figure 1 shows a summary of median occupant age in all three databases. As shown by the figure, the median age of occupants in hybrid vehicles are generally older than occupants of conventional vehicles. In fatal crashes extracted from FARS, the median age of fatally-injured hybrid occupant was 59 years while the median age of fatally-injured conventional vehicle occupants was 36 years. For all occupants with MAIS2+ injuries in NASS/CDS, the median age for MAIS2+ injured hybrid vehicle occupants was 53 years, and 35 years for conventional vehicle occupants. For all exposed occupants in NASS/CDS, the median age for hybrid occupants was 42 years while the median age for conventional fleet occupants was 29 years. For all occupants in NASS/GES, the median age for conventional vehicle occupants was 32 years while the median age for hybrid occupants was 44 years old.



**Figure 1. Summary of Median Occupant Age in Crashes (1999-2013)**

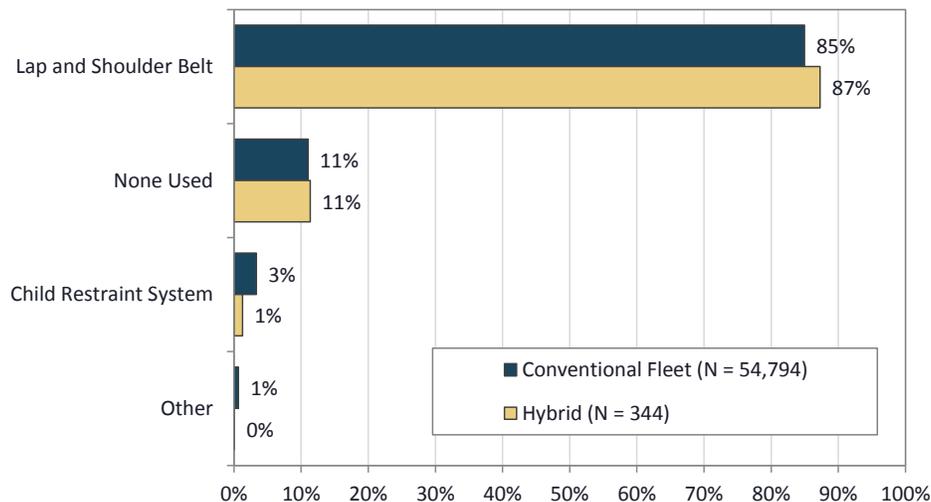
**Occupant Restraint Use** The following subsection presents the occupant restraint use in each of the three databases. Only occupants with known restraint use are included in the distributions shown. The “Other” restraint category includes occupant wearing restraint other than lap and shoulder belt or a child restraint, such as lap belt only, shoulder belt only, or wearing the restraint improperly.

Figure 2 shows the distribution of occupant restraint use in fatal crashes extracted from FARS. The comparison between fatalities in hybrid occupants and fatalities in conventional vehicle occupants shows that belt usage was much higher in hybrid fatality crashes. Approximately 75% of occupants in hybrid vehicles were belted, while only 47% of occupants in the conventional fleet were belted.



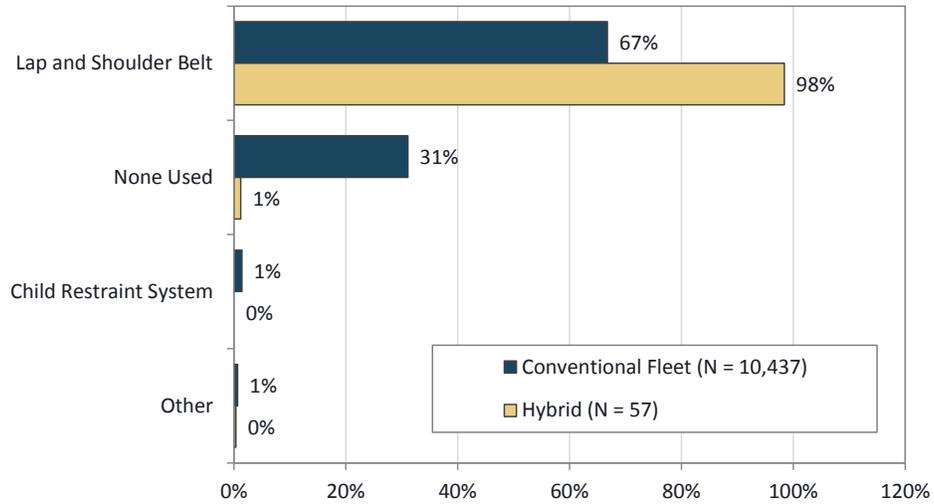
**Figure 2. Distribution of Occupant Restraint Use in Fatal Crashes (FARS 1999-2013)**

Figure 3 shows the restraint use distribution for all occupants exposed to crashes in NASS/CDS. Approximately 90% of both hybrid and conventional fleet occupants were belted.



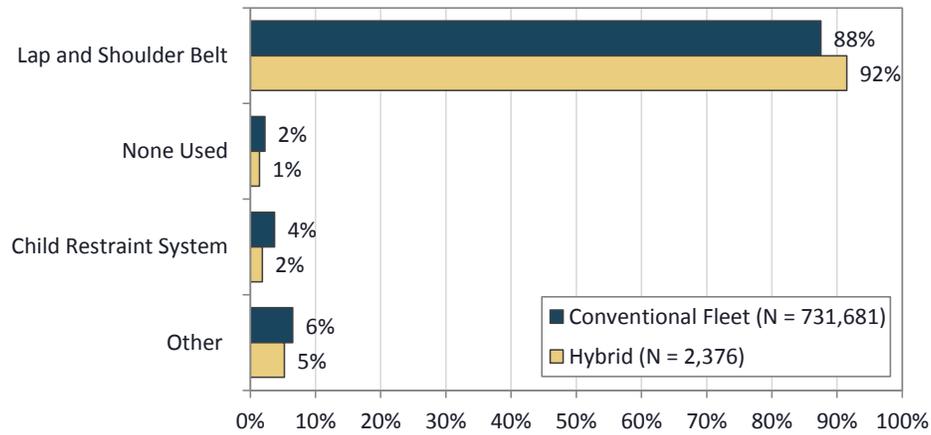
**Figure 3. Distribution of Restraint Use in All Exposed Occupants (NASS/CDS 1999-2013)**

Figure 4 shows the distribution of distribution of restraint use in MAIS2+ injured occupants in NASS/CDS. Compared to the distribution of all exposed occupants, the restraint use in MAIS2+ injured conventional vehicle occupants decreased from 85% to approximately 67%. On the other hand, the restraint use for hybrid vehicle occupants increased from 87% to 98%.



**Figure 4. Distribution of Restraint Use in MAIS2+ Injured Occupants (NASS/CDS 1999-2013)**

Lastly, Figure 5 shows the distribution of restraint use in all occupants involved in crashes in NASS/GES. As shown from the figure, conventional fleet occupants and hybrid occupants have similar restraint use. Approximately 88% of occupants in the conventional fleet were belted, and about 92% of hybrid occupants were belted.



**Figure 5. Distribution of Occupant Restraint Use in All Occupants (NASS/GES 1999-2013)**

Figure 6 shows the summary of occupant restraint use in all three databases. In the distribution shown, restrained occupant refers to any occupant wearing a lap and shoulder belt, lap belt, shoulder belt, or child restraint. As shown in Figure 6, occupants in hybrid vehicles were generally more likely to be restrained.

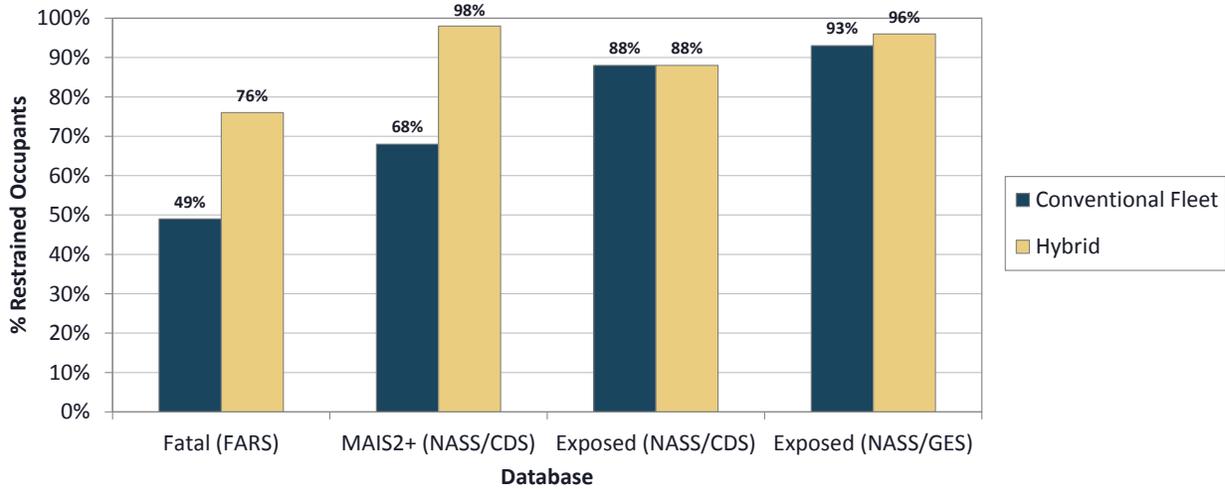


Figure 6. Summary of Occupant Restraint Use (1999-2013)

**Occupant Risk of Injury** The comparison of occupant injury was conducted using injury information reported from NASS/CDS. In this study, the risk of injury for a particular body region is calculated as fraction of cases at a given severity, as shown in Equation 1.

$$\text{Risk of Injury} = \frac{\text{Number of Injuries to Body Region}}{\text{Total Number of Known Injuries}} \quad (1)$$

Figure 7 compares the risk of AIS2+ injury by body regions for each occupant of hybrid and conventional vehicles. For both vehicle types, the risk of head injury was very similar (2.5% vs. 2.0%). Similarly, there was little difference in risk of chest injury (1.6% for conventional vehicle occupants and 1.2% for hybrid occupants). However, our sample predicted a higher risk of upper extremity injury for hybrid occupants (2.9% vs. 1.6%), and a lower risk of lower extremity injury for hybrid occupants (0.5% vs. 1.9%). When interpreting this plot, we caution again that the hybrid AIS2+ injuries are based upon a very small number of cases for occupants in hybrid vehicles.

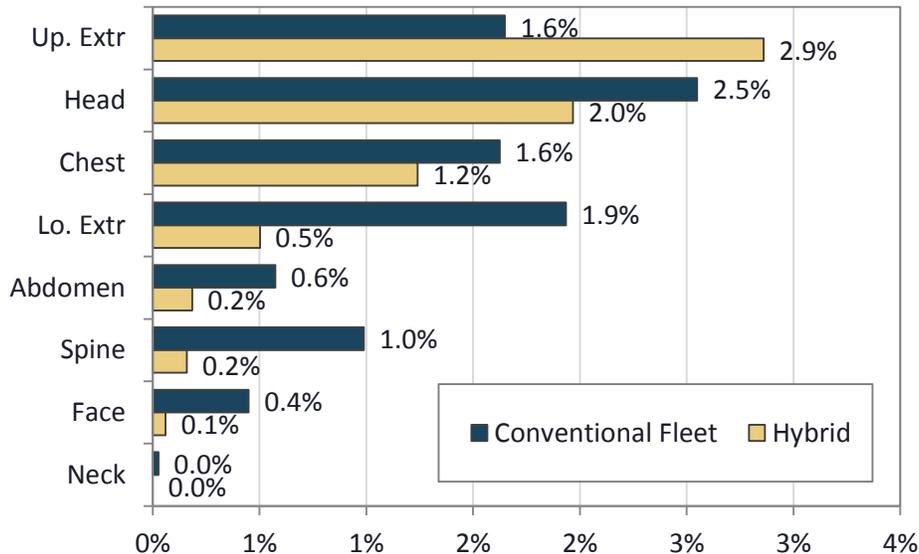


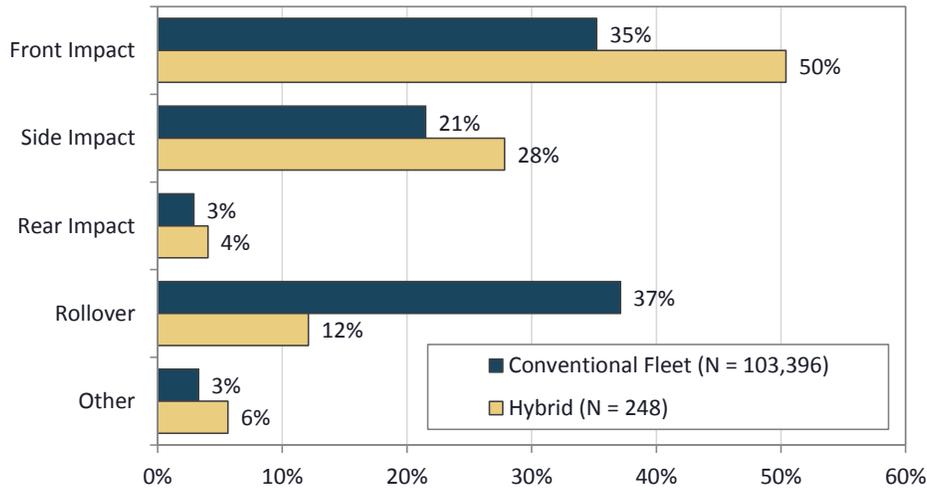
Figure 7. Risk of AIS2+ Injury by Body Region (NASS/CDS 1999-2013)

### Crash Characteristics

**Crash Mode** Figure 8 presents the distribution of fatal crash modes for hybrid and conventional fleet vehicles. The distribution of crash mode is based on the most harmful event during the crash. However, after

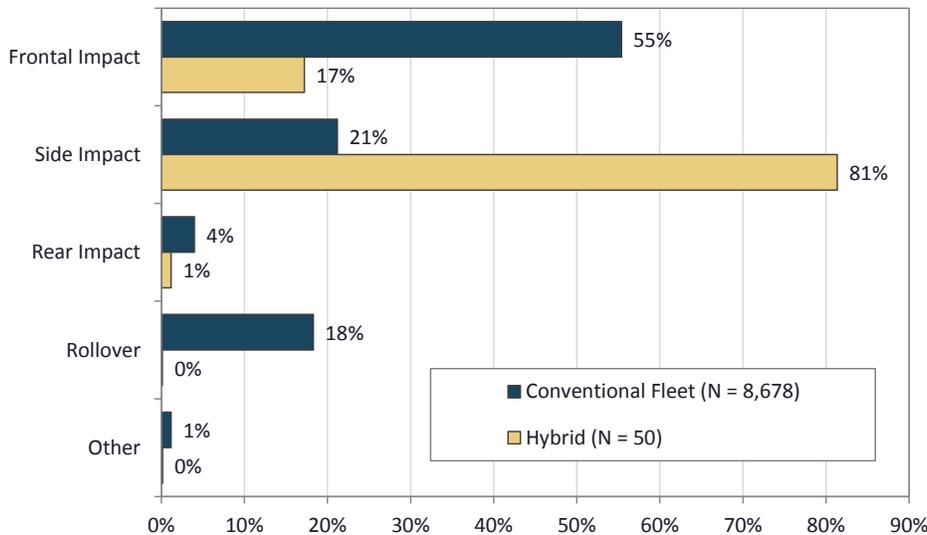
year 2011, the definition of crash mode was changed in FARS. Therefore, the distribution shown in Figure 8 is limited to case year 1999-2011.

As shown by the figure, frontal crashes comprise the majority (50%) of fatal crashes, and side impact accounts for the second most common fatal crash mode (28%). For conventional vehicles however, rollover crashes and frontal crashes account for nearly equal percent of fatal crashes (37% and 35%, respectively). The increased incidence of rollover in conventional vehicles may be due to the large number of SUVs and pickup trucks in the fleet, which have a much higher risk of rollover.



**Figure 8. Distribution of Crash Mode in Fatal Crashes (FARS 1999-2011)**

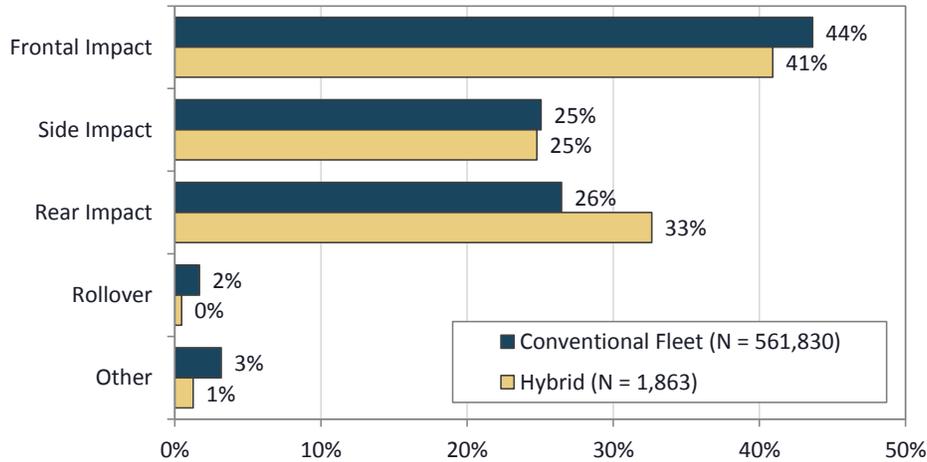
In the NASS/CDS dataset, the most common crash mode for MAIS2+ injured occupants in conventional vehicles was frontal impact, as shown by Figure 9. Over half of all MAIS2+ injured occupants in conventional vehicle were involved in a frontal impact. Side impact, including impacts to both the left and right side of the vehicle, was the most frequent crash mode for hybrid vehicles. Over 80% of all MAIS2+ injured hybrid occupants involved in a side impact. Rollover was more frequent in conventional vehicles as compared to hybrid vehicles, with 18% of all MAIS2+ injured conventional vehicle occupants exposed to rollover and less than 1% of all MAIS2+ injured hybrid vehicle occupants were exposed to rollovers.



**Figure 9. Distribution of Crash Mode in MAIS2+ Injured Crashes (NASS/CDS 1999-2013)**

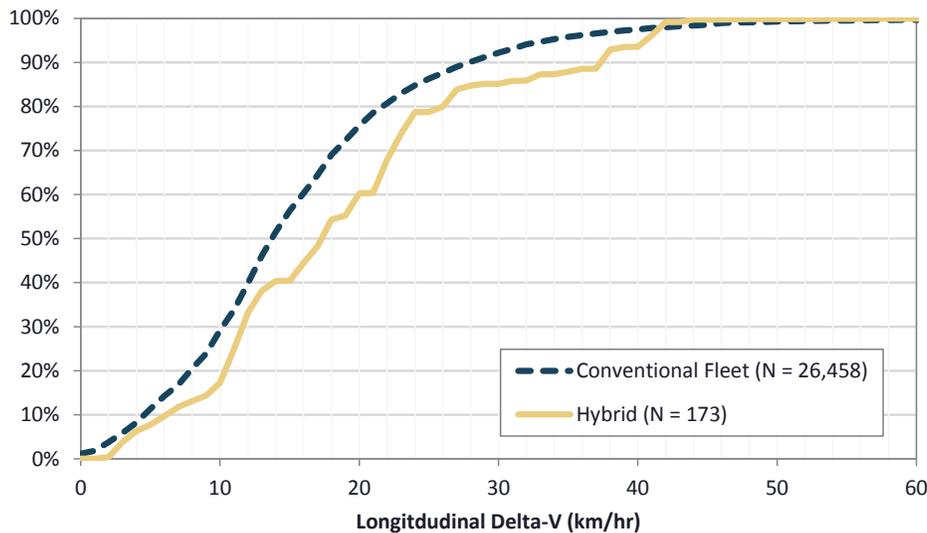
Figure 10 presents the distribution of crash modes in the NASS/GES database. As observed in the FARS and NASS/CDS analyses, frontal impact was the most common crash mode for both vehicle types, and accounted for

approximately 40% of all crashes for both vehicle types. However unlike FARS and NASS/CDS, rear impact was a close second in frequency with 26% of crashed conventional vehicles and 33% of crashes hybrid-vehicles. Rear impact is a common crash mode, but does not carry the injury risk of other crash modes. We hypothesized that rear impact was more common for hybrid vehicles as these are more likely to be drive in urban environments where frequent stop-and-go traffic leads to increase chance of rear end crashes.



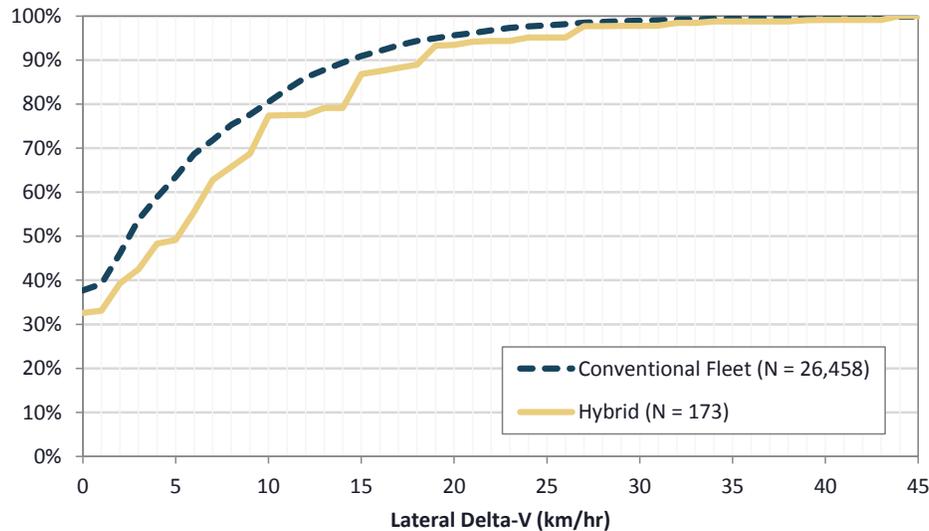
**Figure 10. Distribution of Crash Mode in All Crashes (NASS/GES 1999-2013)**

**Crash Severity** The struck vehicle change in velocity, or delta-V, is a widely used measure of crash severity. Longitudinal delta-V for all exposed occupants is presented in Figure 11. The median longitudinal delta-V for hybrid vehicles was 18 km/hr while the median delta-V for conventional vehicles was 14 km/hr. The delta-V for hybrid vehicles was higher as hybrids are in general lighter than conventional vehicles, which include a large number of SUVs and pickup trucks.



**Figure 11. Distribution of Longitudinal Delta-V for All Occupants (NASS/CDS 1999-2013)**

The lateral delta-V distribution was very similar for occupants of both hybrid and conventional vehicles. As shown by Figure 12, the median lateral delta-V was approximately 5 km/hr for hybrid vehicles and 3 km/hr for conventional fleet vehicles.



**Figure 12. Distribution of Lateral Delta-V for All Occupants (NASS/CDS 1999-2013)**

## CONCLUSIONS

The goal of this study was to characterize the factors which influence the risk of serious to fatal injury in U.S. hybrid and electric passenger vehicle crashes. The study was based upon the analysis of three U.S. crash databases: (1) the Fatal Analysis Reporting System (FARS), (2) the National Automotive Sampling System / Crashworthiness Data System (NASS/CDS), and (3) the National Automotive Sampling System / General Estimates System (NASS/GES).

The analysis datasets included 421 hybrid vehicles from FARS, 377 hybrid vehicles from NASS/CDS, and 1,863 vehicles from NASS/CDS. Only 2 electric vehicles were found in NASS/CDS, and 18 electric vehicles were found in NASS/GES and, therefore, we could not further investigate electric vehicles in this study.

Fires were rare in both hybrid and conventional vehicles. Fatal crashes involving fire constituted 2.6% of hybrid cases and 4.4% of conventional vehicle cases. No cases of fire or electric shock injury for hybrids in NASS/CDS 1999-2013. Only 1 case of a hybrid fire was found in NASS/GES. The incidence of fire was lower for hybrids than conventional vehicles in all three databases.

The gender of fatally injured hybrid and conventional vehicle occupants was very similar. Males were more likely than females to be fatally-injured. For the population as a whole as described in GES, hybrid occupants were more likely to be female (53%) than conventional vehicle occupants (50%).

Hybrid occupants were more likely to be older than conventional vehicle occupants in all three databases. In FARS, the median age of fatally injured hybrid occupants was 59 yrs vs. 36 years for conventional vehicle occupants. In NASS/CDS, hybrid occupants were more likely to be older (42 yrs) than conventional vehicle occupants (29 yrs). In GES, hybrid occupants were more likely to be older (44 yrs) than conventional vehicle occupants (32 yrs).

The risk of MAIS2+ head and chest injury was very similar for both hybrid and conventional vehicles. Upper extremity injury risk was higher while lower extremity risk was lower for occupants of hybrids than those in conventional vehicles.

Frontal impact was more frequently the fatal crash mode for hybrid (50%) than conventional vehicles (35%). In NASS/CDS, frontal impact was more frequently the injury crash mode for conventional vehicles (53%) than hybrid vehicles (40%). In GES, frontal impact was most frequently the crash mode for both hybrids (41%) and conventional vehicles (44%).

Hybrids and conventional vehicles had similar crash severity based on cases included in NASS/CDS. Longitudinal delta-V for hybrids was 18 km/hr and 14 km/hr for conventional vehicles. Lateral delta-V were similar for both vehicle types.

Our study found little difference between hybrid/electric and conventional vehicle crashes, in either crash performance or injury outcome between the two groups. No unique factors that could influence the crash outcome of these advanced fuel vehicles were found in this study. However, the hybrid/electric vehicle population is currently only a small percentage of the market share. Future studies will benefit from examination of larger population of hybrid/electric vehicles.

#### **ACKNOWLEDGEMENTS**

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