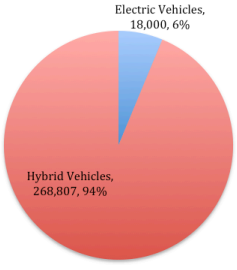
GLOBAL FEATURE STUDY
EV SAFETY IN THE US

A Growing New Market

Still in its infancy, the U.S. electric vehicle market is poised to grow dramatically in the next few years in terms of both sales and models offered. GM and Nissan were the first major automakers to introduce plug-in electric vehicles to U.S. consumers in December 2010, when they respectively sold 326 Volts and 19 Leafs[1]. Sales in 2011 were widely deemed disappointing given that both companies had announced a goal of selling 10,000, but fell short: Leaf sales totaled 9,674 units, while Volt sales only reached 7,671 units. Overall, close to 18,000 EVs were sold in 2011[2]. However, these figures compare favorably with first-year sales of the first hybrid vehicle introduced to the U.S. market, the Honda Insight, which registered sales of 17 units in its first month (December 1999) and 3,788 units in its first full year. Toyota's Prius, the enduringly and by far most popular hybrid in the U.S. appeared on the U.S. market eight months after the Honda Insight and registered sales of 5,562 units in 2000. Yet Prius sales almost tripled the following year, peaked at 181,221 units in 2007, and are projected to reach a record 244,632 in 2012 as Toyota rolls out two additional Prius hybrid models[3]. EV sales are following a similar growth curve thus far, with sales in the first half of 2012 already almost equal to annual sales in 2011[4]. As Chart 1 illustrates, hybrid sales totaled 268,807 units in 2011. Together, hybrid and electric vehicles accounted for 2.25% of the 12,734,356 vehicles sold in the U.S. in 2011[5].

Chart 1: Hybrid & EV Sales in the US, 2011



While total vehicle sales in the first half of 2012 are 15% higher compared to the same period last year, hybrid sales are up 63.5% and plug-in sales have increased over 161%. Hybrid and electric vehicles account for 3.25% of vehicles sold through June this year[6].

In terms of number of automakers involved and models offered, the EV market is growing at a faster rate than the hybrid market did in its first years. Charts 2 and 3 show that it took a dozen years for ten automakers to start producing hybrid vehicles, while the EV market included ten automakers this year, just four years after Tesla introduced the first EV to the U.S. market. In their fifth year on the market, hybrid vehicles were only available in three models from two automakers. Chart 3, which includes highway-capable electric vehicles produced for sale, shows that in the same time span, the portfolio of EVs has grown to eleven models from ten automakers[7].

Chart 2: Number of Hybrid Vehicles by Automaker

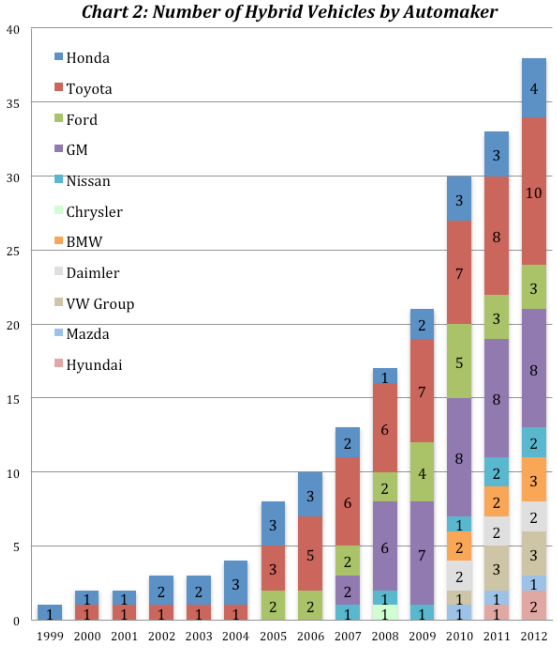
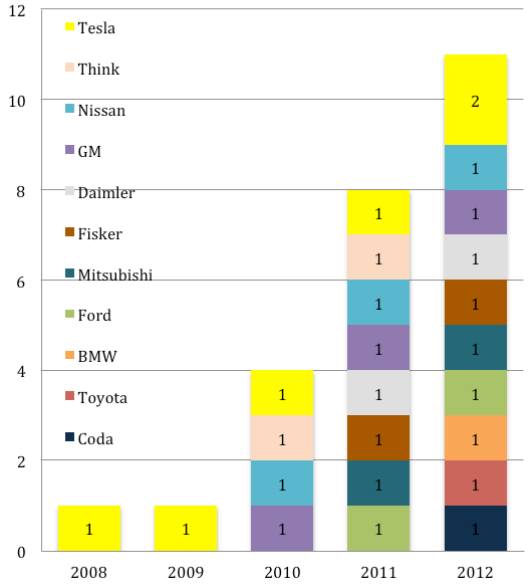


Chart 3: Number of EV Models by Automaker



Considering that EVs were introduced during the Great Recession and face greater adoption challenges linked to limited range and charging infrastructure and to their significant price premium, EVs are faring quite well relative to the hybrid market's experience. However, a series of recalls and the fallout from a Volt catching fire after NHTSA testing have cast a pall over the EV market. Of all the hurdles to the successful deployment of electric vehicles, the safety of EV lithium-ion batteries has recently come to the fore.

EV Recalls for Fire Hazard

To date, the National Highway Traffic Safety Administration (NHTSA) has issued a total of eight EV recalls involving four automakers, as detailed in Table 1[8]. Most of the recalls were for components that are not EV-specific, such as wheels, seat belts, defrosters, transmissions, and steering. In fact, BMW's recall included both an EV model – the Active E, and an ICE model – the Z4. To compare with the ICE safety track record, of the thousands of recalls NHTSA has issued since 1990 the most commonly cited faulty component has been the gasoline fuel system, which accounted for 327 recalls affecting 29,548,405 potentially affected vehicles[9].

Three of the EV recalls cited a fire hazard. In the case of Tesla's 2010 Roadster 2 the issue was not the battery, but the improper routing of low voltage auxiliary cables[10]. The risk was that a cable might become lodged against the wheel well cover, and exposed from repeated rubbing. A short circuit might then result from its contact with the vehicle's carbon fiber armature. This chain of events could end in electrical arcing and a fire in the headlamp area, from which the main battery pack is isolated. Tesla launched a voluntary recall after a customer reported an occurrence of this malfunction, smoking, and "possible fire"[11]. Most recently, Fisker initiated a voluntary recall of its 2012 Karma due to an internal fault in the low-temperature cooling fan located at the front of the vehicle. The fault might cause the unit to overheat and develop a slow burning fire[12]. The recall was announced in the aftermath of an incident that occurred on August 10, 2012, when a Fisker caught fire at the front of the vehicle on the passenger's side (the fire did not spread to the interior).

Only one recall presented an EV battery fire hazard, which was attributable to a defect in the battery pack. Fisker initiated this recall in December 2011 after workers assembling the Karma vehicles at Valmet Automotive's plant in Finland noticed leaking coolant[13]. Incorrectly assembled hose clamps were identified as the cause. Interference with the battery compartment's cover risked creating a coolant leak from the cooling hoses into the battery, potentially causing an electrical short and fire[14]. Fisker expanded the recall in May 2012 after its battery supplier A123 notified it of additional potentially defective batteries[15]. Between the two recalls, Consumer Reports announced that a new Fisker Karma it had purchased for testing broke down during its check-in process[16]. Upon investigation, Fisker found that the battery presented a defect, but one that was unrelated to the battery defect cited in the recalls. In this instance, faulty calibration on one of the welding machines at A123's plant in Michigan produced misaligned cells that could create an electrical short in the battery pack. Likely consequences included battery failure or reduced battery performance and/or life, but not fire. A123 has repaired the Karma batteries with malfunctioning hose clamps and entirely replaced the cell-damaged battery packs supplied to Fisker and several other customers[17].

It is noteworthy that the list of NHTSA EV recalls is entirely composed of start-ups (Tesla, Think and Fisker) and a premium automaker (BMW). These two segments of the automotive market are generally most prone to reliability issues, in the first case due to inexperience and in the second by dint of being at the forefront of new technology. EV start-ups combine both factors. As Consumer Reports conceded with regard to Fisker, "In fairness, the challenges Fisker has surmounted in going from a start-up to a bonafide automaker over a short period are monumental. Some birthing pains are not unexpected, especially as it is presumed the company faced significant timeline challenges to reach milestones necessary to obtain funding. Further, the Karma is a leading-edge car. Check the reliability track record for other companies pushing tech boundaries (ahem, Mercedes-Benz) and you will often find hiccups"[18]. Indeed, while the first two major automakers to introduce EVs – GM and Nissan – have benefited from their experience making limited quantities of EVs in the 1990s and have not issued any recalls for the Volt and Leaf, both have conducted customer service campaigns to address unanticipated issues[19].

Table 1: NHTSA EV Recalls

Auto-maker	Model (potentially affected vehicles)	Report Date	Component	Issue
Tesla Motors	2008 Roadster (345)	5/22/09	Wheels: cap, cover & hub	Under-torqued rear hub flange bolts may become loose and cause driver to lose control of the vehicle.
Tesla Motors	2010 Roadster2 (439)	10/1/10	Electrical system: battery cables	12V auxiliary cable to low voltage system may be improperly routed, rub against the carbon fiber and eventually expose wire, causing a short circuit. A fire might ensue.
Think	2011 City (16)	1/19/11	Seat belts	Seat belts may be improperly installed and fail to restrain a child.
Think	2011 City (23)	1/21/11	Visibility: defroster	Fluid heater malfunctions might cause performance failure of the defroster and compromise visibility.
Think	2011 City (23)	2/15/12	Power train: automatic transmission lever & linkage	Improper adjustment of transmission park mechanism might result in vehicle's failure to hold in park position.
Fisker	2012 Karma (258)	12/21/11 5/25/12	Electrical system: battery propulsion system	Improper installation of hose clamps within the high-voltage battery may cause coolant to leak into the battery compartment, resulting in an electrical short and fire.
BMW	2011 Active E (162, including Z4 2012 models)	6/28/12	Steering: electrical power assist system	Current variations in electric power steering may lead to sudden loss of steering assistance.
Fisker	2012 Karma (2,400)	8/18/12	Cooling fan	An internal fault in the low temperature cooling fan may cause failure, overheating and fire.

Source: NHTSA, Safercar.gov

In sum, no EV model has been recalled in response to a real-world battery fire. Only one EV model has been preventatively recalled because of a battery fire hazard, which was traced back to an A123 battery defect that does not affect any of A123's other customers.

NHTSA Investigations of Battery Fire Hazards

In addition to on-scene examinations that NHTSA's Special Crash Investigation Division has performed after EV accidents, the agency has investigated three fires involving EVs and launched one formal defect investigation into an EV battery fire hazard.

Table 2: NHTSA investigations of fires involving EVs

Vehicle	Date	Location	Status	Investigation result
GM Volt	11/2011	Mooresville, NC	Charging	EV was not the cause
GM Volt	04/2011	Barkhamsted, CT	Charging	EV was not the cause
Fisker Karma	05/2012	Houston, TX	Parked	Ongoing

Table 2 shows that neither of the two first residential garage fires investigated by NHTSA were found to have originated from a charging Volt. NHTSA has not released any results from its third investigation yet. Thus far it appears that the Fisker Karma involved was a post-recall model purchased in April, and that two other, non-EV vehicles were parked in the garage. The chief fire investigator at the scene suggested the fire originated with the Karma, while Fisker claims its vehicle's battery pack was found intact and was unlikely to have caused the fire[20].

NHTSA opened its only formal defect investigation into an EV battery fire on November 25, 2011, citing two Volt battery fires that had occurred after a series of tests. The first fire broke out on June 6 at a testing facility in Wisconsin following New Car Assessment Program (NCAP) crash tests. NHTSA had conducted an oblique side impact test that resulted in a transverse stiffener under the driver's seat piercing the Volt's high-voltage battery and causing battery coolant to leak. Next, a rollover test caused the coolant to saturate the battery and electronic components. The vehicle was then placed in storage, its battery pack cells damaged; an electric shorting produced a fire three weeks later. Four other Volts that underwent side pole tests displayed no battery intrusion (except for minor plastic damage in one case) or coolant leakage[21].

In partnership with the U.S. Departments of Energy (DOE) and Defense (DOD), NHTSA developed a test to replicate the battery damage that had precipitated the Volt fire. In November, NHTSA used this test to intentionally damage three battery packs, which were then placed in storage for observation. The Volt's LG Chem-supplied batteries were tested in isolation, outside of the vehicle. Within a week one battery pack caught fire, destroying another. The third pack was found smoking and sparking. This prompted NHTSA to open an investigation on the Volt. It was an unusual step given the absence of any real-world incidents. NHTSA cited the vehicle's new technology as a major factor in its decision to formally investigate. Another three tests were conducted in December on three new Volt battery packs to isolate the cause. The battery used to isolate the shorting of the battery bus bar to the chassis caught fire 6 days after the test[22].

Although NHTSA did not identify a defect warranting a recall and GM stood by the safety of its battery packs, the automaker initiated a customer satisfaction campaign on January 5 to address three weaknesses raised by NHTSA's investigation. GM offered to make the following modifications to 2011 Volt models: strengthen the vehicle structure where the battery intrusion occurred during NHTSA's testing; add a sensor and control system to monitor coolant loss and prevent battery recharging when excessive coolant is lost; and proof the coolant system from tampering so that consumers are unable to add coolant[23]. The changes have been incorporated into the 2012 model, which cleared NHTSA's side-pole test without any intrusion.

NHTSA closed the Volt investigation on January 20, concluding that the Volt did not present any defects, that GM's voluntary modifications had reduced the risk of a fire-causing intrusion – an event that was highly unlikely to occur in the first place – and that there was no record of real-world crashes involving any electric vehicle model that had produced a battery-related fire. As stated by the agency, "based on the available data, NHTSA does not believe that Chevy Volts or other electric vehicles pose a greater risk of fire than gasoline-powered vehicles"[24].

Safety Standards in Battery Support and System

NHTSA ended its statement on the Volt investigation by noting that EVs require EV-specific safety measures. Yet it did not follow such measures during its testing of the Volt. At a Congressional hearing on NHTSA's handling of the Volt fires, the agency could not provide a convincing explanation as to why it had placed a Volt with a damaged battery into storage without first disconnecting and discharging the battery. NHTSA's own Interim Guidance for EVs provides the following post-incident instruction in all three of its guides – for law enforcement, emergency medical services, and fire departments; for vehicle owners and the general public; and for towing and recovery operators and vehicle storage facilities: "Do not store a severely damaged vehicle with a lithium-ion battery inside a structure or within 50 feet of any structure or vehicle"[25]. The importance of post-crash handling illustrates the need to adopt a systems approach to battery safety. An initially safe battery might become a hazard if it is improperly integrated into a vehicle's structure and electronics, if it is exposed to high temperatures or moisture, or if it is mishandled at any point during its lifecycle.

In general, as Micheal Smyth, assistant director for training and curriculum development at the National Alternative Fuels Training Consortium (NAFTC), a program of West Virginia University, explained in an interview, a key safety measure to follow after any accident involving an electric vehicle is to disable the high-voltage system. The NAFTC's first responder safety training manual recommends that standard first responder procedures be followed when an EV is involved in an accident, i.e. "immobilize, stabilize, and disable". The main difference with EVs is that "disable" refers to not only disabling the vehicle's capability to move, but also refers to the vehicle's high-voltage system, which needs to have the high voltage energy isolated from the vehicle's battery pack by turning off the vehicle's ignition, placing any smart keys more than 25 feet away from the vehicle[26], and cutting the 12-volt auxiliary battery's negative cable. Disabling the auxiliary battery will also result in the high-voltage system's capacitors discharging within 5 minutes in most cases[27]. The NAFTC's training also instructs personnel working with an electric drive vehicle during or after an accident to be aware of the possibility of a damaged high voltage battery overheating, creating the risk of an explosion or fire.

Standards development has a large role to play here in ensuring that best practices are adopted and gaps are addressed. Table 3 details battery-related education and training standards and battery safety standards, the issues addressed, the standards development organizations (SDOs) involved, and the gaps that the American National Standards Institute (ANSI) has identified. Only standards that apply in the U.S. are listed, although not all of the SDOs are U.S.-based. The SDOs that cover battery safety and education standards include the Institute of Electrical and Electronics Engineers (IEEE), International Electrotechnical Commission (IEC) International Organization for Standardization (ISO), National Fire Protection Association (NFPA), NHTSA, Society of Automotive Engineers (SAE), and Underwriters Laboratories (UL).

Table 3: Battery-related safety standards

ISSUE	AGENCY	STANDARD	STATUS	GAP
Education and Training				
Vehicle emergency shutoff	SAE	J2990	In progress To be published in Fall 2012	Safety labeling of batteries, cables & disconnect devices
Battery discharge & recharge in emergencies	N/A	N/A	SAE & NHTSA are potential developers	Standard needs to be developed
First responder training	NFPA	N/A	Complete & growing	None
Safety & Testing Specifications				
General battery safety standard for EV applications	ISO	12405-3	In progress	None
Short circuit, over - charge & - discharge tests	IEC ISO	62660-2 12405-1	Published 2010 Published 2011	None
Protect people in & outside vehicle	ISO	6469-1	Published 2009	None
Protect people from electric shock	ISO	6469-3	Published 2001	None
Safety following crash	SAE	J1766	Published 2005 Under revision	None
Response test to potential abuse	SAE	J2464	Revised 2009	None
Min. criteria for battery use in EV	SAE	J2929	Published 2011 Under revision	- Delayed battery overheating events - Loss of control/dual mode failure
Abuse testing for cells, modules & packs; evaluation of assembly	UL	2580	Published 2009	None
Protect people from electrolyte spillage, electrical shock during crash	NHTSA	FMVSS 305	Revised 2011	None

Source: ANSI Standardization Roadmap for Electric Vehicles

ANSI has not identified any gaps in emergency first responder training standards. However, the institute calls for the development of standards in the safety labeling of batteries, cables and disconnect devices so that first responders can quickly identify them. ANSI also recommends developing guidelines for EV battery discharging and recharging in an emergency to create a consistent user's interface for first responders[28].

With regard to battery safety and testing specifications, ANSI has identified two gaps that should be addressed shortly by the SAE in the revision currently underway of minimum safety criteria for batteries to be used in an EV high voltage power train (J2929). First, battery failure modes are currently designed to address hazards occurring within minutes or hours of a fault. However, over a longer period of time less detectable stray currents might build up a battery pack's temperature to dangerously high levels.

ANSI therefore recommends that the SAE include delayed battery heating in its revised standard[29]. The second gap concerns double fault conditions. For example, a battery's overcharge protection might fail when the battery is overheated. SAE is currently researching this issue in order to address it in the J2929 standard[30].

Finally, new and revised battery safety standards from the ISO, NHTSA, and SAE are in the works and scheduled for publication beginning this year.

The EV Safety Perception Gap

Over a quarter million vehicle fires occur every year on U.S. highways, causing hundreds of deaths. Not one of these has involved an electric vehicle. The DOE's Advanced Vehicle Testing Activity reported almost no adverse events from data collected in 2011 for 6,500 EVs that had covered over 26 million miles[31]. Volts alone have accumulated the same mileage without recording any thermal incidents. Yet in the wake of NHTSA's Volt investigation, the politicization and media magnification of the Volt's safety created a wide gap between consumers' perception of EV safety and the actual safety record of EVs. In the immediate aftermath, the number of consumers who would consider buying a Volt halved[32]. A 2012 Consumer Reports survey showed 28% of respondents deeming EV's to be less safe than ICEs[33]. Furthermore, 42% were concerned about the risk of fires during charging at home, 39% about crash protection, 35% about post-crash protection, and 30% about electric shock.

Ironically, the very same testing that prompted NHTSA to open the Volt investigation was the basis of its decision to award the Volt its highest safety rating. As table 4 shows, the Volt also received the highest safety ratings from the European New Car Assessment Program (Euro NCAP) and the Insurance Institute for Highway Safety (IIHS), which selected the Volt as a top pick for safety. The Leaf received the highest ratings from all three agencies as well. The Mitsubishi i scored very well for a subcompact model, garnering 4 stars from both NHTSA and Euro NCAP. The Tesla Roadster and Model S, Think City, Smart Fortwo ED, Fisker Karma, Ford Focus Electric, BMW Active E, Toyota Prius PHV, and Coda sedan have not been rated by any of the agencies yet. NHTSA has announced plans to rate the 2012 Coda and Focus Electric[34]. In addition, it is planning NCAP and compliance testing of Toyota's Prius plug-in and upcoming RAV 4 Electric[35].

Table 4: EV Safety Ratings

	Nissan Leaf	GM Chevrolet Volt	Mitsubishi i
NHTSA **Scale: 0-5 stars**			
Model year(s)	2011, 2012, 2013	2011, 2012, 2013	2012, 2013
OVERALL RATING	**5**	**5**	**4**
Frontal crash	4	4	4
Side crash	5	5	3
Rollover	4	5	4
Euro NCAP **Scale: 0-5 stars**			
Model year(s)	2012	2011	2011
OVERALL RATING	**5**	**5**	**4**
Adult protection	89%	85%	73%
Child protection	83%	78%	78%
Pedestrian	65%	41%	48%
Safety assist	84%	86%	86%
IIHS **Scale: Good, Acceptable, Marginal, Poor**			
Model year	2011, 2012	2011, 2012	Not Tested
OVERALL RATING	**Top Pick**	**Top Pick**	
Frontal offset	Good	Good	
Side impact	Good	Good	
Roof strength	Good	Good	
Rear crash	Good	Good	

Note: The Euro NCAP's child and adult protection scores are derived from frontal, side and pole impact tests. The safety assist score is mostly based on the presence of electronic stability control.

The consumer perception gap on EV safety is bound to narrow as additional models are tested and rated, standards are firmed, and the number of electric vehicle models and miles driven increases. In the meantime, there is no evidence to suggest that EVs are less safe than ICEs in the U.S.

[4] The Hybridcars.com June 2012 Dashboard shows a year-to-date total of 17,530 sales for plug-in electric cars, including the Chevrolet Volt, Prius plugin hybrid, Nissan Leaf, Smart for Two EV, Ford Focus Electric, BMW Active E, and Mitsubishi i. Additional models sold include Tesla's Roadster and Model S, Fisker's Karma, and Coda's sedan; these automakers do not release monthly U.S. sales data.

[5] December 2011 Dashboard, HybridCars.com.

[6] Based on data from the HybridCars.com June 2012 Dashboard.

[7] The 1996 GM EV1 and 1997 Toyota RAV4EV and Honda EVPlus, and 1998 Ford Ranger EV were the first highway-capable EVs introduced to the U.S. market, in California, to meet the California Air Resources Board's (CARB) zero-emissions vehicle requirements. However, the vehicles were only available for lease and were destroyed after CARB loosened the requirements. Only Toyota eventually made several hundred of its original EVs available for sale.

[8] NHTSA requested that Fisker label the expansion of its 2012 Karma recall as a new recall.

[9] See Edmunds Auto Observer' data center, "NHTSA Recalls by Vehicle Component" table.

[10] See NHTSA recall summary, campaign ID number 10V458000.

[11]Tesla press release, "Tesla initiates voluntary recall after single customer incident", 10/1/10.

[12] Fisker press release, "Woodside, CA incident", 8/18/12.

[13] Valmet Automotive is a contract vehicle manufacturer that focuses on premium, convertible, and electric vehicles. In addition to Fisker, clients include THINK, Porsche, Daimler, Renault, BMW's Mini division, and VW's Bentley division.

[14] See NHTSA recall summary, campaign ID number 11V598000.

[15] Anita Lienert, "Fisker Expands Recall of 2012 Karma for Fire Hazard," Edmunds Inside Line, 6/4/12.

[16] See Tom Mutchler, "Bad Karma: Our Fisker Karma plug-in hybrid breaks down," Consumer News, ConsumerReports.org, 3/8/12.

[17] A123's customers include Daimler, General Motors, SAIC Motor, Smith Electric and Tata Motors. Customers using A123 cells made in China were not affected. See Craig Trudell and Alan Ohnsman, "A123 Replacing Batteries That Led to Fisker Karma Shutdown," Bloomberg, 3/26/12.

[18] Jeff Bartlett, "Consumer Reports is not the only Fisker owner to experience bad Karma," Consumer News, ConsumerReports.org, 3/16/12.

[19] Nissan conducted a customer service campaign April 2011 to reprogram vehicles with an electrical glitch that was preventing them from restarting following the use of air conditioning. This resulted from an oversensitive safety mechanism whereby the AC demand for power triggered a high voltage alert. See John O'Dell, "Nissan Leaf Quality Glitch Detected," Edmunds AutoObserver, 4/12/11. See next section for more on GM's customer service campaign for the Volt.

[20] For a full account of the incident, see David Arnouts, "Official claims Fisker Karma to blame in Texas house fire," Autoweek, 5/8/12.

[21] NHTSA, "Chevrolet Volt Battery Incident Overview Report," January 2012, p. 2.

[22] The factors isolated in the two other tests were cell damage and battery coolant leakage. See NHTSA, "Chevrolet Volt Battery Incident Overview Report," January 2012, p. 3.

[23] NHTSA defect investigation summary.

[24] NHTSA statement regarding the conclusion of its safety investigation into the post-crash fire risk of Chevy Volt (PE11037), 1/20/2012.

[25] See NHTSA, "Interim Guidance for Electric and Hybrid-Electric Vehicles Equipped with High Voltage Batteries," January 2012.

[26] NAFTC, Advanced Electric Drive Vehicle Education Program at West Virginia University, "First Responder Safety Training", sections 2-28 & 2-29.

[27] Smart keys may automatically enable a PHEV's low-voltage system.

[28] Electric Vehicles Standards Panel of the American National Standards Institute, "Standardization Roadmap for Electric Vehicles", Version 1.0, April 2012, pp. 97-100.

[29] Id., p. 58.

[30] Id., p. 59.

[31] David Howell, DOE, "U.S. DOE Perspective on Lithium-ion Battery Safety" Presentation at Technical Symposium: Safety Considerations for EVs powered by Li-ion Batteries, NHTSA, May 18, 2012.

[32] Bill Vlasic and Nick Bunkley, "G.M. Re-examines Volt as Safety Concerns Rise", New York Times, 12/7/2011. The article notes, however, that the Consumer Reports' survey showed 93% of Volt owners would purchase their vehicle again.

[33] See Consumer Reports 2012 Car Brand Perception Survey. Note that 63% deemed them as safe or safer, and 9% did not know. .

[34] NHTSA press release, 10/13/11.

[35] Claude Harris, "Overview of NHTSA EV Safety Testing and Research May," Presentation at Technical Symposium: Safety Considerations for EVs powered by Li-ion Batteries, NHTSA, May 18, 2012.

