UL 2272 AND THE SAFETY OF PERSONAL E-MOBILITY DEVICES

Overview

Personal electro mobility (e-Mobility) devices were some of the hottest selling items of the 2015 U.S. holiday shopping season.[1] But initial consumer enthusiasm evaporated in the wake of widespread reports of fires traced to the rechargeable lithium-ion batteries used in some self-balancing scooters (more commonly known as hoverboards). The U.S. Consumer Product Safety Commission (CPSC) reports that, during the period from December 1, 2015 through February 17, 2016, the agency received notices from consumers of 52 separate fires directly related to hoverboards, resulting in more than $2 million (USD) in property damage.[2]

In response to the heightened risk associated with rechargeable battery systems used in hoverboards and other personal e-Mobility devices, UL published an early 2016 version of a Standard which by the end of 2016 is now a consensus based, American National Standard (ANSI) and National Standard of Canada (NSC) by the Standards Council of Canada (SCC), accredited edition of UL 2272, Standard for Safety of Electrical Systems for Personal e-Mobility Devices. In contrast to standards that are applicable only to lithium-ion batteries themselves, ANSI/CAN/UL 2272 takes a system-wide approach to the electrical safety of e-Mobility devices that incorporate drive systems using rechargeable lithium-ion batteries. Specifically, the Standard details requirements related to the construction of e-Mobility devices, and prescribes electrical, mechanical and environmental testing to assess electrical safety.

This UL white paper discusses the fire-related safety issues associated with personal e-Mobility devices and presents a summary of the requirements found in UL 2272. Beginning with an overview of lithium-ion battery safety, the paper reviews personal e-Mobility device-related fires as well as actions taken by some manufacturers and retailers to reduce consumer risks. The white paper then provides details on the requirements of UL 2272, and concludes with compliance guidelines for manufacturers and retailers.

Background on Lithium-Ion Batteries

Over the past 25 years, rechargeable (also known as secondary) lithium-ion battery technologies have evolved, providing increasingly greater energy density and longer cycle life. Commercial lithium-ion batteries now power a wide range of consumer electrical and electronic devices, medical devices, industrial equipment and automotive applications. The worldwide market for lithium-ion batteries is projected to exceed $13 billion (USD) in annual sales by 2020, with the market for rechargeable lithium-ion batteries representing nearly 90 percent of those sales ($11.9 billion).[3]

However, as the use of lithium-ion batteries grows globally, and with large numbers of batteries powering a wide range of products in a variety of usage environments, there have been reported incidents raising safety concerns. While the overall rate of failures associated with the use of lithium-ion batteries is low, the consequences of failure can be quite severe. Several publicized examples involving consumer products like laptop computers and electronic toys have led to numerous product safety recalls by manufacturers, the CPSC and others. Some of these cases have been linked to overheating of lithium-ion batteries, leading to fire or explosion.

A LITHIUM-ION BATTERY is an energy storage device in which lithium ions move through an electrolyte from the negative electrode (the “anode”) to the positive electrode (the “cathode”) during battery discharge and from the positive electrode to the negative electrode during charging.

Electrochemically active materials in lithium-ion batteries typically include a lithium metal oxide for the cathode, and a lithiated carbon for the anode. The electrolytes are typically a liquid organic solvent in most commercial designs, but some are a gel polymer or ceramic. For most lithium ion batteries, a thin (on the order of microns) micro-porous film called a separator provides electrical isolation between the cathode and anode, while still allowing for ionic conductivity.

Variations on the basic lithium-ion chemistry exist to address various performance and safety issues. In general, however, the safety of lithium-ion cells is chiefly dependent on battery design and manufacturing quality control. First, the design of the battery cell needs to be sufficiently robust to withstand the anticipated use conditions of the device being powered. Second, manufacturing processes need to be tightly controlled to ensure that contaminants and other impurities from material sourcing and production processes do not make their way into the final product.

Safety Issues with Hoverboards

While fictional hoverboards date back to the 1989 movie Back to the Future, Part II, interest in real hoverboards took off dramatically in mid-2015, fostered in part by social media posts from celebrities and athletes. Despite some concerns about patent infringement,[5] demand for hoverboards quickly peaked, with eBay reporting orders for nearly 7500 hoverboards on Cyber Monday (the Monday after the U.S. Thanksgiving holiday) alone.[6]

But just as quickly, numerous reports surfaced of incidents and injuries related to hoverboard operation, primarily connected with falls and collisions involving moving hoverboards. To cite just one example, research by athenahealth found that, during the second half of 2015, 144 patients within its U.S. healthcare partner network of 55 million people included the word "hoverboard" as a cause of a present illness.[7] Headaches, wrist fractures and concussions were among the most common injury and pain-related diagnoses identified with these incidents.

Of even greater concern during this period was the number of fires connected with hoverboards. In some cases, the devices caught fire or exploded while being charged. In other instances, some hoverboards caught fire while in use, endangering riders and the general public. By mid-December 2015, the CPSC had received reports of at least 16 fires in 12 states related to hoverboards. By mid-February 2016, the number of hoverboard-related fires reported to the CPSC had grown to 52. These statistics included a home in Nashville, TN valued at $1 million that was completely destroyed by a fire traced to a hoverboard.

CERTIFICATION MARKS PRIOR TO THE PUBLICATION OF UL 2272

Before the publication of UL 2272, hoverboard safety issues were exacerbated by the apparent use or misuse of certification marks that could mislead consumers regarding any compliance testing that may have taken place. According to the CPSC, certification marks appearing on hoverboards or product packaging may reflect testing and certification of individual components but not the entire hoverboard system, an important distinction. In certain instances, certification marks were actually counterfeit, leading consumers to believe that safety testing had been performed when it had not.[8]

Recent Actions to Mitigate Safety Risks

Efforts to address the potential dangers associated with hoverboards were swift and extensive. A number of sellers, including Amazon, Overstock and Target, removed hoverboards from their websites and retail store shelves. Some retailers even offered refunds to customers who previously purchased hoverboards.

In addition, more than 60 separate airlines, including all major U.S. carriers, banned hoverboards on their flights, both as carry-on and as checked items.[9] Complete or partial bans against hoverboards were also put in place at more than 20 colleges and universities across the U.S.[10] And, New York City's Metropolitan Transit Authority (MTA) banned hoverboards from all forms of public transportation in the city due to concerns about the risk of fire in enclosed spaces (i.e., subway trains and buses).[11]

Most important, the CPSC issued a Notice to manufacturers, importers and retailers of hoverboards, urging them to comply with "currently applicable voluntary safety standards, including all referenced standards and requirements contained in UL 2272." In its Notice of February 18, 2016, the CPSC said that it "considers self-balancing scooters that do not meet (UL 2272) to be defective," and that the Agency could seek a recall of such products, or detain or seize non-compliant products at import.[12]

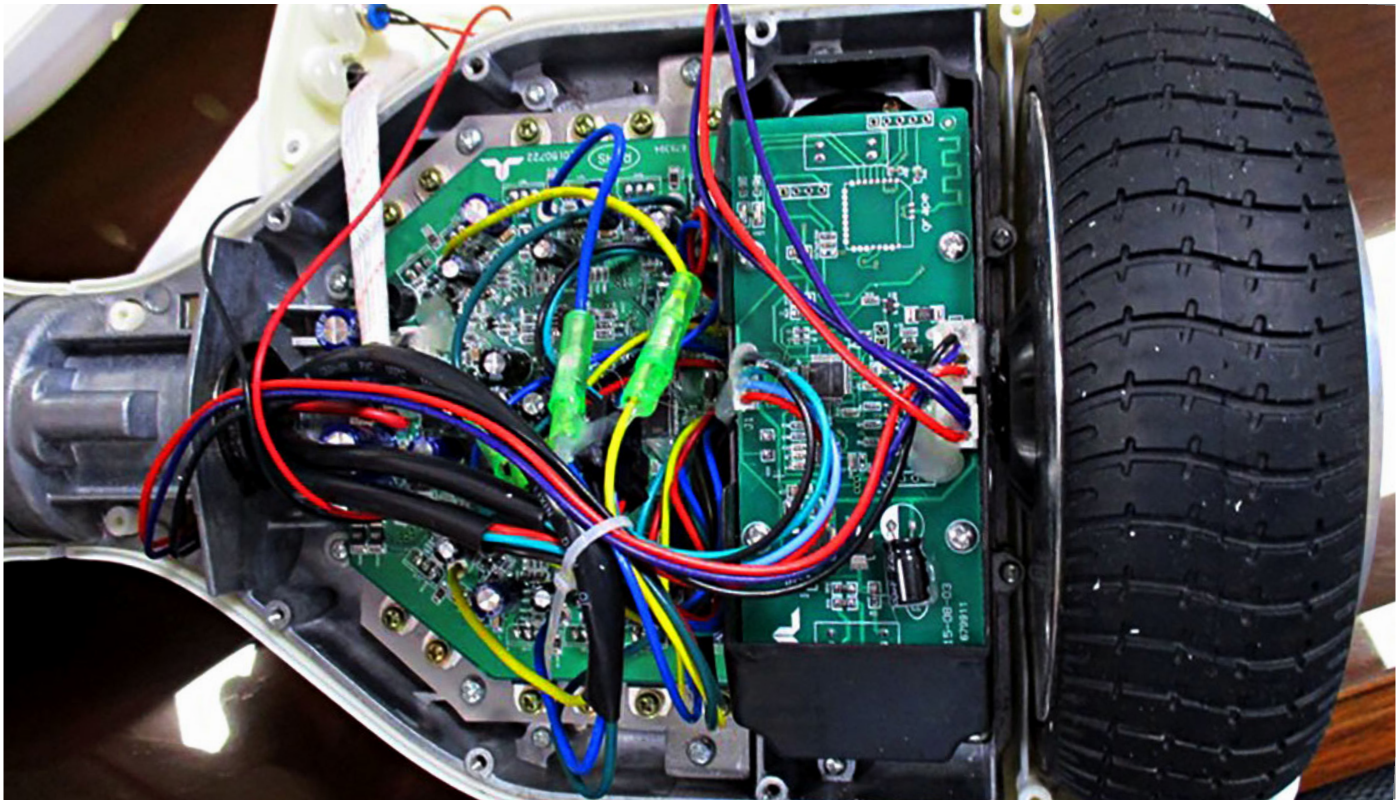
UL 2272—A System-Level Approach to Battery Safety in Personal e-Mobility Devices

Safety testing of individual power system components used in hoverboards and other personal e-Mobility devices, such as lithium-ion battery cells and battery packs, chargers and power supplies, has been available for several years. However, individual components that have been tested for safety may not perform as expected when combined with other components in a given application. This is especially true in cases of electrical systems, where individual components must be carefully matched to support the complete range of anticipated use conditions of the end product.

Rather than assessing the safety of individual components, UL 2272 approaches the evaluation of personal e-Mobility devices from a system-level perspective, examining the entire electrical system from several vantage points to identify all potential electrical and fire-hazard safety risks. This system-level approach better anticipates the full range of safety conditions, allowing manufacturers to address them prior to their products reaching the market.

In general, testing under UL 2272 is conducted on samples of entire personal e-Mobility device systems. Most individual tests also subject sample systems to a charge/discharge cycle if the sample is operational after a given test has been completed. And compliance requirements are consistent, easing the assessment process.

Specific testing and other requirements contained in UL 2272 and applicable to personal e-Mobility devices are described in the following sections.



Electrical Testing

Personal e-Mobility devices are subject to a number of different electrical tests. Several of these tests, including the overcharge, short circuit, overdischarge and imbalanced charging tests, consider single fault conditions in the protection circuitry that have not been previously evaluated for functionality or reliability. Specific electrical tests include:

- **Overcharge–** The overcharge test evaluates the ability of a sample device (the device under test, or DUT) to withstand an over charge condition under both non-faulted conditions and under a single fault condition without causing an explosion, fire or rupture of the battery. The voltage limits for charging are to be maintained.

- **Short circuit–** The short circuit test evaluates the ability of the battery circuit within a personal e-Mobility device to withstand a short circuit condition under both non-faulted conditions and under a single fault condition in the discharge protection circuit, without causing an explosion, fire or rupture of the battery.

- **Overdischarge–** This test evaluates a DUT's ability to withstand an overdischarge under both non-faulted conditions and under a single fault condition in the discharge protection circuitry, without causing an explosion, fire or rupture of the battery. Voltages on cells are not to exceed their specified end of discharge condition.

- **Temperature–** Temperature testing determines whether or not component cells in a given sample are maintained within their specific operating current, voltage and temperature limits during maximum charging and discharging conditions. Temperature testing also determines whether temperature sensitive safety critical components and temperature sensitive materials remain with their temperature ratings. This test considers specified ambient temperatures for charging and operation when determining compliance.

- **Imbalance charging–** This test is conducted to determine whether a DUT with battery cells connected in series can maintain those cells within their specific operating parameters without causing an explosion, fire or rupture of the battery, even when a single cell becomes unbalanced.

- **Dielectric voltage withstand–** The dielectric voltage withstand test evaluates the electrical insulation including the electrical spacings for any hazardous voltage circuits (if applicable) within the DUT. This test is used to evaluate the electrical insulation after various tests in the standard.

- **Leakage current test–** This test is intended to evaluate a DUT containing hazardous AC voltage circuits that can connect to mains AC during charging for hazardous levels of leakage current on accessible surfaces. Using the leakage current measuring circuit, the measured leakage currents on accessible surfaces of a sample device while charging cannot exceed 0.5 milliampere.

- **Grounding continuity test–** This test is conducted on those e-Mobility devices that are provided with grounding and measures the impedance of the grounding circuit. The total impedance between any two points of the system must not be greater than 0.1 Ohm.

- **Isolation resistance–** The final electrical test, the isolation resistance test, determines whether DUT insulation provides adequate isolation of hazardous voltage circuits from accessible conductive parts. This test may be used as an option to the dielectric voltage withstand test for evaluating the electrical insulation after various tests in the standard.

Mechanical Testing

Under UL 2272, the assessment of the mechanical safety of personal e-Mobility devices includes the following tests:

- **Vibration–** The vibration test determines whether the electrical system of the DUT is robust enough to withstand effects of vibration during use without resulting in loose connections or parts that could create a hazardous condition. The test utilizes a random vibration profile.

- **Shock–** This test determines whether or not the DUT can withstand a mechanical shock, consisting of half-sinusoidal pulses, to which a device may be subject when in use without causing an explosion, fire or rupture of the battery.

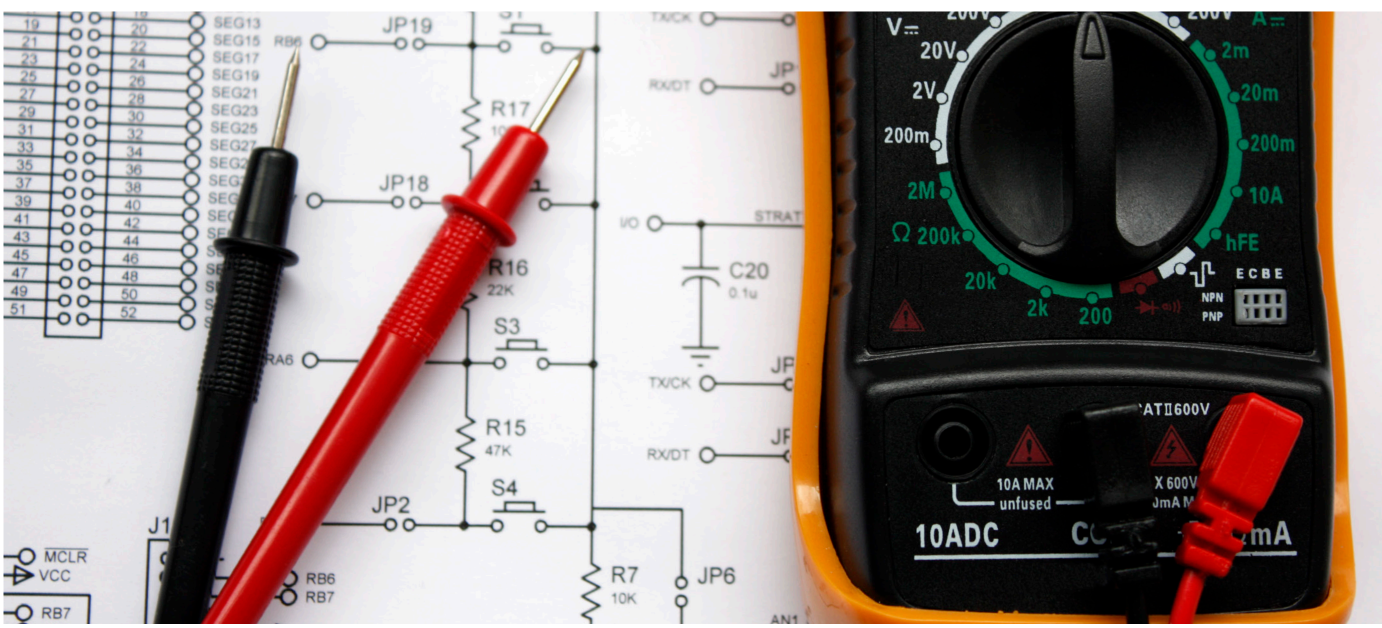
- **Crush–** The crush test is conducted to determine the DUT's ability to withstand an anticipated crushing event due to specified weight limits being exceeded that could occur during use without causing an explosion or fire.

- **Drop–** This test evaluates whether a hazard is created when a DUT is inadvertently dropped during handling or lifting, and involves dropping the DUT three times from a height of approximately one meter on to a concrete surface.

- **Mold stress relief–** The mold stress relief test is a type of accelerated aging test that determines whether any shrinkage or distortion on a molded or formed thermoplastic enclosure that occurs due to internal stresses results in the exposure of hazardous parts or the reduction of electrical spacings.

- **Strain relief–** The final mechanical test consists of two strain relief tests, a strain relief pull test and a push-back test, designed to assess non-detachable exposed device cords and cables that may be subjected to pulling or pushing during anticipated use.

- **Handle loading test–** This test consists of subjecting an e-Mobility device equipped with a handle that can be used to pick up the device to a total force of 4 times the weight of device for one minute without damage to the device or the integrity of the handle connection.



Environmental Testing

Environmental testing of personal e-Mobility devices includes water exposure testing and thermal cycling. Water exposure testing includes an assessment in accordance with the requirements of IEC 60529, *Degrees of Protection Provided by Enclosures (IP Code)* minimally for IPX4 for exposure to splashing water, as well as a partial immersion test intended to simulate exposure to puddles of water.

Thermal cycling testing specified in UL 2272 is intended to determine the extent of an e-Mobility device's ability to withstand exposure to rapidly changing temperatures (such as when a device enters a heated environment after being outdoors) without evidence of damage that could lead to a hazardous event.

Material and Component Testing

Material testing of personal e-Mobility devices includes testing for flame resistance of non-metallic materials. All materials used in device enclosures must comply with the enclosure requirements detailed in UL 746C, *the Standard for Safety of Polymeric Materials – Use in Electrical Equipment Evaluations.* In addition, polymeric materials used in enclosures must have a minimum flame rating of V-1 as defined in UL 94, *Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances.* Flammability rating can also be assessed using the 20 mm end product flame test detailed in UL 746C.

There are also tests to evaluate the safety of a device's motor under conditions of short circuit and overload to determine that there is no potential for overheating that could lead to a fire. The motor tests include an overload test that evaluates its ability to safely withstand a condition in which a motor is forced into a mode where it draws more than rated current, and a locked rotor test to evaluate a motor's ability to safely withstand a condition where the rotor is prevented from moving.

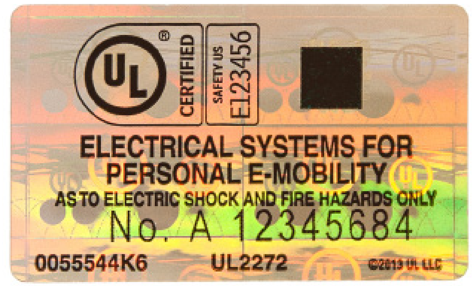
Adhesive labels that are applied to the surface of an e-Mobility device that have not been subjected to prior evaluation must be assessed for their permanence.

Marking and Instruction Requirements

Finally, under UL 2272, personal e-Mobility devices must be marked with the manufacturer's name, model or part number, electrical ratings and the date of manufacture. Devices must also be marked with charging instructions, and all terminal and connection points must be identified and, if applicable, include polarity markings. Devices with hazardous voltage circuits must display a warning to that effect.

All e-Mobility devices must also be marked to warn consumers to read the instruction manual accompanying the device to reduce the risk of injury, and be accompanied by instructions for their proper use, including charging, operating, storage and disposal. UL 2272 also specifies instruction requirements for temperature limits, charger and weight limits, and replacement of user replaceable parts such as fuses and lightbulbs. For devices equipped with removable battery packs intended for removal and charging outside of the device, additional instructions addressing the safe handling and charging must also be provided.

Guidelines for Manufacturers and Retailers



Manufacturers of personal e-Mobility devices are strongly advised to promptly seek UL 2272 testing and certification for their products. The CPSC's stated position regarding hoverboards, for example, means that non-conforming devices may be subject to recall, or may be detained or seized by customs and border officials at U.S. ports of entry. Such enforcement actions can have costly consequences for manufacturers, and compromise the integrity of their brand with consumers.

For manufacturers, evidence of UL 2272 certification is also expected to become a procurement requirement for both online sellers and traditional retailers as part of their overall effort to reduce potential product liability exposure. Retailers will likely require manufacturers of personal e-Mobility devices to supply documentation that supports their claims of product safety testing and certification, and can be expected to verify such claims against the records maintained by independent testing organizations to protect themselves and their customers from products bearing counterfeit safety marks.

UL and other safety testing organizations maintain online certification directories, providing both retailers and consumers with quick access to information about certified products. In addition, e-Mobility devices that have been tested and certified as compliant with the requirements of UL 2272 will bear a specialized holographic version of the UL Mark to help thwart the use of counterfeit safety marks. The holographic mark will enable retailers and consumers alike to visually verify that a given e-Mobility device has been appropriately evaluated and tested to the most rigorous safety requirements.

The Future of UL 2272

The dramatic increase in electrical safety issues associated with hoverboards and other personal e-Mobility devices has prompted quick action from regulators and retailers, and has also resulted in the development of UL 2272. Rather than evaluating a single component, UL 2272 takes a system-wide approach to the safety of electrical systems used in personal e-Mobility devices to reduce the overall risk of fire, explosions and other electrical hazards. This makes testing and certification to UL 2272 essential for manufacturers of personal e-Mobility devices.

The initial version of UL 2272 was published in January 2016. Since then, the UL 2272 Standards Technical Panel (STP) has continued to evaluate the applicability of the Standard's requirements to a broader range of personal e-Mobility devices, including those devices equipped with a handle or handles that eliminate the need for self-balancing by the user. Ultimately, representatives of the STP, including manufacturers, government stakeholders, retailers, lithium cell makers, testing organizations, end users and other interested parties, voted on an expanded scope of the Standard that resulted in the publication of a consensus edition of UL 2272 in November 2016.

This consensus-based edition of UL 2272 has now been adopted as an American National Standard by the American National Standards Institute (ANSI) and a National Standard of Canada (NSC) by the Standards Council of Canada (SCC). As a bi-national Standard, ANSI/CAN/UL 2272 defines the de facto safety requirements for electrical systems of personal e-Mobility devices sold throughout the North American market.

Summary and Conclusion

UL continues its own research, standard development, and testing into safety issues related to personal e-Mobility devices as well as the broader category of personal e-Transportation which includes standards for pedelecs (e-bikes with pedals), over-the-road e-scooters, over-the-road e-motorbikes (no pedals), and unmanned aerial vehicles (drones). UL 2849 and UL 3030 address the electrical systems of these type of systems.

At the same time, in light of increased safety concerns, the CPSC has agreed to undertake an extensive study in 2017 regarding the safety of lithium ion batteries. These efforts, along with reports based on actual field experience, are likely to serve as the basis for further revisions to Personal e-Transportation standards as well as other battery operated product based standards as a means of improving the safety of the systems as a whole.

For more information about the safety of personal e-Mobility devices, including UL's efforts to combat counterfeit safety marks, visit **www.ul.com/PeM**. For information about testing and certification to the requirements of UL 2272, email **eMobility@ul.com**.

Endnotes

[1]See "Cyber Monday Recap: Top Selling Items on eBay," December 1, 2015. Web. 20 February 2016. https://www.ebayinc.com/stories/news/cyber-monday-recap-top-selling-items-on-ebay/.

[2]See letter from Robert J. Howell, acting director of the Office of Compliance and Field Operations, U.S. Consumer Product Safety Commission, to manufacturers, importers and retailers of self-balancing scooters, February 18, 2016. Web. 20 February 2016. http://www.cpsc.gov/Global/Business-and-Manufacturing/Business-Education/SelfbalancingScooterLetter.pdf?epslanguage=en.

[3]"Lithium Batteries: Markets and Materials," BCC Research, Report FCB028G, January 2016. Web. 4 March 2016. http://www.bccresearch.com/market-research/fuel-cell-and-battery-technologies/lithium-batteries-materials-report-fcb028g.html.

[4]"Hoverboard 101: What you need to know," USA Today, December 2, 2015. Web. 4 March 2016. http://www.usatoday.com/story/tech/nation-now/2015/12/02/hoverboard-holiday/76621864/.

[5]For an excellent summary of the patent battle over hoverboards, see "How 'Hoverboards' Epitomize Our Broken Patent System," Wall Street Journal, December 20, 2015. Web. 4 March 2016. http://www.wsj.com/articles/how-hoverboards-epitomize-our-broken-patent-system-1450674060.

[6]"Cyber Monday Recap: Top Selling Items on eBay," see Note #1 above.

[7]"Roads? Where we're going, we don't need roads," CloudView blog posting, December 15, 2015. Web. 4 March 2016. http://www.athenahealth.com/blog/2015/12/15/roads-where-were-going-we-dont-need-roads.

[8]"Statement of U.S. CPSC Chairman Elliot F. Kaye on the Safety of Hoverboards and the Status of the Investigation," U.S. Consumer Product Safety Commission, January 20, 2016. Web. 6 March 2016. http://www.cpsc.gov/en/Newsroom/Press-Statements/Statement-from-US-CPSC-Chairman-Elliot-F-Kaye-on-the-Safety-of-Hoverboards-and-the-Status-of-the-Investigation/?utm_source=rss&utm_medium=rss&utm_campaign=Press+Statements.

[9]"Here are all the airlines that have banned hoverboards—and why," posting on Fusion.net, December 29, 2015. Web. 6 March 2016. http://fusion.net/story/250086/airplane-hoverboard-ban-list/

[10]"Colleges Are Starting To Ban 'Hoverboards,'" Huffington Post, January 7, 2016. Web. 6 March 2016.

[11]"Hoverboards are now banned from New York City subways, trains and buses," posting on The Verge, January 27, 2016. Web. 6 March 2016. http://www.theverge.com/2016/1/27/10842342/nyc-hoverboard-ban-mta-subways-buses.

[12]See Note #2 above.