Staff Report

Potential Hazards Associated with Emerging and Future Technologies

January 18, 2017

The views expressed in this report are those of the CPSC staff, and they have not been reviewed or approved by, and may not necessarily reflect the views of, the Commission.

EXECUTIVE SUMMARY

New products under the jurisdiction of the U.S. Consumer Product Safety Commission (CPSC) are being introduced into the marketplace and consumers' homes every day. In light of the impact these new products could have on the way consumers and families lead their lives, CPSC Chairman Elliot F. Kaye asked CPSC technical, compliance, and information technology staff to research what new and potential consumer products may become available, or gain wider use, in the next 3 to 5 years, and to identify potentially new, increased, or decreased consumer hazards associated with these emerging technologies.

This report provides a brief overview of some of the potential emerging consumer products and technologies that may become available or gain wider use in the next few years. These new products are expected to provide improved performance and can introduce previously unimagined features. However, the introduction of new consumer products and technologies also could expose users to new or increased hazards. For example, as a battery's energy capacity increases, the uncontrolled release of that energy may increase the chance of fires or burns. As sports equipment gets stronger and lighter, the increased speed at which a ball is batted or a hockey puck is slapped could increase the severity of an impact. Smart appliances may change their performance through software upgrades that are automatically installed over the Internet.

Staff identified several technological and societal trends that are likely to influence the marketplace for consumer products:

- Increased integration of smart technology and the Internet of Things (IoT);
- An aging population, aging-in-place, and multi-generational homes;
- Large data set analysis, or "Big Data"; and
- E-Commerce and direct-to-consumer transactions.

Recognizing these trends, staff also researched new and potential consumer products technologies and the potential consumer safety issues–as well as opportunities for enhancing product safety–which the Commission may want to consider in further analyzing, prioritizing and managing consumer risk. Emerging and future consumer products and technologies identified in this report include:

- 3D Printers and the printed products;
- Internet-home based smart technologies;
- Software as a component part;
- Wearable products and technologies;
- New materials, including nanomaterials;
- Virtual reality (VR) and augmented reality (AR) games;
- Personal transportation products;
- High capacity energy storage and energy generation;
- Robotics, including robotic products to assist older adults; and
- Brain-machine interface/implantable technologies.

These new and emerging consumer products and technologies may mitigate some product hazards, but they also may simultaneously introduce new hazards. Among the potential hazards are:

- *Loss of a safety function*: Safety devices, or products connected (either physically or digitally) to safety devices, may fail to operate, or may cause another device to fail to operate under hazard conditions.
- *Fires and burns***:** If a product or technology contains, or is connected to, an energy source (*e.g.*, battery, liquid fuel, power cord), the rapid, uncontrolled release of that energy could ignite the product, ignite nearby combustibles, or make an accessible surface hot enough to pose a potential burn hazard. New technologies that employ low-power devices, or new materials that are resistant to burning, for example, can reduce the risk of fire or burn.
- *Shock***:** If a new product or technology uses voltage in excess of 30 Vac or 60 Vdc, a potential shock hazard may arise.
- *Chemical Exposure***:** New materials, including novel textiles, may expose users to irritating or toxic compounds. The effects of exposure could be chronic or acute.
- *Laceration/contusion/trauma/crush/impact/amputation:* Mechanical hazards may be created or exacerbated with new products. A device with increased kinetic or potential energy, or one that transports a user faster, may pose an increased risk of falls or a more severe impact.
- *Choking/strangulation/asphyxiation***:** Wearable and other small devices must be designed to avoid creating a risk of choking.

This report aligns with the CPSC's 2016-2020 Strategic Plan, which includes initiatives to drive the discovery of innovative safety solutions for emerging technologies and to monitor continuously the ever-changing consumer product safety landscape. Although predictions about the future are uncertain, the CPSC can take steps to discern potential trends and products that may enter the marketplace, or become more widely used, and identify possible consumer product hazards associated with those products. Staff recognizes that not all of the concerns with new technologies, such as data privacy or potential medical uses, fall within CPSC's jurisdiction.

Participating in voluntary standards development is a key tool in CPSC's risk management toolbox. For many new and/or future products and technologies identified in this report, CPSC is likely initially to work to eliminate or reduce risk through active participation in voluntary standards committees and by collaborating with consumer and industry stakeholders and our federal partners.

ACKNOWLEDGEMENTS

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1 INTRODUCTION

At the request of Chairman Elliot F. Kaye, staff of the Office of Hazard Identification and Reduction (EXHR), the Office of Information and Technology Services (EXIT), and the Office of Compliance and Field Operations (EXC) provides a brief overview of some of the potential emerging consumer products and technologies that may become available, or gain wider use, in the next 3 to 5 years. We also identify possible trends that could affect the consumer product marketplace. For the emerging, and potential future consumer products or technologies, we list potential consumer product hazards.

The overview is not comprehensive because consumer products or technologies with promise may not materialize in the marketplace, or unforeseen products or technologies may or may not find rapid adoption. Not all of the potential consumer product hazards associated with an emerging consumer product or technology are likely to materialize. Designing safety into products, good manufacturing practices, and use of new, safer products, likely will eliminate or mitigate many potential hazards.

The evolving marketplace for consumer products under the CPSC's jurisdiction means new technologies can be applied to existing consumer products, or can be used to create new products that were not previously imagined. New materials, techniques, applications, or products, plus novel uses of existing products, could introduce known or new types of consumer product hazards.

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Voluntary standards development is a key tool in our risk management toolbox. For many new and/or future products and technologies identified in this report, CPSC is likely, initially, to work to eliminate or reduce risk through active participation in voluntary standards committees and by collaborating with consumer and industry stakeholders and our federal partners.

2 TRENDS INFORMING THE CONSUMER PRODUCT ENVIRONMENT

Consumer products introduced in the next 3 to 5 years and beyond are likely to be influenced by several societal and technology trends. The trends mentioned here have the potential to change hazard patterns, as well as provide opportunities for CPSC to mitigate new hazards and encourage the acceptance of safer technologies. Discussions on products and hazards related to each trend are found in later sections of this report.

[i] U.S. Consumer Product Safety Commission Strategic Plan 2016-2020. https://www.cpsc.gov/th/content/rca-cpsc-2016-2020-strategic-plan.

2.1 Smart Technology and the Internet of Things

Smart-enabled devices are changing the ways consumers use everyday products and what they expect from them. Smart home devices, such as thermostats, light fixtures, and security systems (including smoke and carbon monoxide (CO) alarms) anticipate needs and send alerts. Smart technologies are finding their way into an array of consumer products, such as toothbrushes, tennis rackets, refrigerators, garage doors, and gas grills.

When consumer products–from doors and windows, to home appliances–have sensors and an Internet capability that make them uniquely identifiable and accessible to the consumer from anywhere, and when these products can exchange messages with other products, irrespective of the manufacturer, you have the Internet of Things (IoT). Smart technology offers both product safety opportunities (*e.g.,* automatic product registration, increased recall effectiveness) and challenges (*e.g.*, hacking susceptibility, failed software updates that affect performance).

2.2 An Aging Population, Aging in Place, and Multigenerational Homes

The population age 65 years and older is projected to nearly double over the next 3 decades, ballooning from 48 million to 88 million persons by 2050.[1] Falls are the leading cause of accidents for people over the age of 65.[ii] Reduced hearing acuity may affect older adults' ability to discern smoke and CO alarms. In anticipation of the increased number of older adults, on May 19, 2014, then-Acting Chairman Robert Adler announced the Senior Safety Initiative to focus a portion of our resources on reducing consumer product-related deaths and injuries suffered by seniors (adults 65 and older).

Many older adults desire to "age in place," living permanently and independently in homes that may not necessarily be adapted to their specific needs. The high cost of elder care and child care, as well as a desire by many families to live together, is fueling a trend in multigenerational homes. A study by the AARP (formerly the American Association of Retired Persons) Public Policy Institute indicates a sharp rise in multigenerational homes between 2008 and 2011,[2] comprising 7.1 million multigenerational households, or 6.1 percent of all households. In fiscal year 2016, CPSC partnered with the National Fire Protection Association (NFPA) on a messaging campaign on fire safety for multigenerational families living together. Additional information on multigenerational family fire safety can be found on the CPSC's website.[iii]

There are few existing voluntary standards that specifically address product hazards related to older adult safety. CPSC's efforts to focus on older adult hazards could include working with standards development organizations (SDOs), including ASTM International and the International Organization for Standardization's (ISO) Consumer Policy Committee (COPOLCO), to focus voluntary standards development work on this vulnerable population. CPSC can partner with other federal agencies, such as the U.S. Fire Administration (USFA) and

[ii] Hazard Screening Report: Consumer Product Related Injuries to Persons 65 Years of Age and Older. S. Hanway, U.S. Consumer Product Safety Commission. 2013. https://www.cpsc.gov/s3fs-public/pdfs/seniorhazardssketch2013.pdf.

[iii] https://www.cpsc.gov/Safety-Education/Safety-Education-Centers/Fire-Safety-Information-Center.

the Department of Health and Human Services (HHS) to leverage resources to improve safety messaging for older adults.

2.3 Large Data Set Analysis or "Big Data"

Data gathered from multiple sources (including social media applications, such as Facebook and Twitter), often referred to as "Big Data," can now be combined using ever-more refined analysis algorithms to draw insights on consumer behavior, which were impossible to observe previously. CPSC might be able to use large data set analysis to look for unrecognized correlations in consumer purchasing patterns and to exploit this information to target safety messaging. For example, if CPSC could predict that a consumer was going to purchase a children's product online, micro-targeted safety messages could be triggered, including messaging on proper use, maintenance, and any recommended protective gear, as appropriate.

"Big Data" also could be used to provide CPSC insights into consumer behavior and product use. Large data set analysis might be used as an early warning monitoring system to look for correlations between a product and safety-related complaints before they appear in our traditional data systems. Using this information, CPSC could reach out to manufacturers, importers and retailers to discuss consumer complaints before a death or injury confirms a prediction. Additionally, CPSC should expect large data set analysis to be used by stakeholders, including consumer groups and trade associations, to inform agency priorities.

2.4 E-Commerce or Direct-to-Consumer Transactions

Firms like Alibaba and madeinchina.com are cross-border, e-commerce trade platforms that are changing the traditional consumer product distribution chain. When consumer products are made in foreign factories, purchased by, and then shipped directly to consumers, compliance and enforcement issues arise regarding the nature of this new marketplace. Staff is aware that very small lots–the one- and two-item purchases of a product–likely will be classified as "samples," and therefore, U.S. Customs and Border Protection will not examine them, allowing potentially hazardous or untested products to reach the consumer. E-commerce puts an additional burden on consumers to determine if the product complies with applicable safety standards.

3 EMERGING CONSUMER PRODUCTS AND TECHNOLOGIES

3.1 Three Dimensional (3D) Printing – Additive Manufacturing (AM)

Rapidly developing 3D printing technology is expected to have a significant impact on the commercialization of many types of consumer products.[3] A 3D printer allows a consumer to create a three-dimensional object by forming successive layers of material until the object is complete or by using light to cure a liquid resin to form a solid component part. Product designs can be created with 3D modeling programs,[4] copied from an existing product by using a scanner coupled to Computer Aided Design (CAD) software, or downloaded from the Internet. These methods allow consumers to design and print 3D objects quickly.

With new advances in technology, a consumer can easily "scan" an object and "print" it using a relatively inexpensive printer.[5] The costs of the printers and the time to print a product are declining, which leads to greater consumer use of printers and a wider range of products manufactured and used in the home.[6] Entrepreneurs may establish micro-manufacturing facilities in their homes that contain several printers making products for sale. The safety implications for

product printing include the composition of the filament (the printing material), the high temperature of the printing process, chemical and particulate emissions during printing, and the safety and durability of the final product during consumer use.

Potential hazards that may be related to 3D printing include:

- Filament: The filament is the source material used to produce a product with extrusion processes. The filament can be made from a wide range of base materials, such as polycarbonate, acrylonitrile butadiene styrene, or polylactic acid (a corn-based polymer). Other compounds can be added to the base materials, such as metals, hemp and nanomaterials. Filaments containing carbon nanotubes are available, and these materials may be used to print out children's products. Because filament composition varies, and consumers have many filament choices, the chemicals consumers may be exposed to can vary dramatically. Consumers also may be exposed to the filament materials during printing, which occurs at high temperatures (~250 °C, or 480 °F), or during product use.

- Liquid resin: Some types of consumer 3D printing processes rely on the polymerization of a liquid into a solid by ultraviolet or other light. The liquid matrix can be composed of a wide range of compounds that solidify into either rigid or flexible materials. Consumers may be exposed to chemicals or compounds released from the liquid matrix that may cause health effects when used without sufficient ventilation.

- Printing[7]: Some printers may have a heated platform on which the product is produced. The high temperatures of the material and the surfaces on which the products are made may present a burn hazard for consumers. Chemical components that are volatile or semi-volatile likely will be released into the air during printing, creating a potential exposure. Nano- and micro-particulates, if present, are also released during printing which may take up to 8 hours or more, depending on the product.[8] If there are impurities contained in the filament, these impurities also may be released.

- Products: The quality of the product produced on a 3D printer may be considerably less than products produced through traditional manufacturing processes. Products may deteriorate more quickly or may be made of an inappropriate plastic, resulting in small parts, sharp edges, or particulates that may pose hazards, especially for young children. Printed products may also have uncured polymers or potentially toxic materials.[9] Printed products with integrated active chemistries also might pose adverse health effects.

3.2 Internet Home-Based Smart Appliances and Security Systems

Homeowners are increasingly investing in intelligent or smart technologies. Various home-based smart technologies offer streamlined processes, intended to reduce time, costs, manual efforts, and energy inefficiencies with suites of automated devices.

One of the first smart technology offerings, and a top reason for continued growth in home technology, was based in household security solutions to protect family health and property from fire and CO hazards, and intrusion. A smart home security system's advantage over a standard standalone device includes alerting the home occupant to a burglary, high CO levels, or a fire event, even if the occupant is not within the sounding alarm's range. In the last several decades,

the expansion of home security began to include the connectivity of devices into a system for monitoring and communication for fire suppression, alerting first responders, and the remote accessibility of home via video surveillance. Newer home security technology continues to add functionality to smart security systems.

Home monitoring and automation technology has expanded to meet the monitoring needs of the home's vulnerable older, disabled, and younger occupants. The advanced technologies enable remote monitoring of home occupants to ensure their safety in arrivals, departures, and activities.[10] Occupant activities can be sensed and recorded into Internet data logging and analysis systems that can provide a distress signal to first responders and keep homeowners aware of the activities going on in their homes at all hours.

Specifically targeted smart technologies for older adults are available as passive or active sensors, monitoring systems, environmental control systems, and electronic aids to daily living. These technologies assist older adults in living independently longer and with less reliance on family members or paid caregivers. Examples of such systems' features include monitoring or alerts prompting the resident to take daily medicine, turn off the stove, close the blinds, or attend to visitors at the door. A remote family member can also track the routines and activities of older adults. Critical vital signs can be monitored through devices like a smart shirt, which can provide data (*e.g.*, heart rate, electrocardiogram, respiration, temperature) to a remote family member or physician.[11]

New home-based networks can interconnect many products (*e.g.*, security sensors, cameras, thermostats, smart plugs, lights, entertainment systems, locks, appliances). The independent design of each component represents a potential problem for homeowners. The connection and control of each smart and connected product is individual, without regard to a centralized network. In this product-centered paradigm, each Internet-ready household appliance has a separate control scheme, often with very little internal security. These appliances' logic controllers enable data connections and communications, but are not necessarily designed to be secure.[12]

Each smart device represents an opening to hackers or software failures that can interfere with the device's basic operation. One potential hazard is that a homeowner may believe that an alarm is seemingly functional, yet through software bugs or intentional interference, the safety device is not responsive to conditions like rising CO levels, and does not alert the household.

Beyond the software and data security, electronic disturbances in the home environment also may prevent proper product operation. With more home appliances and devices using interconnected wireless communications, the possibility of electromagnetic interference (EMI) increases. Current surges, voltage spikes, or an increase in the EMI noise level may interfere with the functionality of the appliance or alarm system. Electromagnetic signaling has two interference modes to consider. The incoming signal may be distorted by another electronic device, or the output signal amplitude may distort another device's incoming data signal.

CPSC could work through the products' associated voluntary standards to ensure that, not only do the products operate safely, but the products also do not adversely affect the operation of other devices.

3.3 Software as a Component Part (Softwarization)

Smart watches, smart phones, smart appliances, smart fabrics, smart cars, robots, drones, the "things" with the potential for interconnection appear unbounded, and the associated embedded data communications and processing are seemingly ubiquitous. One common theme that runs through these modern devices and applications is software. This "software-enabled concept," according to Antonio Manzalini, Chair of the Institute of Electrical and Electronics Engineers (IEEE), is being called "softwarization."[13]

Softwarization attempts to make consumers' lives easier by automating routine tasks, anticipating consumer wants, and enabling new capabilities. For example, smart watches and phones help consumers stay connected to the Internet and to each other. Smart appliances allow consumers to check the status of their appliances, and even turn them on and off remotely. Smart fabrics can enhance athletic performance, monitor vital signs, or light up and change color for aesthetic reasons.

Over the past 40 years, CPSC has worked with stakeholders to develop mandatory and voluntary standards for consumer products, and frequently, their component parts. However, beyond the tangible materials, an essential part of all smart products is software. Along with the softwarization of consumer products comes an increasing risk of hazard to consumers related to software. These hazards could manifest in software that operates incorrectly (*e.g.*, a bug creates an abnormal operating condition, malware changes the software function, an unforeseen input leads to an abnormal operating condition), or fails to operate when a response is required (*e.g.*, a safety monitoring system does not respond when a hazardous condition is detected).

A challenge currently facing the CPSC is that there is no standard for the testing and certification of software as a component part of consumer products. With the increasing role software plays in an ever-expanding list of products, we can expect the potential consumer hazards associated with software to increase. CPSC currently does not have expertise on staff to evaluate software as a component part in consumer products. The agency may wish to consider securing software engineering and evaluation skills as an added means of protecting consumers.

3.4 Wearable Consumer Products and Technologies

"Wearables" are devices or objects that are connected to the body, either by direct contact with the skin, or otherwise attached outside of clothing. Wearables may be physically large, such as exoskeletons that could be used to augment muscle power or increase fine motor movement precision.[14]

Most wearable consumer products or technologies involve a form of data collection, either for real-time processing and display, or for later batch processing and analysis. Some of the myriad examples include:

- Shoes that count steps, compare the pressure on each foot (for balance), self-tighten,[15, 16] or shoes with global positioning system (GPS) and navigation capabilities[17];
- Neuro-stimulation, in which a device claims to activate a user's "natural state of energy or calm"[18];
- Wearables to allow gesture control of devices, and wearable toys that interact with gaming sets[19];

- Wearable sweat sensors (*e.g.*, glucose, lactate, sodium and potassium, skin temperature) to track health or provide training feedback[20];
- GPS trackers for children.[21]

Because wearable products are in close proximity to the body, there is the potential for a range of hazards, including:

- Muscle strain, if a powered exoskeleton moves beyond the range of motion of a user's joint(s);
- Skin irritation from chemicals contained in the wearable devices;
- Chemical burns, if a battery leaks a reactive material;
- Thermal burns, if a wearable battery suddenly discharges its stored energy; or
- Hearing damage, if an implanted audio device malfunctions or "plays" a signal from another source.

There are no voluntary standards specific to wearable technology. Instead, designers highlight general product safety practices. The IEEE has initiated a project on personal health devices, which includes health-oriented wearables. If the CPSC wishes to address potential safety issues in this area, new voluntary standards development, in collaboration with other organizations, could be considered.

3.5 New Materials

Advances in computer technology, diagnostics, chemistry, materials science, and other related fields have accelerated the rate at which new materials are entering the market. The United States has made the development of new materials an important goal for economic development. The Materials Genome Initiative[22] is a multi-agency initiative designed to create a new era of policy, resources, and infrastructure that support U.S. institutions in the effort to discover, manufacture, and deploy advanced materials twice as fast, and at a fraction of the cost compared to current practice.[23] Given these and other private efforts, consumers will likely experience an acceleration of new materials entering the marketplace. As these materials are incorporated into consumer products, potential safety issues that may arise from these materials must be addressed.

Some wholesale specialty stores, retailers and European markets are using recycled materials for plastic toys or play surfaces. The manufacturers of these children's products are claiming non-toxic, safe, hypoallergenic and environmentally friendly products from their use of recycled material. Several manufacturers are producing plastic pellet material intended as a replacement for sand box sand, sensory tables, or craft projects. The plastic resin material is likely a polyethylene blend with most of the recycled product a polyethylene terephthalate (PET). Much recycled material is made from PET because it can be reheated, reformed, and recycled many times. The content in these products may be a blend of various recycled material with uncertain chemical properties. The recycled materials are unlikely to be homogenous. An increased risk of at least trace amounts of hazardous heavy metals or compounds is present with the increased use of recycled materials. Chemical testing may be used to evaluate these recycled products; however, whether the manufacturer conducts testing is unknown.

Most sports and recreational equipment will likely continue to evolve in the traditional ways that have been characteristic of these product areas. We anticipate that both product areas will continue to rely on newer materials to make lighter and stronger products.[24, 25] Athletes continue to seek protective equipment that has the least effect on performance, which usually translates to thinner, lighter sports equipment for baseball, football, soccer, lacrosse, and other sports. Concurrently, these products will be required to maintain the same or a higher level of protection for the athletes.

To achieve these multiple objectives, new materials are emerging. We anticipate that material advances to athletic equipment, such as baseball bats,[26] lacrosse sticks, or mouth guards[27] could enhance the performance of athletes. Similarly, advances in materials will result in recreational products that are potentially stronger and lighter. These advances could allow consumers to undertake higher-risk activities with products such as bicycles. New recreational products will likely emerge as lighter, stronger materials facilitate the development of powered devices that were not previously feasible.[28]

Mild traumatic brain injuries are not a new issue, but they are expected to be the main focus of sports and recreational product development in the near future. As the traumatic brain injury mechanism comes into focus, we expect a surge in the development of sports and recreational equipment designed to mitigate these injuries. A potentially completely new approach to headgear design could be required, or other types of products could be introduced that limit the rotational effects of the headgear on the brain during impacts. We expect that these products will require specialized materials to manage the energy associated with this type of potential injury.

The potential hazards associated with new and emerging products in this area are generally expected to be similar to those that exist with current products in this area, including:

- Impact Hazard: This type of injury is mostly associated with sports and commonly results from ball, bat, or stick impacts. Lighter materials could cause higher-speed projectiles in sports, such as baseball, hockey, or lacrosse, where the athlete transmits more energy to the ball or puck. This could result in an increased risk to surrounding players who would be required to react faster to avoid injury.
- Neck/Spine Injuries: As headgear using new materials is developed to manage rotational energy, there is the potential to increase the risk of neck and spinal injuries, especially to youth players in sports such as football. Energy management that is solely focused on head injuries could increase the forces placed on the neck in an impact, even in cases of lighter headgear. This could have the effect of reducing mild traumatic brain injuries, but increasing the rate of neck and spine injuries resulting in paralysis, or even death.
- Chemical exposure: Newer materials being incorporated into sports and recreation equipment could result in unintended exposure to hazardous substances. For example, softball bats use nanotechnology in newer designs, but the newer designs may expose players to an increased risk from normal use and abuse, or occasional failure of the bat. Additionally, protective equipment can be worn directly against the skin, which could provide a similar exposure risk.
- Fire: Newer materials allow existing products to adopt functions that were previously not possible, such as developing a powered feature. Products similar to hoverboards are expected to become more popular in the future. Ride-on products used for recreational

activities, such as skating, are more likely to appear, due to lighter-weight materials in combination with more efficient energy sources. The risk of injury due to falls is expected to continue, but the added energy source likely would result in an increase in the additional risk from fire or shock.

There are many existing voluntary standards for sports and recreational equipment that cover the majority of products in these areas, including ASTM International (ASTM), the American National Standards Institute (ANSI), and the National Operating Committee on Standards for Athletic Equipment (NOCSAE). CPSC could work with these standards organizations to address the potential consumer hazards associated with emerging technology in these type products. CPSC could collaborate with the National Institute for Standards and Technology (NIST) to understand the implications of potential new materials for sports and recreational equipment.

3.6 Nanotechnology

Nanotechnology is an emerging science that involves the understanding and manipulation of matter at a small scale, approximately 1-100 nanometers (nm), where unique physical and chemical properties of matter at this scale enable novel applications.[29] The materials produced at this scale, nanomaterials, can be incorporated into a wide range of consumer products, where their unique properties, such as altered electrical activity, optical properties, increased strength, and anti-microbial activity, can be exploited to improve the performance of these nano-enabled products (*e.g.*, stain-resistant clothing, sports equipment, and anti-bacterial children's products).[30]

The United States has developed a National Nanotechnology Initiative (NNI) that involves more than 25 federal agencies, which collectively have spent nearly $20 billion to develop and commercialize new nanomaterials and applications.[31] Given this investment and the private sector's commitment to nanomaterial use and product development, we expect that the number of consumer products containing nanomaterials will increase considerably over the next 5 to 10 years.

Nanomaterials vary considerably in their physio-chemical properties, morphology, and uses. Compounds, such as nanosilver and nano titanium dioxide, have anti-microbial and photocatalytic properties. Carbon nanotubes (CNT) have broad uses in material composites, polymers and flame retardants, as well as in electronic circuits and batteries. Other nanomaterials include the nano forms of aluminum, boron, carbonaceous compounds,[iv] cerium, cobalt, copper, silica, and zinc. Examples of select uses by material and the function that nanomaterial provides include:

- Carbon nanotubes[32]: CNT resins and composites are found in baseball bats, bicycle frames, anti-ballistic panels (providing energy dispersion, stiffness, and increased strength), flame retardants, yarns (stiffness), coatings and films (CNT has anti-corrosion properties), microelectronics, transistors, energy storage, computer and notebook batteries;

[iv] Carbonaceous compounds are materials that contain a form of carbon.

- Titanium dioxide (TiO_2)[33]: Applications for nano TiO_2 include pigments, paints (where the TiO_2 provides optical and photocatalytic properties), cements, windows, tiles, solar cells, and liquid crystal display (LCD) screens (exploiting TiO_2's electrical properties);
- Silver/silver nano-wires[34]: Nano silver can add anti-bacterial properties to clothing, food storage containers, baby bottles, paints, plastics, footwear, and toys. Nano silver can be used in composites, electronics, flexible electronics, electronic screens, and biosensors; and
- Innovations: Nanomaterials, including boro-nitride nanotubes and graphene, have application potential in sensors, solar cells, micro-electronics, and 3D printing/additive manufacturing.

The effects of nanomaterials vary, depending on the route of exposure and the state of the material (*e.g.*, agglomerate, matrix bound). Because of their small size and novel properties, nanomaterials may be able to cross the blood-brain barrier and other physical defenses. Unintended consequences may occur if nanomaterials are released from consumer products. Once a nanomaterial is deposited into tissues or organs, there is the potential for adverse effects. Carbon nanotubes that are inhaled have been shown to cause granulomatous changes in the lung.[35]

Nano-enabled composites can provide increased strength with reduced weight to a product. These properties may indirectly lead to more injuries. As mentioned above, the enhanced performance and altered characteristics of sports equipment may increase the risk of injuries to users or sport participants (*e.g.*, baseball bats, bicycles).

Voluntary standards activities have been initiated to address the potential implications of nanomaterials in consumer products. The ASTM E56 and ISO TC 229 groups are examples of voluntary standards efforts that are developing a wide range of documentary and testing standards. These standards include methods for in-vitro toxicity testing, approaches for characterizing the leaching of nanomaterials from products, and the labeling of consumer products containing nanomaterials. The CPSC has requested funding in its 2018 budget to establish a research center to develop methods to quantify consumer exposure and potential health risk resulting from the use of nano-enabled products. This center will be developed in cooperation with the National Institute for Environmental Health Sciences (NIEHS).

3.7 Virtual Reality/Augmented Reality

Virtual reality (VR), also known as immersive multimedia, or computer-simulated reality, is a computer technology that creates a three-dimensional "environment" and simulates the user's position and orientation in it. VR systems, at a minimum, consist of a processor to create the environment, a display (often a headset) to create images for each eye, and a form of head tracking, so that the simulated view can change as the user's head moves from side to side, or up and down.[36] In addition to vision, VR systems can include audio and touch (haptic) feedback,[37] when headphones and hand accessories are included.

VR replaces the user's view with what appears to be a three-dimensional environment because the images provided to each eye are slightly shifted from each other. As the user moves or turns his/her head, the environment point of view and field of view adjust accordingly, giving the user the experience of moving in a three-dimensional landscape.

The first wide-scale applications for VR are in the computer gaming industry.[38] Additionally, VR is being promoted as an educational tool, replacing traditional books and providing virtual field trips to exotic locations.[39] The development of eye tracking systems allows future VR users to interact with their virtual environments, based on what they're observing.[40] One application of VR technology is virtual attendance at a live event. In essence, each member of an audience can have the same courtside seat at a basketball game.

VR replaces the visual field of the consumer with a digital environment. Because the user's view of the physical world is replaced with a digital world, the possibility of falls, trips, and bumping into real objects exists. If a user attempts to lean on a virtual object, or "sees" a hallway where a physical wall or a stair exists, an injury may occur. To the extent that VR headsets are heavy, or may contain high-energy batteries, there could be a risk of neck strain or fire/burn in the case of a sudden release of the battery's energy.

Augmented reality (AR, or mixed reality) differs from VR in that the user's physical world is supplemented with images, text, graphics, or holographic images, rather than replaced by a virtual environment. Thus, the physical world and digitally created objects co-exist in real time.[41] AR systems usually consist of transparent lenses through which the user sees, and that have supplemental information projected into the field of view.[42]

The digital information added to an AR view can include bearings, global positioning system information, directions, Rich Site Summary (RSS, Really Simple Syndication) feeds, or information on an object being observed.[43] Additionally, holographic images can be created and added to the environment of the user. Thus, items such as a computer or television screen can be virtually created on a wall, or floated in the air. Holographic objects and mixed physical and virtual "landscapes" can be created in which the user moves.[44] AR headsets can include microphones, speakers, accelerometers, magnetometers, and other sensors to obtain environmental information.

Objects in "real life" may be moving differently than the image visible to the user. Bright, moving, or human-shaped virtual objects can distract an AR system user while he/she is performing an important task, such as crossing a street.[45] A projected object may obscure a user's view of a physical object to be avoided, or the projected object may confuse a user who may attempt to interact mechanically with the object (such as sitting on virtual furniture). Similar to VR, the AR environment can contribute to the possibility of falls, trips and bumping into real objects.

3.8 Personal Transportation Products

Using the lessons learned from hoverboards, which presented both foreseen and unforeseen hazards, we anticipate a variety of new and emerging personal transportation consumer products which may present similar hazards. These technologies are either in the research, prototype, or commercialization stage. Some take existing modes of transportation powered by humans and modify the product by adding electro-mechanical components. Some examples of new personal transportation products include:

Pedal Electric Cycle (Pedelec)/Conversion Kits. A pedelec is a bicycle where the rider's pedaling is assisted by an electric motor; thus, a pedelec is a type of low-powered moped.

Pedelecs include an electronic controller that disconnects power to the motor when the rider is not pedaling, or when a certain speed (about 24 kilometers per hour (kph), or 15 miles per hour (mph)) has been reached. Conventional bicycles can be converted to pedelecs, with the addition of the necessary parts (i.e. motor, battery, and controller).

Electric Kick Scooters/Personal Scooters. An electric kick scooter is a small platform with wheels that is driven by an electric motor.[46] The rider also can stand with one foot on the scooter and push the device forward. The most common scooters today have two hard small wheels and are made primarily of aluminum and fold for convenience. Kick scooter variations include models with three or four wheels, models made of plastic, large models, or non-folding scooters. Electric kick scooters differ from electric scooters in that they also allow human propulsion and have no gears.

Hydro Propulsion Products. A new application of jet pack technology uses water as a propulsion fluid. This requires a very large mass of fluid that makes a self-contained jetpack infeasible. Hydro propulsion separates the engine, fuel, and fluid supply from the pilot's flying apparatus, using a long, flexible hose to feed the water to the jet nozzle pack attached to the pilot's body.[47] These inventions are known as "hydro jet packs," and successful designs have used jet ski technology as the power plant operating in a body of water (*e.g.*, ocean, lake, pool) to provide the needed propulsion. Several hydro jet pack approaches have been successfully tested and put into production. A flyboard[48] is a type of hoverboard with water jets under each of the pilot's feet. An optional feature is a lower-thrust water jet for each arm for greater control.

Electric Skateboard. An electric skateboard is a modified skateboard propelled by an electric motor.[49] The skateboard's power is usually controlled with a radio-frequency (RF) remote control. The electric skateboard batteries are either sealed lead acid (SLA) or lithium iron phosphate ($LiFePO_4$). SLA batteries employ the same technology as used in car batteries and scooters, but they are adapted for an extended-duration application, using constant current and deep discharge. $LiFePO_4$ batteries are rechargeable and more advanced, offering longer life, less weight, and constant power before reaching full discharge. As with a regular skateboard, an electric skateboard is steered by the rider shifting their weight.

Electric Shoes/Skates. There are now motorized electric roller skates that propel a wearer at up to 19 kph (12 mph) for a range of about 26 km (16 miles).[50] Two sets of step-in footplates secure to most types of footwear with strap bindings similar to those on snowboard boots. The skates have a motor integrated into their frames. Tilting forward on the toes accelerates, while tilting back on the heel causes the skates to brake. The footplates also pivot down to put the rider's foot in contact with the ground for walking or climbing stairs.

Personal transportation devices potentially present a wide range of safety hazards to consumers, by combining the hazards present from the existing modes of transportation powered by humans, and adding the hazards presented by the electro-mechanical components and energy storage. These include:

- Laceration/contusion/trauma/crush/impact/amputation: Mechanical hazards may exist with new products. Personal transportation devices often are capable of transporting

riders at speeds greater than 19 kph (12 mph) and may pose a risk of impact or falls. Additionally, the higher speeds may increase the severity of an impact or fall.

- Fires and burns: Most personal transportation products contain or are connected to an energy source (battery); there is the potential for an uncontrolled release of energy that could ignite the product, ignite nearby combustibles, or make an accessible surface hot enough to pose a potential burn hazard. New technologies that employ low power devices, or new materials that are resistant to burning can reduce the risk of fire or burn.

3.9 Robotics

Generally, the term "robot" refers to a machine, especially one that is programmable, capable of carrying out a complex series of actions automatically. Consumer product robots in use now are found in applications, including vacuums, gutters, and pool cleaning, sweeping, and lawn mowing.[51]

Robots are appearing as personal assistants or companions in the home. Typically, these robots have sophisticated algorithms for interacting with people and performing a number of tasks, including[52,53]:

- Recognizing faces to customize the interaction and responding to spoken commands;
- Recording video images and serving as a mobile telepresence;
- Serving as a communications hub for the household and its connected devices;
- Acting as a family planner, alarm clock, and task-list keeper;
- Connecting to information sources on the Internet; and
- Monitoring the house for unusual events, such as a sudden temperature rise that may indicate a fire.

Service robots are appearing as another type of technology for consumers. Service robots are capable of performing mechanical tasks, such as retrieving an object and delivering it to a user.[54] Potential applications for service robots include assisting the elderly, the disabled, or persons with injuries, to perform routine household tasks (*e.g.*, lifting assistance out of chairs or beds, pouring, opening doors, or serving as a communications hub).

As consumer robots continue to develop, additional efforts are likely to be directed toward:

- Increased cognition: A consumer environment cannot be predicted precisely. Robots designed to make decisions based on complex environments will increasingly need the ability to perceive, understand, plan, and navigate by sensing and learning, including the use of "deep learning"[v];
- Improved manipulation: Precise control and dexterity for manipulating objects in the environment allows a robot to perform increasingly complicated tasks, such as folding clothing; and

[v] Deep learning is a form of machine learning based on a set of algorithms that attempt to model high-level abstractions in data by using multiple processing layers, with complex structures or otherwise, composed of multiple non-linear transformations.

- Human-centric interfaces: Robot interaction algorithms can be expected to continue development toward greater seamlessness, more intuitive and easier use by people. Voice recognition and analysis, facial expression interpretation, and gestures may be used to teach the robot the most effective way to communicate and understand users.

Depending on the type of robot, a range of potential hazards can be present, such as:

- Noise: Robots with speakers may suffer a malfunction that results in broadcasting loud sounds;
- Mechanical: Mobile robots may knock over an object. If the object is a lit candle, a fire may ensue. If a robot spills a liquid, a slip hazard may be created;
- Fire: Robots carry battery packs. If a battery failure releases its stored energy suddenly, nearby combustibles may be ignited (Typical robot battery voltages are too low to represent a potential shock hazard.)

There are existing ISO voluntary standards for industrial robots and "personal care robots." CPSC could work with ISO to address potential consumer hazards associated with robots through a voluntary standards process.

3.10 Energy Storage/Generation

Energy storage is a necessary feature for mobile devices, for stationary devices without access to grid electric power, or for non-grid-connected homes (including as a backup power supply). In general, energy can be stored by mechanical means (*e.g.*, flywheels, compressed air, water stored at a height), as chemicals (*e.g.*, fuels from hydrogen gas to liquids that are burned, fuel cells, charged battery chemistries), or electrical means (*e.g.*, super-capacitors).

Currently, a range of batteries using a variety of chemistries is available for consumer products. Lithium-ion and lithium-polymer batteries have among the highest energy densities for a competitive cost, and are often used in consumer products requiring stored electrical energy.[55] Super-capacitors are a type of energy-storage device capable of very high power outputs,[56] which allows the devices to charge in a small fraction of the time required to charge lithium-ion batteries (*e.g.*, 30 seconds to charge a super-capacitor versus an hour for a comparable battery). House-scale fuel cells (devices that convert chemicals directly into electricity, water and carbon dioxide) are available and often use propane or methane as a fuel source.[57]

Battery chemistries continue to be developed to increase the energy density, maximum power output, reliability, safety, and battery life, while decreasing the charging time.[58,59,60] Super-capacitor research has pushed its energy storage capacity to levels comparable to lead-acid batteries (but still at about one-quarter to one-sixth of the energy density of lithium-ion batteries).[61]

Battery storage systems for intermittent power sources (*e.g.*, wind, solar) are intended to increase power availability during periods of non-generation.[62] Efforts to increase solar cell efficiency at a reasonable cost continue through means as varied as reflecting the sun's heat away from the cell,[63] to using coatings to concentrate sunlight,[64] to singlet fission (generating two electrons per photon, instead of one).[65]

Other potential energy generation or storage technologies involve creating MEMS (micro-electromechanical systems) Stirling engines, which convert heat to mechanical energy, compressing or liquefying air, and developing photovoltaic transparent glass, so that any window can be used for energy generation.[66]

For any energy storage or generation medium, if the energy is uncontrolled, a consumer hazard may be created. If the energy in a device is misdirected or discharges quickly, there are potential risks, including:

- Fire and burn risk, if the energy involves high heat (*e.g.*, solar concentrators, rapid battery discharge);
- Laceration risks, if a mechanical failure occurs (*e.g.*, pressurized tank ruptures, flywheel breaks);
- Chemical exposure, if a battery, fuel cell or other chemical storage/generation system with hazardous constituents leaks;
- Shock hazard, if high voltages are present;
- Thermal hazards from cryogenic or other liquefied gasses are released; and
- Loss of function, if a power source fails. If a safety device's energy source is interrupted, a consumer hazard could be created.

There are several existing voluntary standards for energy storage and generation technologies issued by organizations such as UL LLC (UL, formerly known as Underwriters Laboratories), and the International Electrotechnical Commission (IEC). CPSC may consider collaborating with UL and the IEC regarding existing standards to address potential safety issues associated with energy storage and generation.

3.11 Brain-Machine Interface/Implantable Technology

Non-invasive brain stimulation devices or transcranial direct current stimulation (tDCS) devices are products that are used to probe and alter brain function. Some devices are promoted as being able to modify motor skill learning.[67] Many of the devices are intended for the consumer market, with claims that they can increase cognitive performance, mathematical ability, attention span, problem solving, memory, and coordination.[68] Research scientists, through peer-reviewed journals, report that these devices may be effective for some applications, such as learning improvements.[69] Given those learning and memory improvement claims, we assume that school-age children and older adults will be primary target markets for these devices.[70]

The devices use many approaches for stimulation, including the placement of electrodes on the patient's scalp, using a headband, or using a headset to direct energy waves into the brain. Home "kits" are already available that allow consumers to construct their own devices.

CPSC staff is unaware of standards activities regarding brain stimulation devices.

4 POTENTIAL CONSUMER HAZARDS

New and emerging consumer products and technologies may mitigate some product hazards, but these products and technologies also may simultaneously introduce new hazards. Among the potential hazards that may be associated with consumer products are:

- **Loss of a safety function:** Safety devices, or products connected (either physically, or digitally) to safety devices, may fail to operate or may cause another device to fail to operate under hazard conditions. Products connected to the IoT may change their performance through software upgrades that are automatically pushed out over the Internet.
- **Fires and burns:** If a product or technology contains, or is connected to, an energy source (*e.g.*, battery, liquid fuel, power cord), the rapid, uncontrolled release of that energy could ignite the product, ignite nearby combustibles, or make an accessible surface hot enough to pose a potential burn hazard. New technologies that employ low-power devices, or new materials that are resistant to burning, can reduce the risk of fire or burn.
- **Shock:** If a product or technology uses voltages in excess of 30 Vac or 60 Vdc, a potential shock hazard may arise. New devices that operate only on low voltages, or that employ Safety Extra-Low Voltage ("SELV")[vi] circuits, are a low risk for shock.
- **Chemical Exposure:** New materials, included novel textiles, may expose users to irritating or toxic compounds. The effects of exposure could be chronic or acute.
- **Laceration/contusion/trauma/crush/impact/amputation:** Mechanical hazards may exist with new products. A device with increased kinetic or potential energy, or one that transports a user faster, may pose an increased risk of impact or falls.
- **Choking/strangulation/asphyxiation:** Wearable and other small devices must be designed to avoid creating a risk of choking.
- **New consumer product or technology hazards:** As the data acquisition, data processing, interconnection, and integration of more consumer products continues, consumers may be exposed to new hazard categories, such as:

    - Loss of Connectivity: A fault in a device, such as a product serving as a communications hub for a household, may result in the loss of access or control to the Internet or other connected devices in the home.
    - Data Integrity: If accurate data support a safety function, avoiding data corruption is imperative.

5 POTENTIAL CPSC-SPONSORED INITIATIVES AND COLLABORATIONS

Staying abreast of emerging and potential future hazards, and the ability to address new hazards presented by the IoT, requires new skill sets and innovative approaches. For example, CPSC does not have expertise on staff to evaluate software as a component part in consumer products. The agency may wish to consider securing software engineering and evaluation skills as an added means of protecting consumers. In addition, not all of the potential concerns with new technologies, such as data privacy or potential medical uses, fall within CPSC's jurisdiction. CPSC could work with our federal partners on issues of mutual concern.

CPSC could develop a program similar to the Occupational Health and Safety Administration's (OSHA's) Alliance Program to leverage resources and expertise from industry groups, professional organizations, faith- and community-based organizations, businesses, and

[vi] UL 60950-3, *UL Standard for Safety for Information Technology Equipment*, defines an SELV circuit as one whose voltages under single fault conditions does not exceed 42.4 Vac, or 60 Vdc.

educational institutions to help protect consumers from unsafe consumer products and to gain awareness of emerging product hazards. Through the Alliance Program, OSHA works with groups committed to worker safety and health to prevent workplace fatalities, injuries and illnesses. Participants in the OSHA Alliance Program develop Alliance agreements and implement project plans that emphasize, among other things, raising awareness of OSHA's rulemaking and enforcement initiatives through information sharing, outreach and communication, and training and education. These are formal, signed agreements between OSHA and stakeholders. CPSC could adopt a similar strategy–a CPSC Alliance Program–in which the Commission works with groups committed to product safety to prevent deaths and injuries from consumer products, through formal agreements.

The CPSC could solicit from the public, information on new and emerging consumer products and technologies. For example, a series of workshops, each dedicated to a technical area of interest, could be sponsored by the CPSC to gather interested parties and discuss the types of technology applications that are possible, and consider how any potential consumer safety hazards can be eliminated, mitigated, or warned against.

The CPSC could employ social media to organize forums, chat groups, or other online communities to identify and explore safe technology applications in consumer products.

6 CONCLUSIONS

Some products employing new and emerging technologies will have a long, public development period, while other products with new technical approaches will seemingly appear overnight. Modern manufacturing methods are increasingly adept at rapidly bringing new consumer goods into production at scale (the fashion industry is one example of a production system tuned for rapid turnover and high volume production).

Using the tools in our risk assessment and risk management toolbox, including voluntary standards development and collaborative work with stakeholders, including our federal partners, CPSC can maintain an awareness of consumer product technology trends and position itself to protect consumers from potential product safety hazards that may be associated with those trends.

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