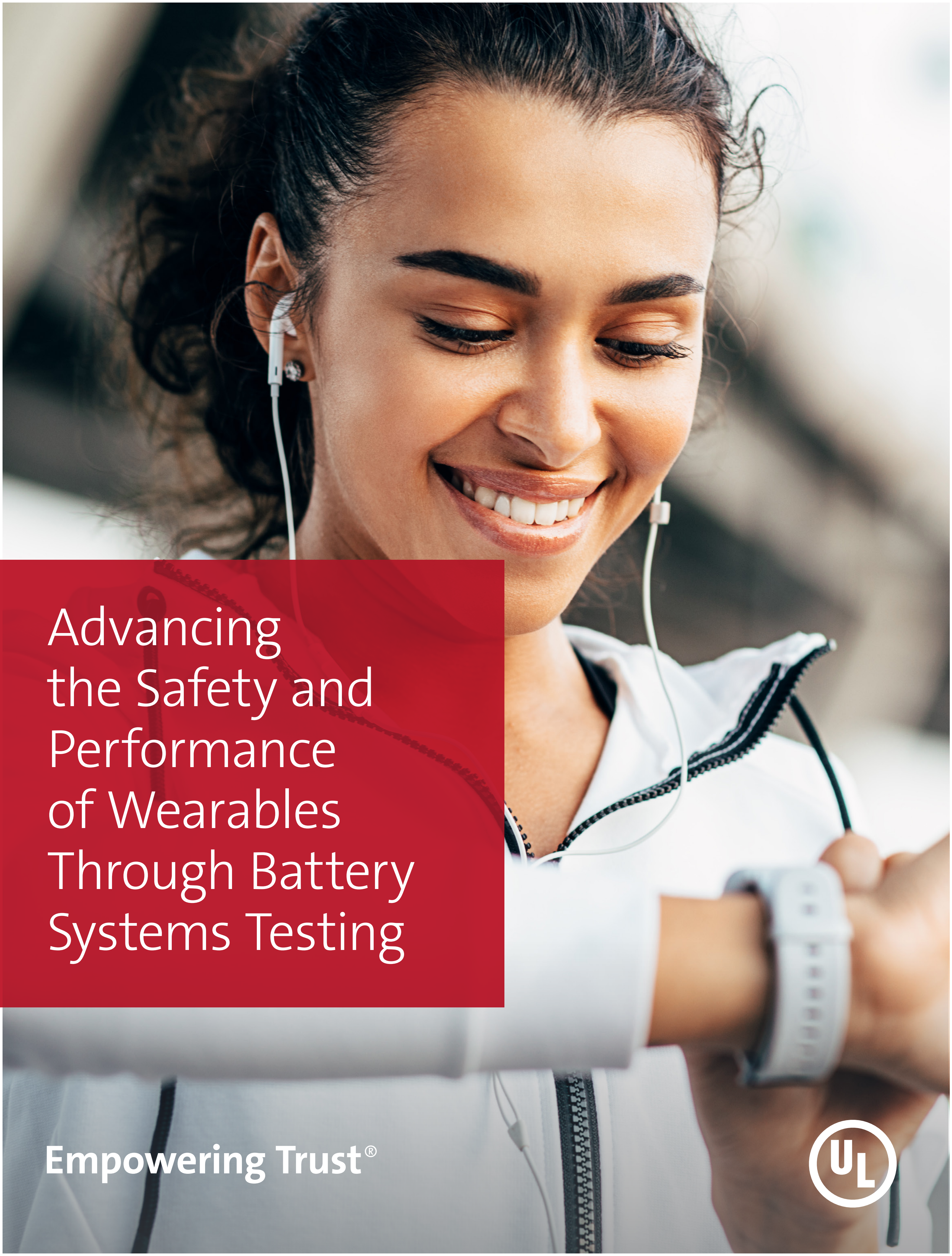

Advancing the Safety and Performance of Wearables Through Battery Systems Testing

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The worldwide market for wearable technologies is expected to reach $265.4 billion (USD) by the year 2026, up from just $116.2 billion in 2021. This anticipated growth in the wearable technologies market depends on the continuous development of new technologies such as wireless technology, smart electronics and advanced energy storage systems that can provide consistent and reliable power without compromising the overall user experience. However, accredited certification organizations should thoroughly evaluate and test wearables comprising new power and connectivity technologies for potential safety and performance concerns.

This white paper from UL discusses testing and evaluation considerations for battery and end-product design used in wearable technologies. Beginning with a brief history of wearables and trends in the emerging landscape, the paper highlights the rise of new approaches to powering wearable technology devices and their advantages over current technologies. The white paper then summarizes potential safety and performance considerations for batteries used in wearable technologies. It also details specific design evaluation and testing criteria useful for applying for product safety certification, along with staying current with regulations and customer expectations. The paper concludes with additional recommendations for assessing battery and end-product designs used in wearable technology devices.

Product evolution accelerates as wearables advance

From smartwatches and head-mounted wearables to health and fitness wristbands and monitors to smart masks and safety clothes, wearable technologies enable users to quickly and easily capture, share and access information in real time, regardless of their location. The proliferation of wearables supports the developing Internet of Everything (IoE) ecosystem, contributing to wearables' potential long-term usefulness.

While widespread adoption of wearable technology devices among consumers has occurred only in recent years, the idea of wearable technologies is not new. In fact, scientists and engineers have worked for decades to evaluate ways to safely integrate advanced computing technologies into portable devices small enough and comfortable enough to be worn. Some of the earliest wearable technology prototypes included eyeglasses designed to reflect an image from an LCD panel embedded in the earpiece (1997), a sensor-embedded jacket that tracked a wearer's movement (1999) and a portable telemedical wrist monitor (2002).

Advancing from prototype to commercially available wearable technology devices and apparel products has required developers to address a number of key technical challenges and usability over time. These challenges included the need to miniaturize critical components; integrate wireless communications capabilities; and develop smaller, more efficient user interfaces. Brands have developed a host of advanced technologies such as new wireless connectivity protocols, touch screens, voice recognition software, durable sensors and body monitors to meet these challenges. The widespread acceptance of the current generation of wearable technology devices is due in no small measure to these and other technology developments. Continued technology advancements, in addition to changing market conditions, have led to the acceleration of wearable adoption. Several key trends driving adoption include:

- **Prioritization of health —** Health and fitness wearables and connected medical devices experienced a stepwise increase amid the pandemic. According to the "Digital Health Consumer Adoption Report 2020" from Rock Health, consumer use of health and fitness wearables rose from 13% in 2015 to 43% in 2020, with a 10-point gain in 2020. From body temperature to electrocardiograms (ECG), blood pressure and blood sugar monitors to oxygen saturation, movement and sleep quality, consumers continue to prioritize their health with wearables and connected medical devices that provide critical health-monitoring and medical data instantly.
- **Miniaturization enables new form factors —** Following the life cycle curve of technology, wearables will become smaller and cheaper over time. Enabled by innovations in power and processing technologies, components will become smaller and smaller, allowing them to fit into shoes, clothing, glasses and other daily wear items. Miniaturization of technology components also enables an expansion of form factors.

Worldwide wearable device end-user spending by type, 2019–2022 (millions of U.S. dollars)

	2019	2022
Smartwatch	18,501	31,337
Ear-worn	14,583	44,160
Head-mounted display	2,777	4,573
Smart clothing	1,333	2,160
Smart patches	3,900	7,150

Source: Gartner, "Forecast Analysis: Wearable Electronic Devices, Worldwide," Gartner, January 12, 2021.

- **Proliferation of 5G –** The increasing availability of 5G networks provides faster data transfer, connectivity with a large number of devices and the ability to accommodate the enormous amounts of data that wearables generate by the second. 5G will also support the delivery of sophisticated augmented reality/virtual reality experiences, such as those delivered by head-mounted displays and smart glasses.

A number of technology advancements and engineering feats combine to innovate the latest wearable technologies. The resulting wearable devices deserve comprehensive evaluation for performance and safety, which must advance at the speed of innovation.

Increased battery capacity for a new generation of wearables

Perhaps the biggest ongoing technical challenge facing wearable technologies is the need for small, highly efficient and safe battery systems that are suitable for use in a wide variety of applications. The current generation of wearable technologies has greatly benefited from the development of lithium-ion (li-ion) batteries that represent significant advances over the bulky battery packs used in earlier prototype devices. Li-ion batteries are attractive due to their relatively high energy/density levels, low weight-to-volume ratios and scale of commercialization, reducing costs.

However, li-ion battery technology is likely to prove inadequate in meeting the power, performance and safety specifications required for future generations of wearable technology devices and apparel products. For example, increases in Li-ion energy density are not keeping pace with performance improvements seen in other mobile technologies. Li-ion batteries are hitting their physical limits, offering maximum densities of 140 to 210 watt-hours per kilogram.

In addition, the form factor and construction of Li-ion batteries are likely to impose additional constraints on their use in future wearable technologies.The innovation of smaller, lighter batteries that can provide power and maintain battery life will open the door to technology advancements. Meeting both power and energy density requirements in a smaller format may represent an insurmountable challenge for li-ion battery technology.

Fortunately, emerging advancements in battery technologies are already catalyzing the development of future generations of wearable technology devices. Scientific and engineering developments in several key areas have led to new battery systems for wearable technologies that are smaller, more powerful and safer to use than Li-ion batteries.

Some recent advances in battery and energy storage technologies include:

- **High-performance battery chemistry —** Upgraded battery technology using silicon powder packs more lithium atoms into a smaller space, improving battery efficiency and power density. These new chemistries allow for more power in a smaller format, opening the door to additional high-performance, light wearables. Other chemistry combinations, such as zinc-polymer, aluminum and lithium carbon fluoride (CFx), are also in development.
- **Solid-state batteries —** Considered to be the next generation of power options, new solid-state batteries offer the benefit of higher energy density over conventional lithium-ion batteries. Some designs are manufactured on silicon wafers using semiconductor fabrication techniques allowing for smaller and more compact use cases.
- **More flexible packaging —** New battery chemistries may not require rigid protective packaging and it may be possible to more easily integrate them into flexible materials — an especially important consideration for smart apparel and new forms of wearables.
- **Higher energy densities —** For wearable technologies with minimum power requirements, new high-energy-density batteries based on lithium carbon fluoride (Li-CFx) chemistries are in development and could potentially power a wearable device for its entire anticipated life without recharging.
- **Wireless charging —** In addition to these advancements, new wireless charging technologies are emerging that enable wearable devices to directly harvest ambient energy using a transducer and store it for future use. Radio charging that wirelessly transmits energy via magnetic fields is another recent wireless charging innovation.
- **Piezoelectric energy-harvesting technologies –** Emerging self-powered technologies enable devices to maintain their own operation by collecting energy in the working environment without an external energy supply. Powered by sources like sweat, body temperature, movement or breathing, energy-harvesting technologies could completely change the wearables industry's landscape and potential expansion.

Safety and performance considerations for battery systems

Technical advances in battery technology hold considerable promise for expanding the usefulness and convenience of wireless technologies. At the same time, because they supply or generate electrical energy, these advanced battery systems pose many of the same safety risks to users as li-ion batteries and other sources of power. Common safety risks associated with all types of batteries for wearable technologies include:

- **Explosion —** Li-ion batteries can overheat and explode or burst into flames under certain conditions. While batteries based on different chemistries may be inherently more stable, their widespread use in future wearable technologies may expose other, as-yet unknown vulnerabilities that put wearers at risk.
- **Fire —** Even when there is no explosion, battery systems that are not properly controlled can release their electrical energy into thermal energy, creating fires within the cell or nearby materials such as plastic enclosures, electronic circuit boards, fabrics and other combustibles that are part of the wearable end-product.
- **Burns —** The temperature of many energized devices often increases during normal use. In addition, battery systems typically integrate microprocessors and other modules in a small form factor that further contributes to elevated operating temperatures. Batteries used in devices designed for direct and prolonged body contact are of particular concern.
- **Chemical reactions —** Metals, synthetic fabrics and other materials used in the battery construction may contain chemicals that can produce rashes or other allergic skin reactions as a result of prolonged contact. In addition, the electrolytes in some batteries contain lithium salt, which is corrosive and can be toxic.

- **Electric shock —** Any energized device poses a risk of electrical shock due to worn or defective circuitry or accidentally exposed components, especially during charging. When any device is designed to be worn or placed close to the human head or body, the severity of electrical shock increases.
- **Exposure to electromagnetic energy —** Continuous and prolonged exposure to even low doses of electromagnetic energy may result in adverse health effects.
- **Human factors —** Mechanical design factors in batteries and energy storage systems, such as sharp corners and edges, device housings, and straps, may cause cuts, irritate the skin or cause discomfort with extended use.
- **Hazardous environments —** Finally, wearable technologies that rely on wireless recharging may pose specific hazards when worn or operated in potentially explosive environments.

Recommended product safety standards for batteries used in wearables

Worldwide regulatory requirements generally mandate that manufacturers conduct a range of compliance testing on their products to identify potential safety risks to users. Specific safety standards apply to batteries and end-products. They vary from jurisdiction to jurisdiction and will also depend on the type of technology and its anticipated use. Some specific standards that may apply to batteries used in wearable technology devices include:

- IEC/UL 62368-1, the Standard for Audio/Video, Information and Communication Technology Equipment - Part 1: Safety Requirements (formerly IEC/UL 60950-1, the Standard for Information Technology Equipment - Safety - Part 1: General Requirements, or IEC/UL 60065, the Standard for Audio, Video and Similar Electronic Apparatus - Safety Requirements)
- UL 8400, the Standard for Virtual Reality, Augmented Reality and Mixed Reality Technology Equipment
- UL 8139, the Standard for Electrical Systems of Electronic Cigarettes and Vaping Devices
- UL 2056, the Outline of Investigation for Safety of Lithium-ion Power Banks
- UL 2054, the Standard for Household and Commercial Batteries
- UL 1642, the Standard for Lithium Batteries
- IEC/UL 62133-2, the Standard for Secondary Cells and Batteries Containing Alkaline or Other Non-Acid Electrolytes - Safety Requirements for Portable Sealed Secondary Cells, and for Batteries Made from Them, for Use in Portable Applications - Part 2: Lithium Systems

The above Standards feature various construction, design, labeling, marking, material and test requirements. A product must meet every applicable requirement in a product safety Standard in order to achieve compliance. While the most familiar aspect of product safety is testing, many additional steps are required on the path to safer products. Common tests found in battery and wearable end-product Standards include:

Electrical tests:

- External short circuit test — Creates a direct connection between the positive and negative terminals to determine a battery's ability to withstand a maximum current flow condition without causing an explosion, fire or electric shock
- Abnormal charging or overcharging test — Applies an overcharging current rate and charging time to determine whether the product or component can withstand the condition without causing explosion, electrocution or fire
- Overdischarge or forced discharge test — Attempts to continue discharging beyond the specified discharge limit and/or to verify safe operations if there are unevenly charged cells within the battery pack

Mechanical tests:

- Crush test — Determines a product or component's ability to withstand a specified crushing force applied by two flat plates
- Impact test — Determines a product or component's ability to withstand a specified impact applied by a cylindrical steel rod
- Shock test — Involves securing a product or component to a testing machine calibrated to apply a specified average and peak acceleration for the specified duration of the test
- Free-fall (or drop) test — Subjects a product or component to a specified number of falls onto a hard surface; the sample is examined following each drop for damage
- Vibration test — Applies a simple harmonic motion to each sample at a specified amplitude with variable frequency and time

Environmental tests:

- Heating test — Evaluates a product or component's ability to withstand a specified application of an elevated temperature for a given period of time
- Temperature cycling test — Subjects each sample to specified temperature excursions above and below room temperature for a specified number of cycles
- Low pressure (altitude) test — Evaluates a battery's ability to withstand exposure to less than standard atmospheric pressure, which may occur in an aircraft cabin that experiences a sudden loss of pressure

Additional specialized tests:

In addition to these common tests, certain safety standards and testing protocols for batteries and wearable technology require additional specialized testing. These specialized tests address specific use applications and/or operating conditions in which wearable devices might be expected to operate.

- Electromagnetic Compatibility (EMC) — Regardless of their energy source, electrical devices must not create unintended electromagnetic interference with other electrical devices and must also be immune to electromagnetic interference from other devices. Due to the environment in which wearable devices and apparel products are used, batteries and energy storage systems should undergo testing for both emission and immunity characteristics.
- Specific Absorption Rate (SAR) — Wearable devices that incorporate wireless technology are often subject to SAR testing to determine the amount of electromagnetic radiation produced by a device under the most extreme use conditions at a given distance from the human head or body.
- Chemical content and biocompatibility — The components and materials used in batteries and the enclosures of wearable technologies may include chemicals that can be harmful with prolonged exposure. A chemical content assessment identifies levels of potentially harmful chemicals in these materials.
- 5G Compliance Testing — Wearables manufacturers are eager to unlock the potential 5G offers for high speeds and low latency. 5G compliance testing helps ensure the safety, connectivity and performance of devices operating on sub-6GHz and millimeter wave (mm wave) frequencies.
- Interoperability solutions for the IoT — As systems and devices become more complex in the IoE ecosystem, it becomes increasingly difficult to avoid product connectivity problems post-launch. Interoperability testing helps ensure that products work as expected with all other relevant devices and conform to the appropriate standards and technology platforms.
- IoT Device Security — Cybersecurity for wearables and some IoT products is critical to protecting users' privacy and safety. Cybersecurity testing helps identify risks and vulnerabilities in connected devices.
- UL Marketing Claim Verification — Unverified marketing claims can result in eroded brand trust or legal action. Third-party verification lends confidence that marketing claims are accurate and credible and that products perform as advertised.

Many wearables focus on wellness or medical applications, as these devices monitor, treat or diagnose patients. Market access and regulatory approval require relevant product safety standards for medical devices. Some of the specific end-product standards that command broad recognition for the majority of regulatory markets include:

- ANSI/AAMI ES 60601-1:2005+A1:2012 – Medical Electrical Equipment - Part 1: General Requirements for Basic Safety and Essential Performance
- IEC 60601-1-6 Edition 3.1 – Medical Electrical Equipment - Part 1-6: General Requirements for Basic Safety and Essential Performance - Collateral Standard: Usability
- ANSI/AAMI HA 60601-1-11 Edition 3.1 – Medical Electrical Equipment - Part 1-11: General Requirements for Basic Safety and Essential Performance - Collateral Standard: Requirements for Medical Electrical Equipment and Medical Electrical Systems Used in the Home Healthcare Environment
- Depending on the device's performance, various part 2 standards will apply, focused specifically on the performance and technology, e.g., ECG, oxygen saturation, body temperature, etc.

Building a strategy for risk mitigation

Even the list of standards and testing above is not exhaustive. By using a risk assessment approach, manufacturers can assess the safety risks associated with a given wearable technology and identify the need for additional testing. Further, other tests may be required to address application-specific requirements or jurisdictional regulations applicable to batteries used in wearable technologies. Finally, manufacturers of wearable technology devices and apparel products are still subject to compliance with equivalent, nonwearable device and product requirements.

These complexities can result in a seemingly endless array of testing to assess the safety of a given wearable technology device or apparel product. Developing a comprehensive strategy at the outset of the product development process can reduce overall expenditures, save time and help avoid unanticipated safety and performance issues that could delay market introduction. At a minimum, the process of developing a comprehensive strategy for batteries intended for use in wearable technologies should include the following steps:

Step 1:
Risk assessment

- Evaluate potential safety risks and hazards associated with the power source.
- Identify necessary design changes to address risks and hazards.
- Pinpoint other safety evaluation and testing criteria that may be required.

Step 2:
Understand the regulatory landscape

- Identify target markets and relevant regulations in each geographic location.
- Investigate and outline baseline requirements.
- Map evaluation, testing and/or certification plans based on regulatory requirements.

Step 3:
Consider marketplace requirements and customer expectations

- Identify requirements or measures that could result in competitive advantage.
- Map any evaluations, tests and/or certifications required to validate product claims, enhance product acceptance or differentiate offerings.

Step 4:
Seek expert advice and counsel

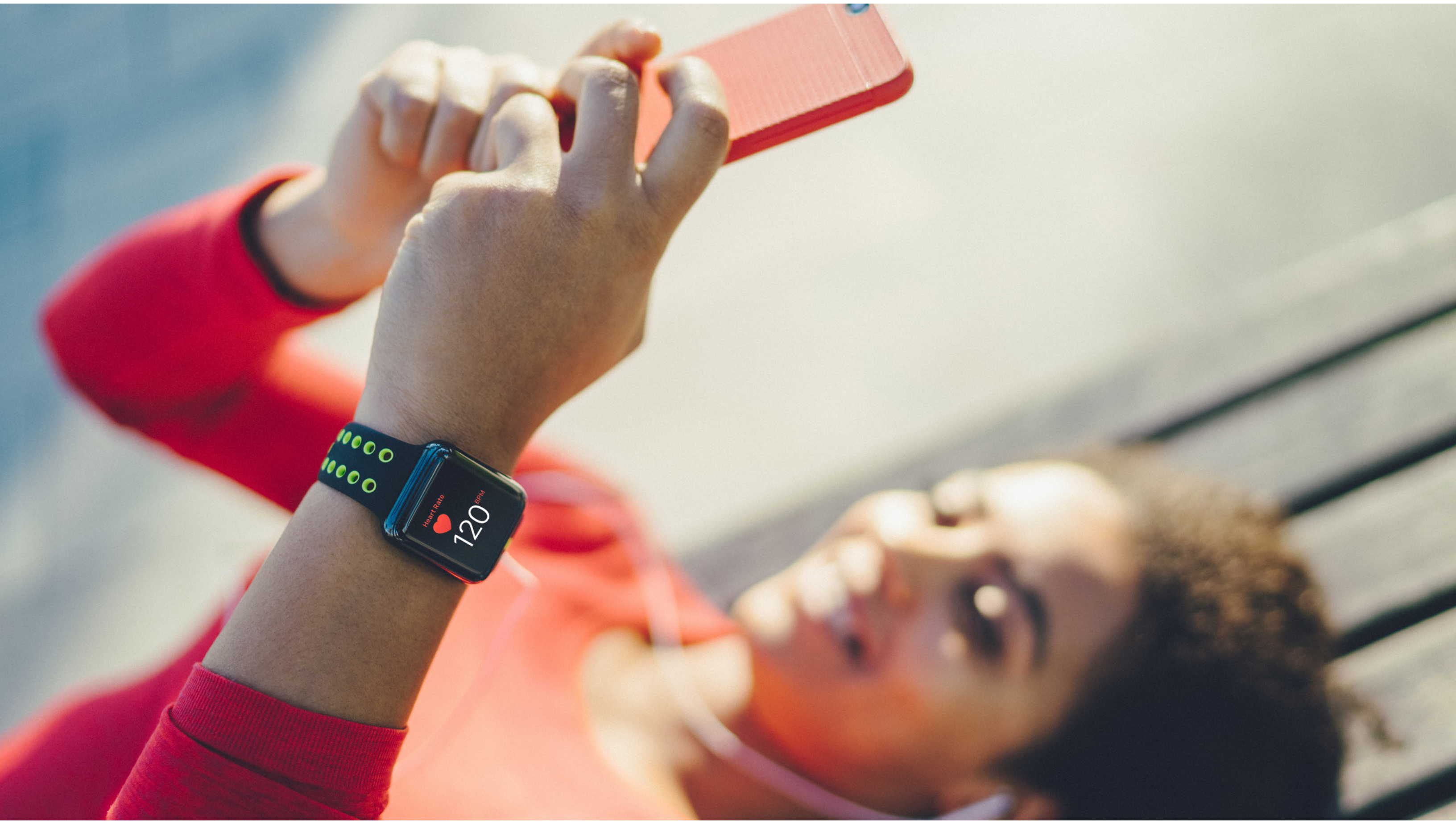
- Identify independent accredited ISO 17065 certification organizations to facilitate planning.
- Outline cost-effective evaluation, testing and certification strategies for long-term savings.
- Ask questions about international requirements.

Looking toward the future of wearables

Ongoing developments in battery and wearable technologies will lead to new systems suitable for a variety of wearable technology devices. These developments are likely to support such systems' accelerated adoption. New and advanced batteries may pose new safety risks and hazards to users. A comprehensive plan for batteries used in wearable technology devices following a robust risk assessment can mitigate these concerns, resulting in safer products with improved performance.

UL offers a complete range of services for testing and certifying wearables, including battery technology used in wearable technology devices. UL's staff have extensive knowledge of the regulatory approval process in key target markets. In addition, UL provides specialized evaluation, testing and certification services for 5G, Bluetooth®, EMC, energy efficiency, interoperability, product performance and reliability.

Find solutions to the challenges you face around batteries in wearables and discover how testing and certification can help you evaluate consistency and compliance in these products. For additional information, please visit us at www.ul.com/industries/technology-and-electronics/consumer-electronics and www.ul.com/services/battery-safety-testing. To contact UL, visit www.ul.com/contact-us or email us at batteries@ul.com.



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