WHITE PAPER

# Safety Concerns of Aftermarket Smartphone Replacement Lithium-Ion Batteries

UL Solutions

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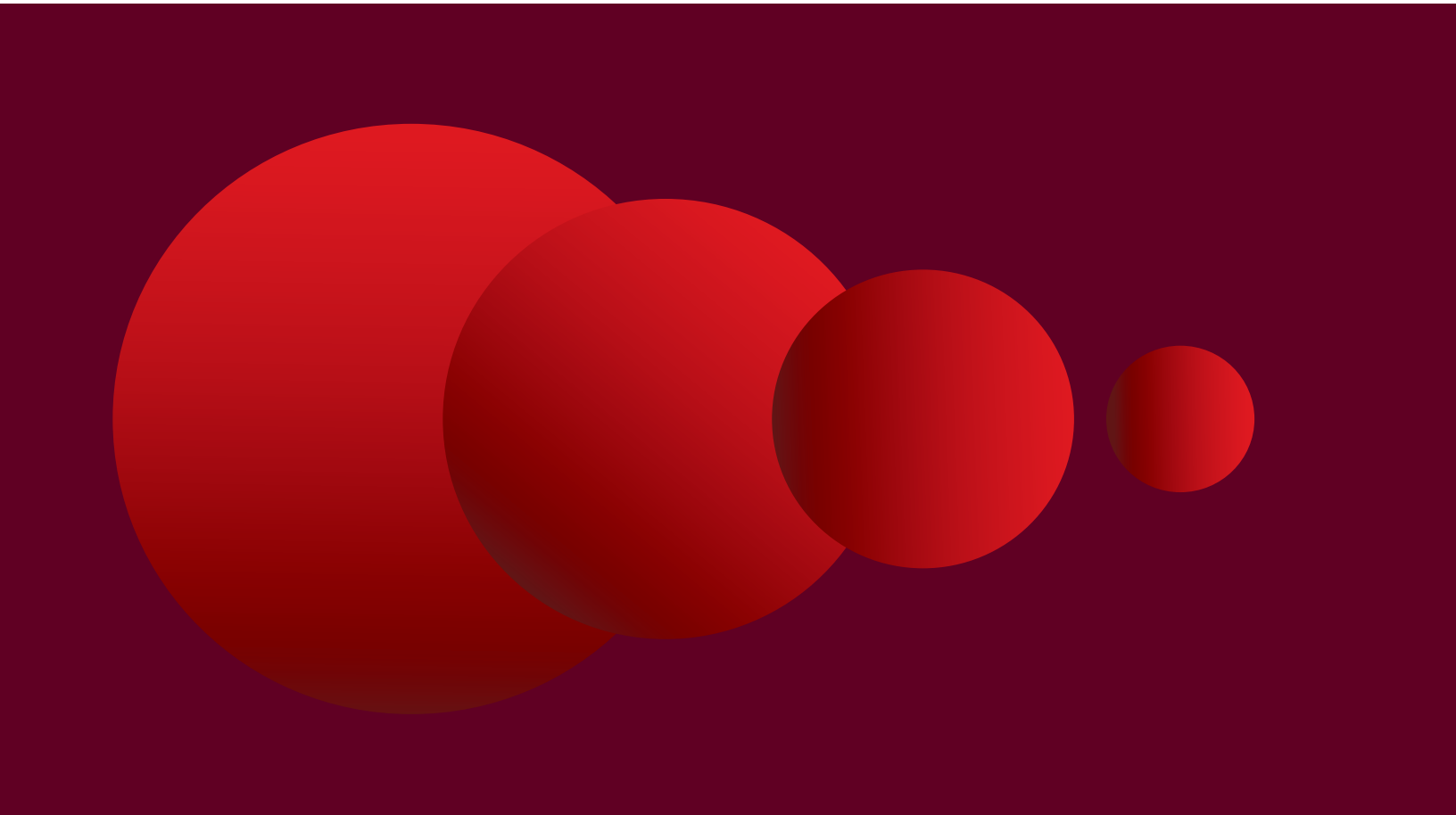


# Executive summary

When it comes time to replace the battery in a mobile device, consumers have options. They can purchase original equipment manufacturer (OEM) approved batteries from an OEM authorized service provider, purchase OEM-approved replacement batteries, or they can choose to purchase aftermarket (non-OEM) batteries and have them installed by a third-party repair shop or follow the instructions available on the internet to replace the battery themselves. The latter choice of purchasing aftermarket batteries brings with it safety risks.

This white paper presents the findings of a series of tests and evaluations conducted by UL Solutions of various aftermarket smartphone replacement batteries sourced from different publicly available outlets to assess the compliance of aftermarket smartphone replacement batteries to battery safety standards. Thirty-three aftermarket battery brands (totaling over 1,200 battery pack and cell samples) were assessed against key evaluation and test requirements from several regional battery standards. None of the battery brands purchased were safety-certified to the applicable regional standards. Twenty-nine of the 33 (88%) battery brands exhibited failures to such standards. All of the failed battery brands exhibited fire and explosion events either at pack or cell level. Such findings highlight a concerning trend — uncertified aftermarket smartphone replacement batteries often fall short of meeting established safety standards, posing potential concerns for consumer safety. In extreme cases, this could lead to thermal runaway[1], explosions or fires, causing immediate harm to consumers. To minimize such risk, consumers should purchase aftermarket smartphone replacement batteries from trusted and reliable sources that meet applicable regional safety standards.

A global leader in applied safety science, UL Solutions transforms safety, security and sustainability challenges into opportunities for customers in more than 100 countries. UL Solutions delivers testing, inspection and certification services, together with software products and advisory offerings, that support our customers' product innovation and business growth.

# Growth of smartphone replacement batteries

Smartphones have become an indispensable and pervasive necessity in our daily lives. As of 2023, a staggering 7.33 billion people own smartphones, constituting 90.97% of the world's population. Smartphones are also portable electronic devices crucially reliant on batteries. According to Research and Markets, the global mobile battery market was $23.05 billion (USD) in 2023 and expected to grow to $29.9 billion (USD) in 2027. Among the different types of batteries, lithium-ion batteries dominate the market due to their high energy density and lightweight nature.

However, despite advancements in lithium-ion battery technology, an inherent challenge persists — a gradual and irreversible capacity reduction due to aging. This phenomenon, called capacity fade, leads to a reduction in operating time after each charging cycle. Eventually, the battery reaches a condition unacceptable for daily operation and must be replaced. By the end of 2023, it was expected that more than 50% of iPhone users would be using secondhand smartphones, many of whom would seek a battery replacement to extend the smartphone's life.

# Replacing smartphone batteries

As previously noted, to replace smartphone batteries, consumers may purchase OEM-approved batteries or they may choose to purchase aftermarket batteries. Replacement batteries approved by the smartphone manufacturer should function similarly to the originals, with the same safety certifications, performance and cycle life characteristics.

However, consumers may not choose OEM-approved batteries due to cost or lack of availability. Increasingly, consumers are approaching third-party repair shops for aftermarket batteries or purchasing them online and following instructions available on the internet to replace the battery themselves. These aftermarket batteries often come at a lower price than OEM-approved ones, with promises of comparable or better performance. Due to the European Union (EU) and U.S. state-specific regulations, such as in New York, more and more consumers are expected to find resources for replacing batteries on their own.

OEM-approved batteries normally undergo various international or regional safety standard evaluations and tests to obtain safety certifications. This helps ensure product performance and reliability and provides a level of fire risk mitigation. In contrast, most aftermarket replacement batteries not recommended for use by the manufacturer typically lack such claims in their product labels, suggesting a lack of certification to any battery safety standard.


Lithium-ion batteries can potentially pose a safety risk to users, as their failure can release significant energy. When a battery is overcharged, exposed to high temperatures or subjected to other safety test requirements, it may cause a fire in a process called thermal runaway, resulting in property damage, severe injuries or even death. Leakage of the electrolyte or venting of gases are other possible related hazards that may arise when batteries are damaged or mistreated, causing internal chemicals to leak with the potential to harm devices or users.

Purchasing batteries certified to applicable safety standards is an effective method of mitigating safety concerns. Figure 1 illustrates the relationship between battery cells, battery packs, mobile devices and corresponding safety standards. Two well-known battery safety standards that are used to evaluate, test and certify batteries are UL 1642, the Standard for Lithium Batteries, applicable to battery cells, and UL 2054, the Standard for Household and Commercial Batteries, applicable to lithium-ion battery packs. These standards are commonly used for lithium-ion battery safety certification, particularly in North America.

# Safety assessment of smartphone batteries

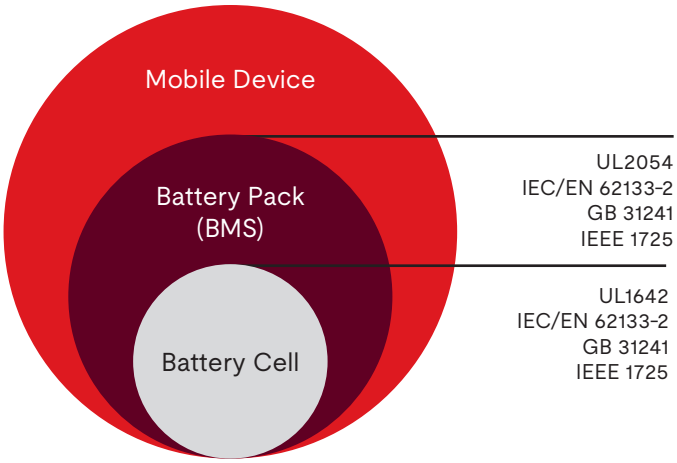



Figure 1: Standards for Battery in Mobile Devices.

The primary difference between a battery pack and a battery cell is the introduction of electronic controls known as a battery management system (BMS). Lithium-ion batteries used in smartphones and other mobile devices, whether they are from the original manufacturer or other authorized sources, should be selected from battery brands with UL 2054 Certification to reduce the risk of fire and explosion within a mobile device. UL 2054 also mandates that all lithium-ion cells used in the battery pack comply with UL 1642.

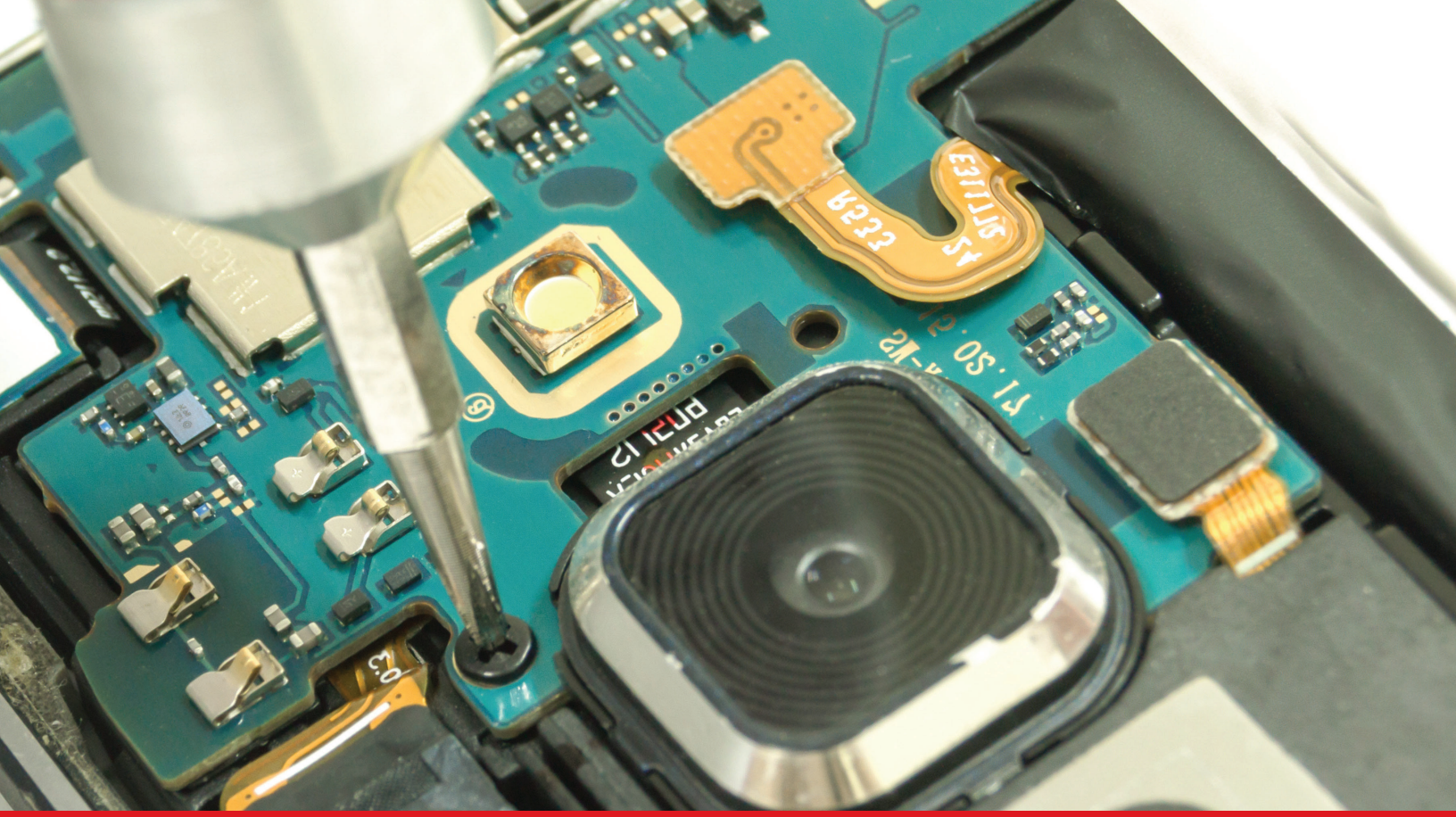
UL 2054 provides a comprehensive safety assessment for a battery pack under normal and abnormal use. When users replace the battery of a smartphone with one that has not been certified to UL 2054 or an applicable safety standard, they are assuming increased safety risk. Two of the major safety concerns with uncertified batteries are that the BMS may not function correctly to protect the battery cell and that the battery is not equipped with overcurrent or overtemperature protection devices. Also, uncertified batteries may fail to stop or eliminate the hazards caused by foreseeable misuse conditions, such as overcharging or an external short circuit. These conditions can lead to fire or explosion, causing damage to the smartphone and potentially injuring users.

In addition to UL 1642 and UL 2054, different countries or regions have their own specific safety standards. For example, IEC/EN 62133-2 is a common European battery safety standard. Cellular carriers in the U.S., EU and some Asian countries require IEEE 1725. In addition, GB 31241 is China's general lithium-ion battery safety standard. These different battery safety standards share common requirements and may feature unique ones, but their ultimate purpose is to serve as the basis for battery product safety certification.

# The UL Solutions study [6]

UL Solutions conducted a series of tests and evaluations of various aftermarket smartphone replacement batteries sourced from different publicly available outlets to assess the compliance of aftermarket smartphone replacement batteries to battery safety standards. The goal was to evaluate aftermarket battery compliance with prevailing regional safety protocols. To that end, a set of aftermarket battery samples was tested in accordance with the safety standards of the respective regions where they were purchased. Key standards include UL 1642 and UL 2054 for North America, IEEE 1725 specified by the U.S. CTIA Wireless Association, IEC/EN 62133-2 for Europe and GB 31241 for China.

Each standard consists of several tests representing various foreseeable misuse conditions that are likely to occur during smartphone use. To accommodate a higher number of aftermarket battery brands and samples, the tests that represent the highest risk conditions were chosen for this study. A failure to pass these critical tests indicates an increased risk and hazard exposure for consumers.



# Results and key findings

This section provides an overview of the research findings based on regional battery safety standards. None of the battery brands evaluated and tested were safety-certified. The appendix contains the test result details.

## GLOBAL

### IEEE 1725

Twenty-seven of the uncertified battery samples from various brands were evaluated at the cell level to selected CTIA Wireless Association requirements. Isolation and electrode geometry tests were selected from those requirements, and a limited safety assessment was performed on these samples. The isolation test aims to ensure that the separator/cell design can maintain isolation under high-temperature conditions for a reasonable period to maintain cell safety. The electrode geometry test checks that the electrode alignment parameters are designed and controlled such that cell safety is not compromised. Results showed 10 battery brands failed the isolation verification.

# NORTH AMERICA

### UL 1642

These eight battery pack brands were further evaluated according to some key tests in UL 1642 at the battery cell level. One model did not pass the short-circuit test at room temperature, three brands did not pass the short-circuit test at 55° C, and all eight brands failed the heating test. The heating test evaluates the ability of a cell to withstand a specified application of an elevated temperature for a specified duration. To pass the short-circuit test, a sample must not explode or ignite. Cells with poorer thermal stability are less likely to pass the heating test in UL 1642. If such cells are used in a pack, a higher probability exists that a thermal runaway event triggered in one cell could lead to a more extensive fire.

Additionally, there was a ninth battery pack model that was also tested at cell level. This battery pack reused the OEM's original BMS and reconnected it to a non-OEM cell. The non-OEM cell also failed the heating test.

### UL 2054

Initially, five replacement battery brands obtained in North America underwent evaluation and testing to the UL 2054 Standard. Such evaluation and testing encompassed various assessments, such as electrical and mechanical construction, component and material analysis, environmental conditions, and tests, such as external short-circuit, abusive overcharge, limited power source, battery pack component temperature, and the markings/instructions requirements. None of the initial group of batteries complied with the UL 2054 Standard.

Among all the safety test requirements, external short-circuit and abusive overcharge tests reflect the foreseeable misuse scenarios that are more commonly observed in the field. In the initial investigation, some batteries failed these tests. Additionally, none of the battery samples passed the limited power source test. Therefore, these three tests were selected for a follow-up study of a wider range of battery brands. As a follow-up to our initial testing, eight different brands of replacement batteries were procured from the North American market. Safety testing on these battery samples was carried out, focusing on the external short-circuit, abusive overcharge and limited power source tests, as well as a construction review and a review of their markings and instructions. At this stage, all the batteries failed to pass at least one of the tests. As for the markings and instructions, the investigation revealed that many uncertified smartphone replacement batteries had noncompliance issues with UL 2054. Smartphone batteries not independently certified to UL 2054 represent a real safety concern for consumers.

# EUROPE

### IEC/EN 62133-2

In the EU region, uncertified batteries from 10 different brands underwent IEC/EN 62133-2 standard evaluation and testing. For cell-level evaluation, the testing included external short-circuit and thermal abuse. Eight brands failed the thermal abuse test, and four brands failed the external short-circuit test. At the pack level, marking, overcharge and external short-circuit tests were conducted. Marking inconsistencies were observed in all pack samples, and four brands failed the external short-circuit test at the pack level. Fire and explosion were observed as the common failure modes at both the cell and pack levels.

# CHINA

### GB 31241

Finally, packs from the Chinese market were evaluated and tested following GB 31241. For cell-level evaluation, the tests included short circuit at room temperature, short circuit at 55° C, overcharge and heating. Results indicated that in the 10 brands tested, one model failed the room temperature short-circuit test, two brands failed the short-circuit test at 55° C and four brands failed the heating test. Fire and explosion were observed as the common failure modes at the cell level. At the pack level, marking, low pressure, overcurrent charge and external short-circuit tests were performed on 10 uncertified battery samples. All samples passed low pressure, overcurrent charge and external short-circuit tests, but none fully met the marking requirements.

# Summary and recommendations

With the implementation of new EU and U.S. state regulations, smartphone designs allowing users to replace and repair batteries themselves are becoming inevitable. While this addresses environmental and consumer demands, it increases the safety risks associated with uncertified smartphone replacement batteries.

This study procured aftermarket smartphone replacement batteries from the market, assessing 33 battery brands against key evaluation and test requirements in regional battery standards worldwide. Twenty-nine of the 33 (88%) battery brands exhibited failures to these standards. All of the failed battery brands exhibited fire and explosion events either at the pack or cell level. Such findings highlight a concerning trend — uncertified aftermarket smartphone replacement batteries often fall short of meeting established safety standards, posing potential concerns for consumer safety. In extreme cases, such shortcomings could lead to thermal runaway, explosions, or fires, causing immediate harm to consumers.

A comprehensive examination reveals that none of the aftermarket battery brands in this study had safety certification, nor did they fully comply with global battery safety standards. Figure 2 illustrates the results of this study, exposing major safety issues, such as poor construction quality, poor electrical safety design and component/material selection, noncompliance with essential test requirements in battery safety standards, and a likelihood of experiencing thermal runaway (Figure 3) under critical foreseeable misuse scenarios, such as external short-circuit, heating test and abusive overcharging.

Figure 2 Investigation of uncertified batteries safety performance by regional battery safety standards

**UL 1642 (Cell) - Battery brands: 8**
13% fail to short-circuit (room temperature)
38% fail to short-circuit (55°C)
100% fail to heating

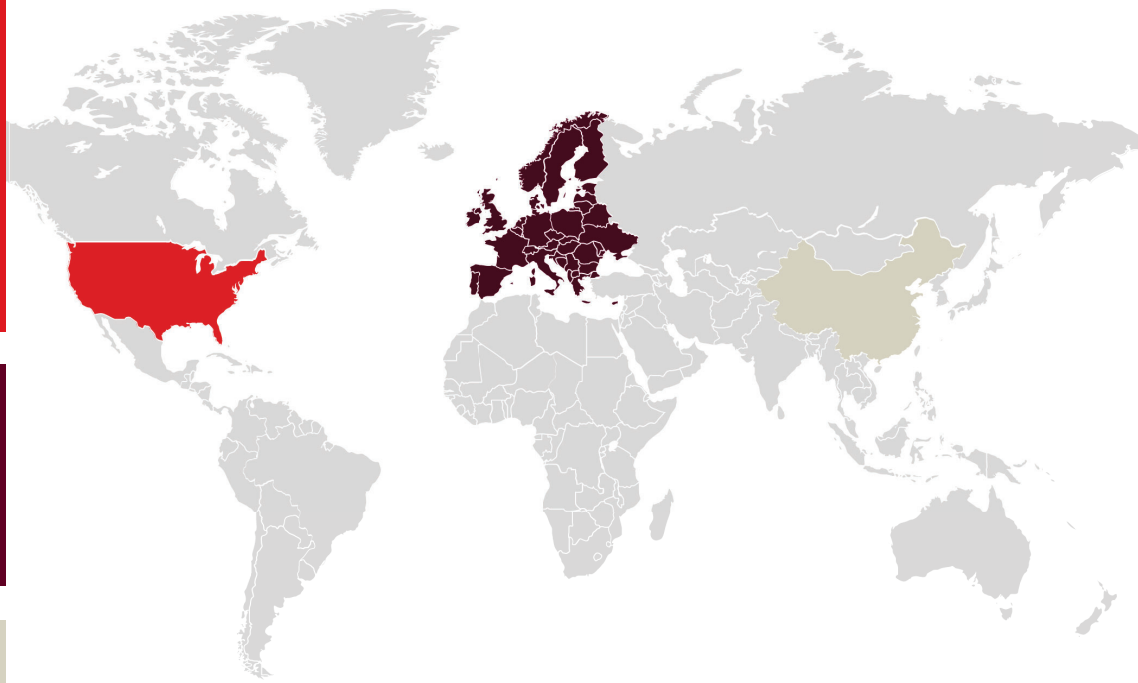
**UL 2054 (Pack) - Battery brands: 13**
100% fail to construction review
15% fail to short-circuit
100% fail to abusive overcharge
100% fail to limited power source 77% fail to markings/instructions

**IEC 62133-2 (Cell) - Battery brands: 9**
44% fail to short-circuit
89% fail to heating

**IEC 62133-2 (Pack) - Battery brands: 10**
90% fail to battery markings
40% fail to short-circuit

**GB 31241 (Cell) - Battery brands: 10**
10% fail to short-circut (room temperature)
20% fail to short-circut (55 ° C)
40% fail to heating

**GB 31241 (Pack) - Battery brands: 10**
100% fail to battery markings



## CTIA (Cell) - Battery brands: 27

37% fail to isolation

## Total (Pack) - Battery brands: 33

88% failed test requirements with fire/ explosion events

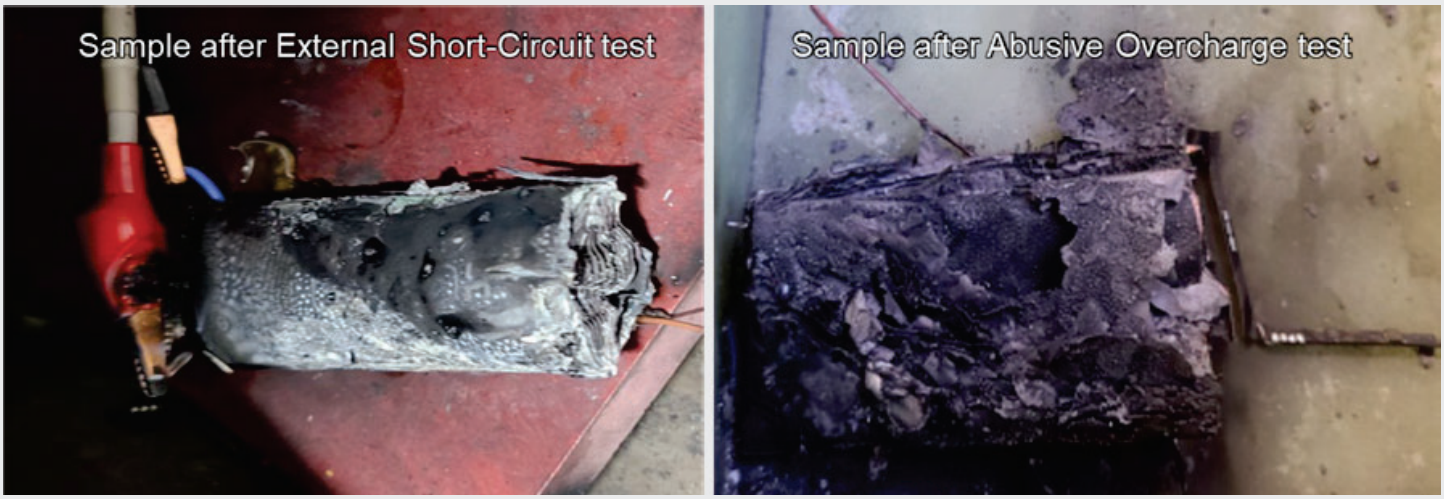



Figure 3 Battery samples after External Short-Circuit and Abusive Overcharge tests

Table 1 Results of Phase I Study – Safety Assessment by UL2054

| | BRAND 1 | BRAND 2 | BRAND 3 | BRAND 4 | BRAND 5 |
|---|---|---|---|---|---|
| Construction review | N | N | N | N | N |
| Short-circuit test | Y | Y | N | N | Y |
| Abnormal charge | Y | Y | Y | Y | Y |
| Abusive overcharge | N | N | N | N | N |
| Forced-discharge | Y | Y | Y | Y | Y |
| Limited power source test | N | N | N | N | N |
| Battery pack component temperature test | N | N | N | N | N |
| Battery pack surface temperature test | Y | Y | Y | Y | Y |
| Battery enclosure tests | Y | Y | Y | Y | Y |
| Markings and instructions | N | Y | N | N | N |

Table 2 Results of Phase II Study – Limited Safety Assessment by UL2054 (Pack level)

| | BRAND 6 | BRAND 7 | BRAND 8 | BRAND 9 | BRAND 10 | BRAND 11 | BRAND 12 | BRAND 13 |
|---|---|---|---|---|---|---|---|---|
| Construction review | N | N | N | N | N | N | N | N |
| Short-circuit test | Y | Y | Y | Y | Y | Y | Y | Y |
| Abusive overcharge | N | N | N | N | N | N | N | N |
| Limited power source test | N | N | N | N | N | N | N | N |
| Markings and instructions | Y | N | N | N | N | N | Y | N |

Table 3 Results of Phase II Study – Limited Safety Assessment by UL1642 (Cell Level)

| | BRAND 6 | BRAND 7 | BRAND 8 | BRAND 9 | BRAND 10 | BRAND 11 | BRAND 12 | BRAND 13 |
|---|---|---|---|---|---|---|---|---|
| Short-circuit at room temperature | Y | N | Y | Y | Y | Y | Y | Y |
| Short-circuit at 55oC | N | Y | N | Y | Y | N | Y | Y |
| Abnormal charging | Y | Y | Y | Y | Y | Y | Y | Y |
| Heating test | N | N | N | N | N | N | N | N |
| Low pressure | Y | Y | Y | Y | Y | Y | Y | Y |

# Appendix

Table 4 Results of Phase III Study – Limited Safety Assessment by IEC/EN 62133-2 (Cell & Pack Level)

| | | BRAND 14 | BRAND 15 | BRAND 16 | BRAND 17 | BRAND 18 | BRAND 19 | BRAND 20 | BRAND 21 | BRAND 22 | BRAND 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cell level | External short-circuit | Y | **N** | Y | **N** | Y | **N** | Y | - | Y | **N** |
| | Thermal abuse | **N** | **N** | **N** | **N** | **N** | **N** | **N** | - | Y | **N** |
| | Battery marking | **N** | **N** | **N** | **N** | **N** | **N** | Y | **N** | **N** | **N** |
| Pack level | Overcharge | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| | External short-circuit | Y | Y | Y | Y | **N** | **N** | **N** | **N** | Y | Y |

Table 5 Results of Phase III Study – Limited Safety Assessment by GB 31241 (Cell & Pack Level)

| | | BRAND 14 | BRAND 15 | BRAND 16 | BRAND 17 | BRAND 18 | BRAND 19 | BRAND 20 | BRAND 21 | BRAND 22 | BRAND 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cell level | Short-circuit at room temperature | **N** | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| | Short-circuit at 55oC | **N** | Y | **N** | Y | Y | Y | Y | Y | Y | Y |
| | Overcharge | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| | Heating test | Y | **N** | Y | **N** | **N** | **N** | Y | Y | Y | Y |
| | Marking | **N** | **N** | **N** | **N** | **N** | **N** | **N** | **N** | **N** | **N** |
| Pack level | Low pressure | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| | Over-current charge | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| | External short-circuit | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |

**N** Not comply **Y** Comply **-** Not Tested

# SAFETY CONCERNS OF AFTERMARKET SMARTPHONE REPLACEMENT LITHIUM-ION BATTERIES

Table 6 Results of Phase III Study – Limited Safety Assessment by CTIA (IEEE 1725 – Cell Level)

| | CELL: ISOLATION PROPERTIES | CELL: ACOH (ELECTRODE GEOMETRY) |
|---|---|---|
| Brand #6 | Y | Y |
| Brand #7 | Y | Y |
| Brand #8 | **N** | Y |
| Brand #9 | Y | Y |
| Brand #10 | Y | Y |
| Brand #11 | Y | Y |
| Brand #12 | **N** | Y |
| Brand #13 | Y | Y |
| Brand #14 | **N** | Y |
| Brand #15 | Y | Y |
| Brand #16 | **N** | Y |
| Brand #17 | **N** | Y |
| Brand #18 | **N** | Y |
| Brand #19 | - | Y |
| Brand #20 | **N** | Y |
| Brand #21 | - | Y |
| Brand #22 | **N** | Y |
| Brand #23 | Y | - |
| Brand #24 | **N** | Y |
| Brand #25 | Y | Y |
| Brand #26 | Y | Y |
| Brand #27 | Y | Y |
| Brand #28 | **N** | Y |
| Brand #29 | Y | Y |
| Brand #30 | Y | Y |
| Brand #31 | Y | Y |
| Brand #32 | Y | Y |
| Brand #33 | Y | Y |

# Endnotes


1. https://ul.org/library/what-thermal-runaway-fact-sheet
2. https://www.bankmycell.com/blog/how-many-phones-are-in-the-world
3. https://www.researchandmarkets.com/reports/5744128/mobile-battery-global-market-report
4. https://www.forbes.com/sites/barrycollins/2023/10/10/half-of-iphones-will-be-second-hand-by-end-of-2023/
5. A battery management system, or BMS, is an electronic regulator system incorporated into lithium-ion batteries to oversee cell voltages, temperatures, and battery operation. A BMS electronically supervises battery conditions and operation to enhance lithium battery safety, lifespan and efficiency.
6. This study was funded in part by Apple Inc. UL Solutions performed all tests presented in this study and verified the results. All conclusions presented in this white paper are those of UL Solutions.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