Richardson Electronics
POWER & MICROWAVE TECHNOLOGIES

DESIGNING THE FUTURE OF ENERGY STORAGE WITH ULTRACAPACITORS

A deep dive across industries highlighting how ultracapacitors and batteries serve different roles in modern energy systems.

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1. Executive Summary

Ultracapacitors are emerging as a high-performance alternative to traditional batteries in applications demanding rapid power delivery, high cycle life, and robust thermal tolerance. This white paper presents a comprehensive overview of ultracapacitor technology and its deployment across sectors such as agriculture, heavy industry, transportation, UPS, signaling, and grid infrastructure.

Unlike batteries, ultracapacitors store energy electrostatically, enabling symmetrical charge/discharge cycles, over one million cycle lifetimes, and efficiencies approaching 99.8%. Their ability to deliver peak power in milliseconds, operate reliably from –40°C to +65°C, and function maintenance-free makes them ideal for systems requiring frequent, high-current events and long-term durability.

The document outlines a scalable product portfolio—from high-capacitance cells to modular and rack-level systems—designed for seamless integration into diverse electrical architectures. Technical comparisons highlight ultracapacitors' superior power density, transient response, and safety profile versus lithium-ion batteries, while hybrid configurations are recommended to optimize energy and power management.

For engineers designing next-generation energy systems, ultracapacitors offer a compelling solution to improve reliability, reduce operational costs, and enhance system resilience in demanding environments.

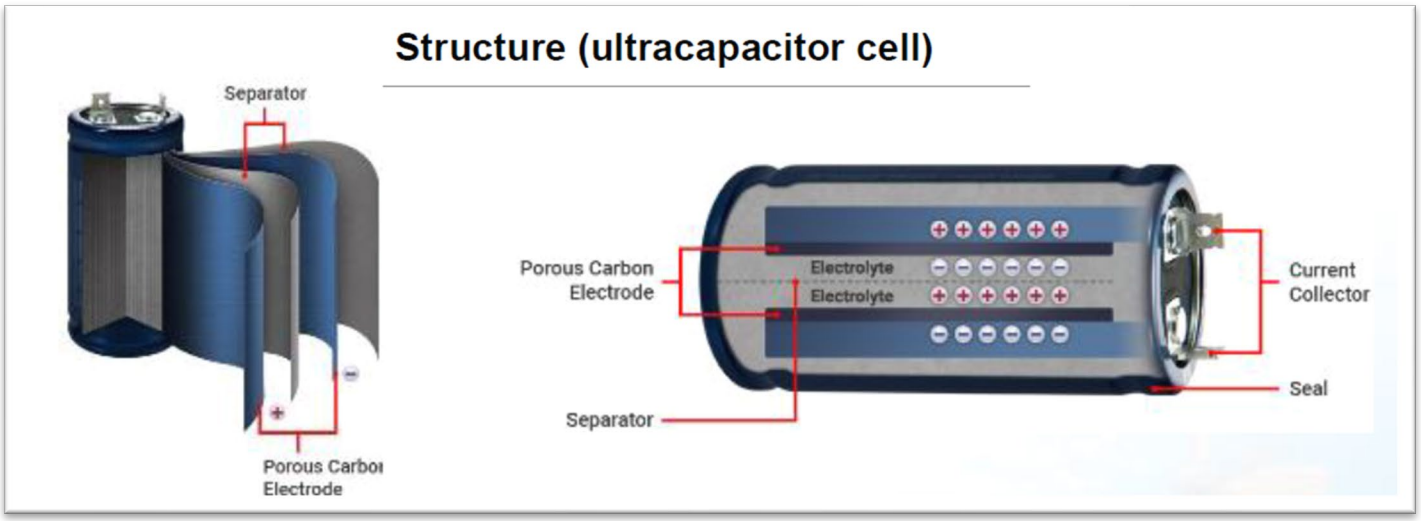
1.1 Strategic Partnership for Next-Generation Energy Storage

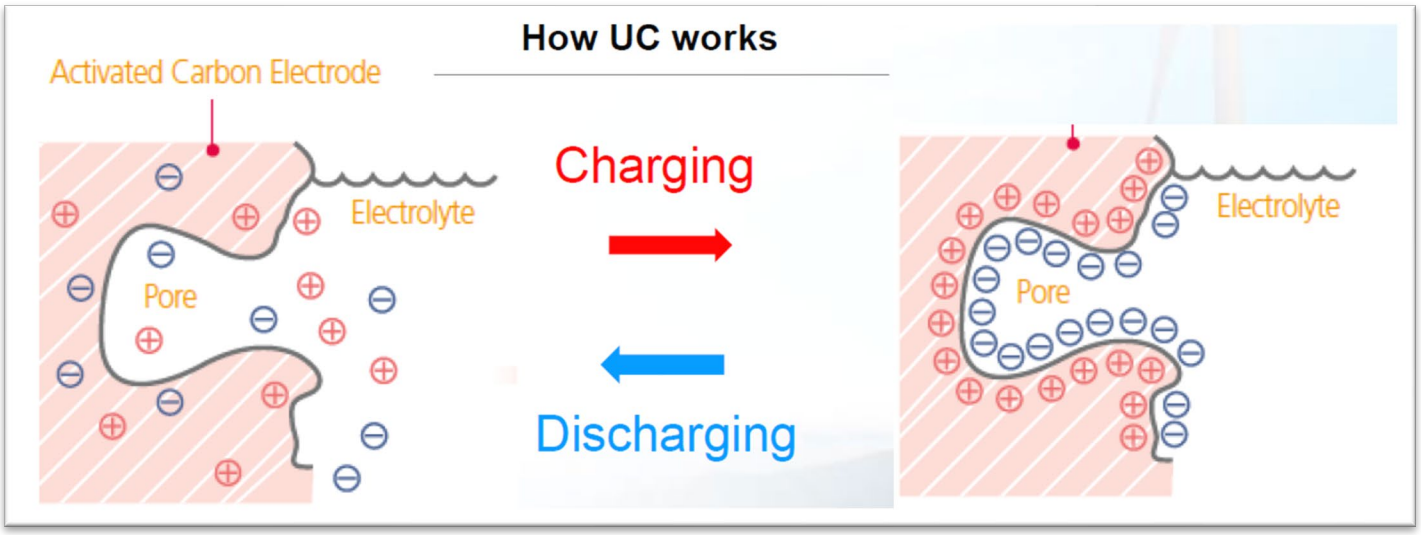
The partnership between Richardson Electronics and LS Materials brings together advanced ultracapacitor technology and deep engineering expertise to solve complex energy storage challenges across industries. Richardson Electronics enhances this offering with its global infrastructure, design-in support, and consulting-driven approach, ensuring seamless integration and long-term reliability. This synergy enables customers to deploy ultracapacitor-based solutions that outperform traditional technologies like lithium batteries and electrolytic capacitors, which often suffer from limited cycle life, chemical degradation, and safety risks—especially in demanding environments such as renewable energy systems, transportation, industrial automation, and grid infrastructure.

LS Materials complements this with a robust portfolio of ultracapacitor cells, modules, and rack systems engineered for scalability and performance. With over one million charge-discharge cycles, rapid response times, and reliable operation across a wide temperature range, these solutions meet the rigorous demands of applications in agriculture, heavy industry, UPS, signaling, and more. Richardson's engineering-first approach ensures that each deployment is optimized for electrical, mechanical, and thermal requirements, delivering safe, high-performance energy storage systems that reduce maintenance, extend service life, and improve overall system efficiency.

2. What is Ultracapacitor Technology?

Ultracapacitor technology differs fundamentally from batteries in that it stores energy through electrostatic charge separation rather than chemical reactions. This purely physical mechanism enables symmetrical charge and discharge, cycle life exceeding one million cycles, and efficiencies approaching 99.8 percent, while maintaining stable performance from –40°C to +65°C. These intrinsic properties deliver engineering advantages across demanding applications: stabilizing renewable energy by smoothing transient fluctuations, supplying high-power bursts for regenerative braking and start-stop in transportation, ensuring low-maintenance energy buffering in industrial automation, and providing rapid-response, long-life backup for mission-critical power and grid infrastructure systems.





The technical advantages of LS ultracapacitors also translate into quantifiable performance metrics. With specific power ratings reaching up to 19.8 kW per kilogram, they deliver instantaneous energy far beyond the capabilities of traditional batteries. Their design allows for extremely low equivalent series resistance (ESR), ensuring efficient high-current operation and minimal energy loss. Combined with high energy density compared to conventional capacitors, this makes LS ultracapacitors uniquely capable of bridging the gap between power and energy, offering a balance that few technologies can achieve.

2.2 Success Story: Railway Maintenance Systems with Ultracapacitors

High-power electrical panels in railway infrastructure are typically designed in a 1+1 configuration: the main line powers critical systems such as lifting devices, service equipment, and operations, while the secondary line is dedicated to lowering and controlling level-crossing barriers and other safety devices. The electrical grid typically powers these panels; however, in the event of a blackout, continuity must be ensured. When the grid fails, the first level of ultracapacitors immediately delivers backup power; if the outage persists, a second ultracapacitor line ensures redundancy and full reliability.
Ultracapacitors provide a decisive set of advantages in this environment:

- Instant Power to activate safety systems without delay.
- Safety & Reliability by securing critical railway functions during grid failures.
- Low Maintenance, with over 1 million cycles and a long operational lifetime, avoiding frequent lead-acid battery replacements.
- Reduced Operating Costs thanks to fewer service interventions and longer component life.

A first major use case is railway crossing barriers. These systems must be able to open and close even in case of power loss, with a short but critical power requirement. Ultracapacitors are the ideal choice: each crossing can be equipped with cabinets hosting multiple UC modules, ensuring barrier movement and operational safety regardless of grid status.

A second important application is emergency railway signaling. Alongside the tracks, power cabinets must keep the signaling links transmitting emergency data—such as fault location and fault type—operational, even during outages. The requirement is to ensure sufficient backup power for reliable communication. Each cabinet integrates ultracapacitor modules, mirrored for redundancy, to guarantee uninterrupted operation as a safety-critical function.

In summary, ultracapacitors are becoming a key enabler for railway maintenance systems: they guarantee uninterrupted safety functions, reduce operational costs, and support applications ranging from level-crossing barriers to emergency signaling infrastructures.

2.3 Success Story: Locomotive Start System

Richardson Electronics has developed an integrated ultracapacitor-based cranking support system to reduce idle time and road failures while extending locomotive battery life.
Traditional locomotive start systems rely heavily on lead-acid batteries, which are subject to cold-cranking limitations, voltage drop, and accelerated wear due to frequent deep cycling. By introducing an ultracapacitor-based starting support unit, Richardson Electronics reduces the load on standard batteries,

enabling reliable starts, fewer idle hours, and longer battery life.
These ultracapacitor units operate seamlessly with the existing battery start system, providing cranking support and reducing idle times otherwise required for battery charging in diesel locomotives. They are virtually maintenance-free and designed for a 10+ year operational life.

Key Benefits:

- Supports up to 3 successful cranks on a depleted battery that cannot crank alone
- Oversized capacitor ensures 3 reliable starts at end-of-life (10 years) with no loss of functional performance
- Provides >60% of starting current (800A)
- Limits voltage drop during start sequences
- Includes charge indicator light both on the ultracapacitor and inside the battery box
- Prevents “dead won’t start” failures
- Requires no additional maintenance
- Reduces idle times linked to battery charging, supporting CARB/EPA/AESS compliance
- Extends battery lifespan by up to 50% due to reduced cycling
- Enables additional fuel savings measures with ensured starting capability

2.4 Success Story: Richardson Electronics’ Patented ULTRA3000® (Pitch Energy Module for Wind Turbines)

A flagship example of this vertical integration utilizing LS Materials' ultracapacitors is Richardson Electronics' ULTRA3000. This Pitch Energy Module (PEM), using Richardson’s patented technology, is an ultracapacitor-based plug-and-play replacement for batteries within wind turbine pitch systems. The energy storage and power delivery engineered solution for wind turbine pitch systems transforms traditional energy storage concepts into a plug-and-play, maintenance-free system with unmatched reliability and simplicity.

Ultracapacitor-based energy storage solutions have significantly enhanced reliability in electric pitch control systems. Ultracapacitors, unlike batteries, can deliver quick bursts of power in a short timeframe, making them an ideal function for emergency pitching in a wind turbine generator (WTG). They must:

- Adjust blade angle to maximize energy yield
- Protect the turbines in storm conditions
- Guarantee safe shutdown even during grid loss

Conventional battery-based systems face frequent failures, high maintenance costs, and limited lifetimes. The ULTRA3000® redefines this application by offering:

Advantages of Richardson Electronics' ULTRA3000® (PEM):

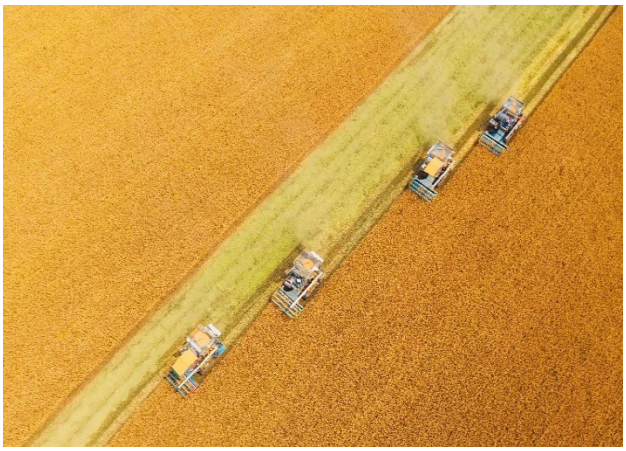
- **Plug & Play Integration** – factory preassembled, the module can be installed in **just 15 minutes**, simplifying retrofits and new deployments.
- **OEM Compatibility** – ULTRA3000® is designed to be fully compatible with systems from major global wind turbine OEMs, making integration seamless across existing fleets and new platforms
- **Cost Efficiency** – fewer service interventions, fewer spare parts, and extended lifecycle lead to significant total cost of ownership savings.
- **Ultra-Long Lifetime** – powered by LS Materials ultracapacitors, ULTRA3000® operates reliably for **15+ years** without replacement cycles, far exceeding the lifespan of lead-acid batteries.
- **Maintenance-Free Operation** – no sulfation, no deep-discharge degradation, and no scheduled replacements, dramatically reducing OPEX.
- **Instant Power Availability** – ultracapacitors deliver immediate current to drive pitch motors, ensuring safe blade positioning even in emergencies.
- **Consistent Performance** – guaranteed operation across a wide thermal range (–40 °C to +65 °C), suitable for turbines in diverse climates.

With the ULTRA3000®, Richardson Electronics and LS Materials provide the wind energy industry with a scalable, OEM-compatible, and future-proof solution for pitch control. Combining large-scale in-house manufacturing with cutting-edge ultracapacitor technology, Richardson's engineered solution – ULTRA3000 ensures safer turbines, lower operating costs, and unmatched system reliability for decades.

3. Ultracapacitors Across Industries

The versatility of LS Materials' ultracapacitors allows them to address critical challenges across a wide spectrum of industries. Unlike conventional batteries, which are limited by cycle life, chemical degradation, and safety risks, ultracapacitors offer exceptionally high-power density, long service life, and reliable operation in extreme environments. This uniquely positions them to support sectors where performance, durability, and safety are non-negotiable.

3.1 Agriculture



Modern agriculture is transforming, with the increasing electrification of tractors, harvesters, and other field machinery. Seasonal peaks in workload require energy systems that can deliver high bursts of power instantly while ensuring long-term reliability in harsh outdoor environments. LS ultracapacitors meet these demands by supplying immediate torque for hybrid drivetrains, auxiliary motors, and heavy-duty starting systems without imposing stress on batteries. Their ability to endure over one million cycles guarantees reliable operation year after year, reducing the cost and complexity of battery replacements. Unlike traditional batteries, ultracapacitors remain fully functional in extreme temperatures, from frosty mornings in early spring to the heat of midsummer harvests.

Quantified Benefits:

- **Peak Power Delivery:** up to **10–20x higher specific power** than lithium-ion batteries (up to 15 kW/kg vs. 1 kW/kg)
- **Cycle Life:** ultracapacitors exceed **1 million cycles**, compared to ~3,000 for lithium-ion, extending drivetrain reliability by **>300x**
- **Fuel Savings:** hybridization with ultracapacitors reduces diesel consumption by **10–20%** in heavy-duty field operations (e.g., plowing)
- **Battery Lifetime Extension:** by shifting peak power to ultracapacitors, lithium-ion packs can last **2–3x longer** (from ~5 years to ~10–12 years in seasonal usage)
- **Response Time:** full discharge/charge in **<1 second**, enabling immediate torque assist during load spikes

3.2 Heavy Industrial

Industrial environments, such as mining, construction, and material handling, expose power systems to shock, vibration, dust, and extreme temperatures. Equipment such as cranes, excavators, forklifts, and drilling machines demand immediate energy surges and must remain operational under the most challenging conditions. Ultracapacitors are uniquely suited for this environment, as they deliver peak current in tens of milliseconds, capture regenerative braking energy to improve efficiency, and operate reliably across a wide thermal range. Their long cycle life reduces downtime associated with frequent battery replacement, and their maintenance-free nature lowers the total cost of ownership.

Quantified Benefits:

- **Peak Power Delivery:** ultracapacitors supply surges up to 15–20 kW/kg, enabling safe lifting and acceleration of heavy loads
- **Response Speed:** current is delivered in <1 second, ensuring immediate torque availability for start-up operations
- **Energy Recovery:** regenerative braking can recapture 20–30% of energy (Note: this limitation is set by the efficiency chain of mechanical and electric power conversion; the UC itself may reach >90% efficiency), reused instantly for the next lift or movement
- **Cycle Life:** exceed 1,000,000 cycles, versus ~3,000 for lithium-ion or <1,000 for lead-acid batteries
- **Battery Lifetime Extension:** by absorbing peak loads, ultracapacitors reduce battery stress by 35–45%, extending service life from ~4 years to 8–10 years
- **Temperature Resilience:** reliable operation from -40 °C to +65 °C, critical for mining and outdoor construction sites
- **OPEX Reduction:** downtime and replacements cut, lowering total ownership costs by up to 25–30% over equipment lifetime

3.3 Automated Guided Vehicles (AGVs)

AGVs are increasingly deployed in factories, warehouses, and logistics hubs to enable 24/7 automated material handling. These vehicles face highly dynamic duty cycles, characterized by frequent acceleration and deceleration, as well as peak power demands during lifting or towing operations. Traditional batteries are subject to stress under such conditions, leading to premature aging, downtime, and increased operating costs. LS ultracapacitors address these challenges by providing instantaneous bursts of power, stabilizing DC bus voltage, and absorbing regenerative braking energy without degradation.

Quantified Benefits:

- **Peak Power Delivery:** Ultracapacitors can deliver **up to 10–15x higher power density** than lithium-ion batteries, ensuring smooth acceleration even under full load.
- **Cycle Life:** with **>1,000,000 cycles**, ultracapacitors outlast batteries by a factor of **300–400x** (AGVs typically demand >50,000 cycles per year)
- **Battery Lifetime Extension:** hybridizing with ultracapacitors reduces battery depth-of-discharge stress by ~**30–40%**, extending battery lifetime from ~3 years to **7–8 years**.
- **Energy Recovery:** during braking/stop cycles, up to **25–30% of kinetic energy** can be recuperated and reused instantly via ultracapacitors
- **Response Time:** Ultracapacitors supply and absorb current in tens of **milliseconds (<1s full charge/discharge)**, ensuring stable voltage during rapid duty cycles
- **Maintenance Savings:** fewer battery replacements can lower TCO (total cost of ownership) by **20–25%** across a fleet of AGVs over 10 years

3.4 Uninterruptible Power Supply (UPS)

UPS systems protect critical infrastructures, such as data centers, hospitals, telecom networks, and industrial control systems, by ensuring continuous power during outages or grid instability.

Ultracapacitors are an optimal choice for short-duration UPS, typically in the 1–10 second range, and in some cases up to 30–60 seconds, depending on system conditions. In high-power, short-duration UPS systems, ultracapacitors offer advantages in terms of cost, reliability, longevity, and performance.

Quantified Benefits:

- **Seamless Transition:** Provides power continuity for **1–60 seconds** with response time **<10 ms**, ensuring zero interruption to critical loads during grid outages
- **High Power Output:** Capable of delivering **10–20 kW/kg** in short bursts, supporting immediate high inrush currents required by servers, drives, and medical equipment
- **Energy Recapture Efficiency:** Charge/discharge efficiency up to **98%**, minimizing system losses and maximizing available backup power
- **Longevity:** Operational life expectancy of **10–15 years** without performance degradation, enabling long-term protection without replacement cycles
- **Thermal Robustness:** Stable operation across **–40 °C to +65 °C**, ensuring reliable backup in harsh or uncontrolled environments
- **Maintenance-Free Operation:** Requires no periodic replacement or capacity testing, reducing **OPEX by up to 30–40%** over system lifetime
- **Compactness:** By addressing power rather than energy, systems can be **30–50% smaller and lighter**, optimizing footprint in data centers, telecom shelters, and industrial control rooms

3.5 Transportation

The transportation sector is one of the most dynamic areas of ultracapacitor application. From buses and trains to ships and electric vehicles, modern transportation systems require rapid power exchanges for acceleration, regenerative braking, and start-stop cycles. Ultracapacitors excel in these roles by storing braking energy and releasing it instantly during acceleration. This reduces overall fuel consumption, lowers emissions, and extends the life of lithium-ion batteries by absorbing the most stressful power demands. Their robust performance across all climates ensures reliability in urban mobility, long-haul transportation, and harsh weather conditions.

Quantified Benefits:

- **Energy Recovery:** regenerative braking stores up to **25–30% of braking energy**, which can be reused during acceleration
- **Cycle Life:** ultracapacitors sustain **>1,000,000 cycles**, compared to ~3,000 for lithium-ion batteries
- **Battery Lifetime Extension:** by shifting acceleration peaks to ultracapacitors, battery lifetime can be extended by **2–3x**, from ~5 years to ~10–12 years
- **Fuel/Energy Savings:** hybrid bus fleets report **10–15% lower energy consumption** compared to battery-only designs
- **Response Time:** charge/discharge occurs in **milliseconds (<1s)**, ensuring seamless acceleration in stop-and-go urban traffic
- **Temperature Resilience:** reliable performance from –40 °C to +65 °C without degradation, ensuring operation in extreme climates

3.6 Signaling Systems

Signaling systems in railways and infrastructure networks are mission-critical, ensuring safety, punctuality, and communication across vast transportation networks. These systems must remain reliable under all conditions, from extreme heat to sub-zero temperatures, often in remote or inaccessible locations. Ultracapacitors provide instantaneous backup energy during voltage fluctuations or power outages, guaranteeing uninterrupted operation of signaling equipment. Here, the decisive factor is the immediate availability of power: ultracapacitors deliver the required current within milliseconds, preventing even the slightest disruption. Their extremely long cycle life reduces the need for frequent field interventions, lowering the total cost of ownership and minimizing operational risks associated with system downtime.

Quantified Benefits:

- **Instantaneous Backup:** ultracapacitors react in **<10 ms**, ensuring uninterrupted signaling during grid dips or blackouts
- **Cycle Life:** with **>1,000,000 cycles**, ultracapacitors last **200–300x longer** than lead-acid batteries (≈3,000 cycles)
- **Temperature Resilience:** full operation is guaranteed from **-40 °C to +65 °C**, critical for remote outdoor installations
- **Reduced Maintenance:** replacement intervals can be extended from ~3–5 years (batteries) to **>15 years** with ultracapacitors
- **System Reliability:** MTBF (mean time between failures) improves by **2–3x**, minimizing costly railway downtime
- **Cost Savings:** fewer field interventions reduce OPEX by up to **30%** over system lifetime

3.7 Grid

One of the most pressing challenges in modern power systems is the frequency stability of grids with high penetration of renewable energy sources. Solar and wind generation fluctuate rapidly based on weather conditions, while conventional fossil-fuel plants, which have historically provided grid inertia, are being phased out. This creates short-term imbalances between supply and demand, which, if uncorrected, can destabilize the grid and trigger cascading failures. Ultracapacitors are uniquely suited to addressing this problem because they can deliver or absorb large amounts of power within milliseconds. Unlike batteries, which are limited by their electrochemical reaction rates, ultracapacitors react instantly to frequency deviations, injecting or absorbing current as needed to restore grid balance. Their ability to cycle over one million times without degradation makes them a long-term, low-maintenance solution for continuous grid stabilization.

Quantified Benefits:

- **Response Speed:** ultracapacitors inject/absorb current in **<50 ms**, compared to 1–10 seconds for lithium-ion batteries
- **Power Density:** deliver up to **10–15 kW/kg**, ensuring rapid correction of short-term imbalances
- **Cycle Life:** exceed **1,000,000 cycles**, while lithium-ion cells typically reach ~5,000 cycles—**200x improvement**
- **Grid Stability:** frequency deviations can be corrected within **±0.1 Hz**, supporting compliance with ENTSO-E and IEEE standards. The demand fulfilled by the ultracapacitor is typically 0.1 Hz/s continuously, 2.5 Hz/s for 2s, and a phase jump above 25° for 1s
- **Temperature Range:** full functionality from **-40 °C to +65 °C**, critical for field substations exposed to harsh climates
- **Operational Expense Reduction:** ultracapacitor-based systems cut replacement and maintenance costs by **25–35%** over a 15–20 year lifetime

4. Ultracapacitors vs. Batteries: A Detailed Technical Comparison

Ultracapacitors and rechargeable batteries address different parts of the energy–power spectrum. LS Materials ultracapacitors store energy through purely physical charge separation (electric double layer) rather than electrochemical reactions, enabling high-power delivery, rapid cycling, and a long service life. Batteries, by contrast, rely on chemical intercalation/conversion, which offers much higher specific energy but with slower dynamics and finite cycle life due to degradation mechanisms. LS Materials' product data and technical notes consistently position ultracapacitors for applications with frequent, high-current, short-duration events and wide temperature operation, while acknowledging the complementary role of batteries where energy capacity dominates

Technology	Typical Key Performance Characteristics	Primary Advantages
Ultracapacitor Cells (LSUC Series)	• 2.7-3.0 V per cell • 5F - 3400F • Very low ESR • >1,000,000 cycles • Operating range: -40 °C to +65 °C	• Extremely high power density • Instant charge/discharge • Long service life (>10 years) • Multiple form factors and terminal options
Ultracapacitor Modules (LSUM Series)	• 16 V - 400 V • 50F - 500F typical • Active/passive balancing • CAN communication & monitoring • Scalable Cell-to-Cell architecture	• Ready-to-use assemblies • Enhanced safety with monitoring • Simplified integration • Flexible and customizable configurations
UltraGrid Rack Systems	• Up to 1,440 V nominal (72 kV max series) • >2 kWh capacity • 10 modules per rack • Seismic & thermal compliance • 19" rack standard format	• Grid-scale scalability • Robust, maintenance-free design • Long lifetime and reliability • Easy integration into infrastructure

4.1 Energy Density vs. Power Delivery

Batteries lead in energy density: typical lithium-ion "energy cells" cluster around **~200–250 Wh/kg**, with many commercial implementations cited near **~200 Wh/kg**; LS Materials' brochure uses **~200 Wh/kg** as a representative Li-ion figure. Ultracapacitors, by design, trade energy for power and cycle life; their energy density is orders of magnitude lower than that of Li-ion batteries, but their **specific power** is far higher, and they deliver energy in milliseconds. LS materials Brochure Low LS modules and racks quantify this trade-off at the system level. For example, the **LSUM 144R0C 0070F EA** module (144 V, 70.8 F) provides **~204 Wh** of stored energy, suitable for high-power bridging and cycling; the **UltraGrid 19" rack** scales to **~2,040 Wh** at 1,440 V nominal with a max series rating of 72 kV, illustrating how system integration can raise total energy while preserving ultracapacitor power advantages. In practice, the **Ragone-plot** positioning means that batteries serve energy-oriented duties (minutes to hours), while ultracapacitors excel at power-oriented duties (milliseconds to seconds), particularly when numerous charge/discharge events occur.

Li - ion Battery		VS		Ultracapacitor
Low		Power Density		High
Under 5000cycles		Cycle Life		Over 1 Million Cycles
High		Energy Density		Low
Chemical reaction		Operating Principle		Physical movement of charges
0°C ~ +45 °C		Operating Temp.		-40°C ~ +65°C
Possible		Risk of Thermal runaway		Not Possible
Anode	Lithium & other metals	Composition Materials	Anode	Activated Carbon
Cathode	Graphite		Cathode	Activated Carbon
Electrolyte	Lithium salts and organic solvents		Electrolyte	Ammonium-based organic solvent

4.2 Cycle life and durability

According to LS ultracapacitor literature, projected cycle life can reach up to 1,000,000 cycles at 25°C with less than 20% capacitance change and 100% ESR change—an order of magnitude beyond typical battery figures. The modules are also specified for a 10-year projected life at 25°C and an operating range of –40°C to +65°C. For comparison, independent references describe consumer-grade lithium-ion batteries as typically offering 1,000 to 3,000 cycles at full depth of discharge. Li-ion battery longevity is strongly affected by temperature and voltage ceilings and can be significantly extended with partial cycling. While some manufacturer brochures may cite more conservative figures (~400 cycles on a 100% DoD basis), the higher range is more representative of modern, mainstream chemistries.

4.3 Efficiency and transient response

Ultracapacitors are **high-efficiency** devices in power cycling; LS materials are characterized by very frequent, high-current; short-duration use with minimal losses and an immediate response. System notes for LS modules show **low-ESR designs purpose-built for high currents (e.g., 3,200 A peak for LSUM 144R0C 0070F EA) and thermal paths sized for continuous-current** constraints (ΔT-based). For lithium-ion, the LS brochure lists **charge/discharge efficiency ~80–90%** and **specific power ~0.2–0.4 kW/kg**, highlighting slower transient response vs. ultracapacitors.

4.4 Temperature performance

LS ultracapacitors operate broadly from **–40 °C to +65 °C** at the module level, suitable for outdoor and industrial environments. System racks (UltraGrid) provide mechanical robustness (e.g., IEEE 693 **seismic analysis**) and thermal protection for infrastructure deployments.
Lithium-ion batteries typically **discharge** between approximately –20 °C and +60 °C, while charging is usually restricted to 0–45 °C to prevent damage, a constraint widely documented in technical guidance. Elevated temperatures and high states-of-charge accelerate degradation.

4.5 Safety mechanisms and failure modes

Because ultracapacitors store energy **electrostatically**, they avoid the **exothermic runaway** mechanisms

associated with battery chemistry. LS datasheets emphasize RoHS/REACH compliance, robust insulation, and controlled peak current usage; modules and racks incorporate **monitoring, balancing, and isolation ratings** (e.g., **4.0 kV** terminal-to-case, UltraGrid **>72 kV** cabinet-to-ground isolator option). Batteries necessarily carry **reaction-driven** risk envelopes; vendor-neutral guidance cautions about **temperature** and **over-voltage** conditions that can precipitate failure, hence the stricter charge/discharge windows and BMS constraints.

4.6 Monitoring, balancing, and controls

LS modules integrate **single-cell monitoring** (e.g., 48-channel cell voltage on LSUM 144R0C 0070F EA), **temperature sensing**, and **Smart Single-Cell Balancing** with **CAN J1939** communications for SoH/SoA reporting. The **CTC (Cell-to-Cell) architecture** scales modules **16–108 V** with flexible balancing and optional group-voltage monitoring, streamlining integration. Battery systems also require BMS, often with stricter **cell balancing and thermal management to protect the chemistry and meet charge-temperature** constraints.

4.7 Maintenance and total cost of ownership (TCO)

With **over 1 million cycles and projections of over 10 years at 25 °C, ultracapacitors significantly reduce field replacements compared** to many battery systems. For LS, this is explicit in both the module and rack-level specifications. By design, there is **no periodic capacity recalibration** or deep-cycle conditioning. Batteries incur **capacity fade** with cycling, time, and heat exposure; standard practice involves scheduled replacements, environmental conditioning, and stricter charging regimes to preserve life factors that influence TCO beyond purchase price.

4.8 Self-discharge and storage

Ultracapacitors typically exhibit higher self-discharge rates than lithium-ion cells due to their physical storage mechanism and very low ESR pathways. In cycling applications, this is rarely limiting because energy is transferred frequently. Long-term **standby** applications favor battery chemistries unless bridged by periodic top-ups or hybrid strategies.

4.9 Standards, compliance, and robustness

LS documentation lists **RoHS** and **REACH** compliance across modules and racks, insulation strength, leakage current guidelines (dependent on balancing), and mechanical robustness (including dimensions, mass, mounting, and shock/vibration references). UltraGrid further cites **IEEE-693** seismic conformance (moderate) and **optional enclosures**.

4.10 Hybrid architecture: combining strengths

LS explicitly recommends an ultracapacitor + Li-ion topology to improve **system efficiency**, ensure **fast response even as batteries age**, and **extend battery life by shaving peak loads**. In these architectures, the ultracapacitor handles **spikes, regenerative capture, and start/acceleration**, while the battery provides **energy** over longer intervals. This approach is consistent with the control features built into LSUM modules (CAN, SoH/SoA, balancing) and with the scale provided by UltraGrid racks for infrastructure.

5. Technology Leadership and Proven Legacy

For over 75 years, **Richardson Electronics** has been an industry-leading global provider of engineered solutions, RF & microwave, and power products. The Power & Microwave Technologies group continues this legacy, complementing it with new products from the world's most innovative technology partners. Richardson Electronics' Power & Microwave Technologies group focuses on what we do best: identifying and designing disruptive technologies, introducing new products on a global basis, developing solutions for our customers, and providing exceptional worldwide support. As a global company, we provide solutions and add value through design-in support, systems integration, prototype design and manufacturing, testing, logistics, and aftermarket technical service and repair—all through our existing global infrastructure.

Richardson Electronics has locations around the world and a 250,000 sq. ft. manufacturing facility located in LaFox, IL (50 miles outside of Chicago). We manufacture a wide variety of RF and microwave components, electron tubes and vacuum devices, and other engineered solutions, such as energy storage modules and power management devices. Our capabilities extend from concept to final release, including design, development, sourcing, manufacturing, and testing.

Richardson's engineered solutions approach puts your needs first while leveraging our expertise in both design and manufacturing. With our passion for product quality, we have built a reputation for unmatched reliability. We stand behind every product we deliver — with our exclusive testing protocols, expert engineering team, and state-of-the-art manufacturing facility, you can be confident that Richardson Electronics is the better choice for your engineered solutions.

LS Materials was founded in 2021 as a spin-off from LS Mtron, but its ultracapacitor expertise is built on more than twenty years of R&D and industrial-scale manufacturing. Over two decades, LS engineers achieved key technology milestones, including the development of large-format 2.8V and 3.0V cells, high-capacitance cylindrical cells exceeding 3000F, and Cell-to-Cell module architecture. These advances established core competencies in electrode design, cell engineering, and module integration, positioning LS Materials as a global technology leader supported by certified, high-volume manufacturing in Korea and a global customer base.

Many applications demand more than standard, off-the-shelf ultracapacitor solutions. **As a certified LS Materials integrator, Richardson Electronics** offers full engineering support for custom module and system designs—from concept through production. Our engineering team collaborates directly with customers to develop solutions optimized for specific electrical, mechanical, and thermal requirements, ensuring seamless integration into existing architectures.

Whether you need a complete custom design or a build-to-print solution, **Richardson Electronics** provides comprehensive services, including design validation, testing, documentation, and certification to meet the most rigorous industry standards. Our in-house manufacturing and quality assurance capabilities ensure each system is built to perform reliably in demanding environments, delivering consistent performance, safety, and long service life.

6. LS Materials: Product Portfolio

LS Materials has developed a comprehensive portfolio of ultracapacitor solutions tailored to meet the diverse needs of modern industries. From compact cylindrical cells to large-scale rack systems, the product range is structured to provide scalability, reliability, and safety at every level of energy storage. This approach enables customers to integrate ultracapacitors into virtually any system, from agricultural machinery and industrial automation to critical infrastructure and grid-stabilization projects.

6.1 Ultracapacitor Cells (LSUC Series)

Ultracapacitor cells represent the core building blocks of the LS Materials portfolio. They are engineered to deliver extremely high-power density and unmatched cycle life, making them suitable for applications that require rapid charge and discharge cycles. Their compact form factors and versatile terminal options ensure ease of integration across a wide range of systems, while their robustness guarantees stable performance even in the harshest environments.

- Capacitance ranges from **100F up to 3,400F**, with rated voltages of **2.7V to 3.0V**
- New small cell line card from 5F up to 100F @3V, diameters from 10mm up to 18mm
- Very low equivalent series resistance (ESR), enabling high-current operation with minimal energy losses
- Manufactured in multiple diameters: **22 mm, 33 mm, 35 mm, and 60 mm**, supporting both compact and heavy-duty designs
- Wide selection of terminal types: **snap-in, lug, weldable, and screw**, ensuring compatibility with diverse assembly methods
- Designed for more than **1,000,000 charge/discharge cycles**, ensuring >10 years of lifetime in most applications
- Operational reliability across a broad temperature range from **–40 °C to +65 °C**, allowing use in outdoor, industrial, and automotive environments
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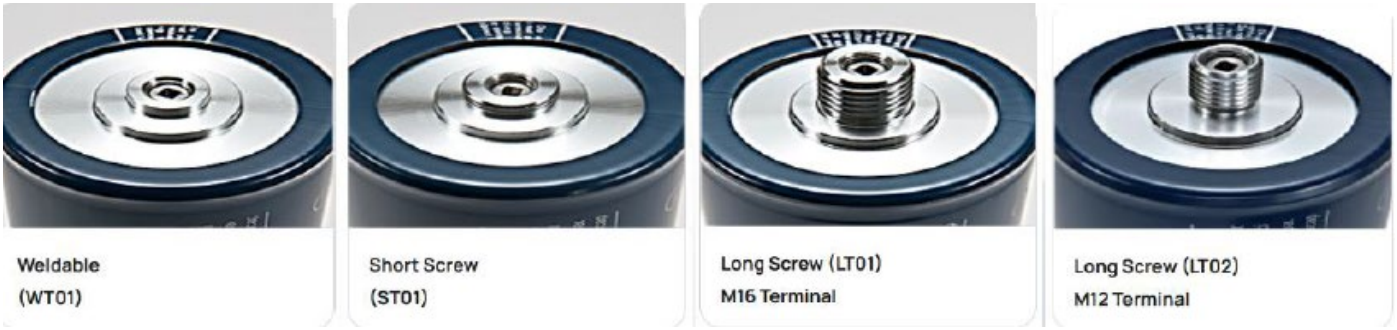


6.2 Ultracapacitor Modules (LSUM Series)

Modules combine multiple ultracapacitor cells into pre-assembled units that deliver higher voltage and optimized performance for specific applications. LS Materials offers several module architectures, each designed to meet different market requirements, from compact electronics to industrial-scale machinery. These modules not only simplify integration but also provide embedded balancing and monitoring systems to guarantee long-term stability and safety.

- Voltage range from **16V to over 400**, covering typical requirements for transportation, industrial, and backup systems
- **PCB-type modules** optimized for compact integration where space is limited
- **Busbar-type modules** designed for heavy-duty applications requiring high currents and low resistance
- **Cell-to-Cell (CTC) modules**, fully scalable and customizable, offering design flexibility without additional development costs
- Available with **active or passive balancing systems** that equalize cell voltage and extend module lifetime
- Integrated monitoring functions include **temperature sensors, cell voltage measurement, and CAN communication protocols**, providing real-time diagnostics and enhanced system control

6.3 UltraGrid Rack Systems

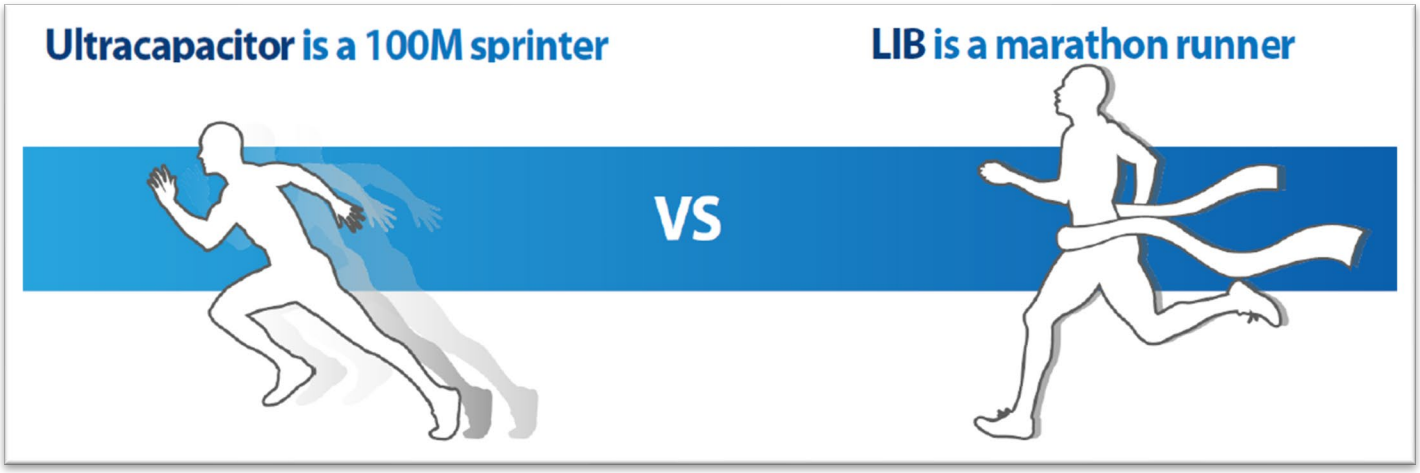
At the top of the LS Materials portfolio are UltraGrid rack systems, large-scale ultracapacitor solutions designed for demanding grid and industrial applications. These systems are engineered to deliver high energy storage capacity, stability, and robustness, all packaged in standardized 19-inch rack formats. UltraGrid systems are particularly well-suited for renewable energy integration, frequency regulation, industrial UPS, and infrastructure requiring immediate, maintenance-free backup power.

- Nominal voltages up to **1,440V**, with maximum series ratings of **72 kV** for high-voltage grid-level operation
- Energy capacity exceeding **2 kWh** per cabinet, providing significant storage for buffering, stabilization, and peak power support
- Modular architecture with **10 modules in series plus CPU control units**, packaged in **43U 19-inch racks**
- Built to meet **seismic compliance (IEEE-693)** and equipped with **thermal protection and safety enclosures**, ensuring operational reliability in critical infrastructure
- Designed for easy scalability, allowing parallel rack configurations to reach megawatt-hour level installations
- Applications include **hybrid energy storage, grid stabilization, large-scale industrial, and artificial intelligence data centers**

- **Portfolio Advantages and Strategic Value.** What unites the LS Materials product family is a consistent focus on safety, reliability, and performance across all levels of the portfolio. Whether used in small-scale electronic devices, industrial automation, or grid infrastructure, LS ultracapacitors provide a durable and efficient energy storage solution.
- Certified to **RoHS, REACH, UL** (for specific products), and compliant with quality and environmental standards such as **IATF 16949 and ISO 14001**
- Long operating life exceeding **1,000,000 cycles** and projected service durations beyond **10 years**, reducing the total cost of ownership
- Intrinsically safe technology with no risk of fire or explosion, unlike conventional chemical batteries
- Maintenance-free operation, reducing field interventions and lowering lifecycle costs
- A modular design philosophy that supports **seamless scalability**, from individual components to full grid-level installations

7. Conclusion and Outlook

- **Choose batteries** when run-time/energy is the constraint and duty cycles are slow/moderate with controlled temperatures (e.g., hours of backup). LS brochure uses ~200 Wh/kg as a representative Li-ion energy density, with 0–45 °C charge window and ~80–90% efficiency.
- **Choose ultracapacitors** when power, cycling, and temperature range dominate: –40 °C to +65 °C, instantaneous response, >1M cycles, and high peak currents (e.g., LSUM 144R0C 0070F EA with 3.2 kA peak; UltraGrid with 3.1 kA system rating).
- **Choose hybrids** to reduce battery stress, increase efficiency, and add power-quality headroom—an approach LS documents explicitly as a best practice.



The journey through the LS Materials portfolio highlights a consistent theme: ultracapacitors are not merely components but **enabling technologies** that redefine the way industries manage energy. From the smallest cylindrical cell to multi-kilowatt-hour rack systems, LS Materials offers a continuum of solutions that can be integrated across diverse sectors, including agriculture, heavy industry, transportation, UPS, signaling, and grid infrastructure.

Richardson Electronics - Ultracapacitor Solutions

The **synergy between Richardson Electronics and LS Materials** ensures that customers receive more than just hardware; they also receive comprehensive support. Together, they deliver technical expertise, system-level guidance, and global supply chain reliability, transforming ultracapacitors into strategic assets rather than commodity parts. This partnership closes the gap between product innovation and successful application in real-world systems. At the heart of the portfolio lies a **clear technological distinction**. Unlike batteries, which prioritize energy density at the cost of cycle life and safety margins, ultracapacitors rely on electrostatic charge separation to deliver instantaneous power, long lifetimes exceeding one million cycles, and consistent performance across extreme temperature ranges. The comparison demonstrates that ultracapacitors excel where power density, cycling, and robustness are critical, while batteries remain valuable where long-duration energy storage is the primary concern. Hybrid architectures that combine the two technologies are already proving to be a powerful solution, balancing energy and power to create systems that are safer, more efficient, and longer lasting. Hybrid architectures that combine the two technologies are already proving to be a powerful solution, balancing energy and power to create systems that are safer, more efficient, and longer lasting, in some applications featuring ultracapacitors in combination not only with batteries but also with primary energy sources such as hydrogen fuel cells, internal combustion engines, or the grid itself.

The **LS Materials portfolio** is strategically structured:

- **LSUC cells** provide the foundational building blocks with unmatched cycling capability.
- **LSUM modules** extend this into scalable, ready-to-integrate solutions with monitoring and balancing features.
- **UltraGrid rack systems** bring ultracapacitors to the grid and industrial scale, with capacities exceeding 2 kWh and compliance with seismic and safety standards.

In practical applications, this translates to reliability in **agriculture, robustness in heavy industry, instantaneous backup for UPS systems, efficiency in transportation, safety in signaling, and resilience for the grid.** Each sector benefits from the unique strengths of ultracapacitors, which replace or complement traditional batteries to deliver measurable improvements in performance and cost of ownership.

Looking ahead, LS Materials continues to advance its technological roadmap with next-generation cells reaching higher capacitance values and 3.0 V ratings, while Richardson Electronics supports customers in adopting hybrid storage strategies tailored to evolving market needs. As global demand for reliable, safe, and sustainable energy solutions intensifies, the role of ultracapacitors will expand even further—from niche applications into mainstream energy infrastructure.

In conclusion, LS Materials ultracapacitors, backed by Richardson Electronics' engineering-driven support, represent a **strategic choice for industries preparing for the energy challenges of tomorrow**. They offer not only technical superiority but also peace of mind: systems that respond instantly, last longer, and operate safely under the most demanding conditions. By integrating ultracapacitors into their designs today, companies ensure a future that is more reliable, efficient, and sustainable.

Disclaimer

Portions of this white paper were developed with the assistance of artificial intelligence tools. All content has been reviewed, edited, and validated by subject matter experts to ensure accuracy and alignment with the company's standards.