





The future  
is here. Now.

## Why Ultracapacitors?

Over the next decade and beyond, automotive companies like yours will be required to achieve dramatic, and at times formidable, improvements in CO<sub>2</sub> emissions to satisfy stricter emission standards.

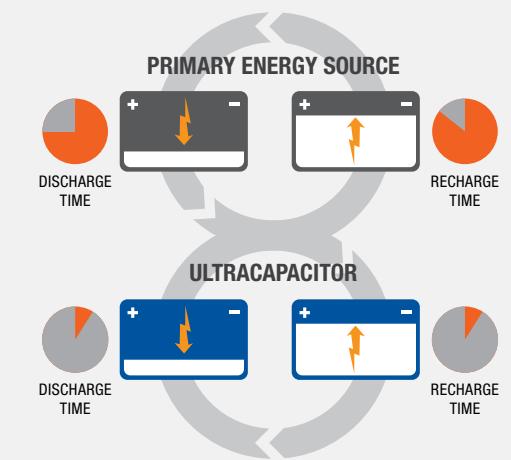
At the same time, consumer demand for more fuel-efficient vehicles continues to drive automotive research and development to reduce weight and fuel consumption, manage continuously increasing internal power loads and harness regenerative energy.

As a result, additional applications for ultracapacitors continue to emerge in the automotive ecosystem, both in conjunction

with batteries and as ultracapacitor-only solutions. These applications include regenerative braking systems, start-stop systems, active suspension systems, voltage stabilization systems and other higher power functions within the automotive boardnet.

Maxwell Technologies is at the forefront of these exciting new automotive developments.

PRIMARY ENERGY SOURCES, like internal combustion engines, fuel cells and batteries, work well as a continuous source of low power. However, they cannot efficiently handle peak power demands or recapture energy in today's applications because they discharge and recharge slowly.



ULTRACAPACITORS deliver quick bursts of energy during peak power demands, then quickly store energy and capture excess power that is otherwise lost. They efficiently complement a primary energy source in today's applications because they discharge and recharge quickly.



Our world-class research and product development teams have established Maxwell Technologies as a global leader in developing, manufacturing and marketing energy storage and power delivery solutions for heavy transportation, renewable energy, backup power, wireless communications, industrial and consumer electronics applications and the automotive industry.

Maxwell products are designed and built to provide consistently superior, failure-free performance for the life of the most demanding applications.

As a market leader and innovator, Maxwell is committed to providing cost-effective, energy-efficient and environmentally conscious energy storage and power delivery solutions that extend the limits of current conventions. Our

success is built on providing unmatched total solutions to our customers – solutions that deliver superior performance, reliability and value, backed by extraordinary application engineering and field support. Our goal is to build long-term customer relationships by listening, understanding customer-specific requirements and exceeding expectations for value and performance.



MAXWELL'S PATENTED MANUFACTURING PROCESS utilizes high-purity activated carbon for our industry-leading ultracapacitors – the amazingly compact, power-dense, energy storage and delivery devices used in boardnet stabilization, distributed power, regenerative braking and more.



#### **K2 2.85V/3400F Cell**

The newest member of Maxwell's K2 family of ultracapacitors is the 2.85 volt, 3400 farad cell with our new DuraBlue™ Advanced Shock & Vibration Technology. It expands the power range of the K2 family by 17% and the energy range by 23%, making it the most powerful cell available in the industry-standard 60 mm cylindrical form factor.



#### **K2 2.7V Series**

Maxwell's K2 2.7V series of ultracapacitor cells provide extended power availability, allowing critical information and functions to remain available during dips, sags and outages in the main power source.



#### **D Cell Series**

Maxwell's D Cell® series ultracapacitor cells are ideal for automotive boardnet stabilization, medical devices, uninterruptible power supplies, backup power and pulse, wind turbine pitch control and many other applications requiring a pulse of energy that cannot be efficiently provided by a battery or power supply alone.



#### **HC Series**

The HC series is also an ideal source of backup. It can provide extended power availability, allowing critical information and functions to remain available during dips, sags and outages in a power supply or battery change. And, like all our ultracapacitor products, the HC series is capable of accepting charges at 95 to 97% rate of discharge.



Maxwell  
is here.

## We're already on the road

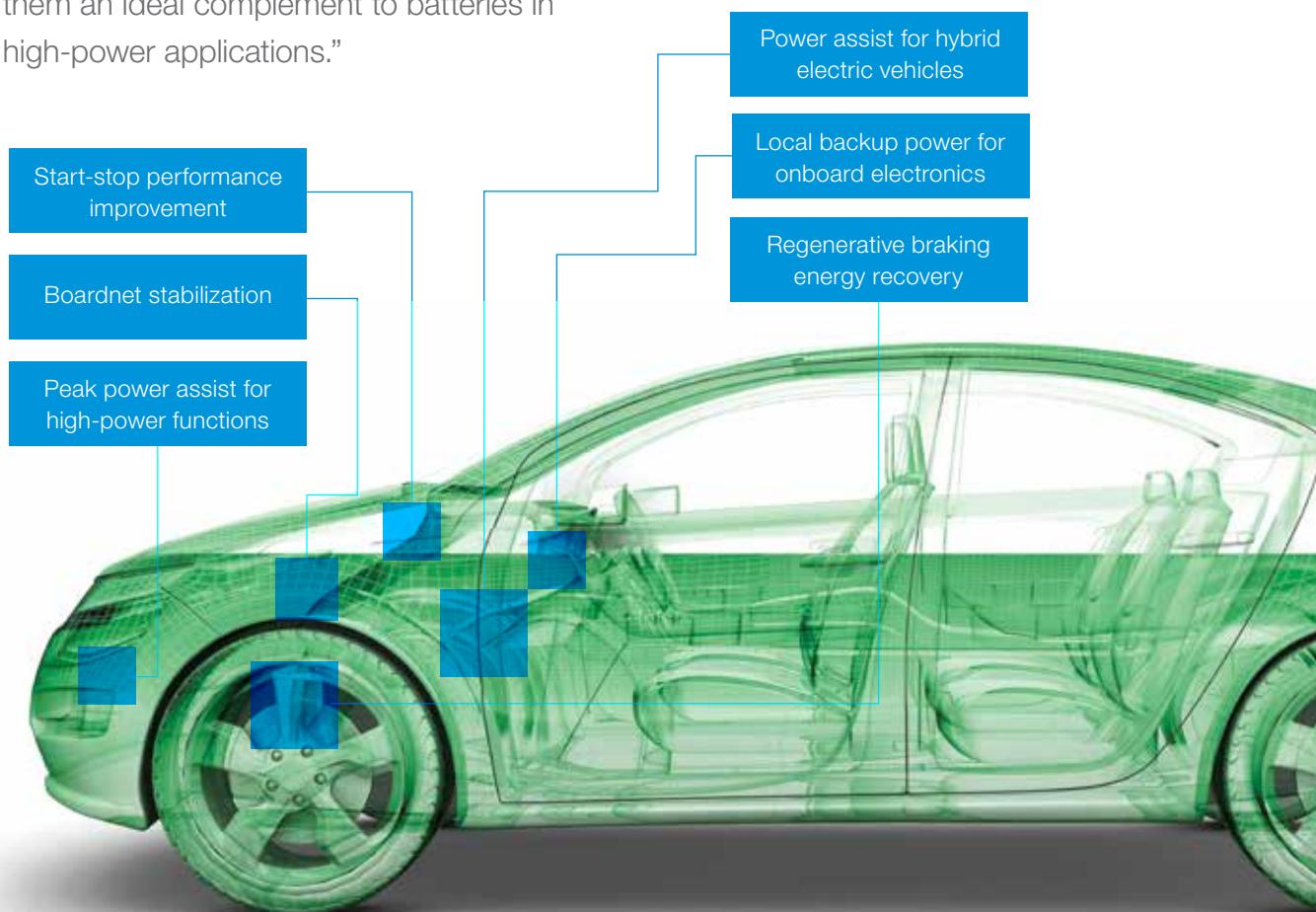
Because Maxwell ultracapacitors hold the required automotive-quality certifications, deliver high power and can accept a high rate of charge, they're ideal for the wide array of emerging automotive applications.

More companies are joining the ranks of Continental, which developed an ultracapacitor-based voltage stabilization system for PSA Peugeot Citroën and Lamborghini that uses ultracapacitors in their start-stop systems. As you are reading this, Maxwell ultracapacitors are already installed in more than 1 million vehicles currently on the road.

### And we've been recognized as a Gartner Cool Vendor

As a result of the increasing relevancy of ultracapacitors, Gartner has chosen Maxwell as a "Cool Vendor" in automotive electronics. Gartner research director James Hines recently wrote, "The high costs and adverse environmental impacts of consuming petroleum-based fuels are driving development of alternative fuels and higher efficiency automotive powertrains. Ultracapacitors are capable of releasing

electrical energy at high power levels, and they can accept a high rate of charge, making them an ideal complement to batteries in high-power applications."





Capture.  
Store.  
Re-use.

In regenerative systems, energy is captured and then re-used at a later time. The energy capture comes from the vehicle braking system, and is subsequently used in acceleration or for boardnet support in vehicle architectures. These events are typically short in duration (lasting just seconds), but very high in power.

Ultracapacitors provide an ideal solution as the energy storage device for these applications. With their high power capability, ultracapacitors are more efficient at recapturing and storing energy, especially when it comes in bursts.

## Power

Charge efficiency is the rate at which an energy storage device or system can be charged or discharged. Rapid, deep discharges to power vehicle acceleration apply stress to batteries and shorten their life. To overcome charge/discharge rate limitations and make rechargeable hybrid and electric application batteries last longer, they typically are oversized, adding to the volume, weight and cost of the energy storage system. The ultracapacitor's ability to recharge, virtually instantaneously, is of great benefit in regenerative energy systems.

## Performance

Batteries generate and store electrical energy in a narrow temperature range. Batteries perform poorly at low temperatures,

and the high temperatures common in engine compartments also impair battery performance, shorten battery life and can create serious safety hazards. The ultracapacitor's ability to retain and release a burst of power in extreme cold environments (all the way down to  $-40^{\circ}\text{F}/-40^{\circ}\text{C}$ ) is another reason to utilize ultracapacitors for regenerative energy applications.

## Life

Every battery has a finite operational life and wears out after hundreds to a few thousand charge/discharge cycles. To extend battery life and eliminate costly replacement, system designers build in power electronics that limit charge rate and depth of discharge. In compensating for those limitations, the battery must be built oversized – meaning

hybrid and electric applications must haul around large, heavy and expensive battery systems. Ultracapacitors, on the other hand, perform reliably for hundreds of thousands charge/discharge cycles, effectively lasting the entire life of the application. Scientists at the Argonne National Laboratory have demonstrated that an integrated system combining batteries with ultracapacitors dramatically improves braking energy recuperation efficiency and eliminates the need for battery oversizing – increasing the life of the battery while reducing the weight and cost of the entire system.



Start.  
Stop.  
Repeat.

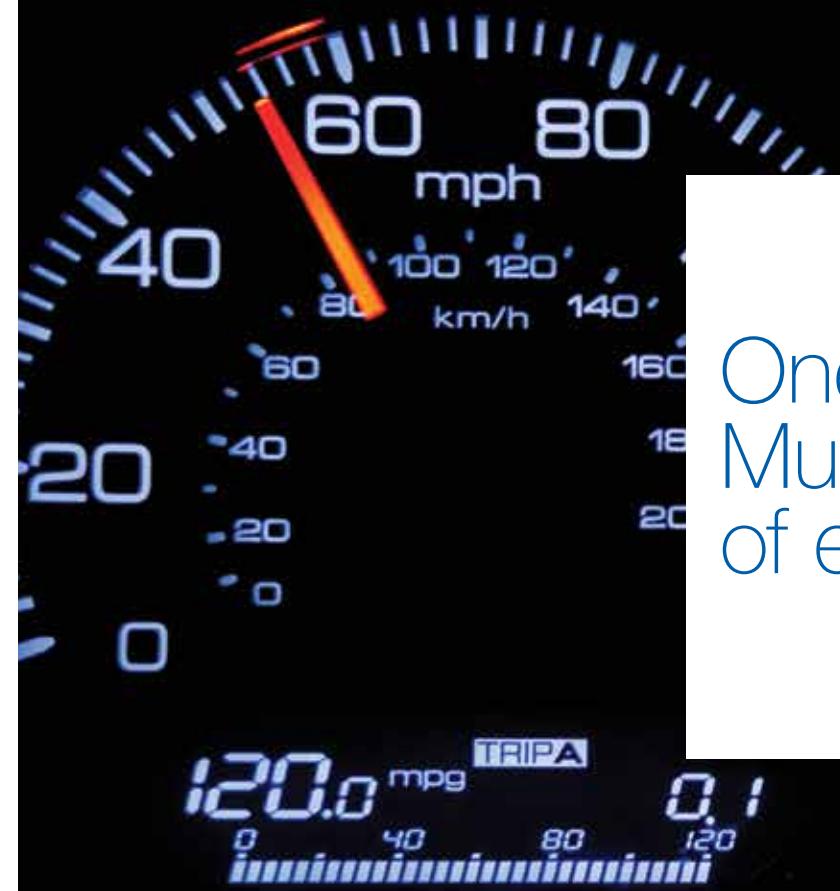


Also known as micro-hybrid technology, start-stop technology enables the engine in a conventional or hybrid-electric vehicle to shut down when it comes to a stop at a red light, or while sitting in traffic.

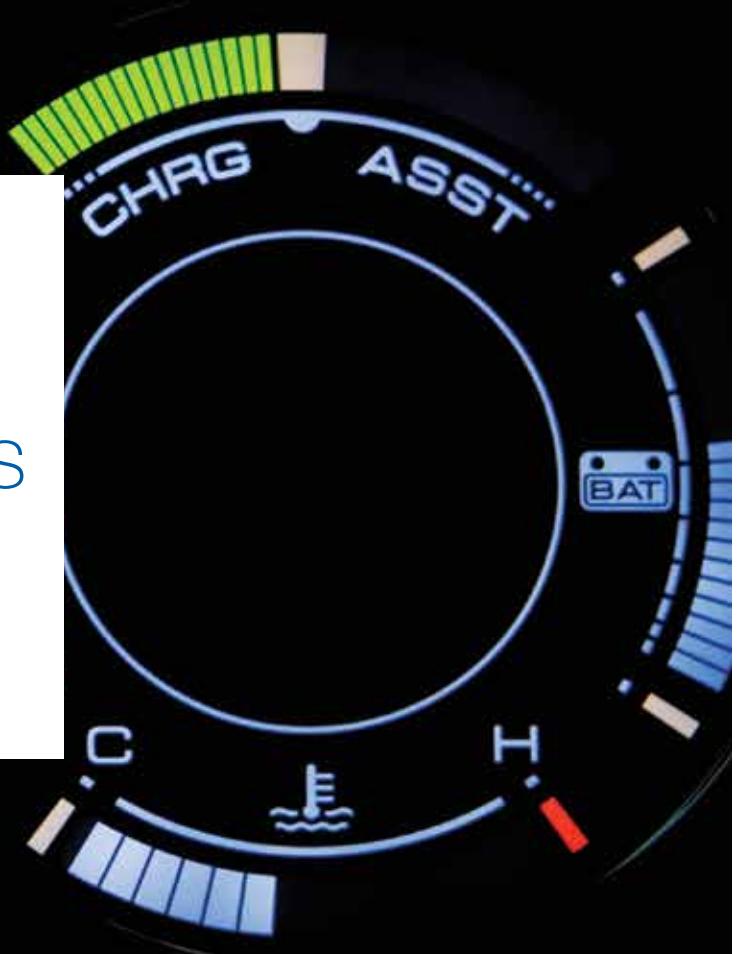
### An intelligent combination

This system is based on an intelligent combination of engine, brake and power management. When a vehicle is at a standstill, the start-stop system will shut down the internal combustion engine, providing improved fuel economy. As soon as the driver depresses the clutch or brake pedal, the system automatically restarts the engine. Maxwell's ultracapacitors are installed in more than 1 million vehicles to support the restart of the engine during a start-stop event.





One vehicle.  
Multiple forms  
of energy.



A vehicle is considered a hybrid if it utilizes more than one form of onboard energy to achieve propulsion. In everyday applications, that means a hybrid will have a traditional internal combustion engine and a fuel tank, as well as one or more electric motors and a battery pack. There are different degrees of hybridization.

### Mild hybrids

In mild hybrid vehicles, the electric motor adds thrust to the combustion engine. Mild hybrids are not capable of purely electric driving.

### Full hybrids (including PHEV)

In full hybrid vehicles, the electric motor not only adds thrust to the combustion engine, it also enables pure electric driving.

### The power of ultracapacitors combined with the energy of batteries

In hybrid and other applications, ultracapacitors combined with the energy of batteries provide the following benefits:



Enables rapid response times

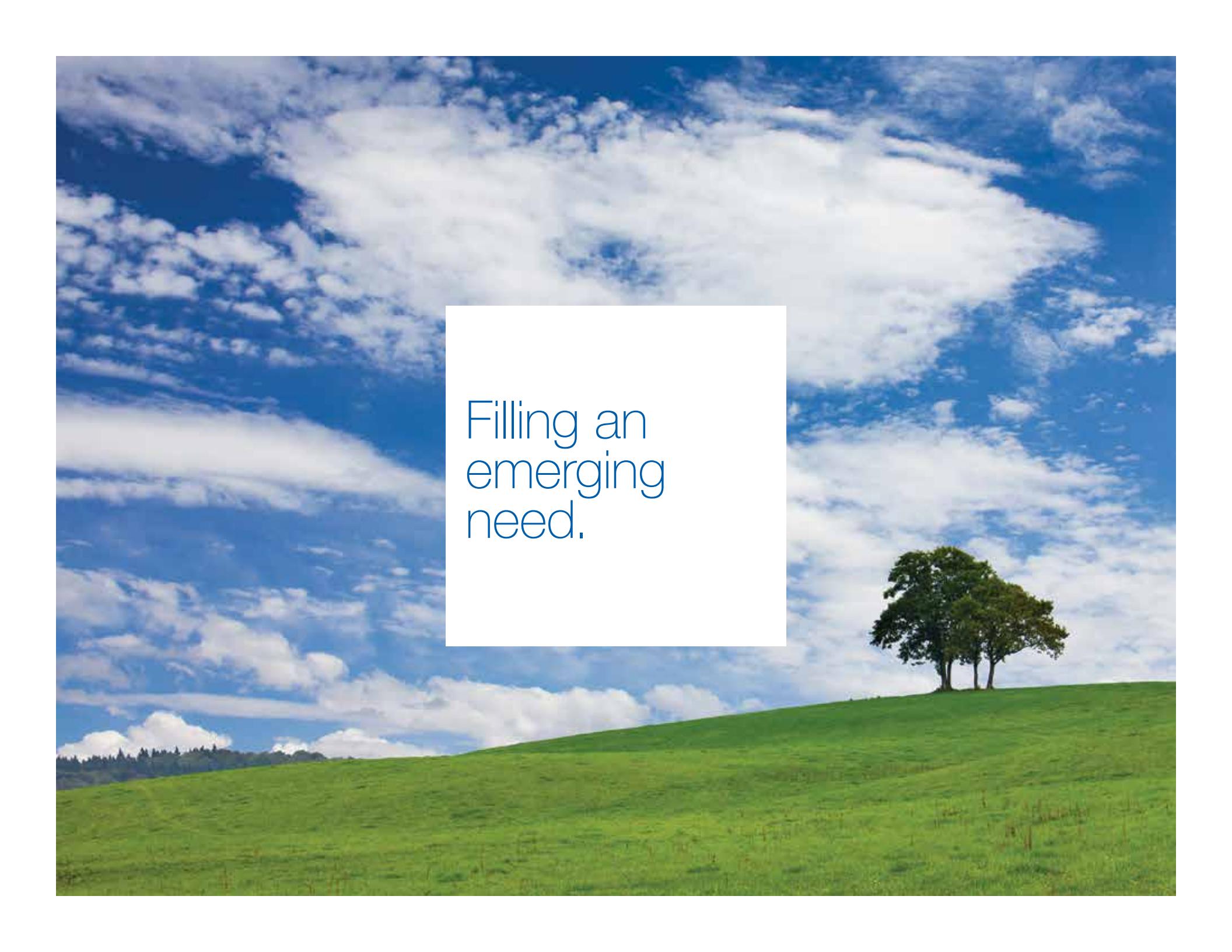


Extends operational temperature range



Lengthens battery life by up to 2x<sup>1</sup>





Filling an  
emerging  
need.



OEMs are facing several challenges in the automotive world – the need for CO<sub>2</sub> reduction, constant change in electric vehicle trends and new boardnet architectures (e.g. 48V) needed to support innovative comfort and safety features.

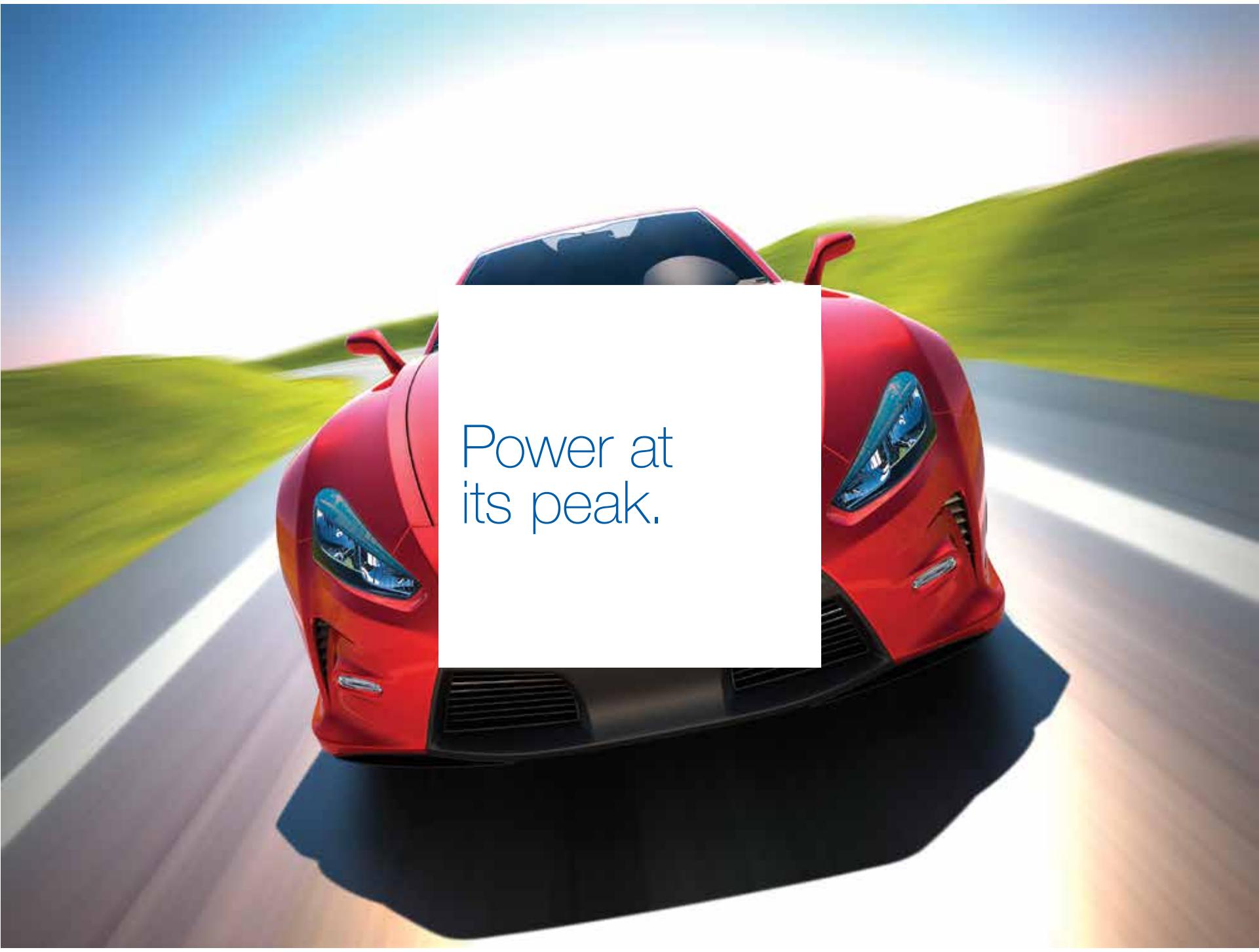
Advanced auto features will improve driver safety and overall driver experience, but will also place high demands on the main power source, the vehicle's battery. This is where Maxwell's ultracapacitors enter the picture.

Ultracapacitors are a reliable backup power solution when the battery fails. Ultracapacitors require little to no maintenance, have long operational lifetimes and can operate at wide temperature ranges (−40°F to 149°F/−40°C to 65°C). For automotive applications, you couldn't ask for a more hardy backup power solution.

#### Examples of backup applications

- Automatic Gearbox Backup Systems
- Automatic Crash Response Systems
- X-by-Wire Controllers





Power at  
its peak.

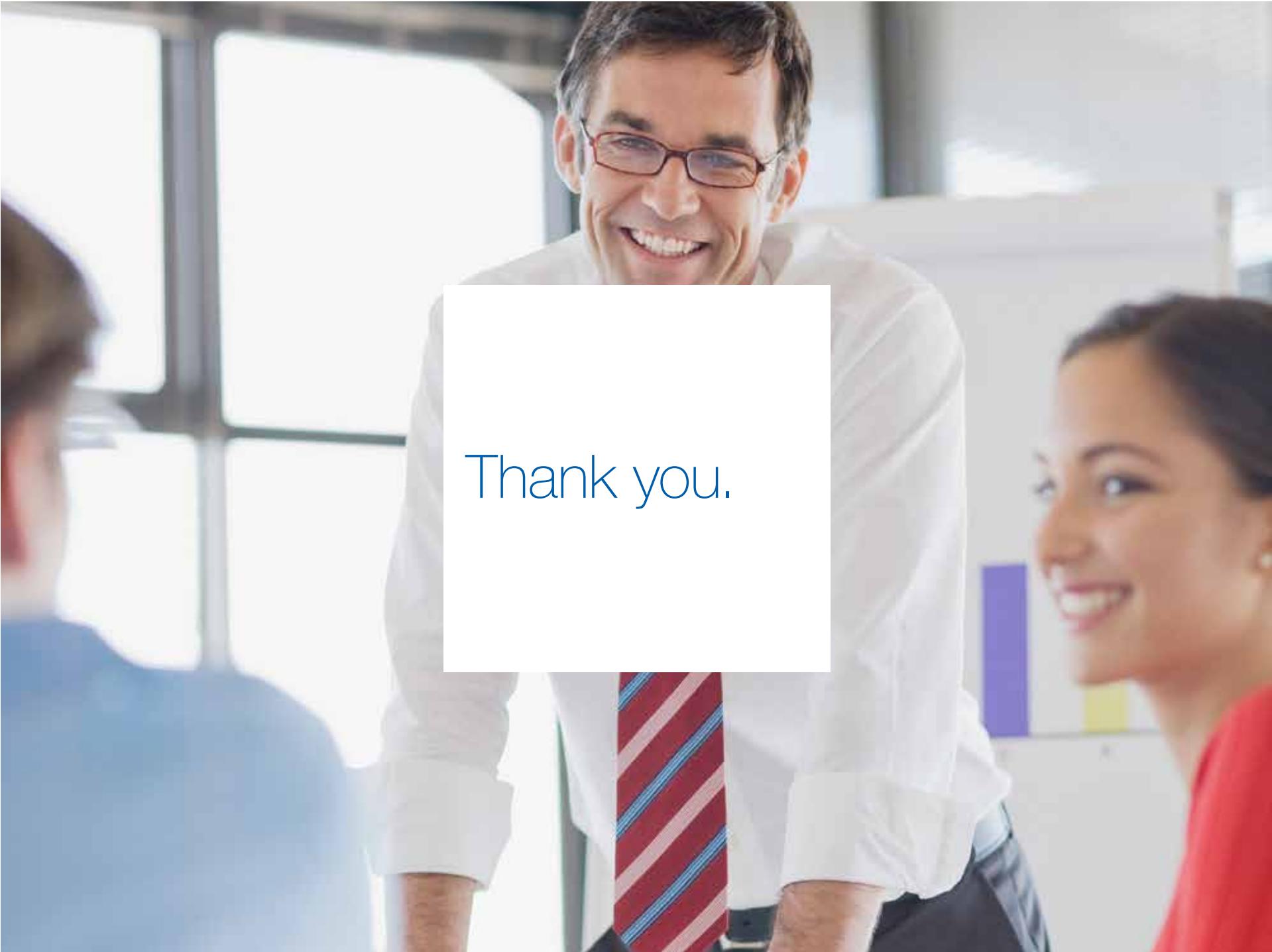
The automotive boardnet is now experiencing increasing demands for frequently available large currents, otherwise known as “peak power.” Lead-acid batteries are able to supply large currents for an extended period of time – as long as their considerable weight and volume does not restrict their use.

Unfortunately, batteries are also sensitive to abuse from over-cycling, reverse polarity and deep discharges. Additionally, the cycling behavior of batteries is poor in comparison to ultracapacitors. Batteries can only perform well within a few thousand cycles, while an ultracapacitor can withstand hundreds of thousands of cycles. When you examine all these factors, it becomes clear that ultracapacitors represent the ideal technology to fill the performance gap in peak power applications.

### Emerging peak power applications

- Electric power steering
- Electric turbochargers
- Active suspension systems
- Boardnet stabilization





Thank you.

Thank you for taking your time to get to know us a little bit better. Of course, this is just the beginning of the amazing and empowering journey we can embark on together. Our engineers stand ready to work with your engineers to steer the future of the automotive industry into bold new directions.

For more information, go to [www.maxwell.com/auto](http://www.maxwell.com/auto)



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