



## Energy Ecosystem Technologies Driving the Future of E-Mobility

These are exciting times for our automotive engineering community as countries around the world fuel the momentum for a cleaner future with incentives for end-users to adopt hybrid electric vehicles (HEV) and electric vehicles (EV).

Contrary to skeptics who just a few years ago said fossil fuels would remain a mainstay for transportation fuel, the trend is moving faster than expected to fuel the e-mobility revolution, with the aim of creating efficient electric powertrains and a seamless energy ecosystem to power the HEVs and EVs of the future.

“The spread of civilization may be likened to a fire; first, a feeble spark, next a flickering flame, then a mighty blaze, ever increasing in speed and power.”  
~ Nikola Tesla

### Growth in fuel use\*

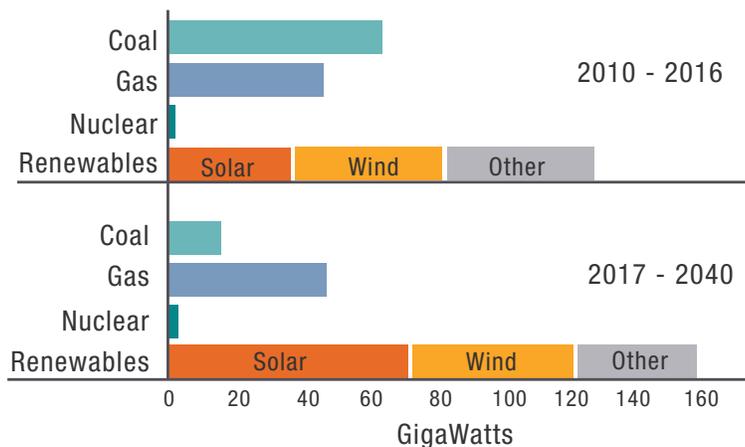


Figure 1: Global average annual net capacity additions by type (Source: IEA)

\* Global average annual net capacity additions by type

High-level initiatives are also being rolled out to obsolete gas and diesel cars in favor of cleaner vehicles, all within the next two decades. While 20 years may seem like a luxurious timeline for rolling out new vehicles, this is a formidable task as an entire engineering paradigm shift towards supporting the e-mobility platform must be addressed.

Supporting the electrification of our modern vehicle is an entire energy ecosystem, from photovoltaic (PV) inverters that harness and convert solar energy, to storage and distribution, whether within microgrids or back to the smart grid, with a host of charging facilities, and the 'behind-the-scenes' cells, batteries and power devices that support this ecosystem. Energy efficiency is a key integral factor across this ecosystem.

As new criteria emerge to regulate the entire industry for safety, performance as well as business viability, the challenge for the engineers is how to verify and test each design, from the development stage to the high-volume production stage, to ensure a smooth and safe transition into this brave new world of e-mobility. As key technologies are playing a vital role to create a holistic ecosystem to support the growth of the e-mobility market, let's explore the challenges and solutions available to help engineers drive their innovations to reality.

## Understanding the Market Shifts

According to studies by the International Energy Agency, improvements in energy efficiency play a huge role in shifting demand away from coal and natural gas. Renewable sources of energy now meet 40% of the increase in primary demand, and their explosive growth in the power sector marks the end of the boom years for coal.

Globally as government policies continue to support cleaner energy sources, investments are concurrently pouring into building renewable energy capacities (see Figure 1).

One of the hottest markets fuelling e-mobile applications is the electric car market, which is seeing exponential growth worldwide (see Figure 2).

### Worldwide electric car fleet

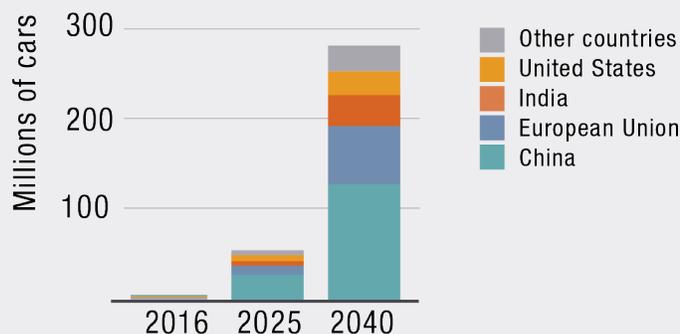


Figure 2: Worldwide electric car fleet, 2016-2040 (Source: IEA)

## Under the Hood – Trends and New Test Challenges

With shortening product development cycle times and a myriad of power configurations (see Figure 3), keeping an eye on the big picture of the fast-evolving ecosystem is as crucial as deep-diving into testing the viability of each design and verifying its ultimate performance.

Behind this electrified vehicle microcosm are a myriad of electronic devices and sub-systems, among of which include the following:

- Power devices
- Power conversion
- Cells and batteries
- EV-to-grid communication

### Electrification of vehicle sub-systems

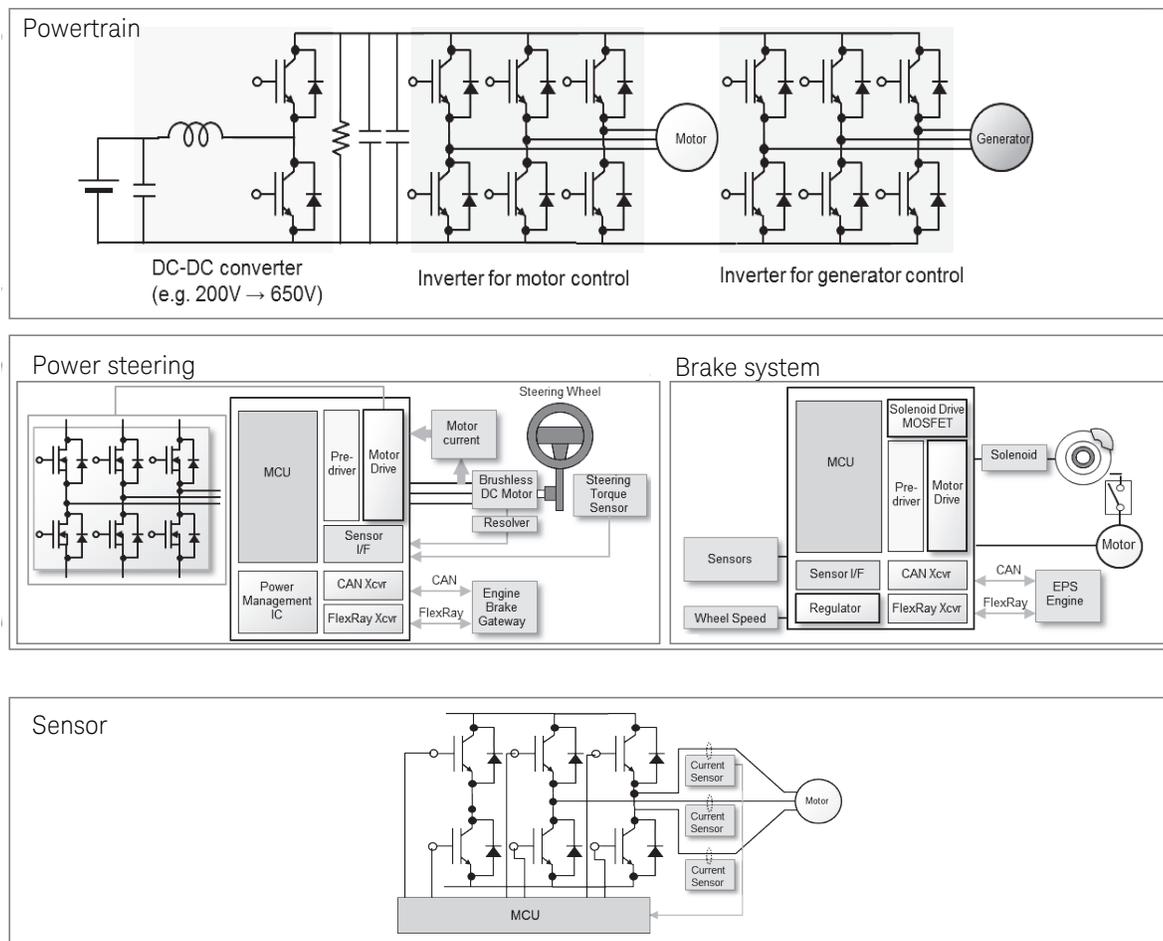


Figure 3: Electrification of vehicle sub-systems

## Power Devices – SiC and GaN vs IGBT

Automotive insulated gate bipolar transistor (IGBT) power devices have been used all this while as the typical switch for high-voltage applications in both conventional cars and hybrid electric vehicles. However, as power demands rise in HEVs and EVs, designers need power devices that can operate efficiently and effectively in an environment with elevated temperatures, and be expected to convert, switch and regulate the mass amounts of high-voltage currents flowing seamlessly in the vehicle.

The potential answer seems to lie with new wide bandgap (WBG) silicon carbide (SiC) and gallium nitride (GaN) based devices, due to the benefits they offer over Si devices:

- **High Temperature Operation:** The thermal conductivity and melting point of WBG devices enable it to operate at temperatures over 300°C, providing a more reliable solution for HEV/EV applications.
- **Efficiency:** Because WBG devices can switch much faster than Si, they reduce switching losses, increase efficiency and the need to dissipate less heat. Additionally, higher frequency means smaller magnetic components, supporting a less costly design.
- **High Voltage Operation:** WBG devices can withstand high voltages (600 V and more). This enables a HV boardnet architecture to power HEV/EV components with less current (i.e. small diameter wires) reducing the weight of wire harnesses.

Many HEV and EV manufacturers are migrating their power-conversion designs to WBG to leverage the benefits of these relatively new devices. However, there are significant concerns about making sure these new designs are reliable and safe.

GaN devices have even higher performance over SiC silicon devices, due to their excellent material properties such as high electron mobility, high breakdown field, and high electron velocity. GaN-based power electronics also have low on-resistance and fast switching, which greatly reduce conduction and switching losses.

The difficulty in power supply design using GaN power transistors is caused by the transistors' extremely fast switching speed. When using a GaN power transistor, the parasitic inductance must be suppressed to a very low level to avoid high levels of EMI emissions or the breakage of the GaN power transistor.

Properly designing circuit configurations and board layouts can solve the problems that reside in SiC and GaN power transistors, but the design is only as good as its end performance. That is why some leading power semiconductor OEMs choose to collaborate with Keysight Technologies and use cutting edge power circuit simulator software to obtain more detailed performance verification during the design phase.



### Resources

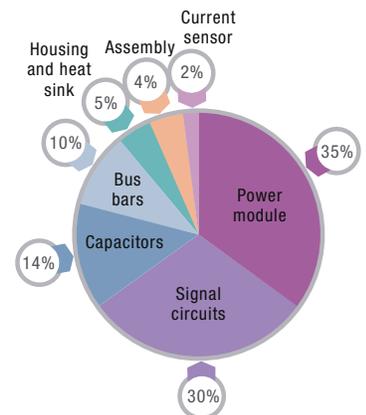
1. Find out more on how advanced modeling tools can help you to eliminate SiC design cycles by creating real-world models resulting in simulations you can trust.
2. GaN Power Devices Start to be Designed into Power Sources: Transphorm Details Know-how around Circuit Design and Associated Layouts - Case Study
3. [www.keysight.com/find/pd1000a](http://www.keysight.com/find/pd1000a)

## Power Conversion – Efficiency & Safety are Key to Success

Based on a 2014 report, the US Department of Energy has set aggressive goals to reduce the cost of inverters (see Figure 4) in HEVs and EVs. Hence, the drive for disruptive and innovative technologies such as those highlighted so far. The end goal is to enable broad adoption to reduce global carbon emissions.

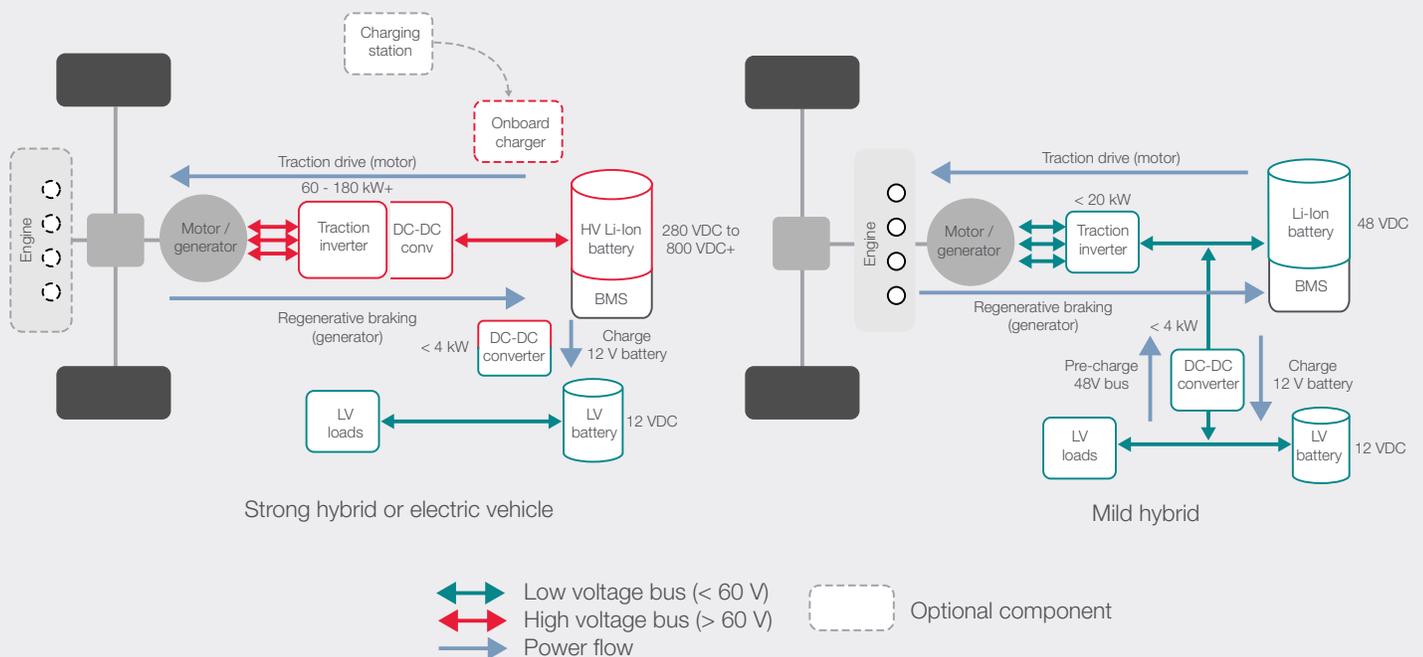
HEVs and EVs have multiple architectural configurations. Figure 5 shows a simplified block diagram of a couple of these architectures. For the strong (or parallel) hybrid and the pure EV (no engine), a high voltage (HV) board net is supplied by a large battery, which powers the electric powertrain.

Power levels of the inverter and motor/generator range from ~50 kW up to and over 180 kW. Along with the large Li-Ion battery, a significant investment is required to develop these architectures. Most of the components support bidirectional power flow. When power flows from the battery to the inverter/motor, the vehicle is propelled. When decelerating, the momentum of the vehicle turns the generator, driving power back through the inverter and charges the battery (regenerative braking).



**Figure 4: Call to drive down inverter cost to \$3.3/kW by 2020 from \$13.7/kW in 2014**

## HEV/EV architectures



**Figure 5: Simplified block diagram of HEV/EV architectures.**

In the mild hybrid (MH), the motor/generator, inverter, DC-DC converter and battery are all bidirectional. The inverter/motor are not large enough to drive the vehicle by themselves (as in the HEV or EV), but instead are used to supplement the engine power during acceleration and recharge the battery during deceleration. This technology also uses a 48 V board net to reduce safety concerns and cost.

No matter which architecture is being employed, there is extreme downward cost pressure on design and test, across the DC-DC converter development life cycle. With silicon (Si) based power converter designs, most DC-DC converters are water cooled. The additional cooling design cost for the HEV/EV manufacturer is passed on to the design and test engineers, requiring reservoirs, pumps and hoses to cool the DC-DC converter during design and test.

To reduce the number of liquid-cooled modules, manufacturers are now integrating multiple power converter applications into a single module (e.g. DC-DC converter + onboard charger), in addition to adopting new WBG power devices. This brings about new test challenges, such as the need for additional design validation and reliability testing to ensure a product will last over time with harsh automotive operating conditions.

With the power and voltages levels used with DC-DC converters are well over the 60 V safety limit, hence designers, technicians and operators need to be careful when testing a converter, and insure that special safety mechanisms (e.g. NFPA 79) are implemented in manufacturing. These safety standards require a redundant system, where one failure of the test system would not expose the high voltage to an operator. These safety systems are often custom-designed and very costly to deploy.

To reduce the cost pressures for designers and manufacturers, Keysight developed a robust commercial off-the-shelf regenerative power system with highly integrated safety features that protects both people and devices under test. The regenerative capabilities of this solution enables the energy consumed to be put back onto the grid cleanly, saving costs from energy consumption and cooling, while not interfering with the grid.



#### Resources

1. Emerging Solutions to Hybrid & Electric Vehicle DC-DC Converter Design and Test - White Paper
2. [www.keysight.com/find/ev1003a](http://www.keysight.com/find/ev1003a)



## Cells & Batteries - The Heart of E-Mobility

Even as engineers finetune and upgrade the capacities of power devices to enable e-mobility applications in the latest electric vehicle, your EV is as good as how far a full charge will take you before you need to plug it into a charging station to power up those batteries.

EV batteries have come a long way since the early 2010s which supplied only 50-60 miles per full charge, often with limited horsepower. Now an average priced EV offers a range of over 100 miles. A 2018 Nissan Leaf sporting 192 Lithium-Ion cells in its 40 kWh battery pack gives a range of 151 miles while a Tesla Model S on the other hand, offers a range of 315 miles, powered by 7,104 Li-Ion cells. This gives us a fair idea of just how significant the cells and batteries market is in the HEV and EV ecosystem.

A forecast by Future Markets Insights stated that the electric vehicle battery is expected to grow at a robust CAGR of 8.5% with a revenue reaching around \$36 billion by the end of 2027 from 2017.

Leading this growth is the Li-Ion battery segment, which is anticipated to have a market value of more than \$23 billion by the end of 2027. With such a huge potential market, the quest is on for batteries that will charge faster and offer better mileage per full charge. Even as demand for Li-Ion cells continues to build momentum, restless researchers are already investigating the potential of a cheaper and more abundant element—sodium, to create the next generation of green batteries.

While each EV OEM is working on its own secret sauce that will create the winning elixir of life for road mileage, there is a common need to find a better way to test the performance of each cell, right from the design stage, including studying a phenomenon known as cell self-discharge, which erodes the overall performance of batteries.

Cell self-discharge is the reduction of the stored charge of the battery without any connection between the electrodes. Self-discharge decreases the shelf life of batteries and causes them to initially have less than a full charge when used.



To detect higher-than-normal self-discharge in Li-Ion cells, developers and manufacturers have traditionally relied on measuring the drop of a cell's open-circuit voltage (OCV) over a period of several weeks or longer to get good validation. Having to wait this long during development results in lost opportunities by being late to the market with new designs. This problem is further compounded if self-discharge testing must be repeated. In manufacturing, having to store large quantities of cells for a long time to screen them for self-discharge presents major expense, logistics, and safety problems to contend with.

Measuring a cell's self-discharge current provides an alternate means to directly determine a cell's self-discharge rate. Cells exhibiting excessively high self-discharge can be identified and isolated in a small fraction of the time compared to the traditional OCV approach, greatly reducing the associated expenses, difficulties and potential hazard.

To address the need of cell developers and manufacturers, Keysight came up with a revolutionary self-discharge measurement solution that slashes the time required to measure cell self-discharge current. For smaller cells like cylindrical 18650 or 21700 cells, testing indicates that you can quickly measure stable self-discharge current in as little as 30-minutes to 2-hours, depending on the cell characteristics. And for larger capacity pouch cells (e.g., 10-60 Ah), this takes as little as 1 to 4 hours.

That is a significant improvement compared to waiting weeks or months for the cell OCV to change enough to determine cell quality, and significantly decreases test cycle and improves time to market.

As research and development intensifies to understand how cells and batteries perform in varying conditions, the elixir of longer battery life may be closer, to the benefit of the e-mobility ecosystem.



#### Resources

1. How to Shorten Li-Ion Self-Discharge Test Time? - White Paper
2. [www.keysight.com/find/self-discharge](http://www.keysight.com/find/self-discharge)



## Next Up: EV-to-Grid Communication

Zooming out from the microcosms of power devices, Li-Ion cells and batteries, and on-board charging systems, these microcosms play vital parts in the e-mobility macrocosm, comprising charging stations, home energy management systems, microgrids and smart grids, with each contributing a vital role towards a more sustainable energy future.

Take charging stations for instance. No longer are they just a ‘plug in and juice up’ station as these points of sale become vital sources of market intelligence for power companies, and also for consumers, who are able to tap into realtime data on energy prices and plan the most economical schedule to power up their EVs.

In a **2016 study** on EV charging patterns in Los Angeles, California, researchers found that most drivers charged up their EVs between 3:00 p.m. to 5:00 p.m., causing a predictable daily energy peak in the electric grid. Such data can help researchers determine new ways to balance the loads on power grids throughout a 24-hour cycle, including offsetting peak demand periods by installing PV panels and solar systems at the charging stations themselves.

Supporting rapidly evolving smart grids are terabytes of big data; vast networks of data which present exciting opportunities to be harnessed into smart data to support applications that will benefit both utilities providers and consumers.

The momentum is certainly gathering speed in different regions across the globe. Europe already has two electric vehicle charging networks – Ionity, supported by BMW, Mercedes, Ford, and Volkswagen, and Ultra-E, which is backed by Allego, Audi, BMW, Magna, Renault, Hubeject, and other players. Earlier in 2018, Allego announced it was launching an even bigger network called MEGA-E, comprising 322 ultra-fast chargers (up to 350 kW) and 27 smart charging hubs throughout 20 European countries.

Designs for faster and higher-capacity charging stations will see demand for cutting-edge conformance test solutions for both the electronics that run such infrastructure. While competing power networks vie for a piece of the growing pie from the EV and HEV markets, what attracts drivers will be economy, range, and convenience. Companies like Bosch and ChargePoint are already supplying applications that allow drivers to charge up at different stations by just tapping on their mobile phone app. Developers will need better solutions and network visibility for securing the vast amounts of data in a world where the Internet-of-Things run our daily conveniences that we take for granted.



### Resources

1. Flexible interoperability testing of the Electric Vehicle Supply Equipment (EVSE)
2. Improve your network security and monitoring insights

## Creating an Energy Ecosystem

Because of the energy market shift and the acceleration of the e-mobility market, this new broad and diverse ecosystem needs flexible and powerful testing solutions to accelerate the design and production of innovative e-mobility solutions.

No single test technology can effectively address the emerging design and verification challenges from the wide range of applications, environments, and requirements of the booming e-mobility ecosystem. Newer and better electric drivetrains will be developed to satisfy consumer demands and fulfill the incentive criteria offered by governments, such as fuel economy and longer ranges.

The coming years will see exciting innovations to develop better power devices, cells, batteries, and the larger charging infrastructure provides interoperability; including new ways to harness natural energy sources such as the sun, to fuel the entire energy ecosystem.

At Keysight Technologies, we are confident of providing you both the depth and breadth of test and measurement solutions to address your unique design and test challenges, and bring the vision of a more sustainable energy ecosystem to reality faster.



Learn more at: [www.keysight.com](http://www.keysight.com)

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