electric & hybrid vehicle technology international

JANUARY 2018

UKi Media & Events

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Can national grids cope with future EV demand? Will rare earth supplies last? These and other questions answered

COLLABORATIVE DEVELOPMENT

In the quest to advance electrification technology, should auto manufacturers go it alone or combine their expertise?

SEMI AND ROADSTER REVEALED

Tesla has stunned the industry by not only unveiling its new electric truck, but also debuting a jaw-droppingly quick Roadster

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Volkswagen's Dr Herbert Diess lifts the lid on the German OEM's extensive plans for its electrified vehicle portfolio

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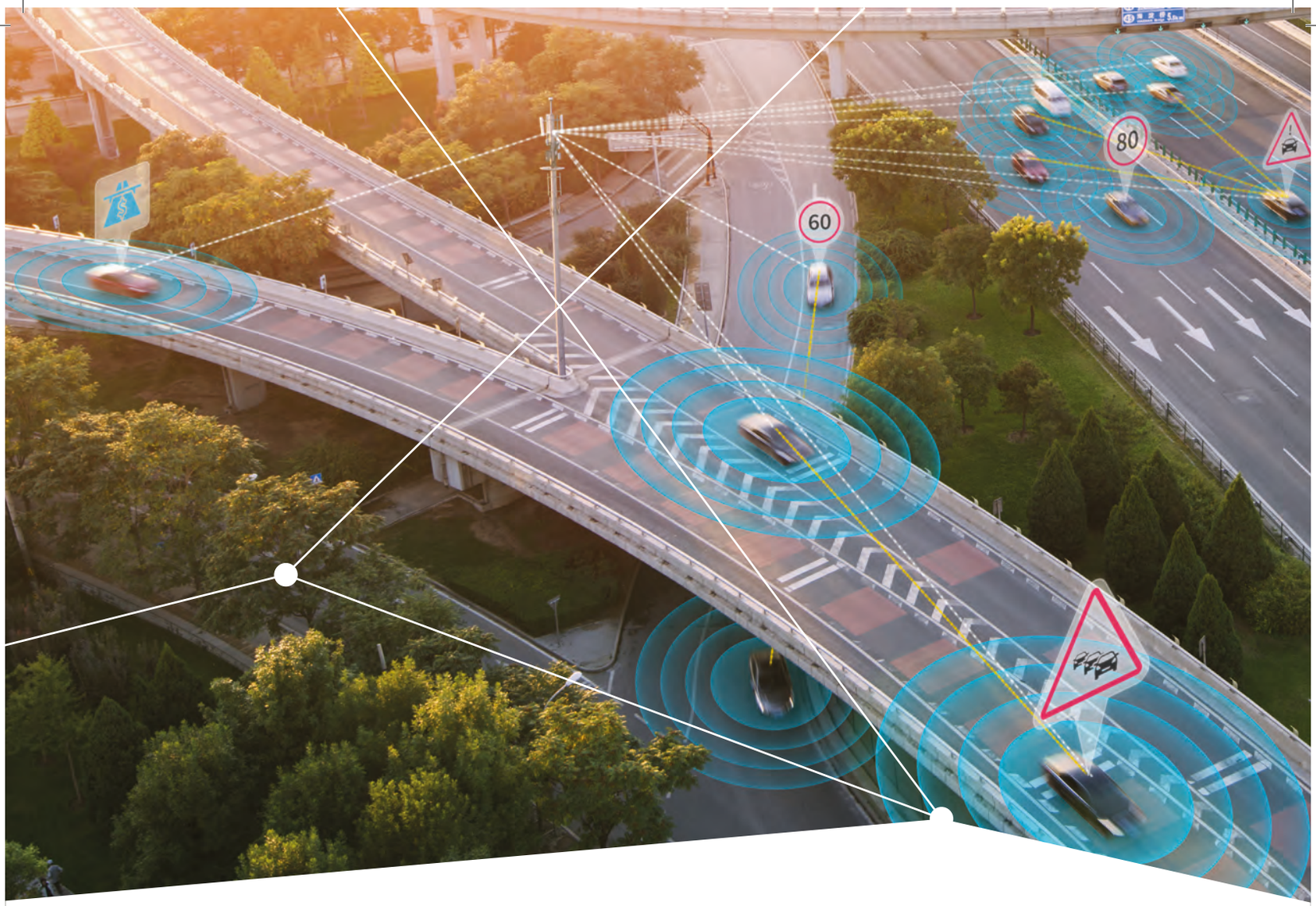

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EDITOR'S NOTE

There are few things as belligerent as a room full of irked automotive journalists. In the past few months, there have been a number of announcements from major OEMs regarding their future electrification strategies – the vast majority of which have been reported on in a responsible, insightful manner. But, as is sadly often the case, there has been a smattering of stories with clickbait headlines and seismic proclamations. "XYZ won't manufacture ANY petrol cars after 2020!"; "ABC will ONLY build electric cars after 2025!"; and so on... The grinding of teeth by the frustrated automotive team at UKi has been deafening.

To say that such stories have misinterpreted these mobility strategies (though whether it's willfully, or just down to sheer ignorance is harder to judge) would be something of an understatement. It usually transpires that, if you look carefully at the actual announcements, XYZ will probably offer an electrified version of every model it builds by said deadline, or ABC has likely committed to including *some* degree of electrification by 10 years from now. But hey, why let the truth get in the way of a good story, right?

Wrong. It's only a small gaggle of misinformed voices making such ridiculous statements, but they do seem to be disproportionately loud. And that's not on. I recently read an article claiming that the BMW 750i "consumes" CO_2 at a rate that compares well with electric cars of a similar size. Sorry Tesla, it seems that the Munich boffins have, with the development of a car *that actually eats carbon dioxide*, solved the emissions problem for everybody. This level of misinformation is not only infuriating, it's actually irresponsible. Never ones to sit and simmer, however, we've done our best to debunk a few of these claims in our mythbusting article, which you'll find on page 6.

That said, the electric and hybrid automotive industry is certainly no stranger to battling against strongly held perceptions. Some are deserved, others are perhaps not. But they all play a role in the unending battle to win over the vehicle-buying public. For instance, just a few days before we went to print with this issue, Tesla dropped not one, but two new vehicles. The Semi, we were expecting, but the surprise reveal of the new Roadster threw this issue's plan into something of a tailspin – thanks a lot Elon...

Aside from the two vehicles, something else jumped out at me when I watched Musk's presentation. Several times, it seemed to me that he was framing the capabilities of the electric truck or the new four-seater in terms of just how Tesla's claims were flying in the face of preconception: everybody knows that Teslas are expensive, right? The Roadster only seats two, surely? Performance is great, but it can only come at the expense of range, correct?

Well, perhaps not. If – and I stress that we'll have to take Musk at his word for the time being – Tesla has managed to not only make the new Roadster the fastest production car in the world (0-60mph in 1.9 seconds, top speed in excess of 250mph!), but also given it a range of 1,000km, then we might actually be at the point where the benefits of EV performance aren't only for those with near-constant access to a charging socket. In the last issue, *E&H Vehicle*'s editor-in-chief Dean Slavnich highlighted how the quest for maximum top speed (I believe he referred to it as a "willy-waving contest") was all well and good, but one of the things consumers really want is range, range, and yet more range. If – and again, it's a big if – Tesla is to be believed, then we might be nearing the moment when we can have both. Enjoy the issue.

Matt Ross

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Published by
Published by UKi Media & Events, a division of UKIP Media & Events Ltd

Subscriptions:
£80/US$104 for two issues

ISSN 1467-5560 (print), ISSN 2397-6322 (online) *Electric & Hybrid Vehicle Technology International*. Printed by William Gibbons & Sons Ltd, Willenhall, West Midlands, UK.

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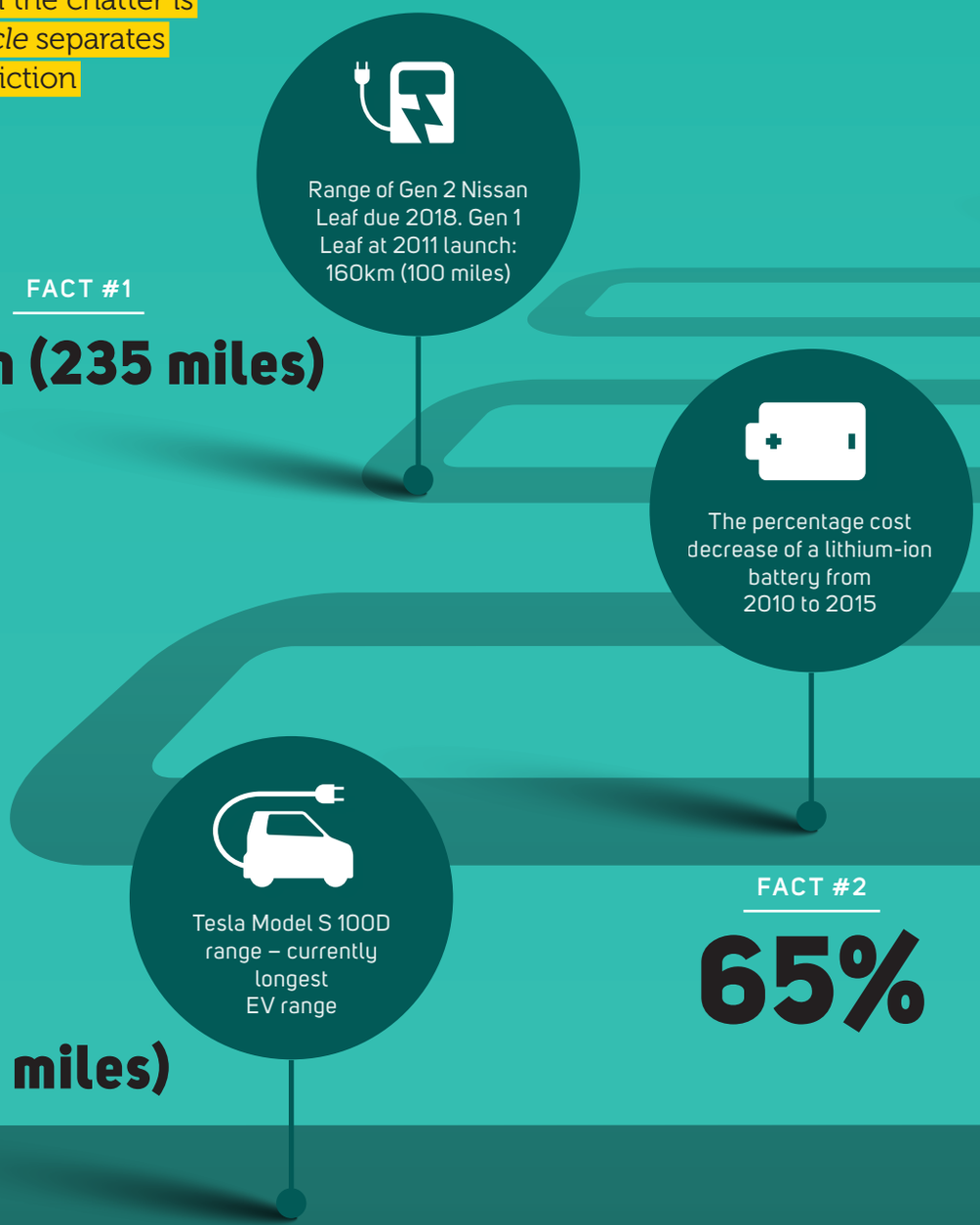
True lies?

A flurry of grandstanding announcements from major vehicle manufacturers has put electrification back in the news. But not all the chatter is entirely accurate. *E&H Vehicle* separates some of the facts from the fiction

WORDS: **JOHN EVANS**



FACT #4

29%

Norway's market share of EVs – the largest in the world – followed by the Netherlands (6.4%), Sweden (4.3%)

FACT #5

2,000,000

World global EV stocks in 2016, compared with 1,000,000 in 2015

FACT #6

140,000,000

Number of EVs on the world's roads by 2030, as predicted by the International Energy Agency

FACT #7

75%

BEV share of EV sales in France and China in 2016 (PHEV 25%). In the Netherlands, Sweden and the UK, the majority of EVs were PHEVs. In other markets sales are more equally split

Alex Brooks
senior analyst, Canaccord Genuity

Myth: **EVs will overwhelm the energy grid**

"In fact, total UK grid capacity is already big enough to handle electric cars. Should 100% of the UK's 32 million vehicles become electric within 15 years, and those vehicles are used as vehicle-to-grid (V2G) dynamic storage, peak grid load would likely remain unchanged.

"From a grid point of view, the relevant number is not the total consumption relative to battery size, but the daily *swing* in consumption. The challenge here is intermittency in [non-constant] supply: the wind doesn't always blow and sunshine is variable.

"We believe the emergence of V2G solutions – which use electric vehicles as part of a distributed grid-scale storage solution for the 90% of the time those vehicles spend parked – are a large part of the solution to daily intermittency.

"Many electric vehicles are being sold with onboard diagnostics that remotely connect to a central facility. You could expand this capability to include returning power to the grid as well as drawing from it. The alternative, expanding the grid system, would require huge investment. At present 35% of the average electricity bill is [for] running the grid. You could double that figure quite easily."

Myth #1

Governments are banning ICE cars in 2040

The requirement to meet the statutory targets defined in the Paris climate agreement means conventional petrol and diesel cars will die anyway, long before they're banned. Recent government announcements from countries such as the UK and France have talked about bans, but industry understands them to mean no new non-hybridized petrol and diesel cars will be sold in 2040. Again, ever-tightening emissions regulations will make this inevitable.

Myth #2

EVs are just a fad

There are still doubters out there but arrayed against them is an industry committed to EVs and, crucially, legislators committed to making them happen.

Future EV market – Forecasts range from 9-20 million cars by 2020 and 40-70 million by 2025. These compare with 88.1 million cars and LCVs of all types sold worldwide in 2016. Bloomberg NEF expects that pure-electric cars will account for 54% of all car sales globally by 2040. Tier 1 supplier Schaeffler is preparing for 30% BEV penetration by 2030.

Biggest EV market today – China accounted for 40% (336,000 cars) of global EV sales in 2016 but by 2025 aims to be registering seven million New Energy Vehicles (BEVs and PHEVs) each year. In the USA, EV sales have grown an average of 32% annually from 2012-2016 (160,000 EVs were sold in the USA in 2016), and 45% during the year ending June 2017.

Myth #3

You can't make people adopt EVs

True, but you can inspire and encourage.

Inspire – Public authorities in 30 USA cities have launched a partnership to mass-purchase EVs for their fleets, an order worth 114,000 vehicles. This compares with total EV sales in the USA of 160,000 in 2016.

Encourage – China is thought to be considering demanding that 8% of global car makers' sales in the country must be EVs as early as 2018, rising to 12% by 2020.

Myth: All new EVs will be BEVs

In a series of bullish statements recently, most major OEMs have committed to producing EVs very soon – but not all the new models will be purely battery powered, and some won't be coming for quite a few years.

BMW
Twelve BEV models with ranges up to 684km (425 miles) by 2025; plans to sell 100,000 EVs in 2017. Planning solid-state BEVs for 2027, FCEV by 2021.

Dyson
Investing £2bn (US$2.6bn) designing and building its first EV in 2020.

Ford
Company's Team Edison is masterminding 13 new EVs over next five years, including a BEV with 483km (300 miles) range by 2020. Will spend US$4.5bn on its plans.

General Motors
Two new BEVs in 2018, and 18 more by 2023.

Porsche
Mission E BEV sports car concept scheduled to go live in 2020 with 20,000 annual sales target. Working with Hitachi on 15-minute fast-charge system as antidote to modest 499km (310 mile) range. Researching solid-state batteries. Next BEV will be an SUV.

Tesla
Model 3 to run to 500,000 units by 2020, six times the number of EVs sold in USA in 2016. Semi truck in 2019, and the new Roadster is due by 2020.

JLR
Electrified powertrains (BEV and hybrid) for all new models from 2020.

Tobias Schätzmüller
international head of automotive,
Clearwater International

Myth: **EV is not OEMs' priority**

"In 2016, when KPMG asked the world's top automotive executives what their number-one priority was, they replied 'Autonomous technology'. EV ranked third, whereas now EVs are at the forefront. It won't be long before the price of a battery pack/kWh is below US$125, where EVs become price-competitive to conventional vehicles. Sales of ICE vehicles are set to increase over the next few years and OEMs must continue to invest in them.

"Meanwhile there is work to do regarding the energy mix. At present, throughout its life, a pure EV using coal-generated electrical power [is indirectly responsible for more pollution] than an ICE vehicle. We have to increase the proportion of renewable power to realize the benefits of EVs.

"The German government will probably not demand that all cars be electric by a certain target date, but instead will define emission targets and give the lead to industry. This would leave room for the development of cleaner, alternative fuels for ICE engines, such as the technology that is promoted by Bosch.

"Not only that, but the specter of job losses in traditional ICE-based industries is a cause for concern. In Germany alone, according to economic research institute Ifo, as many as 600,000 people on the ICE production and supply side may be at risk of losing their job by the time we are 100% EV."

Myth #4

There's no substitute for today's NdFeB magnet-based motors

If all 7.2 million EVs projected by some sources to be in use by 2020 use permanent magnet synchronous motors, between 7,200 and 14,400 tons of NdFeB magnets will be required annually. In 2015, 1,100 tons represented 1% of global NdFeB production.

A study conducted by the European Commission's Joint Research Centre, quoted in a report by Automotive IQ called *Reducing the industry's reliance on rare earth metals*, is forecasting problems sourcing rare earth metals for NdFeB magnet-based motors. It says the EV industry is concerned that China, where most rare earth metals originate, has introduced various measures to limit rare earth production. Another issue is demand for graphite and cobalt. China is home to around 95% of current reserves of natural graphite while the Congo meets almost half of global demand for cobalt.

FACT #8

12

Major cities have signed the C40 Fossil-Fuel-Free Streets Declaration and committed to zero-emissions areas by 2030

Rather than waiting for disaster to strike, though, engineers are reconsidering ferrite magnets. Companies such as TDK have increased their remanent flux density with quantities of lanthanum. Although also a rare earth metal, lanthanum-based ferrite is cheaper than NdFeB-based alternatives.

At the same time, to improve EV range, different technologies such as lithium-sulfur and solid-state batteries are being explored, which could greatly increase battery capacities compared with current technologies.

Finally, machines such as switch reluctance motors, which don't require rare earth materials, are among alternatives being considered.

Myth #5

Electric vehicles won't survive without subsidies

David Martell, CEO of Chargemaster, agrees that sweeping government incentives for EVs cannot last forever. However, he says that some manufacturers such as Volkswagen predict that, within five years, the cost of producing an EV

Smart
Solely BEV by 2020.

Renault-Nissan Mitsubishi
Twelve new BEVs by 2022, sharing platforms and components.

Mini
BEV Mini Electric, planned for production in 2019.

Hyundai/Kia
Promising 31 new EV variants (eight of them BEV) by 2021.

Daimler
Aiming for annual EV sales of 100,000 by 2020; 10 new BEVs, and 15-25% of its range to be electrified, by 2025. New Mercedes GLC F-Cell due 2018.

PSA Group
New generation of five BEVs from 2019-2021; 80% of fleet electrified by 2023.

Maserati
All models at least hybrid by 2019. Alfieri BEV in 2020.

Volvo
After 2019, all models will have an electric motor (BEV, hybrid or PHEV); five BEVs launched 2019-2021 (three Volvos, two Polestars).

Toyota
To work with Mazda and Denso on launching new generation of BEVs by 2020. Planning to launch solid-state BEV in 2022. Mass-production of BEVs in China from 2019.

VW Group
Planning to have 50 new BEVs and 30 plug-in hybrid vehicles on sale by 2025 for two to three million sales. Aiming for all models to have electric vehicle versions by 2030. The VW Group's plans will require the equivalent of four Tesla Gigafactories for battery cells.

will be lower than the cost of producing an ICE vehicle. "The reality is that the concerns some people have about the cost of electric vehicles will diminish very quickly," he says.

Myth #6

The economics of battery recycling don't add up

With the cost of recycling a battery approaching US$1/kg, but the rare earth metal inside it worth just a third, they certainly don't today. However, between now and 2030, if 140 million EVs are expected to be running, as some predict, they would generate 11 million tons of used Li-ion batteries. Marc Grynberg, chief executive of battery recycling company Umicore, says the scale of this battery mountain will make car makers "accountable for the collection and recycling of spent batteries". This should encourage the development of much needed recovery technologies, especially for lithium.

Myth #7

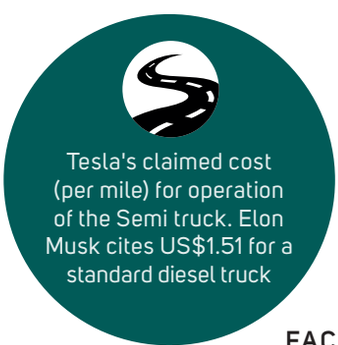
There won't be enough battery factories

The world's biggest battery producer is Panasonic. In partnership with Tesla, it is building the Tesla Gigafactory in Nevada, capable of delivering 150GWh of energy per annum. Terra E Holding is planning to complete a huge battery factory in Germany by 2028. Daimler is planning one in China in partnership with BAIC Motor. VW is also planning to build a huge battery plant.

Myth #8

EVs will always cost more to build

A report by investment bank UBS found EVs are potentially much cheaper to produce than ICE vehicles. It based its findings on a Chevrolet Bolt, which it stripped down to parts and found savings would be possible with greater scale. It says both types of vehicle will be the same price by 2018, but it won't be until 2023 that OEMs could make the same 5% margin on each.



Tesla's claimed cost (per mile) for operation of the Semi truck. Elon Musk cites US$1.51 for a standard diesel truck

FACT #9

US$1.26

David Martell
CEO, Chargemaster

Myth: **The charging network won't be able to keep pace**

"We predict that the number of electric cars on UK roads will rise to over 500,000 by the end of 2020 and to over a million by the end of 2022. Accompanying this rising number of EVs will be an increasing number of charging points, probably keeping a 1:1 ratio with the number of electric cars on the road, with the vast majority being home charging points. This is important as it is where – and will continue to be where – the majority of charging is done.

"In Europe the current electric vehicle parc is around 650,000, which we believe will rise to over one million by the end of next year, increasing to over three million by the end of 2020 and to more than seven million by the end of 2022. It is reasonable to assume that the number of charging points will keep pace with the number of electric vehicles across Europe, too.

"We are a licensee of Qualcomm's wireless electric vehicle charging technology and see it being rolled out for domestic use, in private garages, before it is seen on public networks. The market will be driven entirely by whether manufacturers decide to fit the technology to their vehicles."

Myth #9

Formula E is dead

TV viewing figures have been low, but organizers claim the recent signing of North One Television will help boost Formula E's visibility. It needs to, since a lack of public awareness and clashes with F1 have dogged the series since launch.

Naturally Lucas di Grassi, recently crowned world Formula E champion, is more upbeat.

"To see what Formula E has accomplished in three years is unbelievable," he told CNN. "We now have the most car manufacturers of any series in the world, and it's only going to grow."

Among the new teams signing on last season was Jaguar. New arrivals over the next two years will include BMW, Audi, Mercedes and Porsche. Maserati is also likely to join. Although Renault has left the series to concentrate on its F1 revival, corporate partner Nissan has taken its place as a more natural EV fit.

Lower team budgets and transference of race-proven technology to road-going EVs are part of the attraction. City authorities also see Formula E as a way to promote clean-air zones.

Myth #10

EVs will be dearer to run than ICE vehicles

According to the International Energy Agency, in 2015 electric car costs were higher than those for IC-engined vehicles in all regions. However, by 2030, battery electric vehicles and plug-in hybrids will become fully cost competitive with ICEs in Europe, where fuel taxes are estimated to be high and vehicle attributes (namely power) more favorable to electrification than in other regions.

Myth #11

The current energy mix doesn't favor electric vehicles

A study of America's 50 states conducted by Climate Central found that the energy mix was clean enough in 37 of them to ensure electric cars are more climate friendly than even their most fuel-efficient internal combustion engine counterparts.

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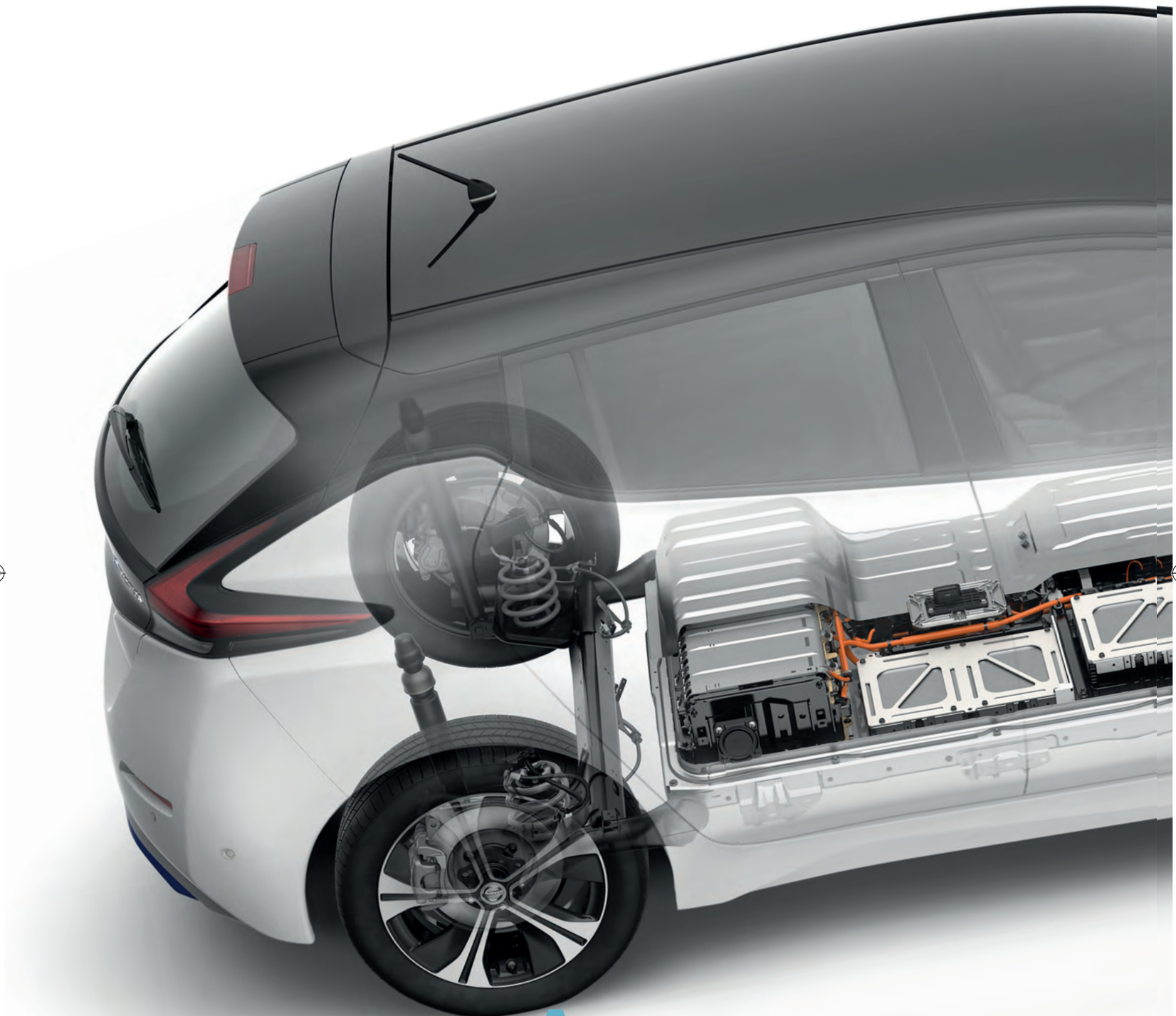

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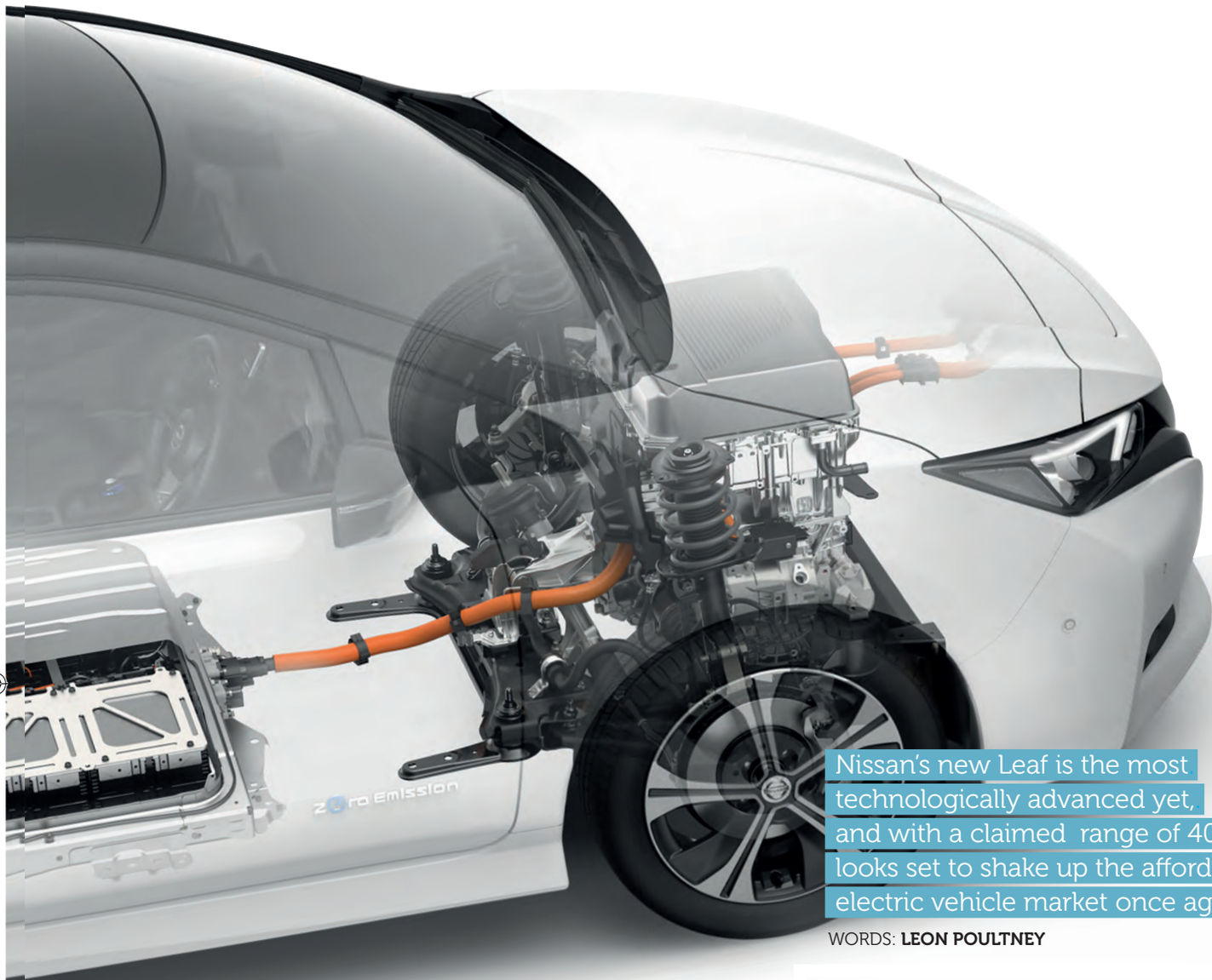

leaf

Nissan's new Leaf is the most technologically advanced yet, and with a claimed range of 400km, looks set to shake up the affordable electric vehicle market once again

WORDS: **LEON POULTNEY**

The Nissan Leaf is far and away the most successful electric vehicle in the world, with some 300,000 models sold to date in 49 markets globally and a staggering 3.5 billion kilometers covered without major incident.

Leaf is often cited as the mass production electric vehicle that encouraged almost every other auto maker to explore battery propulsion, and continues to be the first taste of EV ownership for many customers.

But the Japanese marque feels that the world is now ready for Leaf 2.0 – an electric vehicle that jettisons the twee and often divisive styling, for something more substantial and seductive, introducing greatly improved range and performance, as well as innovative autonomous driving functionality typically reserved for more premium models.

"The new Leaf will no longer be a niche product in the Nissan portfolio, but an integral part of the model line-up," says Hiroto Saikawa, CEO of Nissan Motor Company.

As a result, the OEM believes it will easily sell twice the amount of Leafs as it did with the original, or even three times the amount, should the market be particularly receptive.

The magic number

This lofty ambition is down to three key features that essentially underpin the new model – features that Nissan dubs Intelligent Mobility and that include: Nissan Intelligent Driving, Nissan Intelligent Power and Nissan Intelligent Integration.

The first deals with the numerous autonomous functions that are available in the new Leaf (see sidebar, *Next-generation autonomy*), while the latter refers to its vehicle-to-home abilities, which enable owners to store surplus solar power in Leaf's battery pack during the daytime and then use it to help power the home in the evening, for example.

However, it is the Intelligent Power pillar that provides the most pertinent range and performance upgrades, with an all-new 40kWh Li-ion battery that remains the same physical size as the previous model, but sees range increase by some 40%.

Nissan claims 400km (249 miles) on the Japanese JC08 test cycle, but offers a slightly more conservative 378km (235 miles) on NEDC, while the US EPA test cycle sees a figure of 241km (150 miles) returned.

Hiroki Sobe, chief vehicle engineer at Nissan, says the technology still requires homologation across regions, but states that we'll see concrete range figures released in January, plus an honest 'real-world' figure.

Impressively, Nissan's engineers say that the new battery design adds extra energy

The new Nissan Leaf is designed to serve as a fundamental part of the OEM's model line-up, rather than simply a niche vehicle for a minority of zero-emission aficionados

NEXT-GENERATION AUTONOMY

Despite new Leaf's relatively reasonable price tag, Nissan has seen fit to equip its latest EV with a number of advanced autonomous driving functions, signaling its intention to introduce greater levels of technology in future models. The new ProPilot suite harnesses the power of 12 ultrasonic sensors and four cameras located around the vehicle to introduce single-lane autonomous driving functionality. When activated, the system will automatically keep a set distance from the car ahead (at speeds of between 30km/h and 100km/h) and keep the vehicle in the center of the lane by applying steering torque.

The driver must have hands on the wheel at all times and the system will bring the car to a complete stop if it is required to. The driver then presses the ProPilot button or the accelerator to resume.

In addition, ProPilot Park is a fully autonomous parking system that takes care of numerous parking situations, including parallel, reverse and front-in scenarios. The system automatically scans for a space and the driver selects the appropriate position via the infotainment screen before letting the car do the hard work. Parallel parking requires 60cm of space either side of the vehicle, which could prove a problem in tighter situations, while reverse parking requires enough room to complete the maneuver in seven forward and reverse motions.

ELECTRIC AVENUES

In addition to the expected championing of the new Leaf, Nissan also used the 2017 Tokyo Motor Show to unveil an all-electric, fully autonomous crossover concept vehicle. Dubbed the IMx (and in line with Nissan's Intelligent Mobility vision), the zero-emission concept adopts the Japanese OEM's new EV platform, with a flat floor and low center of gravity. The vehicle is powered by a pair of high-output electric motors, located front and rear, and offering all-wheel drive capability. The combined output of the e-motors is 320kW and an impressive-sounding 700Nm of torque. Power comes from a redesigned and reengineered high-capacity battery, and yields a claimed driving range of more than 600km (373 miles).

At the heart of the IMx is a future version of Nissan's ProPilot technology (seen in the new Leaf) specified for fully autonomous operation. Activating ProPilot stows the steering wheel inside the dashboard and reclines all the seats. Nissan also envisages the IMx as being able to drop off its passengers, park itself at a vehicle-to-grid location – where it will function as a mini power plant – before being summoned to collect its occupants.

storage capacity without increasing the overall footprint. In fact, it was possible to use the existing Leaf battery casing, to cut costs.

"The individual cell structure of the lithium-ion battery cells has been one of the biggest developments," explains Norihiko Hirata, deputy general manager of battery engineering at Nissan. "We have introduced enhanced electrode materials with revised chemistry, so the cells now include a manganese, nickel and cobalt mix, which we've found has improved overall energy density considerably."

The new technology, which was produced in conjunction with AESC, crams eight laminate cells into each module, as opposed to the four in the old model, with each just 0.9mm thicker than before.

As a result, the battery pack weight has increased by 10kg, but Hirata claims that is a very small penalty to pay for the additional range.

In addition to improvements in range, the e-powertrain also benefits from increased performance credentials, with Sobe revealing that the new 110kW front-mounted motor is 15% quicker to 100km/h (62mph) from a standstill than its predecessor (putting the figure at around 9.8 seconds).

In a move that appears lifted from the Tesla book of marketing, Nissan will also offer a higher-capacity battery and more powerful motor in the future, with insiders hinting it will tickle the 50kW mark and come part and parcel of a more 'premium' package some time in 2019.

Nissan claims that the new Leaf will achieve 378km (235 miles) on NEDC, due to a 40kWh lithium-ion battery pack that increases driving range by some 40% over its predecessor model

Figure of fun

But this additional performance hasn't gone unnoticed by the chassis development department, with new Leaf benefiting from a stiffer chassis, updated power steering that offers more linear feedback, revised suspension – including rubber bump stops to replace urethane counterparts in the rear suspension – and Intelligent Ride Control for better torque control when cornering.

"We lowered the center of gravity even further with the new Leaf," explains Sobe. "When you pair this with the increased power, you have a car that's actually very enjoyable to drive."

Driving enjoyment doesn't usually play a part in electric vehicle marketing, but Nissan is pushing the boat out with its *pièce de la resistance* on new Leaf: the e-Pedal.

The system allows the driver to harness the power of regenerative braking using just the accelerator pedal. When e-Pedal mode is activated, it sees the brake pedal reserved only for emergencies, encouraging drivers to speed up in a smooth and linear fashion.

"We have designed the system so it is easy to use and safe," explains Sobe. "When drivers come off the e-Pedal suddenly, the brake lights will illuminate at around 0.07*g* of braking force and the car will come to a complete stop. It will even hold on a hill," he says.

It is an accomplished package from Nissan and with successful vehicle-to-home trials in both Japan and Denmark, it proves the potential of the electric vehicle far beyond a comfortable, clean and cost-effective mode of transport.

Pricing of the new model is yet to be confirmed, but Nissan officials state that they have not increased the price over the outgoing 35kW Leaf and have actually reduced it in certain territories.

Proof, if you needed it, that Nissan, like so many other manufacturers, is beginning to place the electric vehicle at the very core of its business model.

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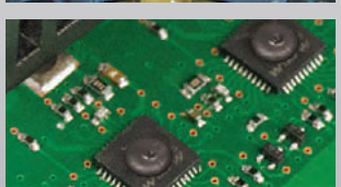

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BATTERY

The new Roadster will have a 200kWh battery pack, good for single-charge range of 1,000km (620 miles)

CABIN

The new Roadster is a four-seater thanks to a 2+2 cabin layout, and will also be a convertible

TOP SPEED

The Roadster will be the fastest production car ever made. It will cover 0-97km/h (0-60mph) in a mind-boggling 1.9 seconds. If that wasn't enough, 0-161km/h (0-100mph) will take just 4.2 seconds, and the vehicle will cover a quarter mile in 8.9 seconds. The top speed hasn't been revealed, but Musk stated that the maximum figure will be in excess of 402km/h (250mph)

MOTORS

The Roadster will have three motors, one in the front and two in the rear. It will be all-wheel drive and produce a staggering 10,000Nm of torque

Hit the road

Tesla rocks the auto industry with two stunning debuts

WORDS: **MATT ROSS**

If you're in the crowd at a Tesla unveiling, it's fair to assume there might be a surprise or two in store. But in November 2017, those gathered in Los Angeles for the unveiling of Tesla's first electric semi-truck were treated to an unexpected debut that really raised the bar. After unveiling the Tesla Semi, Elon Musk then revealed what was hidden inside the truck – the new Tesla Roadster. The second-gen version of Tesla's original EV boasts some staggering numbers and will be available in 2020, a year after the Semi takes to the road.

RANGE

Tesla claims a 805km (500 mile) range for the Semi – crucially, this figure factors in maximum weight and driving at highway speed. The Semi will also be able to replenish 644km (400 miles) of range in 30 minutes at a new Tesla Megacharger. The Semi's battery is in the floor pan, lowering the vehicle's center of gravity

BRAKES

The Semi will feature regenerative braking and feed recovered energy back into the battery. Musk stated that the brake pads on the Semi will never wear out!

PULLING POWER

The Tesla Semi will do 0-97km/h (0-60mph) in 5 seconds. It will also reach 105km/h (65mph) on a 5% grade – Musk took great delight in pointing out that diesel trucks peak at 72km/h (45mph)

SAFETY

The Semi features four independent motors – one on each of the rear wheels – and independent front suspension. This powertrain setup plays a fundamental role in the truck's jackknife prevention, as each motor will dynamically adjust the torque in each wheel in an emergency

Carbon footprint

Williams Advanced Engineering has unveiled a carbon-based vehicle platform that will act as the base for a new sports EV

WORDS: **LEM BINGLEY**

At the UK's Low Carbon Vehicle Show in September, Williams Advanced Engineering (WAE) revealed a new platform for EVs. Conceived as an engineering showcase, the FW-EVX platform will, the company says, provide a suitable base for a £200,000 (US$266,000) sports EV.

The skateboard-style chassis is based on tubular and box-section carbon-fiber components. Li-ion pouch cells are grouped into oblong modules, slotted inside carbon boxes that, bolted together, add to the overall chassis stiffness. The overall weight is 955kg (2,105 lb), of which 344kg (758 lb) is cells.

"If you're going to have electric vehicles, the cells are going to weigh whatever they're going to weigh," says WAE technical director Paul McNamara. "So we've tried to make everything else as lightweight as possible. That's both a materials challenge and an integration of design challenge."

Key elements of the platform serve more than one purpose. As well as stressed battery modules, there are aluminum crash cans at the front that double as ram-air inlet ducts, while the tubular side rails of the chassis provide strength in side-impact pole tests and also serve as radiators.

"Air comes in at the front, travels down through structural ducts into the sill, and then the sill is an extrusion the whole way through that acts as the radiator," McNamara explains. "Air exits in the low-pressure zone at the back, where traditionally you put the diffuser, so you're ramming air in at the front and sucking it out at the back, which is very efficient."

Two small fans at the front, linked to the ducts via active flaps, ensure that cooling can continue when the car isn't moving.

Building long radiators into the sills keeps the fluid flow close to the battery, as well as the YASA motors (two at the rear and one at the front), Sevcon inverters and Brusa onboard charger. "If you imagine having a radiator at the front, then you have to pipe fluid around the place, which is heavy," adds McNamara.

From the radiators, coolant is pumped through short loops in the flat alloy baseplate of the battery, which doubles as the chassis floor. Cells remain dry, thermally linked to the cooled baseplate via alloy sheets in the modules. Each module contains 10 pouches, shock-protected by foam, wrapped in carbon fiber to form a brick-like unit.

Developing processes

The module's carbon housing is formed using a technique called 223 – short for 2D-to-3D – developed by WAE in partnership with the UK's National Composites Centre. The approach mirrors how a cardboard box is formed from a flat, folded sheet.

The 223 process starts with a flat layer of carbon weave, infused with two types of resin that cure at different temperatures. Sections that will form the box sides are stamp-cured at the lower temperature, creating stiff plates joined by flexible edges. The sheet is then folded into shape and cured again at the higher temperature, yielding the final inflexible box. "You can do it all on a single press," explains McNamara. "What we're trying to do is make the production process cheap enough to allow use of an exotic material."

WAE's showcase chassis features 38 modules for an 80kWh overall capacity, within a 2,800mm (110in) wheelbase. "That's about where XE, 3-Series and A4 sit," McNamara says. "We chose a module width of 136mm (5.4in), so if you go up by one row of modules you'll be up where 5-Series and XF sit, or if you delete one you'll end up where Golf and Focus sit."

Carbon fiber is also employed for suspension components, with strands aligned so that they wrap around wishbone bolt-holes for strength. Laid by robot and stamp-cured in a mold at high temperatures and pressures, the result should be 40% lighter than forged alloy.

Wireless sensors could be embedded in carbon wishbones, and WAE has also used a wireless protocol for module communication with the battery management system. "This avoids having wires running all round the battery," McNamara notes, adding that it saves weight while also easing the task of replacing a faulty module.

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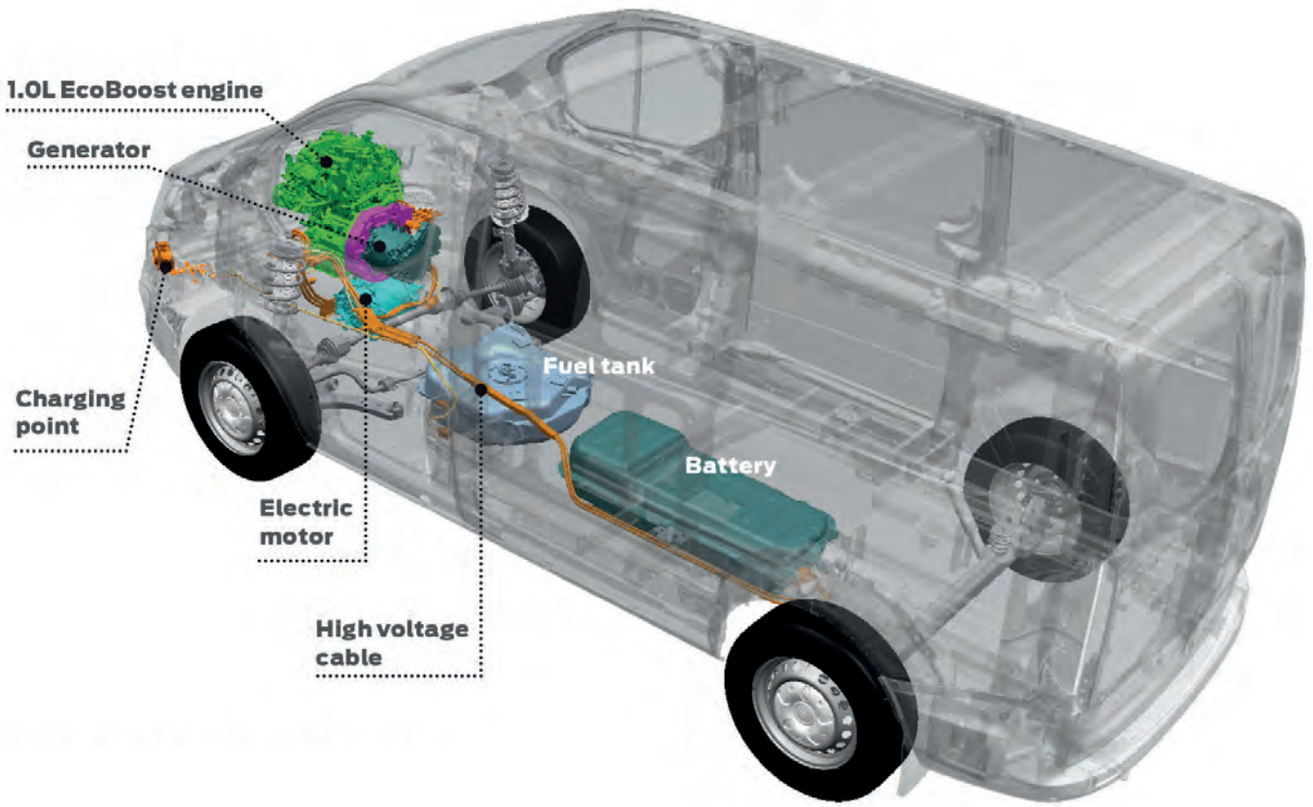


Carrying capacity

The hybrid powertrain in the Transit Custom PHEV provides an emissions-free range of 50km (31 miles)

Ford's hybrid Transit Custom prototype – essentially a range-extended EV – is to undergo fleet trials in London

WORDS: **CHRIS PICKERING**

Further details have been announced regarding Ford's forthcoming Transit Custom PHEV electric van. Although currently only at the prototype stage, a fleet of 20 vehicles will be taking to the streets of London at the end of 2017 as part of a 12-month customer trial.

The purpose of this exercise is primarily to gather usage data before the vehicle goes into production, explains Mark Harvey, director of Ford's urban electrified van program.

"The feedback from our fleets was that they needed an electrified vehicle that delivers without the compromises you get with existing EVs," he says. "We did a lot of work with them early in the program to understand the issues that they face and what they truly want from an electrified van."

The trial includes a diverse range of fleet operators from public authorities and infrastructure providers, through to construction companies and service engineers. "With any commercial vehicle you have a massive range of duty cycles and applications, so this should

In addition to plug-in charging, a 1-liter EcoBoost ICE can be used to charge the van's onboard batteries

The van will automatically switch to electric operation when entering London's ultra-low-emission zone

tell us how that maps out. Obviously we have our own hypotheses, but the results of this trial will help us to fine-tune the production version for 2019," says Harvey.

For the pilot vehicles, Ford is using its 1-liter EcoBoost engine as a range extender. The three-cylinder gasoline unit is mounted longitudinally in the nose, roughly where the engine would sit in a typical rear-wheel-drive configuration. It's coupled directly to the generator, while the motor and transmission sit underneath that package, mounted across the vehicle, driving the front wheels.

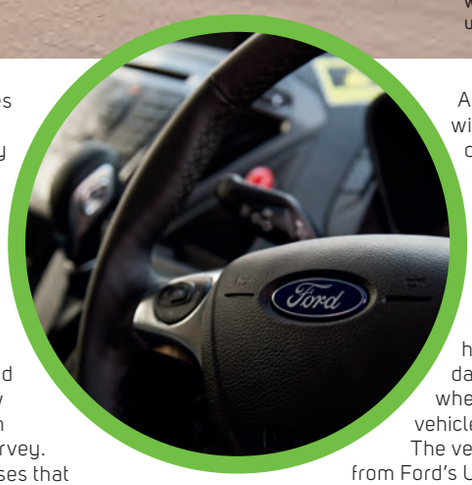
The fuel tank for the combustion engine sits below the passenger compartment, as per the standard design, while the liquid-cooled lithium-ion battery pack is located under the floor of the payload bay. Consequently, the Transit's payload volume is unaffected, and its 1,000kg (2,200 lb) carrying capacity is virtually identical to the diesel offering.

Although described as a PHEV, the Transit prototype is essentially a range-extended EV. There is no mechanical link at all between the combustion engine and the wheels, and the intention is that it could run solely on electric power for most inner-city journeys.

Location, location, location

Ford is targeting a 50km (31 mile)- EV range on the NEDC. One of the aims of the study is to investigate how much electric-only range that will translate to in typical urban fleet use. The rest of the time, the Transit PHEV will run in a series hybrid configuration, targeting a combined range of 500km (310 miles).

Uniquely, it also features a geofencing capability, which can automatically switch the vehicle's drive modes depending on its location. It could, for instance, disable the combustion engine in pre-defined low emissions zones.



"In this pilot, we've set up a geofence around the [proposed] ultra-low emission zone (ULEZ) in London," comments Harvey. "When the vehicle crosses that boundary, it switches to electric-only running. What we want to investigate is whether that then gives the vehicle sufficient range to complete its task. If not, the range extender will kick in – we won't leave them stranded – but it will be an interesting proof point."

Of course, the Euro 6-compliant gasoline engine would also be exempt from the charges for the ULEZ, which is due to come into force in 2019. In the future, though, that may no longer be the case.

"Cities are starting to demand vehicles capable of running with zero emissions," says Harvey. "There are also commercial pressures. One of the fleets we've partnered with currently uses an electric passenger car with the rear seats removed to deliver equipment to building sites because it had to meet a zero emissions quota to win that particular tender."

As part of the trial, Ford will be collecting real-time data from telematics units installed on all the vehicles. This will range from basic monitoring of the motors, batteries and electronics, through to the collection of high-level operational data, such as when, where and how often each vehicle is plugged into the grid. The vehicle trial is being run from Ford's UK technical center at Dunton, which also leads the systems integration for the production project. However, elements of the Transit design, including the battery, come from Ford's Electrified Powertrain Systems group in the USA, which also handled the recently-launched Focus Electric. Prodrive and Revolve Technologies are understood to have contributed to the pilot program, which is backed by a £4.7m (US$6.2m) grant from the UK government-funded Advanced Propulsion Centre.

Further details have yet to be announced, but it seems the prototypes used for the study are relatively close to production intent. "In terms of hardware, we expect a lot of what you see here to be realistic for Job One," comments Harvey. "Based on the results of this study, we will be able to go back and tune the calibration parameters to hit the sweet spot for this market in time for the production version in 2019."

Plug the gap

JLR's march toward lowered emissions takes a major step forward with the car maker's first gasoline PHEV

WORDS: **DEAN SLAVNICH**

Back in 2016, *E&H Vehicle* ran a Jaguar Land Rover exclusive, in which then head of engineering Dr Wolfgang Ziebart explained that one of the greatest technical challenges the British car maker faced was to substantially reduce emissions. "In 2007, our car fleet had an average of 242g of CO_2 [per km]," he said. "But by 2020 that needs to go down to 132g. [As of January 2015] we're at 180g, so there's still a way to go for us to achieve the remaining target."

Since then, JLR has been busy delivering on those green ambitions, helped firstly with its four-cylinder Ingenium architecture and soon an all-electric powertrain that will debut in the Jaguar I-Pace and then make its way across sedan, crossover and SUV applications in all three brands.

But the all-important bridge between frugal IC engines and zero local emissions BEV powertrains – hybrid technology – has remained notably absent from the JLR line-up. Okay, there were the Range Rover conventional diesel-hybrids of 2015 (which didn't exactly make a big impact, either in terms of emissions reduction or sales), but the vital missing link on an international level has been gasoline plug-in hybrids. Until now.

Revealed to the world at the beginning of October 2017, and only a few weeks after a global headline-grabbing announcement that stated that from 2020 all new Jaguar and Land Rover vehicles will have the option of some form of electrification, the Range Rover Sport is the first JLR product to get gasoline PHEV tech.

And if you're a large, 2,000kg-plus SUV, it would seem the wait was worth it, at least when looking at the headline numbers: combined NEDC CO_2 emissions of 64g/km; fuel economy of 101mpg (2.8 l/100km); an electric range of 31 miles (51km); and heady power outputs of 409ps and, perhaps more impressive, 640Nm torque.

Badged P400e, the Sport PHEV combines the aforementioned 2.0 Ingenium four-cylinder, in this guise developing 304ps, with an 85kW e-motor. That combined power – available from the permanent four-wheel-drive system – translates to a real-world 0-97km/h (0-60mph) sprint time of 6.3 seconds and a maximum speed of 220.5km/h (137mph).

Taking charge

But the real point to the creation of the P400e is, of course, efficiency and emissions. From behind the wheel, drivers have been given the option of selecting from two driving modes. The first – parallel hybrid – combines gasoline and electric drive, allowing the driver to optimize battery charge or fuel economy by making use of one of two charge management functions. The first, the Save function, essentially prevents the battery charge from dropping below the level that has been selected; the second – predictive energy optimization (or PEO, as JLR engineers have termed it) – sees the driver enter a destination in the satnav, and the system then uses GPS altitude data to optimize the switch between e-motor and gasoline engine, thus maximizing economy over gradients along the route.

The second driving setting, called EV mode, enables the Sport to run solely on the electric motor using the energy stored in the battery.

The 13.1kWh prism-shaped Li-ion battery pack is mounted at the rear of the Range Rover, beneath the trunk floor. Meanwhile, the IC engine is longitudinally mounted, with the electric motor housed on the transmission at the center of the vehicle along with the 7kW onboard charger. Such an arrangement, says JLR, allows for an ideal weight distribution. The access point for the cable is at the front of the vehicle, hidden behind the Land Rover badge on the right of the grille.

For Nick Collins, vehicle line director, the importance of PHEV tech for JLR can't be understated: "The new Range Rover Sport strikes a compelling balance between dynamic capability, passenger comfort and efficiency. The introduction of our advanced plug-in hybrid powertrain is a watershed moment in the history of our performance SUV."

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Modern makeover

Reinventing an icon from Jaguar's past could mark an important engineering step in the OEM's future

WORDS: **DEAN SLAVNICH**

Jaguar Land Rover's blossoming classic car restoration program – which to date has wheeled out epically beautiful limited series modern-day production runs of the Land Rover Series 1, Jaguar XKSS and a factory-restored 1978 three-door Range Rover Classic – has now embarked on a new e-powertrain chapter, having recently taken the covers off the E-type Zero.

Sitting alongside the production I-Pace BEV SUV at the Jaguar Land Rover Tech Fest, a two-day engineering and design event held at the University of the Arts London in September, the E-type Zero – which features a state-of-the-art all-electric powertrain – overshadowed JLR's main future tech concept at the event, the Future-Type (see sidebar, *Fifth wheel*).

Often described as the most beautiful car in the world, the E-type will nearly always take center stage regardless of the competition, and this even includes one of the most striking 'tomorrow's world' autonomous visions.

And while the E-type was again lauded for its beautiful styling, in this guise it hit international headlines for what is under the skin.

A state-of-the-art electric powertrain developing 220kW has been specially designed for the new E-type Zero, which looks and drives the same as the legendary 1968 Series 1.5 Jaguar E-type Roadster on which it's based

Painstakingly restored and very carefully converted at Jaguar Land Rover Classic Works in Coventry, UK, not far from where the E-type was born back in 1961, the contemporary Zero derivative boasts some incredible numbers, including a 270km (170-mile) real-world range and a 0-100km/h sprint time of just 5.5 seconds, the best part of one second quicker than the original.

And Tim Hannig, Jaguar Land Rover Classic director, says such outstanding performance was purposely capped by the engineering team: "In order to seamlessly combine the new electric powertrain of the E-type Zero with the dynamic setup of the original E-type specification, we have limited the vehicle's power output. We believe this provides the optimum driving experience."

Heart transplant

Based on the 1968 Series 1.5 Roadster, the E-type Zero is totally original in specification, aside from modified instrumentation and fascia, LED headlights, and that rather intriguing new electric powertrain.

The Future-Type concept is Jaguar's vision for an on-demand autonomous vehicle with a connected, intelligent, steering wheel

Developing 220kW, the powertrain has been specifically designed for the E-type Zero, says Hannig, with its 40kWh lithium-ion battery pack having the same dimensions and weight as the XK six-cylinder used in the original E-type. As such, the new unit slots into the same location as the XK engine, while the e-motor (and reduction gear) lie just behind the battery pack, essentially in the same location as the E-type's gearbox. A new propshaft sends power to a carry-over differential and final drive.

Because the new powertrain is essentially like-for-like in dimensions as the outgoing petrol engine and transmission, the car's structure, including suspension and brakes, have not been changed too much, thus simplifying conversation and homologation.

This means front-rear weight distribution is unchanged. And perhaps most surprisingly, despite having to cater for the battery pack and e-motor, the E-type Zero weighs some 46kg less than the original car.

FIFTH WHEEL

Despite being a little overshadowed by the reimagined E-type, Jaguar's Future-Type – the OEM's vision for the on-demand autonomous vehicle of 2040 – still drew its fair share of admirers. A premium compact concept with semi-tandem 2+1 seating, the Future-Type is an autonomous, connected electric vehicle that also epitomizes JLR's vision for future shared mobility: Jaguar imagines a 2040 where drivers might only own the Future-Type's steering wheel.

The Future-Type's steering wheel (named Sayer, after the designer of the original E-type) is at the heart of the concept. Voice activated and integrated into the owner's daily life (JLR envisages Sayer being able to book a table in a restaurant or tell users what's in their fridge), the steering wheel could be the only part of the vehicle that's fully owned. Cars could be summoned via the wheel (or a personal Future-Type called upon if purchased outright) and operate autonomously while passengers relax. Alternatively, drivers can opt to take control of the car with Sayer – although the wheel will also be able to advise on which parts of the journey might offer the best driving experience.

The E-type Zero features a lithium-ion battery pack that has the same dimensions and similar weight to the XK six-cylinder unit used in the original Roadster

"We have integrated the new electric powertrain into the existing E-type structure, which means a conventional engine could be reinstalled at any point," adds Hannig. "We think this is essential as it ensures a period where Jaguar remains authentic to its DNA."

Interestingly, the XK six-cylinder engine, which spanned from 1949 through to 1992, was fitted to nearly all Jaguar models of that period, including the E-type, but also the XK120, Mk2 and XJ6, meaning the new e-powertrain can be dropped into these iconic models too. "We could use this technology to transform any classic XK-engine Jaguar," adds Hannig.

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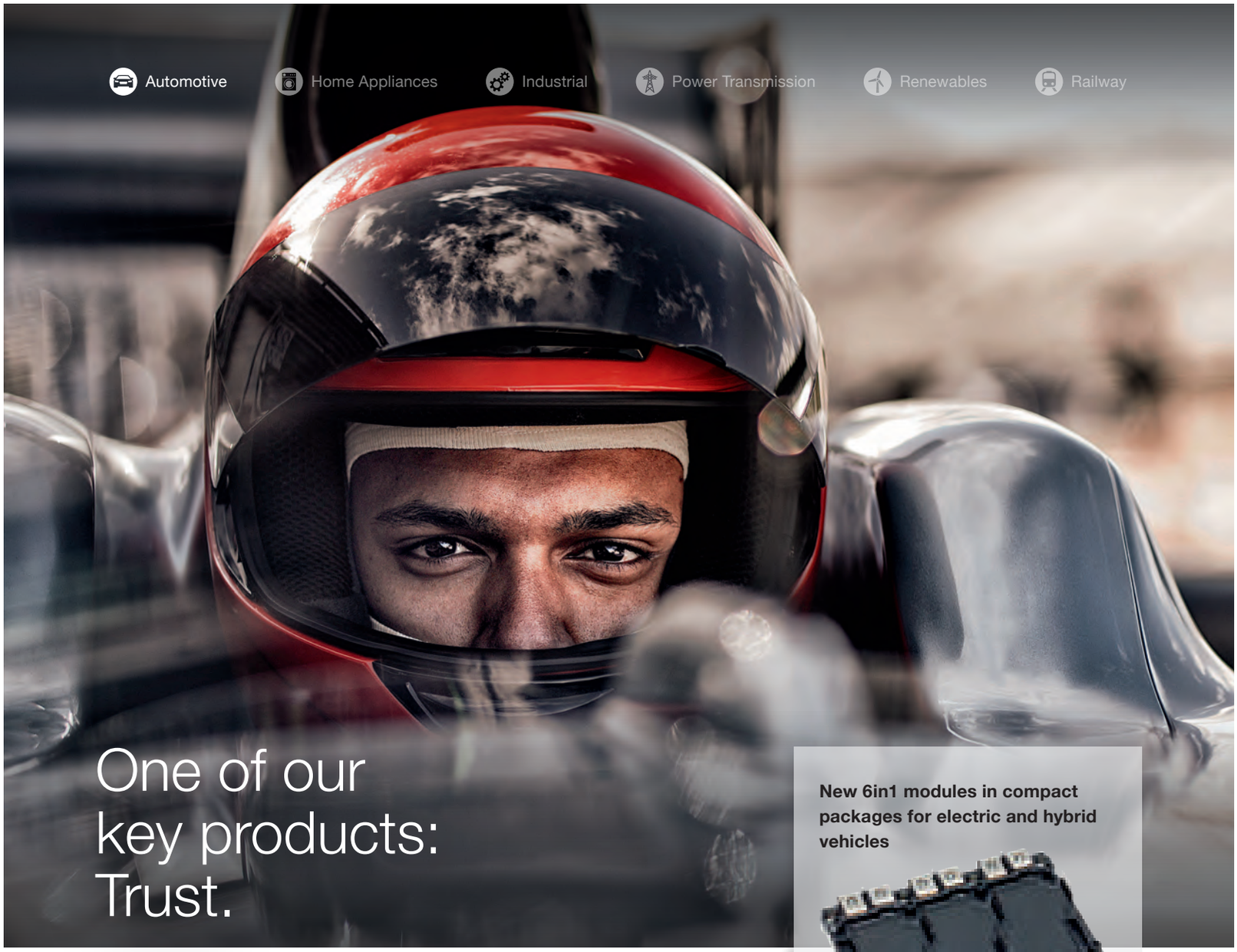

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Starting small

Uniti's CEO Lewis Horne claims the Swedish startup is reinventing the traditional model of electric car design

The CEO of Uniti sheds light on electric powertrain development for the startup's L7e class vehicle

WORDS: **MATT ROSS**

At the end of 2017 Swedish startup Uniti will launch the Uniti Electric Car – an L7e class project that is the product of an entirely new way of looking at vehicle design.

"You could say that we're 50% technology company, 50% behavior change company," says CEO Lewis Horne, who balks at describing Uniti as a traditional car maker.

Speaking in the run-up to the vehicle launch, Horne sounds a little irked at comparisons to established OEMs. When asked if the Uniti EV's overall design had an impact on the powertrain and architecture, or if the motor type and layout was the jumping off point, he's unequivocal.

"Here, everything develops in tandem. Everything is in parallel. The old silo approach is one of the major disadvantages of traditional automotive manufacturing."

The debut vehicle, Horne admits, will not feature the Uniti's production powertrain. But it does offer an interesting insight into the way the final vehicle will shape up.

"That powertrain is not our production powertrain. It's an evaluation prototyping setup. We have about another year's worth of evaluation prototyping for the powertrain with a UK automotive company that I can't say more about right now."

Currently, Uniti is leaning toward hub motors – though, in what is something of a running theme, Horne and his team are reluctant to settle on a solution until they've explored every creative avenue.

"[If you read about the vehicle], we say everywhere hub motors, but of course that's still pending evaluation prototyping. I ask [the team and our partners] to challenge everything we're doing in regard to the powertrain.

The Uniti EV features a swappable three-battery system

"The L7e vehicle class has a 15kW continuous output, but the biggest loophole of the millennium is that this doesn't restrict peak power, which is really the only relevant number. So we're looking at 75kW peak power to deliver 0-80km/h [50mph] in about 3.5 seconds in sport mode.

"Right now, the current evaluation prototype has two [motors] in the rear, but as I said, we'll keep challenging that. Never settle."

Uniti currently has a motor partner that it's working with, and the vehicle's in-wheel propulsion units feature integrated motor control and integrated cooling, but Horne says that it's "highly likely that we'll design our own".

Keeping options open

In terms of battery technology, Uniti is currently assessing its options. "It's definitely a custom battery pack, that's highly connected and customized. Right now, over the next three or four months, we're going to set up a fully automated in-house battery pack testing system with some bigger partners, so that's technically the early days of developing our own battery pack. It remains to be seen if we'll do that. It's a big business decision."

The vehicle – again, currently – uses a lithium-ion battery. "Though that's depending on if we go for stock, high-power, Panasonic-type cells like Tesla. We're also playing around with interesting Toshiba innovations. We have a little project with them. We don't like to make decisions like that too early."

The car will feature a three-battery system – one of which, the auxiliary battery, can be swapped out in just a few seconds. "One can be charging, one can be driving and you can swap energy between them, and you defer damaging charging cycles to the auxiliary pack, which has a shorter lifespan." Horne admits this complexity of battery management is "what we're shooting for" but also claims "any grandma can swap that battery out. Right now it weighs 14kg, and we think we can get that down as well."

The Uniti platform will be modular, and Horne also has tentative plans for other variants – and indeed, other business models. "Initially we'll have a two-seater and a four-seater model available for pre-order. I doubt we'll go up a weight class into the M1 class. It's possible, but I think there are a lot of great car companies already there. We might go lower – and if we make lighter vehicles, they'll be L2e class designed for full autonomy and the city center. We're looking at direct sales to the customer because that's what people know, but shortly after we'll transition to mobility as a service as a primary business model. There's a lot of guys on this team who like building crazy machines. We'll see where it goes from there."

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Raging bull

Lamborghini has raised plenty of eyebrows with the debut of a new electric supercar – the Terzo Millennio

WORDS: **DEAN SLAVNICH**

In collaboration with two engineering laboratories at Massachusetts Institute of Technology (MIT), Lamborghini showcased its latest future electric supercar vision in November 2017, much to the surprise of the watching automotive world.

While most onlookers – and rivals – had been expecting the Italian brand to finally reveal its production SUV, the Urus, which has had its public debut delayed by several months, missing the 2017 Geneva Motor Show in March and Frankfurt Motor Show in September, Volkswagen Group's Maranello chaser instead wheeled out a two-seater e-powertrain technology tour de force.

And perhaps most tellingly, Stefano Domenicali, chairman and CEO of Lamborghini, says such a lab-based academic dream remains a realistic real-world possibility. "Exactly one year ago, we signed an agreement with the MIT-Italy program at MIT, which marked the start of a collaboration between two outstanding entities for the creation of a project that intends to write an important page in the future of super sports cars for the third millennium.

"Collaborating with MIT is an exceptional opportunity for our R&D department to do what Lamborghini has always been very good at: rewriting the rules on super sports cars. Now, we are presenting an exciting and progressive concept car. We are inspired by embracing what is impossible today to craft the realities of tomorrow; Lamborghini must always create the dreams of the next generation."

Titled Terzo Millennio, the concept aims to address five Lamborghini-led dimensions: energy storage systems, innovative materials, propulsion systems, design and emotion.

The first two dimensions – energy storage systems and innovative materials – were conceived together with the two labs at MIT: the Dinca Research Lab, led by Prof. Mircea Dinca from the department of chemistry; and the Mechanosynthesis Group, led by Prof. Anastasios John Hart from the department of mechanical engineering.

Storage solutions

From an engineering perspective, a major point of interest resulting from the collaboration project (which has been substantially funded by Lamborghini), is the energy storage system. This is partly because Lamborghini has gone on record to state that for the next generation of supercars, it wants to revolutionize automotive energy storage, meaning its engineers should look not just at conventional battery tech, like the rest of VW Group, but also supercapacitors – which is exactly what the Terzo Millennio gets.

This line of thinking also stays true to the application of low-voltage supercapacitors in the V12 Aventador. According to Lamborghini, the next step is development of a storage system able to deliver high peak power and regenerative kinetic braking with very limited influence from aging and cycling during the car's life, and with the ability to symmetrically release and harvest electric power.

The tie-up with Dinca specifically aims to overcome the limits of today's technology and close the widening gap on conventional batteries' energy density, while maintaining the high power, symmetrical behavior and very long lifecycle that comes with supercapacitor tech.

As Dinca continues, "This new Lamborghini collaboration enables us to be ambitious and think outside the box in designing new materials that answer energy storage challenges for the demands of an electric sport vehicle."

Tellingly, though, neither Lamborghini, Dinca nor MIT are willing to reveal any numbers related to the Millennio, and that includes even basic data such as power, range and speed.

What is known is that Lamborghini, a huge advocate of four-wheel drive, is looking into in-wheel motor technology, and that's exactly what the Millennio gets when it comes to the propulsion system, in the process realizing high torque, reversibility and the possibility of moving energy by wire.

Material world

On the materials side, Lamborghini says the project furthers its expertise in carbon-fiber structure and parts. Here, the work with Prof. Hart and the team has already been key, investigating new manufacturing processes for carbon-fiber materials constituting the body shell of the Millennio, which will also act as an accumulator for total energy storage and enable the complete body of the car to be used as a storage system.

Perhaps the most radical aspect of the Millennio is that the partners are also looking into self-healing materials; the aim here is to provide the supercar with the ability to conduct its own health monitoring to detect cracks and damages in its substructure from accidents. In this case, a self-repairing process starts via microchannels filled with healing chemistries, reducing the risk of small cracks to zero.

Lamborghini and MIT's Terzo Millennio project benefits from a host of cutting-edge technologies, including in-wheel motors, supercapacitors, new carbon-fiber manufacturing processes and, potentially, self-healing materials

ELECTRIC POWERTRAINS **ON TEST**

Our thoughts on cars we've tested recently, all of which feature some sort of advanced powertrain electrification

VOLKSWAGEN E-GOLF

For those who like the idea of a pure-electric vehicle, but not the image it conveys to fellow motorists, Volkswagen's updated e-Golf could be the answer to their prayers. The vehicle sits in that sweet spot – from the outside, there's very little to suggest that the VW hatch is driven by a 136ps motor rather than an IC powerplant (some eco-blue detailing and aero-friendly alloy wheels aside). Mated to a single-speed transmission, the e-Golf's motor develops 290Nm of torque – and boy does it show. The initial thrill of from-standing power is, thanks to the increasing profile of electric vehicles, less of a surprise these days, but the electric Golf still delivers that acceleration in such a grin-inducing way that even the most ardent of EV naysayers would struggle to suppress a smile.

The initial rush of power tails off as the speed increases, but both cruising at highway speeds and city commuting are handled with aplomb. The selling point of the updated e-Golf is the increased range – VW states NEDC range of 300km (186 miles) – and after a day's charge at our office (from a three-pin wall socket) we were showing around 200km (125 miles). It's a comparable figure for a new EV, but range anxiety still creeps in, not least thanks to a projected range figure that has a tendency to leap up and down depending on current driving conditions. That said, a potential figure is also displayed, which lets you know how many miles you can add by switching off the other electrical draws – and you'll be helpfully prompted to shut the windows to improve aero performance. The range can also be boosted by brake regeneration. Shifting into B mode offers aggressive regen, siphoning energy back into the battery.

Most importantly, the e-Golf is a lot of fun to drive. The steering is direct and the vehicle feels agile – helped out by situating the electric powertrain's weightier components as low as possible. It's a car that doesn't shout about its electric powertrain – quite literally, as it's also eerily quiet, even for an EV – yet expertly delivers the benefits.

HYUNDAI IONIQ PLUG-IN HYBRID

Sliding in alongside its mild hybrid and battery electric counterparts, the plug-in Ioniq is the third element to Hyundai's triple-pronged assault on the electrified hatchback market. That said, there were a few (outside of the editorial office) who thought we'd taken delivery of a Toyota Prius – especially when catching a glimpse of the split-glazed rear. Regardless of any initial mistaken identity, the plug-in Ioniq sets out to be its own animal. The 1.6-liter Atkinson-cycle GDi Kappa engine and 44.5kW electric motor yield a total system output of 141ps. The make-up of the powertrain is essentially the same as the regular hybrid, although the plug-in variant enables inclusion of a larger battery and more powerful motor. The plug-in also shares the 6-speed DCT with its sibling.

In hybrid mode, the Ioniq will rely on its electric motor at start and for low-speed operation. Mash the accelerator or head uphill and both the IC engine and the motor will join forces, while at constant speed one or the other will take charge. Deceleration and downhill travel makes use of the mildly unassuming regenerative braking to recoup a little energy. The interaction between the power sources is relatively seamless, with noticeable switching something of a rarity. As battery levels begin to drop, the petrol engine can be trigger happy, kicking in with little invitation, but the hybrid system is, for the most part, impressively unobtrusive – although at those lower battery levels, the slight jolt of the ICE pitching-in showed signs of becoming more prominent. The claimed EV-only range of 62km (39 miles) was tough to prove – we managed 43km (27 miles) before the Ioniq called time on pure-EV operation – and at lower speeds the pure-electric performance suffers a little from the weight of the powertrain. But that said, this isn't supposed to be a high-performance car (although sport mode and paddle shifts do hint at a more playful side without doing a huge amount to alter the driving experience). Frugality and practicality are, presumably, what Hyundai is going for and, with a generous interior and claimed extended range of 1,062km (660 miles) on a full tank and charge – although we didn't cover enough distance to verify this – the Ioniq certainly stakes a claim for both.

SMART ELECTRIC DRIVE

It's unlikely that anybody will mistake the Smart Electric Drive for any of its IC-engined predecessors. Not only did the all-electric city car we had on test sport bright green detailing, but it also came complete with the vehicle's charging point-based logo stamped on the rear pillar. Anybody encountering the zero-emission two-seater will also hear the distinctive whine as the three-phase synchronous motor gets underway – the Smart is far from noisy, but the absence of any internal combustion means the sound of the powertrain (such as it is) goes unchallenged. Producing 81ps and with a range of 159km (99 miles) – though you'll need a full charge and no other electric draws switched on to get such a distance on the vehicle dash – the Smart Electric Drive's 17.6kWh lithium-ion battery provides power to the rear wheels and makes a speedy getaway possible. It lacks some of the initial punch of other pure EVs, but for city center driving during short journeys – which, let's face it, is what the vehicle is designed for – it's suitably agile. The tight turning circle and responsive steering make the car feel nimble, and you'll have no problem sneaking into gaps or beating the lights thanks to 160Nm of maximum torque.

Put your foot down, and the Smart feels a little less assured. It's electronically limited to 129km/h (80mph), and when you get close to that, wind and tire noise make things feel a little more precarious. Staying at high speed eats into the range a little, but reining in the aggressive driving causes the available mileage to fall more in line with real-world coverage. Regen braking helps during deceleration or downhill travel. For those with short commutes, and decent access to charging, the Smart Electric Drive makes a lot of sense.

LEXUS IS300H

Despite having to coexist in a crowded compact executive sedan market class dominated by several established German-badged 2-liter turbodiesel powertrains, the refreshed Lexus IS300h's 2.5-liter gasoline hybrid unit is a more than capable left-field alternative.

The four-cylinder direct-injection Atkinson Cycle engine, which develops 180ps at 6,000rpm and 220Nm of torque at 4,200-5,400rpm, is mated to a synchronous e-motor that produces 143ps and 300Nm of torque, and nickel metal hydride battery pack, giving the IS300h a maximum combined output of 223ps and a top speed of 201km/h (125mph).

Impressively, the hybrid module of the vehicle's drivetrain, which comprises the electric motor, generator, power split and motor speed reduction device, is housed in a single transaxle casing that's roughly the same size as a conventional gearbox.

And when driven at low speeds, the rear-wheel-drive IS300h provides a quiet and refined driving experience. However, the revs do start to flare at the upper end of the range due to the limitations of the 8-speed e-CVT automatic transmission. And with a 0-100km/h sprint time of 8.4 seconds, the vehicle lacks the punchiness of its diesel-powered contemporaries.

That being said, the stylish IS300h handles well for a vehicle that weighs 1,620kg. And perhaps most importantly it boasts impressive fuel economy (4.1 l/100km) and emissions output (101g/km on models with 17in wheels), meaning Lexus should be able to take the fight to diesel Mercedes-Benz, Audi and BMW models for some time yet.

MINI COUNTRYMAN PLUG-IN HYBRID

If you're looking to sate your appetite for an electrified Mini while you wait for the all-electric Mini EV in 2019, the PHEV Countryman could tick a lot of boxes. Admittedly, the five-door Countryman is on the larger end of the Mini spectrum, but a combination of the famous brand DNA and a hybrid powertrain is intriguing. ICE power comes from a 1.5-liter three-cylinder turbocharged petrol unit, producing 138ps, and supplemented by an e-motor, nudging total system output to 224ps. This enables a 0-100km/h sprint in 6.8 seconds, making the car surprisingly spry. And in Sport mode, the Countryman retains that exciting level of performance for the majority of driving conditions. Take the car out of its most dynamic mode, however, and the extra heft of the hybrid powertrain becomes more apparent. At low speeds, the Countryman feels heavy, and although the excellent 1.5-liter unit is usually more than up to the job, overworking the ICE (such as accelerating hard when also utilizing the Save function to maintain and/or charge the battery) will send the revs soaring. But such situations are rare. If you're close to full charge, and knock the Countryman into Sport and Max EDrive mode, it can be flung around far more than seems feasible for such a big vehicle. We didn't manage to achieve the claimed 42km (26-mile) EV range – though came close when driving carefully – but the Countryman's speedy charge time, and the inclusion of an estimated finish, mitigate this somewhat. The hybrid Countryman does a lot of things very well – and suggests great things for Mini's electrified future.

PROFILE: GASPAR GASCON ABELLAN

Job title: Global director of product engineering
Company: Renault

What career did you want when you were growing up, and what was your first job?
My dream was to become a fighter pilot. My main interest was in physics and mathematics and to understand the technology side. Airplanes were the most sophisticated and complex objects on Earth created by humans. After that, I was very interested in powerplants, not only jets, but internal combustion engines as well as light airplanes. I worked as an intern for one year at Airbus, then worked for another company that did software for satellites, before I got a job with Renault simulating manufacturing systems. I had moved to France in 1995, just as a base engineer developing cylinder heads and camshafts for gasoline engines. I spent two years in France before returning to Spain. I came back to France in 2004 to become a product director for powertrains.

What was the path to your current position?
Car manufacturing is very complex, so you must master several domains. It's better to invest some time to get to know manufacturing, product design, mechanical design and electronics. Once you have a solid base, you can go up quite quickly – you have to be able to put together all the pieces of the puzzle. This has been my career for the 15 first years. [In terms of my career path] I grew up very quickly. I was the head of powertrain engineering for the group for three years, and three years ago I was promoted to head of Renault product engineering, including vehicle powertrains, systems and testing, based in France.

What are some of the best and worst elements of your job?
The best is that you are living the product passion, and in certain ways you can influence a lot about the choices in the product, which is especially good if you like cars – so for me personally, this is absolutely fantastic. You can sometimes change the organization and find new ways of working – this is the creative side of my job. Probably the least enjoyable is when you have to recognize that you have made a mistake, or you have to move people from their jobs. Sometimes it's hard, but you have to do that.

> "The automobile can do 140-150km/h – sometimes more – and we have to take care to preserve the safety of the occupants"

What car do you currently drive?
I'm lucky enough to drive a lot of cars. I test everything – petrol, diesel, electric. I'm not representative of the standard guy, I drive everything and I appreciate everything.

What would be your dream engine specification for today's eco-friendly world?
I think there are nice solutions using different technologies, but my preference is pure electric. Just look at our [Symbioz] concept car. There will be a demo car version of that. There will be some mules based on the Talisman, to prove and validate our autonomous driving future and the connectivity and the tuning of the electric motors. When you put 360kW in the car as a continuous power, but with a peak of 500kW, you will see tremendous acceleration. Add in the facility to maneuver the car with a low center of gravity, and you can create an absolutely fantastic machine.

In your opinion, what is the greatest engine that has ever been produced?
I am a fan of the 2.0-liter turbo petrol four-cylinder from the previous Renault Megane RS. It was not the most efficient in terms of consumption, but it was a quick response engine. I also have a passion for some of the BMW powerplants.

Which OEMs do you have an engineering respect for?
I have a lot of respect for all our competitors. Most car makers are focused on some areas where they want to be excellent. There are good examples everywhere. Frankly, there are no bad guys. The difference between manufacturers is the efficiency of working as a team. This is the only difference, not in the quality of the engineers themselves.

Do legislators help or hinder your work?
We need rules as clear as possible. The automobile can do 140-150km/h [87-93mph] – and more – and we have to take care to preserve the safety of the occupants. I'm not against regulation – they are doing their job. Perhaps legislators have to be a little closer to us sometimes to update regulations to keep up with technology.

What do you think will be powering a typical family sedan in 2030?
I think it will be an EV car with generous proportions. It will be connected online. You will be able to configure the car to your journey. There will be a lot more choice with the layout of electric cars.

GM's Electrovette concept featured 20 lead-acid batteries in place of the rear seats

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Engine reboot

As electrification becomes increasingly common, *E&H Vehicle* takes a look at the Chevrolet Electrovette and an early industry attempt to reinvent the powertrain

WORDS: **SAM PETTERS**

This year has seen an influx of OEMs devote resources and time to powertrain electrification – Volvo, Jaguar Land Rover and Aston Martin are just a few. However, this isn't the first time auto makers have invested in the development of alternative fuel solutions. There is an air of symmetry to the industry as today's OEMs contemplate a possible future without oil – over 40 years ago the prospect of an unsustainable future for the IC engine was beginning to become apparent and US manufacturers focused their energy on the development of a fully electric powertrain.

In 1973 a combination of President Nixon's newly introduced fiscal policy and the USA's ongoing feud with the Organization of Arab Petroleum Exporting Countries (OAPEC) meant that by the following year oil prices were four times higher than prior to the crisis and the US$2.50 gallon was looking increasingly likely. With the industry sent into panic mode, OEMs rushed to develop alternative fuel solutions for the consumer market and GM introduced the fully electric Chevrolet Electrovette.

Developed by GM's Advanced Engineering Division and based on the Chevrolet Chevette, the two-door EV featured 20 12V lead-acid batteries and, thanks to a direct current motor and planetary drive, 50kW could be routed to the rear wheels. This meant a top speed of 85km/h (53mph) and 0-48km/h (0-30mph) in 8.2 seconds. But driving at a constant 48km/h would only get you 80km (50 miles) of battery range. In comparison, the 1.6-liter gasoline Chevette – which was in development at the same time and featured the same silhouette – would achieve 7 l/100km (33.6mpg) and hit 159km/h (99mph).

However, the decision to use a DC motor proved pivotal to the future of the EV project. It required carbon conductors and a copper commutator ring which led to friction, arcing and therefore energy loss, affecting what was already a limited range. Though engineers looked into the development of nickel-zinc batteries, which (it was claimed) could double the vehicle's range, the alternative power source never came to fruition.

A core focus for the project was maximizing the power-to-weight ratio, but despite basing the Electrovette on the smallest car in the country, the retrofitted Chevette compact was no lightweight. With 417kg (920 lb) of batteries replacing the rear seats, the two-passenger prototype weighed 1,338kg (2,950 lb). To combat this, GM worked on lithium and iron sulfide batteries, which would be smaller, lighter and more powerful, but after failing to make a technological breakthrough, the idea was scrapped with an estimated 10 to 15 years of development left to be undertaken.

Despite the experimental nature of the project, GM showed the vehicle publicly at various meetings throughout the USA – and in light of the oil troubles plaguing the country it seemed there was a place in the market for the EV at that time. However, in 1978 the OEM acknowledged the vehicle's flaws and that a major advance in battery technology was needed. These factors, in combination with the USA soon becoming oil-rich once again, ensured that the Electrovette never received the green light.

Looking at the vehicle now, it's clear that the powertrain wasn't the forward-thinking solution that GM intended. However, certain elements hinted at the industry's future direction. This year GM announced its vision for an all-electric future, starting with two new models in 2018 and followed by a completely electric line-up by 2023.

When Honda unveiled the Urban EV at the 2017 Frankfurt Motor Show there was a sense of the industry coming full circle. With its multispoke wheels, round headlights and retro styling, the concept looked not dissimilar to the Electrovette. The modern reality of finite oil resources means that the automotive industry is once again taking innovative design cues from the past. This time, however, they look like they're here to stay.

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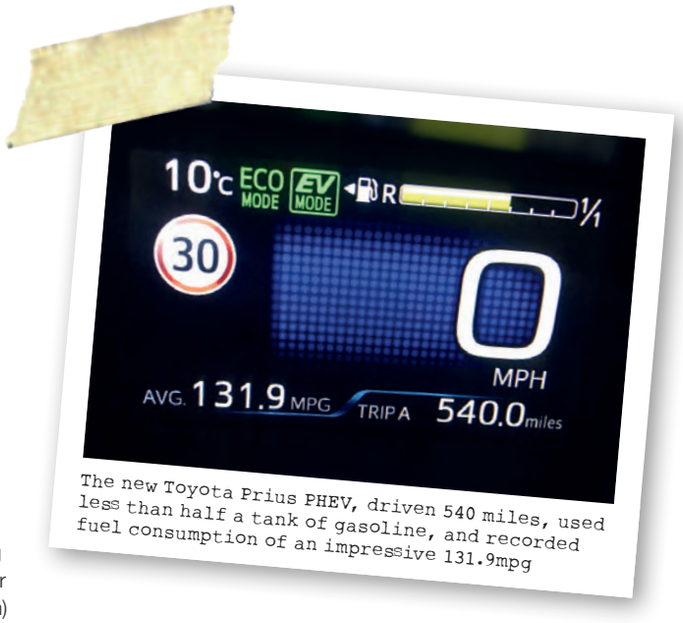

The new Toyota Prius PHEV, driven 540 miles, used less than half a tank of gasoline, and recorded fuel consumption of an impressive 131.9mpg

As any regular driver of a pure EV knows, there are many problems with plug-in-hybrid vehicles. If you drive the best-selling Mitsubishi Outlander and charge it as often as you can, including using rapid chargers on long journeys, you can get impressively low fuel consumption for such a big vehicle. I drove an Outlander 700 miles (1,127km) and got over 90mpg (3.14 l/100km), but I was charging it as much as if I'd been driving a Nissan Leaf. I used Ecotricity rapid chargers at nearly every service area on my route, waiting for about 15 minutes at each charge. Of course, this was before Ecotricity charged for access – introduction of the Outlander was one of the reasons Ecotricity decided to start charging as, by adding CHAdeMO connectivity, Mitsubishi built a car that took advantage of a system they hadn't invested one penny in.

I have since met many Outlander drivers who report much higher fuel consumption – around 30-35mpg (9.4-8.1 l/100km). Some of them charged their car at home every night, but were still way under the claimed figures from Mitsubishi. Two wished they'd bought a Tesla.

So when a new Toyota Prius PHEV was delivered to my house, I was a little skeptical. My wife has been driving the 2012 Prius PHEV for five years. Over the 100,000 miles (160,000km) she's driven in the car, it's been 100% reliable and has worked perfectly. However, it averages about 65mpg (4.35 l/100km). As many diesel drivers will happily tell you, modern diesels can achieve similar figures, and they are cheaper to buy. Sure, the Prius has lower CO_2 and particulates emissions and all that, and no, the batteries won't 'wear out' after three years – they will last longer than the car.

With concentrated effort, charging the plug-in Prius at every opportunity, it's possible to reach over 90mpg (3.14 l/100km). I remember getting 93mpg on a very long drive, but I was driving like a classic hyper-miler: shoes off, super gentle acceleration, super early deceleration, heater off, during the day, in the summer.

> "I have traveled 540 miles, used less than half a tank, and achieved an average of 131.9mpg"

All that said, the new Prius is a massive improvement. When the car is at my house I always charge it, and I have used two public chargers when I've been away from home. Both times I was at the location long enough to refill the car – it takes around two hours on a 16A outlet.

The 4.4kWh battery will power the car for 30 miles (48km), a big jump from the previous model's 10-12 miles (16-19km).

The Prius PHEV has no rapid charge capabilities so I haven't done the motorway charging thing. I zeroed the trip meter when I filled the tank the first time – it was the first petrol I'd bought this year, and I'd forgotten just how expensive it is – and since then I've kept a close eye on the trip meter and average mpg.

I have traveled 540 miles (870km), used less than half a tank, and averaged 131.9mpg (2.14 l/100km). Just let me enjoy saying this. There isn't a diesel that can match that. Anywhere. Ever. There never will be. I'm going to say it again – 131.9mpg over 540 miles. At this rate, I'll get an easy 1,200 miles (1,931km) on a tank of petrol that costs in the region of £45 (US$59). Including the off-peak and solar electricity I use to charge the battery, it's costing about 4p (US$0.05) per mile to drive. That's a little more than a Nissan Leaf or Renault Zoe, about the same as a Tesla Model S, but massively less than any petrol or diesel car.

As for the driving experience – it's a Prius. It gets you from A to B in comfort and safety. The model I'm driving has solar panels on the roof. When parked in the sun it can add, according to Toyota, three miles of range per day. I haven't been able to verify that. I've been impressed, and as a long-time Prius driver (I got my first one back in 2005) this is a big step in the right direction.

Greg Offer


China looks set to dominate its domestic battery industry, but competition for international business could be a much harder-fought battle

Is the future of batteries – and therefore EVs – set to be dominated by China? This is what a lot of industry observers are saying, but how true is it? Yes, China did this for solar panels, capturing a significant share of the global market and driving costs down to a staggering level. China has also invested heavily in batteries over the past 10-15 years, and that investment seems to be paying off. The world's largest gigafactory could be the one being built by CATL in Ningde, China, and not the one being built by Tesla and Panasonic in Nevada, USA. This investment is already being driven by the huge number of electric buses and passenger vehicles being built in response to generous subsidies, and the government in China has signaled it will reward those who grow biggest and fastest.

There has also been a shift in technology – a decade ago, the Chinese battery market was dominated by high-power lithium-ion phosphate cells, whereas now the market is shifting toward the high-energy density nickel cobalt manganese (or ternary cells) typically favored by the automotive industry. As an engineering research group, we need to know the answer to this question, as we need to know who we should work with, and what technologies are going to be important in the future.

China is widely acknowledged for fundamentally changing the economics of solar, by driving down world prices by 80% from 2008 to 2013. However, they did this in unique circumstances. Global demand was rocketing, in large part driven by feed-in-tariffs in Germany. Investors in the USA and Germany, the then-world leaders, were attracted by cheaper operating costs in China. Within a few years, China had built up the world's largest solar manufacturing industry, but it was focused on export from the start. They created a glut that drove down prices, and put most of the competition out of business, and only at that point created subsidies for a domestic market to put the glut to use. Now, China's lead in solar is unassailable.

> "China's investment in batteries and EVs is being driven by domestic demand first"

In contrast, China's investment in batteries and EVs is being driven by domestic demand first. Although companies like BYD are exporting plenty of electric buses, this still pales into insignificance compared with the domestic market. There is another major difference: unlike solar panels, vehicles are not a new product, and the existing automotive industry is keenly aware of the threat of new manufacturers. Tesla woke them up to this threat almost 10 years ago, and market leaders like BMW, Nissan and GM all cashed in their insurance policies against a first mover, taking whatever electric vehicle technology they had been slowly developing in their research and development divisions, and moving it into production divisions to launch products within just a few years of Tesla. The rest followed pretty quickly, and 2020 is looking like it will kick off the decade of the electric vehicle, given the sheer number of models in the pipeline. The existing automotive industry has also been savvy, forming partnerships with Korean and Japanese battery companies, and by working together they are probably having just as much (if not more) impact on driving down prices as the Chinese companies.

This time therefore, unlike with solar, there will be competition. It is obvious China will dominate its own domestic market, and reap a huge economic dividend as a result, but it will face fierce competition when it tries to export, and it won't be able to pull a fast one on the rest of the world like it did with solar.

Dr Gregory Offer is a senior lecturer in mechanical engineering at Imperial College London. His research focuses on fuel cell, battery and supercapacitor technologies, mainly in transport

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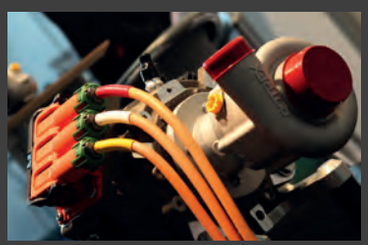


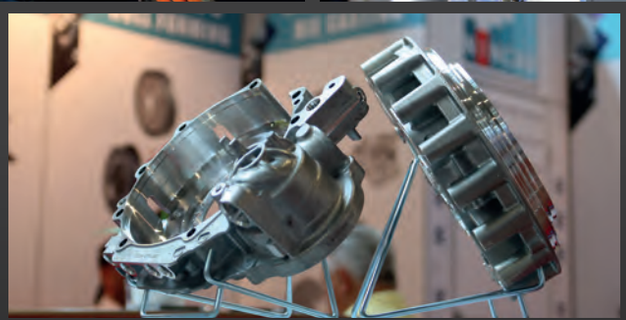


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On the whole, vehicle developers have tended to work alone. But in the ongoing pursuit of advanced electrification, is collaboration the way forward?

WORDS: **LEM BINGLEY**
ADDITIONAL REPORTING: **MATT ROSS**

The advanced fuel cell system revealed by General Motors and Honda in a joint venture where the technology will be used in each company's future products

You can go **your** own way

September 2017 saw British inventor James Dyson announce that his technology company, founded in 1987, would develop an electric vehicle that would launch in 2020. In an email sent out to all Dyson employees, the company's founder recounted that, in 1988, "I read a paper by the US National Institute for Occupational Safety and Health, linking the exhaust from diesel engines to premature death in laboratory mice and rats. In March 1990, a team at Dyson began work on a cyclonic filter that could be fitted on a vehicle's exhaust system to trap particulates."

Frustrated by a lack of interest shown in several working prototypes that Dyson and his team developed, the project was halted – though the problem clearly remained at the forefront of the inventor's mind.

"It has remained my ambition to find a solution to the global problem of air pollution," Dyson continued in his email, revealed to the world's media around the time of the electric vehicle announcement. "Some years ago, observing that automotive firms were not changing their spots, I committed the company to develop new battery technologies. I believed that electrically powered vehicles would solve the vehicle pollution problem. Dyson carried on innovating."

An electric vehicle project – developed by Dyson's engineering experts – will, the founder believes, unite the company's competencies in a single project. And while many might be inclined to seek the guiding hand of an established auto maker, or a proven expert in vehicle electrification, Dyson instead believes that everything required to realize this 2020 target can be found under the roof of its newly-acquired, high-tech Hullavington campus in the UK.

There are – perhaps inevitably – doubters, despite the fact that Dyson has committed £2bn (US$2.6bn) to the project. After all, such a short timeline for a new vehicle would stretch even the most seasoned of auto makers. Uniting the myriad complex, interdependent technologies within a single project is undoubtedly a challenge, as is navigating the various regulatory and legislative checkpoints that lie between concept sketches and vehicles rolling off the production line.

But Dyson seems determined to go it alone, perhaps relying on acquisition rather than collaboration. In November 2017, Fisker filed patents for potentially industry-changing solid-state battery technology. On the development team is an as-yet unnamed key expert from battery startup Sakti3 – which was acquired by Dyson in 2015.

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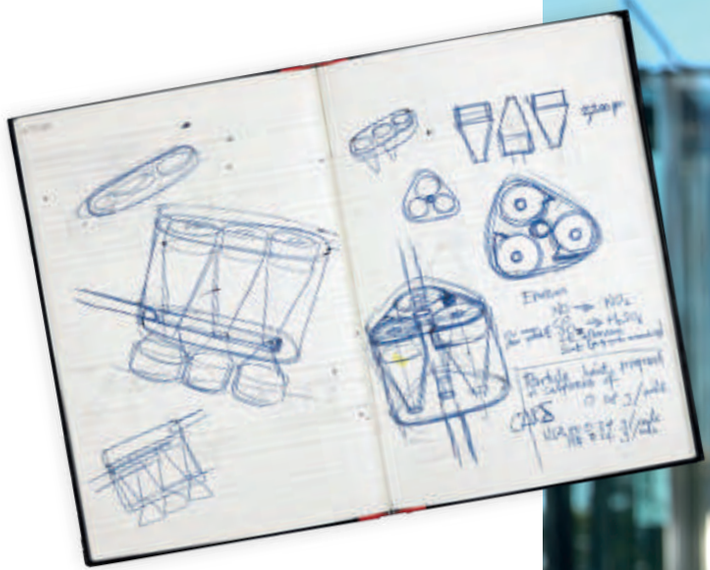

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1. Cyclonic filtration for exhausts spawned Dyson's quest to build an electric car

2. The campus at Hullavington sits on a 517-acre former MoD site in Wiltshire, UK

3. British inventor and engineer James Dyson aims to launch an EV by 2020

"In March 1990, a team at Dyson began work on a cyclonic filter that could be fitted on a vehicle's exhaust system to trap particulates"

James Dyson

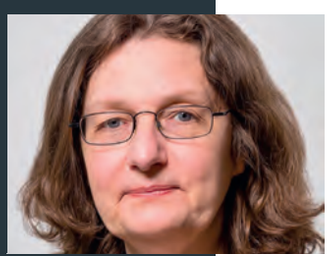
PAIR BONDING

"JVs spring up for every business reason," says Susan Laws, a partner at international law firm Duane Morris. She has worked with automotive joint ventures for more than 30 years, starting with Ford-Iveco in 1986. Given the variety of motivations, there is no such thing as a standard JV agreement. "A good JV should be collaborative and address the needs of both parties," Laws says. "Is it that you need to do R&D but don't have the budget? Is it that there aren't enough experts to support two separate projects? Is it to do with economic development and market positioning? Is it really a trial marriage?"

As Laws notes, the collaborators' goals will shape the working agreement as well as provisions for exit or the framework for settling disputes.

Laws adds that appearances can be deceptive. "People focus on the percentages but I always tell them to forget them," she cautions. "Just because there are 50:50 shares doesn't mean one partner isn't actually in control. A 50% owner may have rights to 90% of the income."

> "A good JV should be collaborative and address the needs of both parties"
>
> Susan Laws, partner, Duane Morris



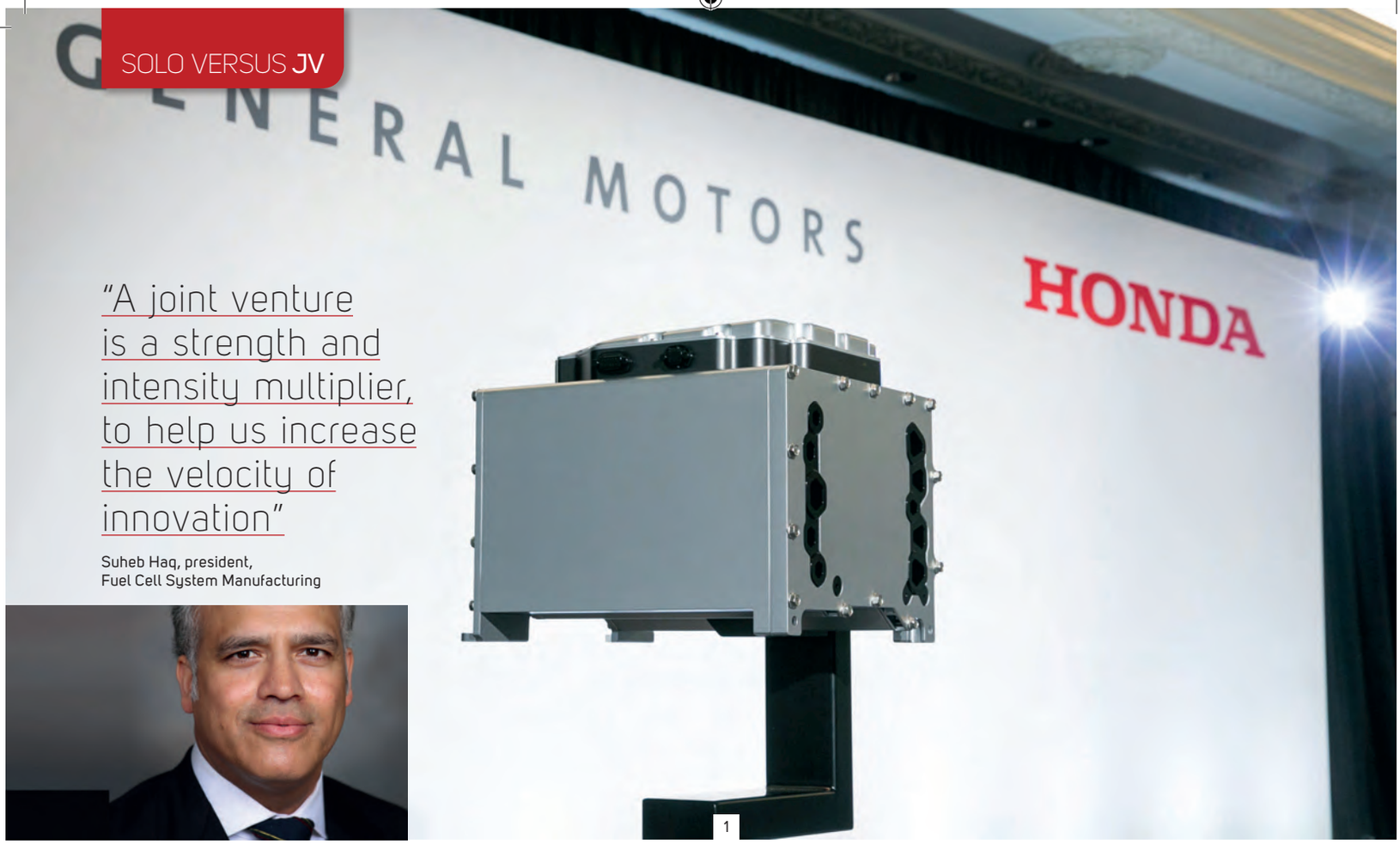
Where controlling interests in companies must be disclosed, 'puppet' JVs are easier to see. "You'll often see a 5% shareholder disclosed as having significant control, whereas if they only had 5% of the voting rights, they wouldn't be," Laws says. In other cases, ownership may overstate a contribution. "Sometimes you'll see incredible vanity when a firm thinks their technology is the bee's knees, insisting on 50:50 billing," she says. "But you look at who's getting the lion's share of the money, and it ain't them."

The key for success is a partnership that's fit for purpose, Laws concludes: "You need to work out who is bringing the strength in each area, get that recognized, and put something in place that lets them do what they do without interference, with checks and balances if anybody goes off-piste."

Two's company

Nevertheless, as car makers grapple with waves of unsettling change, from connected and autonomous vehicles to shared services and alternate powertrains, it's no surprise to see more companies teaming up in joint ventures (JVs) to speed up development of technology. They believe that cooperation is the key to advancing the technologies, and many permutations have begun to appear.

In December 2016 two suppliers joined forces to work on electric powertrains, creating Valeo Siemens eAutomotive. In July 2017 Honda and Hitachi invested ¥5bn (US$44m), split 49:51, to found a new electric motor



"A joint venture is a strength and intensity multiplier, to help us increase the velocity of innovation"

Suheb Haq, president, Fuel Cell System Manufacturing

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company. And in September 2017 Mazda, Toyota and Denso set up a JV to create a common architecture for future EVs.

What do the various participants hope to gain from these kinds of collaborations with their partners and rivals?

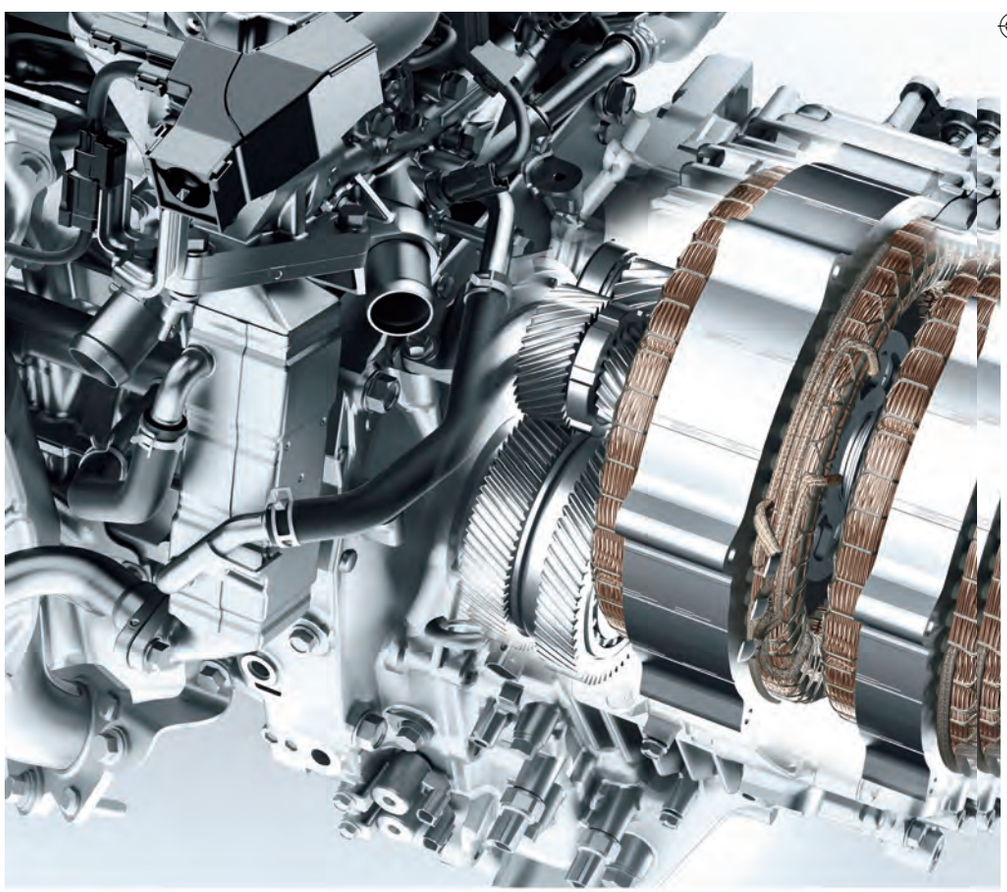
"We believe a joint venture is a strength and intensity multiplier, to help us increase the velocity of innovation," says Suheb Haq, president of Fuel Cell System Manufacturing.

Haq's company is a joint venture between General Motors and Honda, founded in January 2017 with an US$85m investment, split 50:50. The JV followed a period of partnership on fuel cell development that began in July 2013. Collaborations between the two companies stretch back to an engine supply swap two decades ago.

Haq hails from the General Motors side, bringing seven years of experience at GM's joint ventures with Shanghai-based SAIC in both China and India.

"It's very helpful to have a partner because both companies can bring their intellectual horsepower to the common problem," Haq says. "GM brings 50 years of development experience [with fuel cells] and 3.2 million miles of real-world driving credibility."

Fuel Cell System Manufacturing will concentrate on bringing jointly developed technology to market. From 2020 it aims to build production-ready fuel cell stacks in



Brownstown, Michigan – where GM currently assembles the batteries for EVs such as the Chevrolet Bolt.

Units built by the fuel cell venture will power future Honda and GM vehicles, designed independently around a common stack. Those vehicles won't necessarily be passenger cars, however, as Haq notes that "GM continues to look at opportunities for land, sea and air."

The force multiplication Haq describes arises in different ways. "You achieve economies of scale because you've got the volumes of two companies there; you're able to share the investment and operating costs; and I think one of the more important aspects of a JV is that you really do bring the best of what the two companies have to offer. As a small example, I and my Honda partner Tomomi Kosaka are working closely to study each other's manufacturing systems and broader support systems, to make sure we select the best of the two."

With GM and Honda based in opposite time zones, collaborative effort can continue around the clock. But Haq argues that the most valuable aspect of joint working is bringing people and skills together, especially where expertise is rare and thinly spread.

THE CHINESE WAY

Joint ventures are almost unavoidable for foreign OEMs targeting the fast-growing Chinese market. Imported vehicles face hefty tariffs while government rules require Chinese involvement in domestic production. Most OEMs have long since entered into partnerships, typically split 50:50.

"Most of the JVs are quite established," observes Ting Wu, a partner at consulting firm McKinsey, based in its automotive practice in Shanghai. "However, there are 50:50 joint ventures where foreign OEMs have quite a strong say in all the functions."

While there is no fixed approach to dividing responsibilities, at least one joint venture has developed a system of shadow management to share decision making. "For almost all the key functions you might have one foreign manager and one Chinese manager," Wu explains. "For some functions the Chinese manager has more decision power whereas for others it's the foreign manager."

Joint working has typically been mutually beneficial, Wu says: "On the Chinese side, a lot of senior executives have gained considerable experience. The JVs have really trained a generation of technical and management experts in China's automotive industry. And because of the fast growth in China, I think expats who've come to China have also benefited, in terms of their performance and international exposure."

"JVs have really trained a generation of technical and management experts in China's automotive industry. And because of the fast growth in China, I think expats who've come to China have also benefited"

Ting Wu, partner, McKinsey

While JVs between foreign and Chinese firms are common, more partnerships and mergers may start to develop within China itself. "Chinese OEMs are actively thinking about how to move up," Wu notes. "Even from a government perspective we see a potential trend of further consolidation. There are just too many sub-scale, poorly performing OEMs in China supported by local governments. That's not healthy for the further development of the Chinese automotive market."

Honda and Hitachi have teamed up to develop new electric motor tech. Pictured here is Honda's pre-JV motor in the Accord hybrid

2

1. The industry's first hydrogen fuel cell manufactured by a joint venture

2. Hitachi president and CEO Hideaki Seki (left) and Honda CEO Takahiro Hachigo (right)

"JVs rely on individual relationships for success," Haq says. "It's really critical for us to work on the human relationships. If you come to the Global Propulsion Systems headquarters in Pontiac [Michigan] and walk through the fuel cell offices, it is a very common sight to see members from our Japanese and GM teams in meetings and in discussions together. We have teams working together face to face, as well as development activities in each other's labs and facilities."

Pooling of intellectual property (IP) can also accelerate progress. "We're both leaders in fuel cell development and collectively we've got more patents than anybody else in the industry," Haq claims. "Our intention is to share any IP that we co-develop."

"We're happy to work with any supplier in building a complete system. For an OEM, this is a really fast way of getting the latest and greatest in active safety and self-driving"

Erik Coelingh, technology advisor and vice president, Zenuity

Getting to the point

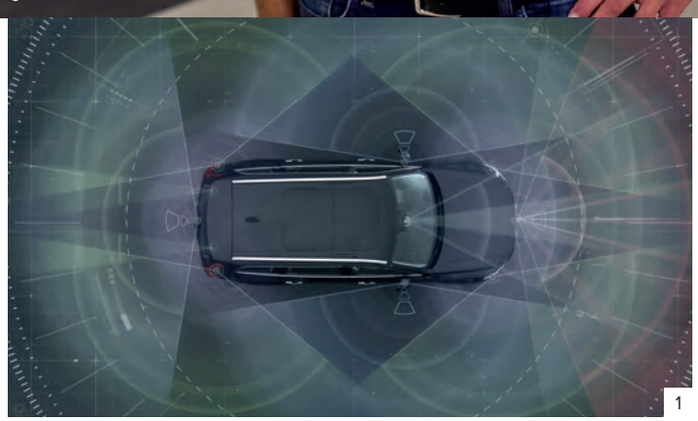
Setting up a JV that has a much sharper focus than its parent organizations can also accelerate innovation. That is the plan behind Zenuity, a Sweden-based JV established in January 2017 by Volvo Cars and Tier 1 supplier Autoliv to work on self-driving cars, with each company investing Skr1.1bn (US$130m) in the new firm.

"Autoliv and Volvo Cars are both large industrial companies and their working procedures are based on making hardware components, together with a lot of innovation in software," observes Dr Erik Coelingh, technology advisor and VP at Zenuity. "By creating this joint venture we have a very agile, fast-moving software company."

Coelingh adds that Zenuity is developing software for a wide variety of advanced driver assistance systems, as well as a complete software stack for self-driving cars. "We do everything from computer vision to decision making, path planning, vehicle control and everything in between – even software at the backend, in the cloud," he says.

Coelingh joined Zenuity from the Volvo side, where he led pioneering work on autonomous emergency braking and pedestrian detection systems. For Volvo and Autoliv, investing in independently run Zenuity provides not just a means to pool efforts on next-generation software development but an arms-length way to profit from their catalogs of existing technology.

"We will supply to Volvo Cars, of course, and we will supply to Autoliv, which can sell to any OEM that's interested," says Coelingh. "We're happy to work with any supplier in building a complete system. For an OEM, this is a really fast way of getting the latest and greatest in active safety and self-driving."



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1. Zenuity's model to supply next-gen safety and assistance systems to OEMs is a fast way to get them on the road

2. Software for self-driving cars can be accessed via the cloud

Keeping up with rivals in the autonomy sector, such as Google spin-off Waymo, which makes safety its primary mission for fully self-driving car technology, appears to be a factor. "The reason we created this company is that we see the area of active safety undergoing a revolution," says Coelingh. "Things are moving extremely fast."

Some JVs like Zenuity are open-ended commercial propositions, while others are intended to reach a particular strategic goal. GM and Honda's fuel cell JV is due to last just six years beyond initial commercialization, so until about 2026. "Our solid intentions are to continue the JV beyond," adds Haq. "We've got a six-year runway, but we expect to continue and grow our relationship."

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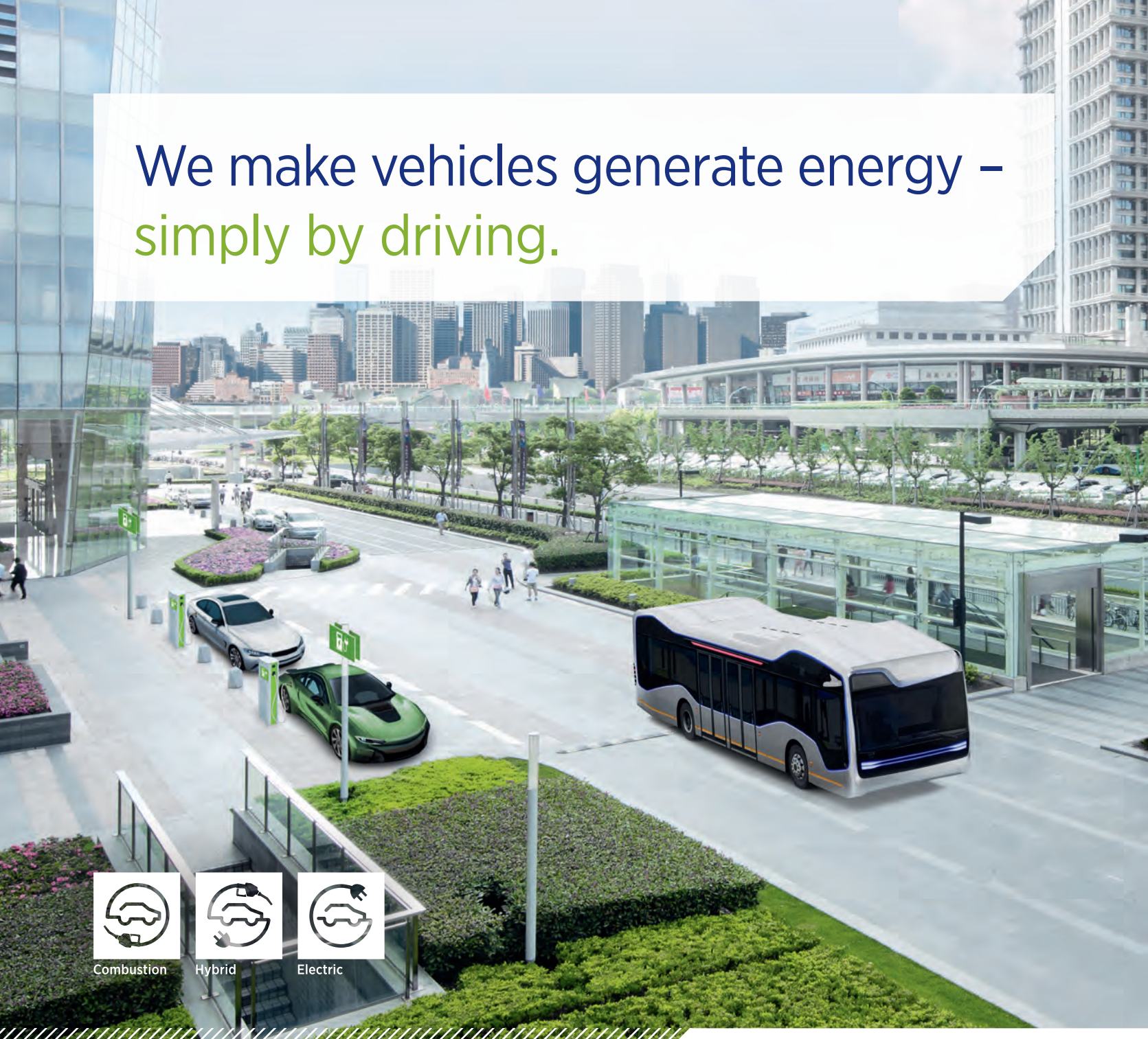

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Mapping the future

Volkswagen's recently announced Roadmap E sees the OEM committing to a major electrification of its range over the next decade. Dr Herbert Diess reveals more about the German auto maker's vision

2025

WORDS: **MICHAEL TAYLOR**

A decidedly chastened Volkswagen is charging toward electrification, but it seems to be skipping over one obvious step.

Dr Herbert Diess – member of the board of management of Volkswagen and chairman of the board of management of Volkswagen Passenger Cars – has admitted the company he leads has no plug-in hybrids planned for the USA and probably not for Europe, either, even though it has developed the technology for production throughout its range. Even if they arrive in Europe, they won't arrive en masse, as Diess believes he can make the Tiguan the world's biggest-selling SUV without it. On the flip side, China will be virtually flooded with the technology,

along with every other scrap of electrification Volkswagen can think of.

Instead of plug-ins, Europe's biggest car brand plans to bring out five battery-electric cars, including two SUVs, before 2022 and everything bar the Up! will adopt a mild-hybrid system sooner rather than later.

Volkswagen is also planning for at least a million BEVs worldwide by 2025, with about 200,000 of them allocated to Europe.

And, in even better news for Volkswagen, Diess insists all of its BEVs will be profitable from day one, with or without plug-in hybrids – see *Drive Talking*, next page.

Clean house

The German auto boss, who arrived at Volkswagen from BMW in 2015 only to be blindsided (much like everyone else) by the worst of the Dieselgate emissions cheating scandal, is instead relying on BEVs to clean up Volkswagen's emissions.

The Volkswagen Group has two BEV architectures: one developed by Porsche that will also be used by Audi, Bentley and, eventually, Lamborghini, and the other (which has been dubbed MEB) developed by the Volkswagen brand.

MEB will host all of the Volkswagen brand's five planned BEVs, plus another 10 BEVs from the group's other brands, including Škoda and SEAT. Others, Diess hints, are sure to follow, with cheaper development costs opening the door to a tantalizing array of low-volume body styles.

It is pre-engineered to be scaled down to the small ID hatch that will be the brand's first standalone electric car in 2019/2020, all the way up to a full-sized SUV. It's also pre-engineered to swallow a solid-state battery pack, possibly as early as 2024.

"For Volkswagen, it makes a lot of sense to make a specific [BEV] architecture"

While high-end consumer electronics brand Dyson has insisted it will deliver a solid-state battery-electric car by 2020, Diess kiboshes any thought of Volkswagen following the same timetable. "Not for the first generation of batteries and BEVs," he insists. "Solid state can only take effect in 2024 or 2025.

"To say 2020, that's courageous. We are invested in a solid-state development project in California with a startup, a spin-off of Stanford University called QuantumScape. We are hedged on solid state.

"There are ups and downs. It's been at 2020, then 2023 and my knowledge is that 2024 will be the first real ones.

"But the advantage is not so big. They are safer in crash conditions, but the energy density is not so much higher. It's another 15% or so."

E numbers

2015

Dr Herbert Diess joins Volkswagen from BMW

2019/2020

The ID hatchback will become VW's first standalone EV

2020

VW agreements with German dealers to be canceled

2022

VW plans to launch five BEVs, including two SUVs, before 2022

1

DRIVE TALKING

Volkswagen's plug-in strategy might seem a little patchy, and when pressed on the matter, Diess races through questions in a cheerfully staccato manner:

You say the Tiguan will become the world's biggest-selling SUV, but it doesn't have a hybrid powertrain yet.
No, not in Europe.

You showed the car originally as a hybrid and it's not a hybrid.
We will have a hybrid.

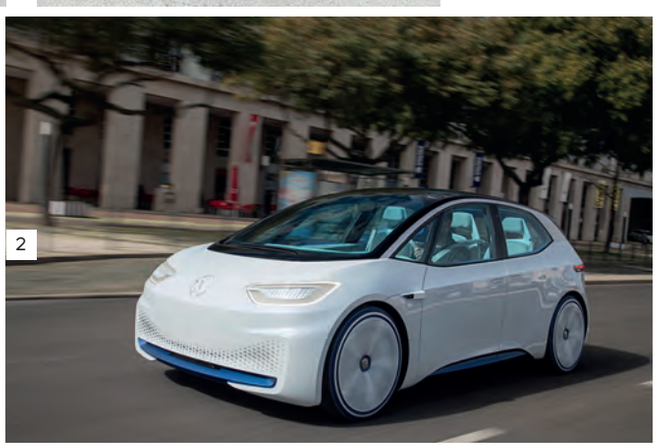
In Europe?
It's not yet decided.

In the USA?
No. For America, plug-in hybrids don't make an awful lot of sense for the upstream emissions and they're just not incentivized by the tax schemes.

So it doesn't have anything to do with how the emissions are measured in the test cycle?
As well, but for the relatively short distances that they run, compared to how much zero-emission range you have, they just don't make sense.

So we're looking at a China-only hybrid vehicle?
Not yet decided. We can decide. The car is being developed. We have time to decide.

But I thought you were a company that was electrifying everything? Is that just market selective?
We are electrifying everything, but with the right product line-up. Plug-ins don't make a lot of sense for us in America – decided. They might make sense for us in Europe – not decided. They make sense in China – decided.



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1. The ID Crozz will sit on VW's MEB electric vehicle architecture

2. The ID, due for launch in 2019/2020, will be VW's first standalone EV

Breaking even

Critically, Diess insists that the whole BEV adventure is cheaper and easier to develop than most people think, with Volkswagen's electric range planned to be profitable from its first day.

He also warns the relatively low entry cost would see buyers flooded with confusing choices they'd never even heard of before. The offset to that is that low-volume niche models would be easier and faster to develop, and Diess hints that he might reanimate quirky machines such as the Volkswagen Dune Buggy or Kübelwagen.

"In the brand we are spending about €3bn [US$3.49bn] including development costs and capex over five years," he admits.

"You always have in your product range more profitable cars and less profitable cars. We will already achieve with the first car (the ID hatch) the same profit range we

2024

VW expects solid-state battery packs by 2024 at the earliest

2025

VW is planning for at least one million BEVs worldwide

The ID Buzz electric vehicle is due to enter production by 2022

achieve with the Polo. I think that's okay. That's not great, but it's okay. That includes the sunk investment.

"What we are spending makes up for less than 20% of our one-time expenditure. It's not so expensive, about 15% of our volume target and 20% of our product-development expenditure."

When it's pointed out that Daimler chairman Dr Dieter Zetsche claimed that electrifying Mercedes-Benzes would soak up half the brand's conventional investments, Diess just shrugs and smiles."Yeah, you know, we are big in volumes...

"For Volkswagen, it makes a lot of sense to make a specific architecture. We have big volumes now and we are going towards 1.5 and two million cars a year off that electric platform. That makes a lot of sense to have a specific electric architecture.

"The economies of scale are really getting thin up there, and you can really unleash the potential of the electric cars.

"Fifteen cars are already decided. The Volkswagen brand will have five, and the group will have 15. Well, five so far. We are adding one a month, it seems."

Wheeler dealers

Even if it goes to plan for VW, the move into the world of BEVs won't be great for every German. Dealers, in particular, will find themselves in the crosshairs.

Volkswagen has written to all its German dealers explaining their agreements would be canceled in 2020, to make way for a smaller dealer body, more direct interaction with customers and over-the-air software delivery.

Diess insists that the country has too many small, unprofitable dealers, which doesn't really help anybody. It is also canceling contracts across Europe to renegotiate on OTA delivery and more direct customer contact for Volkswagen, but the main problem in Germany was poor profitability.

"We need new contracts across Europe because our business model will change with electric cars," he says.

"We are always talking about electric vehicles and drivetrains, but the really big revolution comes with the cars becoming updatable and upgradable," he continues. "When we have the operational system in the car, you will receive an update to your system every year or so.

"You might order specifics from the network directly from the OEM. You might have some direct dialog with the customers, which is not the case today – we don't talk to customers.

"I think dealers are well aware that it will happen because the customer would not accept that you have to go to the dealership to get a software update in the future.

"But we think differently to Tesla. We think we can do it together with our dealers and share the data to provide even better service.

"In the good years, they get to 3.5-4% and that's a good margin for a dealer. There are a lot of people that are far below that.

"We have much happier dealers in other countries than Germany. That's a problem for us. Only a dealer that earns his money will treat his customers well and represent the brand nicely. We don't want dealers losing money on our brand."

"We are always talking about electric vehicles and drivetrains, but the really big revolution comes with the cars becoming updatable and upgradable"

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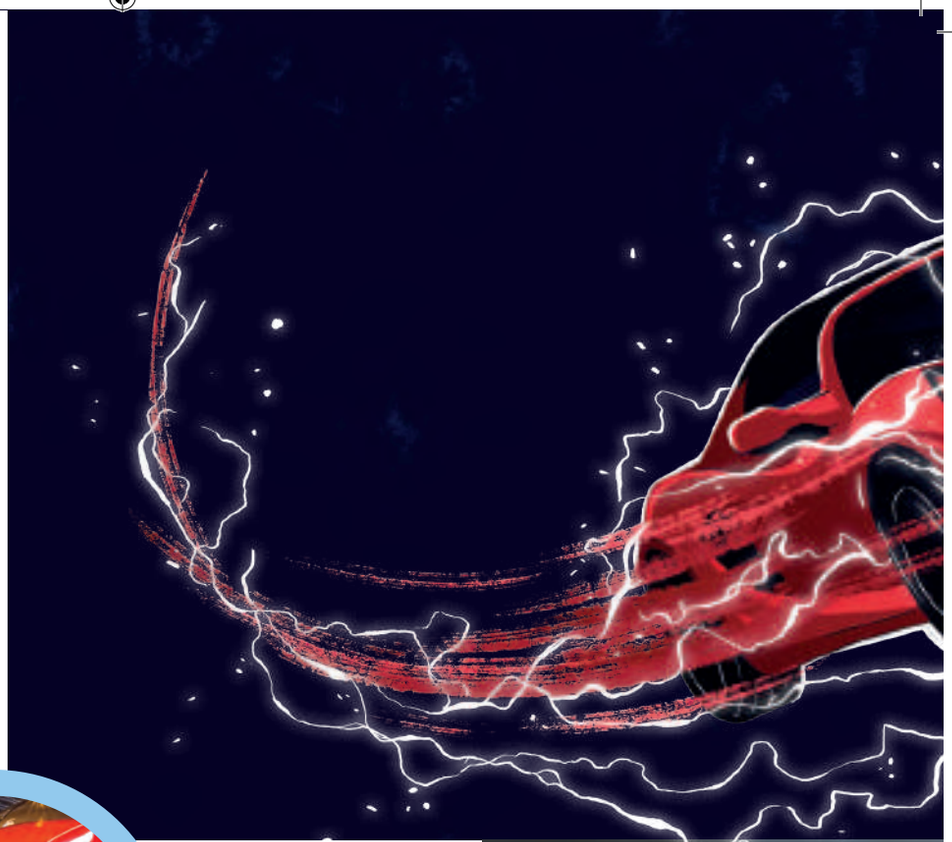
ELECTRIC DREAMS

The Detroit Electric name goes back more than a century but, as chief technology officer **Richie Frost** explains, its greatest achievements could lie ahead

WORDS: **CHRIS PICKERING**

ILLUSTRATION: **MITCH GEE**



Detroit Electric is a small car company with big ambitions. The name may hark back to a turn-of-the-century car maker in Michigan, but the present incarnation is an Anglo-Chinese affair, founded in 2008 by former Lotus CEO Albert Lam. To date, it's best known for the SP:01, a low-volume battery electric sports car spun off the Lotus Elise platform, due to make production later this year. But the company's plans extend much further. Thanks to a US$1.8bn injection of joint-venture funding from the Far East Smarter Electric Group, Detroit Electric now has its sights set on the big time, with a three-car model plan and a target of 100,000 global sales by 2020.

The company's chief technology officer, Richie Frost, seems undaunted by the scale of the task. He started as an electrical systems designer in the motorsport industry, working for Prodrive for many years before setting up his own electric vehicle consultancy. Starting from his spare bedroom, he built up a client list that included Tata Motors, Intelligent Energy and Gordon Murray Design.

Three years later, the company employed 65 people and had taken on another new client in the form of Detroit Electric. It was while overseeing the electrical integration and parts of the control system development for the SP:01 that Frost came to know Lam. The two hit it off instantly and Frost was invited to join Detroit Electric full time. He made the switch in September 2016, bringing a number of his senior engineers to the company's HQ in Leamington, UK.

"We're a new team here, but many of us have been designing and developing electric cars together for seven or eight years, so we've really hit the ground running," he says.

Vehicle range

The company aims to introduce a new model each year from 2018 to 2020. The first will be a comparatively low-volume sports car that's faster, larger and more powerful than the SP:01 and pitched as a more usable everyday GT. With plans to produce fewer than 1,000 a year, it will remain an exclusive proposition. Its role is essentially to define a brand image for the subsequent high-volume models and establish a dealer network.

"We've developed a lot of IP off the back of SP:01, particularly around the battery and the BMS," says Frost. "We learned a lot about thermal management – not just for the battery pack, but also the motors and inverters. We built all the battery packs in-house, so we also learned a lot about the production side. It's one thing to bolt a battery back together, but to make it work reliably, repeatably and efficiently in a real-world application with fluctuations in temperature, humidity and drive cycles is a far bigger challenge."

There will be some technology carry-over to the new sports car, but every element of the

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1. Detroit Electric plans to launch a new GT model that's faster and larger than the SP:01 (above)

2. Though the SP:01 was based on the Lotus Elise platform, every aspect of the new vehicle will be substantially different

2

"We're a new team here, but many of us have been designing and developing electric cars together for seven or eight years, so we've really hit the ground running"

"The key thing for us is differentiating the vehicles from the rest of the pack"

vehicle will be substantially different, Frost promises. Detroit Electric will be partnering with an as-yet-undisclosed supplier for the vehicle's chassis in order to accommodate its aggressive timing plan.

That's just the start, however. Things begin to get serious in 2019 with a mass-produced crossover. Details are fairly limited, but like the sports car, it will use a four-wheel-drive electric-only powertrain, developed in-house. This chassis will be an all-new design, but it will share its platform with a sedan due in 2020. Both are said to target a range in excess of 500km (311 miles) on battery power alone.

"For the crossover and sedan we're hoping to reach more than 50,000 units a year," says Frost. "The production plant we're putting together in China is being built to a capacity of 125,000 units a year. We do have other, higher volume plans beyond that, but it's too early to go into those."

The core philosophy of the new platform is to create a highly adaptable architecture, which can accommodate future technologies, Frost explains.

"We are carrying out research studies on a number of technologies, including range extenders and hydrogen fuel cells," he reveals. "That's not to say either will necessarily feature on the next production vehicles, but they are areas we will pursue – we do see a place for hydrogen in the future."

Autonomous driving is another key area of interest, says Frost: "We have to think hard now about our platform strategy to ensure it caters for full autonomy. Again, that's not to say the cars we're bringing out will be autonomous, but we need to make sure the onboard systems and the vehicle architecture have the ability to support that in the next 10 years."

New facilities

Over half a billion dollars of the company's new funding is going toward a high-tech production plant in China. This will include a battery manufacturing facility, research and development laboratory and test track.

As production volumes grow, the company is turning to a more bespoke approach, Frost explains: "With the sports cars, we are not looking to reinvent the wheel. To a certain extent we're bound by what's already available, because it's a two-year program. For other projects we have longer timeframes and much higher volumes, so we can go to our partners and use their expertise to design bespoke items. With motors, for instance you're confined to the existing torque profile if you're buying off the shelf, but we're looking to define our own specifications."

To that end, the motors and inverters will be collaborative efforts. The battery system design is all being carried out in-house, albeit with the use of third-party cells. Detroit Electric also plans to develop its own chargers and is said to be investing significantly in a team to deliver its own infotainment systems.

Frost promises that the new cars will be quite different to anything else on the market. "The key thing for us is differentiating the

Design and development of battery and powertrain on new vehicles will be carried out in-house, as well as its own chargers

Ambitious global sales targets of 100,000 by 2020 will take aim at rivals such as Tesla

"As a new brand we can take that risk and go really far out there with some new features that no one's ever seen before. We don't want to be just another EV company; we really want to push the boundaries"

vehicles from the rest of the pack," he says. "I think some of the companies out there have been bound by a traditional approach. It's high risk for established brands to do something that's really out there, but as a new brand we can take that risk and go really far out there with some new features that no one's ever seen before. We don't want to be just another EV company; we really want to push the boundaries."

As for what those defining features are, we're going to have to wait to find out. He does, however, emphasize that the Detroit Electric products will be pitched at the upper end of the market with regard to technology, luxury and performance.

The company is embarking on a major recruitment drive to make this a reality. It aims to add another 150-200 engineers to its current line-up. As part of the recent investment, the Leamington R&D center is also undergoing a US$370m redevelopment. Even so, Detroit Electric will have its work cut out to reach the target of 100,000 global sales by 2020. To put that in perspective, Tesla – with a substantial head start and established global presence – sold around 84,000 units last year. If Detroit Electric does hit that target it will surely be a game-changer.

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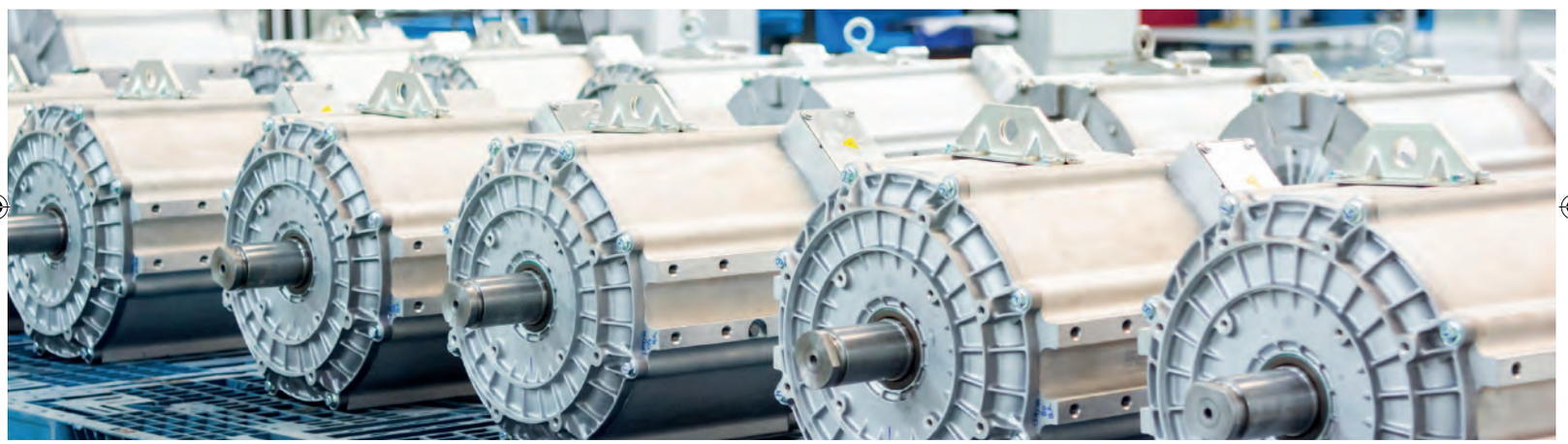

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VITAL STATISTICS

0-100km/h: 2.4 seconds
0-241km/h: 7.8 seconds
Top speed: 257km/h (estimated)
Power: 1,196ps (four-wheel drive); 598ps (rear-wheel drive)
Extended range: 805km
EV range: 193km

HIPERactive

Could the Ariel HIPERCAR shake up the supercar establishment?

WORDS: **CHRIS PICKERING**

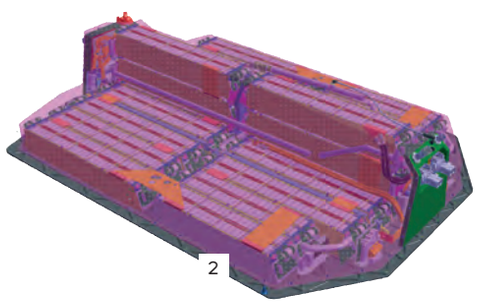
Normally, the announcement that a small independent company plans to build a world-beating 1,196ps electric supercar – equipped with a gas turbine range extender, no less – would be greeted with more than a little skepticism. After all, it's a project that would seem hugely ambitious for even the largest automotive OEMs.

But the Ariel HIPERCAR (the name is derived from High Performance Carbon Reduction) is different. For a start, the company has been manufacturing highly acclaimed sports cars for the best part of 20 years. It's also co-opted a small army of technical partners with proven track records in electric vehicle development. But perhaps most importantly, when the covers came off the HIPERCAR at the recent Low Carbon Vehicle show, it wasn't a rendering or a styling mock-up that emerged, but one of two fully functioning prototypes.

Strictly speaking, the HIPERCAR tag refers to the initial R&D project that kick-started the development process. However, the as-yet-unnamed production variant is expected to retain all the key technology when it goes on sale in 2020.

"We've got the hardware, drivetrain, vehicle packaging and electrical integration done," says Neil Yates, project manager for HIPERCAR at the Ariel Motor Company. "Right now we're in the early stages of vehicle-level testing, with a lot of component-level and subsystem durability testing taking place in parallel."

All the major technology has been developed specifically for the Ariel car platform. However, it's also designed to be scalable for use in other applications and the technical partners retain



The Ariel HIPERCAR's inverter (1), mid-mounted semi-structural battery pack (2) and the chassis and roll structure (3)

the intellectual property they're putting into the designs. That's not to say it's simply a technology demonstrator, however. Yates is keen to stress that the HIPERCAR is intended as a fully fledged production model (albeit a relatively low-volume one at less than 100 units a year).

The vehicle's projected performance figures promise to be nothing short of spectacular. In four-wheel drive form, Ariel aims to cover 0-100km/h (62mph) in a staggering 2.4 seconds and 0-241km/h (150mph) in just 7.8 seconds. Meanwhile, the target is to achieve an electric-only range of 193km (120 miles), with the range extender stretching that to around 805km (500 miles) on the WLTC.

Extreme performance

The HIPERCAR will be offered in two variants – a four-wheel drive model with 1,196ps (880kW) and a 598ps (440kW) model driving the rear wheels alone. In both cases, the motors are identical – one inboard-mounted unit for each driven wheel, with its own integrated epicyclic gearbox and inverter. Each of these assemblies weighs just 57kg (125 lb) yet produces up to 299ps (220kW) and 450Nm of torque.

Developed by Equipmake in collaboration with Aim Co Japan, the motors feature an innovative design, with the magnets arranged radially around the outside of the rotor like the spokes of a wheel. This arrangement is said to improve torque density by as much as 25%, while a sophisticated water-glycol cooling system allows the motors to run at high outputs for a prolonged duration.

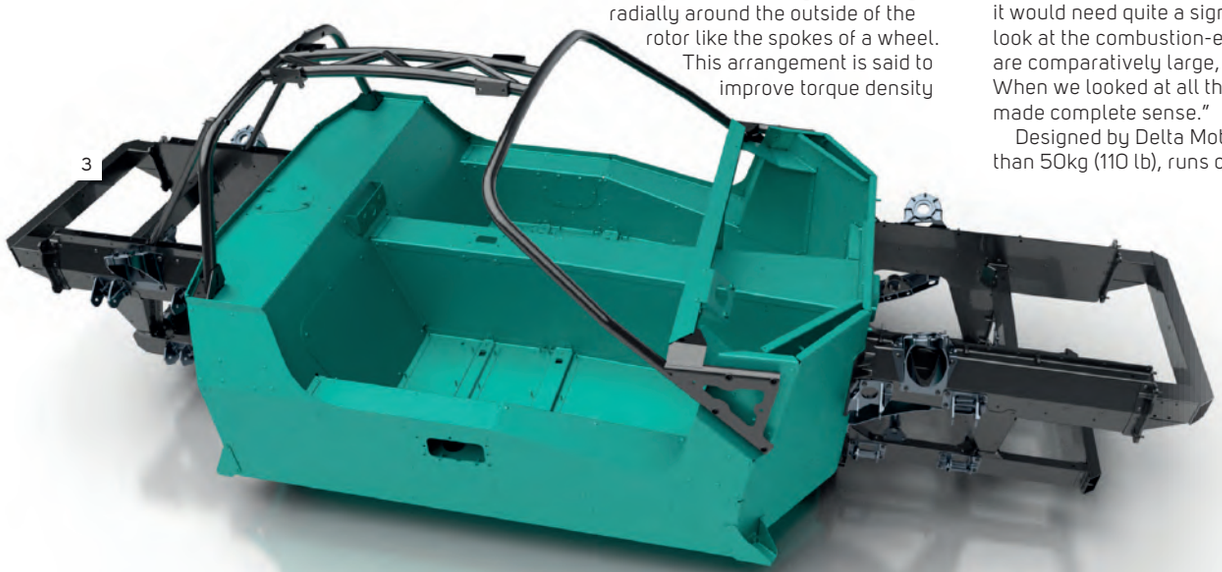
"The motors are a real triumph of design," says Yates. "They produce incredible power – not just peak, but continuous – in a package that's much smaller and lighter than we have seen before."

The two variants will use different battery packs, with cell chemistries tweaked to suit their discharge requirements. Both use liquid-cooled lithium-ion cells, but the 42kWh pack used in the four-wheel drive car is rated to 1,200A, while the 56kWh pack used for the two-wheel drive model is designed to operate at up to 1,050A. Delta Motorsport developed both designs, but the high-energy pack was supported by grant funding through the AMPLiFII project led by Warwick Manufacturing Group (WMG).

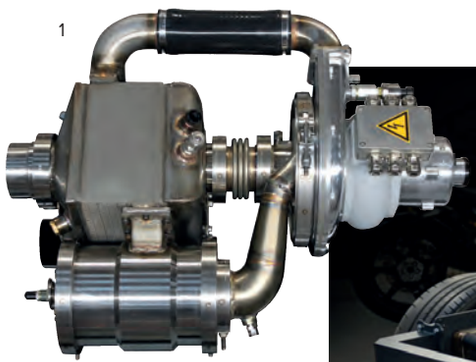
Ariel says it has developed a unique approach that allows the 750V HIPERCAR to charge from the existing charging infrastructure via a standard CHAdeMO or Type 2 connection. However, when the car is off-grid it uses the onboard 35kW micro-turbine range extender.

The decision to use a turbine was taken early in the project, as Yates explains: "We knew we needed a range extender, and having carried out some simulations it became obvious that it would need quite a significant output. If you look at the combustion-engined offerings, they are comparatively large, heavy and inefficient. When we looked at all the factors, a turbine just made complete sense."

Designed by Delta Motorsport, it weighs less than 50kg (110 lb), runs on regular gasoline and



"We have been working with the legislators, helping to inform them about what the design process looks like for a small-volume OEM developing an extremely complex car"



spins at a constant 120,000rpm. The turbine also incorporates a number of sophisticated emissions reduction devices, including a recuperator system. These are said to reduce the HIPERCAR's emissions to well below the level of a combustion-engined car.

The range extender is designed to maintain the battery's state of charge during even the most aggressive road use. However, the simulations highlighted just how broad the duty cycle is for a vehicle of this performance. Flat out on a high-speed track, the average power consumption can be more than eight times higher than on the road, meaning that the range extender simply won't be able to keep up. Under those on-track circumstances, Yates explains, the car should manage around 20 minutes of running before returning to the pits for a 45-minute charge.

Test program

Ariel currently has two early-stage prototypes – one two-wheel drive and one four-wheel drive – testing as rolling chassis. The plan is to produce another five development and validation vehicles over the next 16 months, and the company says its full test program stretches into the hundreds of thousands of miles.

Those seven cars will take the project through to full production intent, with each participating in a 12- to 18-month durability cycle (depending on when it arrives in the program). It's likely that the first testing on the public road will take place in early 2018, with mule bodies fitted over the current bare chassis.

Ariel plans to carry out most of its climatic work in indoor test facilities in the UK. There will also be a mixture of hardware-in-the loop rigs for systems testing and rolling-road running for full-vehicle work.

"In addition to the big test houses there are also a host of specialist providers with the ability to provide test conditions for systems-level validation," Yates explains. "For instance, we worked with Eberspächer on the development of the HVAC system at the company's UK facility in Dorset."

Testing a gas-turbine range-extended EV poses unusual challenges. It's anticipated that the vehicles will need to test without range extenders at times, possibly in remote locations without grid access. With this in mind, Ariel has developed a mobile charging rig that can fully replenish the 750V battery in under an hour.

There are also challenges with the European Community's Small Series Type Approval (EC SSTA) regulations. "There aren't always fully defined standards for testing an EV," says Yates. "We've been working with the legislators to understand where we need to be and helping to inform them about what the design process looks like for a small-volume OEM developing an extremely complex car."

Currently the EC SSTA has no legislation surrounding range extender emissions. Instead Ariel is working to the full Type Approval requirements. Likewise, while the EC SSTA has its own requirements for crash testing, Ariel plans to go much further. A lot of FEA work is said to have gone into evaluating how the mid-mounted semi-structural battery pack and the casing for the 120,000rpm turbine will respond to crash loads.

This all adds up to a major development program for a low-volume manufacturer. Yates and his colleagues are under no illusion about the scale of the task that faces them. But thanks to the unique way they've gone about it, the HIPERCAR project is already well on the way to becoming a reality.

1. The 35kW micro-turbine range extender system was developed specifically for the HIPERCAR project

2. Each of the vehicle motors (developed by UK-based Equipmake and Aim Co Japan) includes an epicyclic gearbox and inverter

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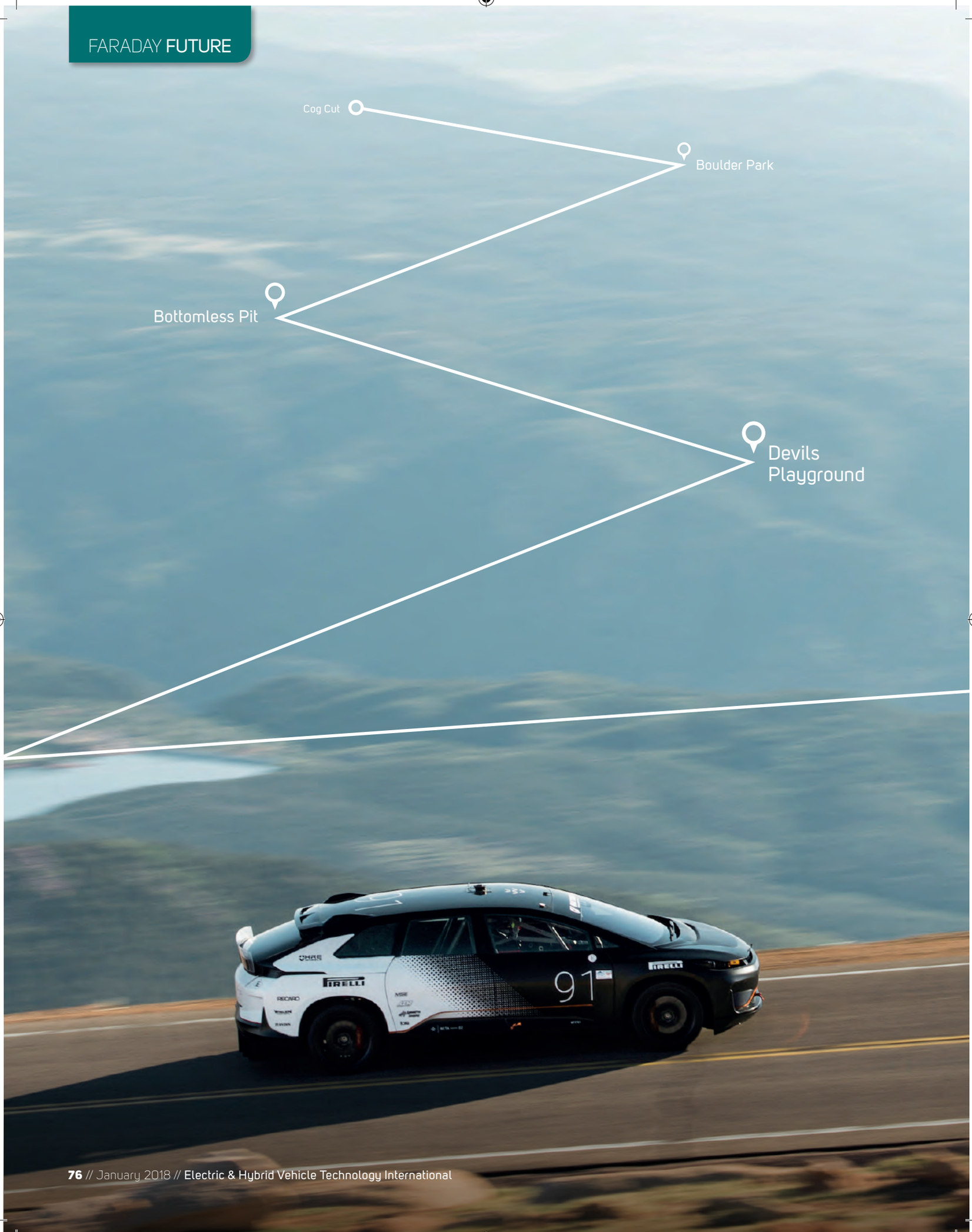
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Peak performance

A record-breaking run up a renowned mountain course yielded vital information as Faraday Future targets the end of 2018 for the first production FF 91

WORDS: **MIKE MAGDA**

Faraday Future remains committed to the first deliveries of the FF 91 at the end of 2018

The FF 91 is built around a modular monocoque platform, offering the possibility of numerous potential battery and motor configurations

Though a combination of financial and personnel issues in the last year may have left Faraday Future bruised, development on the FF 91 luxury EV continues unscathed, with 20 prototypes currently undergoing evaluation – including one race-prepped model that made a very revealing run up the historic 20km (12.4-mile) Pike's Peak Hill Climb course this year.

"The vehicle is pretty well formulated," explains Peter Savagian, director of propulsion engineering at Faraday Future. "We're in our beta phase of development, which means it's in production form. So we are shaking down all the systems now.

"We have the gamma design at a mature state, and we're releasing it as we speak. We pretty much know all the features and content that we intend to have in the production car."

The first beta cars started testing in September 2016. The FF 91 is an ambitious project based on a scalable variable platform architecture (VPA) and an announced 1,065ps that can be tamed to provide an estimated 608km (378 miles) between charges.

In July 2017, Faraday engineer Robin Shute piloted a beta FF 91 up the 156-turn Pike's Peak course in a time of 11:25.083, beating the existing production EV record set in 2016 (in a Tesla) by 20 seconds. But breaking records wasn't the development team's first objective.

"Pike's Peak is a tremendous stressor of the vehicle's propulsion system and the thermal system that keeps it within bounds," explains Savagian, who came to Faraday from GM after 25 years, where most recently he was general director of electric drive systems and new product development. "We confirmed what we already knew about the vehicle driving dynamics and our simulation of that. I think we also better calibrated the battery thermal system. I think we had a real breakthrough insight on our drive units."

The FF 91 is constructed with two motors in the rear and one up-front. Thermal models predicted the car would be near its limits climbing the 1,300m (4,270ft) elevation from start to finish. Faraday says the car used an average of 300kW racing up the hill.

"We thought we'd be close to those limits. In fact, our motors and inverters were as cool as cucumbers. We had actually underestimated the capabilities of those systems to reject heat, which is consistent with my prior experience. I didn't worry about it so much, but it was important to illustrate that candidly."

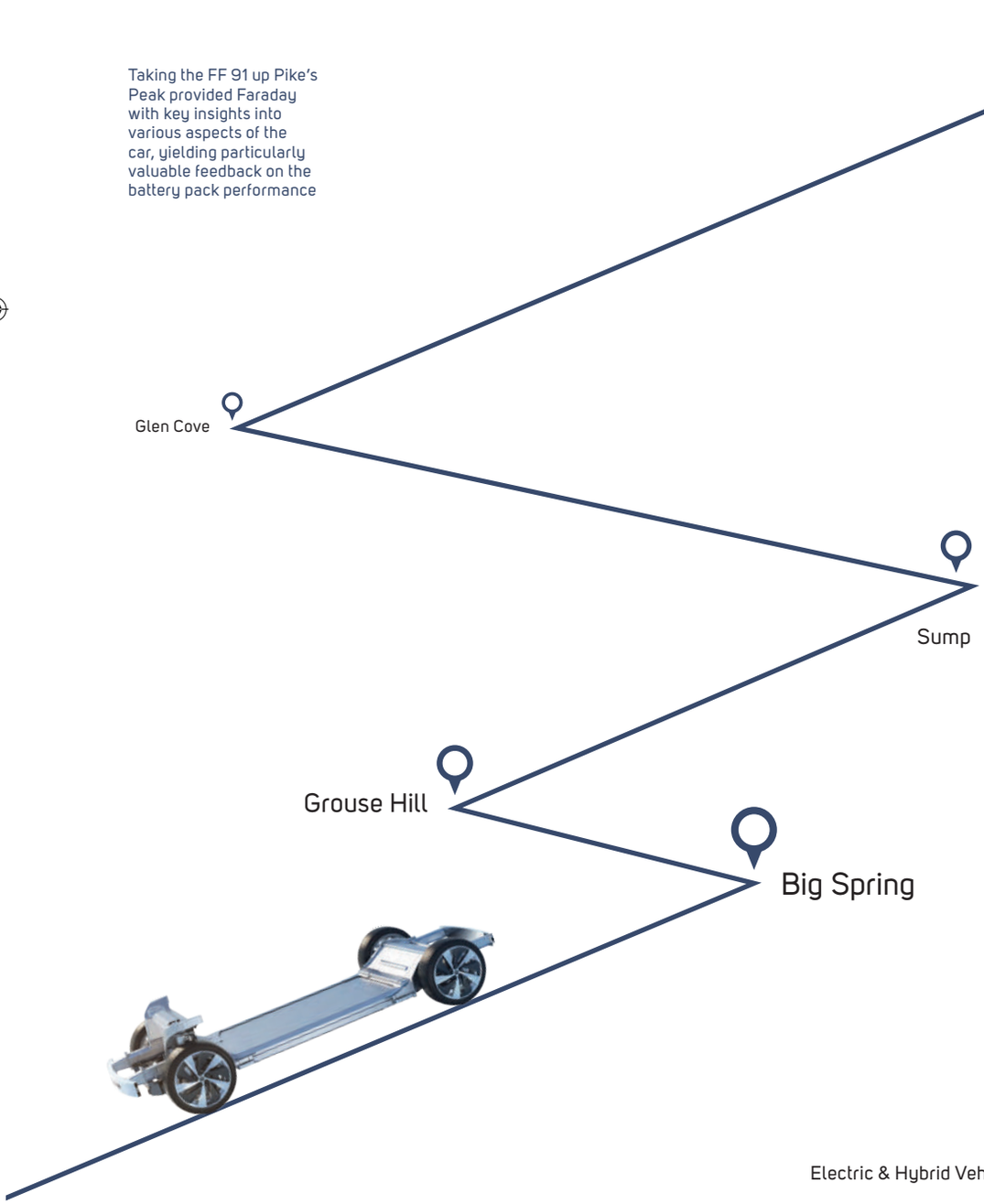
The FF 91's battery was still intact at the finish line, a condition not always enjoyed by other EVs, which can consume the entire unit through overheating.

"We learned a lot about the battery pack," continues Savagian. "Robin made that car handle near its limits, but the handling stresses and the shifting of this huge battery pack brought us some new challenges. We had issues with the electrical interconnect on the battery management system. We had issues with the seals and the battery liquid cooling systems. The seal had let loose because of all the stresses, the shifting, the forces of distortion and the structure of the car relative to the battery pack. They are things we probably would never have seen during a more regimented set of development tests. But by using the race course, I think we expedited our learning."

Power play

Faraday Future has settled on an LG Chem 21700 cylindrical cell for the 130kW battery pack rated at a little over 400V, says Savagian.

Taking the FF 91 up Pike's Peak provided Faraday with key insights into various aspects of the car, yielding particularly valuable feedback on the battery pack performance



"We've looked at cells from other companies that are very similar, but we liked the LG cell the best," he says. "We've created a modular battery pack around these cells, where we package them extremely densely, and we have got a proprietary liquid-cool thermal system.

"It's a large pack, but it is structurally integrated into the floor of the FF 91 so that we at least carry the mass of the batteries low and make the car handle, even though it's heavy. Most of the battery pack is well below the centerline of the wheel axles."

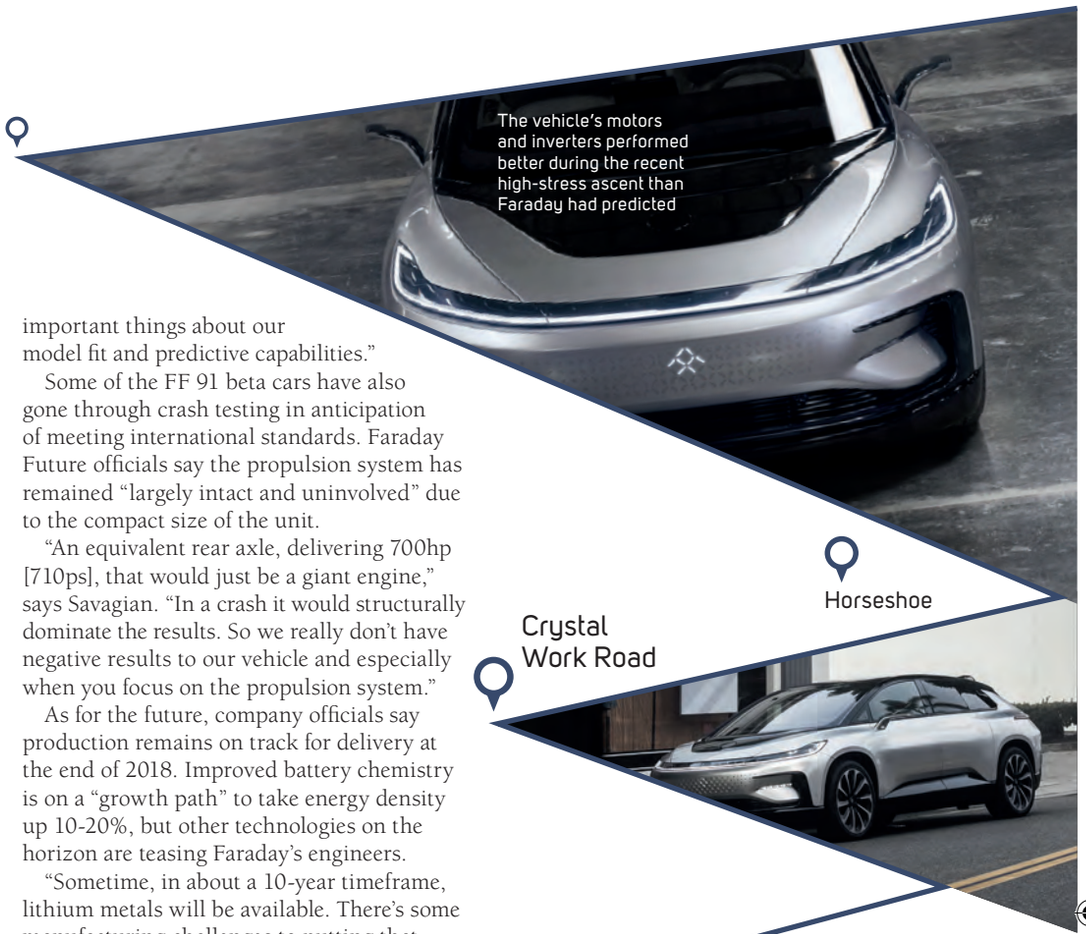
All three motors and inverters are identical and were designed by Faraday engineers. The motors are an interior PM design with direct oil cooling. The inverter is the subject of the company's first patent.

"The power density of our inverters is about 30% higher than anything else in the industry right now," says Savagian proudly. "I worked recently on the Chevrolet Volt, and I would say that our power density relative to the Volt is two times greater than its power density. That inverter is integrated directly onto the motor and the drive unit assembly, so it's kind of a monolithic assembly."

The gearbox up-front is a stepped offset planetary arrangement designed by Faraday, but will be manufactured externally. Reduction is about 6.5:1 and power is delivered to a conventional open differential. Both left and right motor/inverter combinations show up in the rear with the same 6.5:1 gear reduction.

"There's no differential back there, so between the two of them we can operate as if it's an open differential or we can apply a torque vector," says Savagian. "We can operate the torque vectoring at a frequency much higher than could be done mechanically."

The FF 91 is also designed with four-wheel steering. "We can maintain a neutral steering



"Pike's Peak is a tremendous stressor of the propulsion system and thermal system"

Peter Savagian, director of propulsion engineering

vehicle under both accel and decel conditions. We can still have this very linear neutral steering behavior where vehicle yaw is directly proportional to steering input angle," states Savagian, who received a mechanical engineering degree from the University of Wisconsin and an MBA from Duke.

"That's a nice feature we can execute with electric torque vectoring. So even when the accels and decels are abrupt, we can still react to that well within the driving dynamics' blue envelope and not have the latency and delays, and the subsequent steering disruptions, which happen with brake or clutch differential-based torque vectoring systems."

Future performance

As results from the beta tests flow in, FF 91 engineers are comparing numbers against virtual predictions. Early 0-60mph targets were in the 3.8- to 3.9-second range.

"Over time we realized that even though not many buyers would, in fact, do 0-60 very fast, they want to buy a car that they knew was efficient in that category, relative to the options they had," says Savagian. "The options include the Tesla cars and probably Porsche offerings that will have extraordinary performance, so we decided to push ourselves past the 3.8-second level."

At the FF 91's debut in Las Vegas at CES 2017, company officials boasted a 2.39-second 0-60mph time for the production car.

"We conducted a series of development activities that involved our analysis in virtual engineering and then our learning. Improving our ability to control current at higher levels and considering the structural life of the mechanical components really played out more in the plan as we brought acceleration down below 2.5 seconds," explains Savagian. "That's a very short-term piece of testing development, a couple of seconds of all-out performance, but that taught us some pretty important things about our model fit and predictive capabilities."

Some of the FF 91 beta cars have also gone through crash testing in anticipation of meeting international standards. Faraday Future officials say the propulsion system has remained "largely intact and uninvolved" due to the compact size of the unit.

"An equivalent rear axle, delivering 700hp [710ps], that would just be a giant engine," says Savagian. "In a crash it would structurally dominate the results. So we really don't have negative results to our vehicle and especially when you focus on the propulsion system."

As for the future, company officials say production remains on track for delivery at the end of 2018. Improved battery chemistry is on a "growth path" to take energy density up 10-20%, but other technologies on the horizon are teasing Faraday's engineers.

"Sometime, in about a 10-year timeframe, lithium metals will be available. There's some manufacturing challenges to putting that together, but expectation is another 40% in energy density and cost factors," Savagian says.

"There's also less use of some of the other materials that might be becoming scarce as electric vehicles really hit the turning point in terms of market adoption. For example, there'll be a lot more uptake of lithium, but also nickel and cobalt. The lithium metal cells may, in fact, relieve some of that stress. That technology is certainly something that we're looking forward to. And, we look forward to wireless charging as well."

PLANTING THE SEED

As the company continues to aim for delivery of the first FF 91 by the end of 2018, August 2017 saw Faraday Future sign a lease on a new manufacturing facility in Hanford, California. More than 300 company employees pitched in following the announcement of the new facility – which is strategically positioned between Los Angeles and Silicon Valley, the USA's two largest electric vehicle markets – driving to the site to help with the clean-up process.

"Our new production facility is the latest demonstration of our commitment to getting FF 91 on the road by the end of 2018," explains Dag Reckhorn, Faraday Future's vice president of global manufacturing. "Despite significant head winds on the path ahead of us, we are laser-focused on that one key milestone."

Site preparation is ongoing, with previous tenants expected to have left the facility by the end of 2017. Faraday Future then expects considerable progress to be made in early 2018. The new facility measures 1,000,000ft² (92,900m²), and will eventually employ up to 1,300 workers over three shifts.

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Californ dreaming

A fascinating insight into development of the Lucid Air, the luxury EV from California-based startup Lucid Motors

WORDS: **MIKE MAGDA**


LUCID
California
AIR

Lucid engineers predicted that the Air speed test car would achieve 235mph (378km/h). The actual high-speed test saw the real-world car clock up 235.4mph (378.8km/h)

Plenty of people have been watching the progress of the Lucid Air with great interest. And even more sat up and took notice when, in July 2017, a high-speed test run saw the vehicle hit a jaw-dropping 378.8km/h (235.4mph) at the Transportation Research Center in Ohio. In a wide-ranging interview, Peter Rawlinson, vice president and chief technology officer at Lucid Motors, offers a glimpse inside the development of the Lucid Air. Rawlinson, who prior to joining Lucid was the development lead on the Tesla Model S, discusses the wider electric vehicle market, the Air's drivetrain, autonomous functionality and how the development and testing process has yielded some surprising results.

What is your assessment of the current luxury EV market?

The luxury EV market is dominated by one player [Tesla]; it's really monopolized. In short, if you look at the luxury car market worldwide as a whole, it's dominated by IC engine cars, and it's dominated by three players: Mercedes, Audi and BMW. That is an incredible US$100bn a year world market. Electric cars only occupy a tiny fraction of that, and yet that market is really beginning to wake up to the fact that an electric car is inherently a better car than a gasoline car.

We're really looking at the luxury market, which is dominated by ICEs, and we are bringing to market a product that is so superior. I think we will have many people swap from ICE to electric.

Are you still making big changes to the Lucid vehicle platform?

We're currently at Alpha prototype stage, where we are 90% fixed in terms of the car, and I would say probably 95-98% fixed in terms of the core architecture platform. These are not show cars, they're actual Alpha cars, which have been thoroughly figured out in terms of their technical feasibility – so working closely between engineering and the design studio.

I would say the Alphas are 90% production intent, and when we get to Betas in about a year's time, we'll have about 95% production intent, running into production in two years' time. But core architecture has been established, and is working beautifully.

The Air features a new battery cell chemistry designed to optimize fast-charging tolerance

Are your road test results matching up with your virtual test predictions?
Yes, almost to a nauseating degree. My engineers predicted that our speed car test would run at 235mph (378km/h), and it actually ran at 235.4mph (378.8km/h), so that is the level that we can get the predictive computer analysis to today.

That's central to our design and engineering philosophy, to do it 1,000 times on the computer, make all of your mistakes virtual mistakes, and all your learning – as much learning as possible – on the computer. And then make a prototype, not really to learn from, more to validate what you've learned from the computer, and to fine-tune.

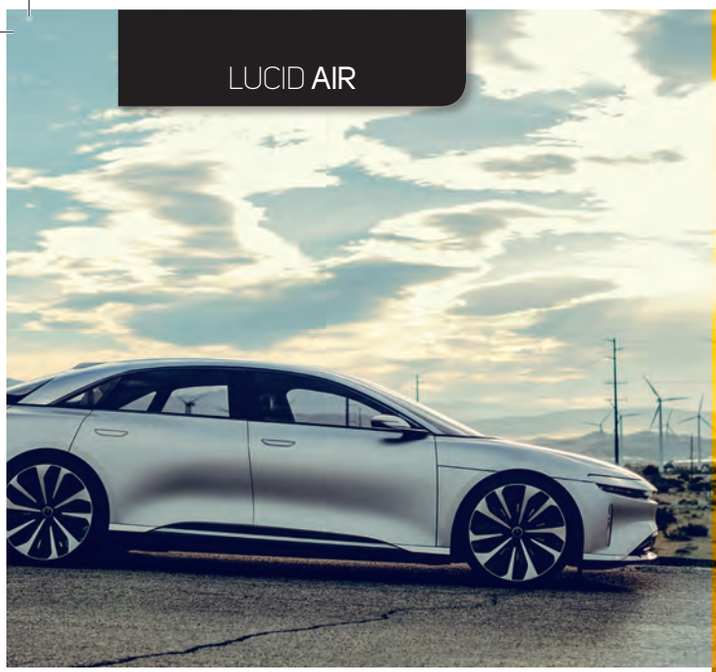
This is in stark contrast to the more standard methodology of the auto industry, which is make a prototype as early as possible, because then you'll figure out all of the problems as soon as possible to maximize time to fix them. That really is planning for failure. What I like to do is counterintuitive, to wait and not be too eager to cut metal, but really figure things out on the computer, make your prototype a little bit later, and be confident that you'll have a great prototype, with none of these phantom problems.

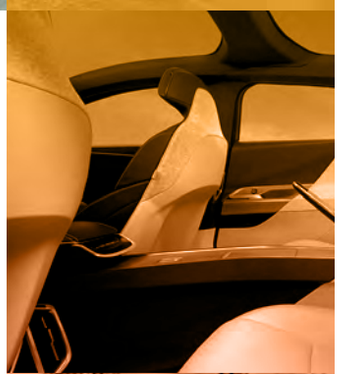
Can you talk us through the design of the battery pack?
Our primary supplier is Samsung SDI. We have co-developed a new cell chemistry, which is quite a big step forward – not so much in energy density, but in terms of its tolerance to repeated fast-charging. This is quite innovative, and particularly relevant with the sort of intense duty cycles that an electric vehicle could be subjected to in an inner-city area, particularly with the advent of ride sharing and the China market with that sort of use pattern that customers see over there. It's a lithium-ion NCA chemistry. We've moved to cylindrical format cells, and we've gone to production with 21700s.

Our voltage runs at a genuine 400V. There's a lot of talk about 800V systems, and particularly 800V charging systems. There are marginal advantages in doing that, but also disadvantages, and I'm pretty well convinced that a genuine 400V car for today's technology is about right.

And the cooling system?
Our cooling system is entirely our own, heavily patented – it's very advanced. The cooling system is central to us being able to achieve over 20% better packing density of our cells than the nearest competitor.

What makes your motors unique compared to the competition?
Right now, our motors are 12% smaller for the same power than the nearest competitor. That number is going to decrease more significantly when we get our next generation in [production]. One of the really great innovations is in terms of efficiency, and that's going to give us unprecedented range. That lies deep in the way we cool the motors. A lot of motor efficiency is a consequence of managing the electromagnetics, but also the core cooling.





And your power electronics?
We have developed our own power electronics in-house, and one of the real keys there is the management of the arrays of switches, the insulated gate bipolar transistors [IGBTs] within that system. We've actually developed our own coding, our own artificial intelligence on our computer system in the way we analyze the formal, electrical and structural elements of that package to best effect.

So, we've got a multiphysics analysis system. We are using our own artificial intelligence coding for the computer to seek the best cooling topology, to enable those IGBTs to be best balanced and best controlled.

How has the autonomous technology option affected range and power draw?
There's a lot of talk about the actual draw of autonomous systems. It largely depends upon one strategy of how much depth of data one collects, and how much processing power is utilized. I think we need to look at this in context for an ICE, and the battery and electric system for that. Yes, the whole autonomous system can represent quite a significant draw. But in the context of an EV – which has got a very considerable amount of electric energy stored and, in instances of cars like ours, is very compatible with the charging – I really see a synergy between the pure electric car and autonomous technology. A real symbiosis, if you'd like.

Can you reveal a little more about the transmission strategy?
We are currently running single fixed reduction gear in most of the Alphas, but we are developing a 2-speed transmission. One of the things that we've developed is patented, our own torque-dense differential. It's an open differential, but instead of the conventional mechanical differential, which has bevel gears, we have a spur gear planetary. It's really fascinating, almost impossible to describe because it's quite bamboozling when you actually see one. It was designed in-house, super compact, super torque capable, and we're going into production with the unit differential now.

It's very interesting because a lot of what we're doing at Lucid is within this new era of software, so autonomous driving, electric cars, high-tech stuff like that, but the simple mechanical differential – which has been around in cars for a century – we've actually reinvented and improved it, which is one of the least expected outcomes of Lucid Air. It's fascinating, and it could be applied to a gasoline car. One of the important other things, though, is the methodology. We consider the electric motor and the transmission to be a single rotational system. I've asked [the motor and transmission engineers] to merge, becoming a motor-transmission team, to look at this in a holistic manner.

Lastly, are you able to give us one revelation from the Alpha speed car test that prompted an alteration to the production vehicle?
We learned a lot about cooling. We learned about, crazily enough, bubbles in the cooling system under extreme conditions, and the need to have some vents in different positions. And we also learned just how accurate our computer models were. In addition, we discovered that the aero wheels work, and they look good too!

"We're looking at the luxury market, which is dominated by ICEs, and we're bringing to market a product that is so superior. I think we will have many people swap from ICE to electric"

Peter Rawlinson, vice president and chief technology officer, Lucid Motors

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CS-17-E30

Electrified powertrains are bucking design conventions established by decades of ICE cars, and changing the vehicle interior as we know it

WORDS: **LEM BINGLEY**

Wide open space

Tesla's skateboard platform frees up vital interior space, freeing the vehicle from the constraints of an ICE

1

1. Tesla batteries feature upright cylindrical cells spread out across the vehicle floor

2. The 'Life' cabin of the BMW i3 sits on top of the 'Drive' chassis, increasing vehicle interior space

October saw General Motors unveil a concept vehicle called SURUS (Silent Utility Rover Universal Superstructure), which lacked an actual body. Instead, SURUS showed the potential of a versatile autonomous platform powered by hydrogen fuel cell technology.

Built for heavy-duty and military use, with four-wheel drive and four-wheel steering, SURUS provides a completely flat deck to support a variety of uses.

"It could be an ambulance, a mobile power generator, it could carry fuel, it could carry water – these are the types of scenarios," says Margarita Mann, GM's global fuel cell engineering business manager. "We're trying to help the customer see what it could be – that we can serve lots of different needs."

Sketches illustrate GM's thinking, showing ambulance, pickup truck and unmanned container variants. A single driver might pilot a convoy of SURUS units configured as autonomous trailers.

SURUS is a chunky example of 'skateboard' construction, with all the vital components packaged together separately from the vehicle body. With powertrain, suspension, structural and control functions built into the chassis itself, skateboards support great flexibility in cabin design.

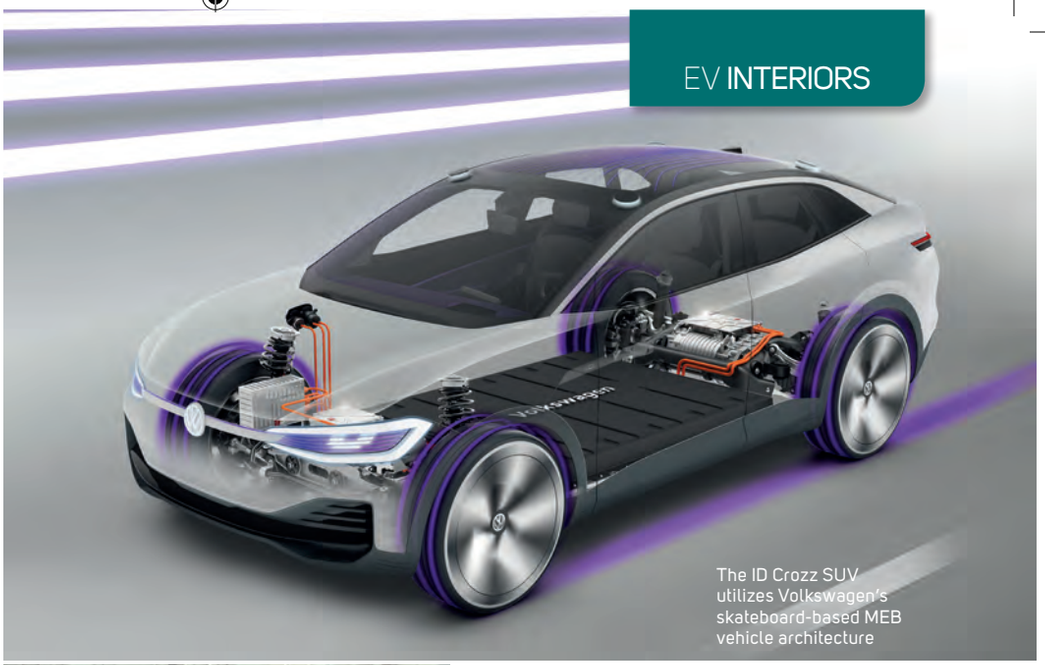
GM pioneered this notion in 2002 and 2003, with two related concept cars, Autonomy and Hy-Wire. Both featured a flat chassis containing hydrogen fuel cell power, hub-mounted motors and drive-by-wire controls. The Autonomy showcased a sporty two-seater body, while the Hy-Wire employed a spacious monobox with a flat floor from nose to tail. Glazing in the Hy-Wire's grille and trunk emphasized the space liberated by the chassis.

Board takeover

More recently, skateboard thinking has surfaced in a number of production vehicles. BMW's i3, for example, employs a 'LifeDrive' modular design with carbon-fiber 'Life' cabin atop an alloy 'Drive' chassis complete with battery, motor and suspension. The layout helps the i3 squeeze a 3-Series-sized cabin into a supermini footprint.

Tesla has also freed up interior space with a skateboard package. Its design allows for the

2



The ID Crozz SUV utilizes Volkswagen's skateboard-based MEB vehicle architecture

now famous front trunk or 'frunk', as well as spacious storage at the rear.

Tesla's batteries use thousands of cells in an upright formation across the car's floor – 5,376 cells in the 60kWh pack, for example. Each cell stands about 70mm high, so the finished battery structure is not particularly deep. With compact motors at hub height, the layout provides fewer constraints on the cabin than a conventional powertrain with engine, driveshaft, fuel tank and silencer.

The prototype B1 off-roader from New York-based startup Bollinger Motors offers an even clearer demonstration of how an electric powertrain can unlock new cabin possibilities. With all the propulsion hardware mounted below floor level, it features a 400-liter frunk that's connected to the main cabin by a pass-through hatch. A drop-down tailgate and a door in the front grille create an open storage space that runs right through the middle of the vehicle and out the other end.

This innovative design makes it possible to enclose a stack of 12ft (3.7m) planks fully inside a vehicle only 12.5ft (3.8m) long. With a little care, the B1 might even transport longer items sticking out both front and back.

Under its boxy body, the B1 features a 290 lb (132kg) aluminum frame chassis.

3

4

3. Assembly on General Motors' Hy-Wire concept, which featured a flat-floor monobox

4. The Hy-Wire was powered by fuel cell technology and hub motors, free of ICE packaging constraints

"The entire back and front of the [Bollinger B1] are identical – mirror images of each other"

Robert Bollinger, founder and CEO, Bollinger Motors

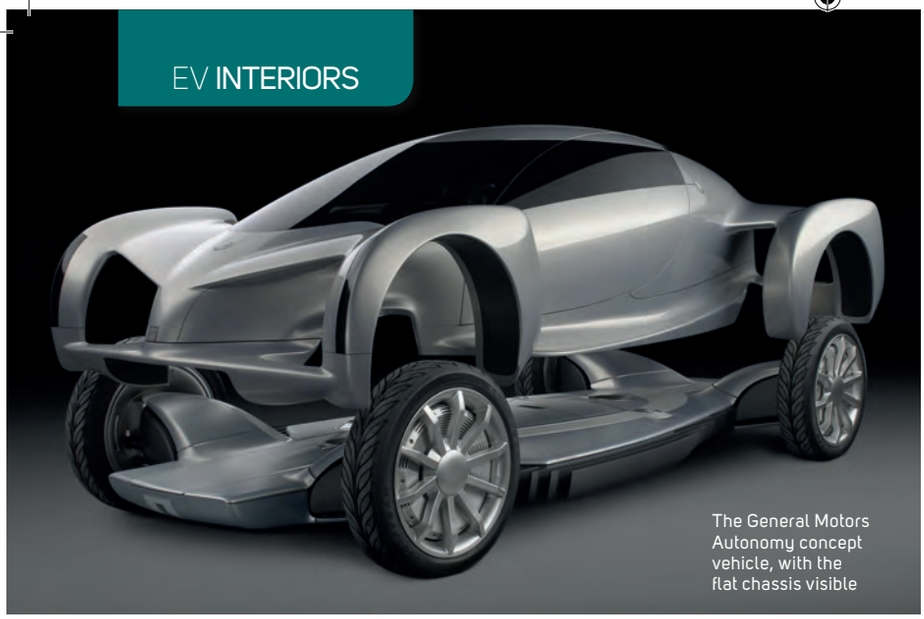
Power electronics plus front and rear drive motors are mounted along the chassis's centerline, with a 60kWh or 100kWh battery split into two removable boxes either side, under the floor beneath the seats. "The entire back and front of the truck are identical – mirror images of each other," says company founder and CEO Robert Bollinger.

To keep the chassis flat and low, and the cabin clear of intrusions, the B1 features compact hydro-pneumatic suspension. "It's a Class 3 truck, engineered for a 10,001 lb (4,536kg) gross vehicle weight," says Bollinger. "If we'd put straight normal shocks on, they'd have stuck up way into the cab."

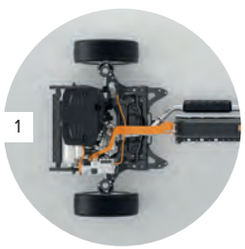
Vehicles like the B1, Model S and i3 have been able to bring the benefits of skateboard thinking into the cabin because they are pure-play EVs. Some mainstream OEMs are now following suit and creating dedicated electric platforms to unlock similar benefits in cabin design. The VW Group, for example, has showcased a variety of future vehicles based on a modular electric platform called MEB, which features a skateboard layout.

To date, MEB has powered only show cars – Volkswagen's ID Crozz and Skoda's Vision E crossovers, the VW ID hatch and ID Buzz – but development of the first production variants is currently underway. ID Buzz best illustrates the platform's potential with a spacious, versatile interior with removable center console and front-trunk storage.

MEB is a significant departure from VW's previous strategy of using common platforms for both electric and conventional vehicles, leading to EVs and PHEVs like the e-Golf and



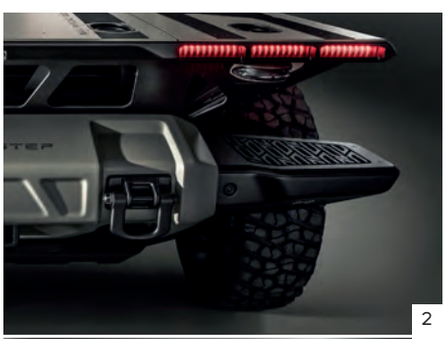
The General Motors Autonomy concept vehicle, with the flat chassis visible



1. CEVT's CMA was designed to support multiple powertrains

2. The SURUS platform provides a flat deck for a wide range of vehicles

3. All of SURUS's vital components are kept separate from the body



Passat GTE that typically provide less cabin space than their conventional counterparts.

Shifting the paradigm

Geely-owned China Euro Vehicle Technology (CEVT) has also engineered platforms for conventional and fully electric vehicles. Its CMA (Compact Modular Architecture), which underpins the new Volvo XC40 and Lynk & Co 01 crossovers, has been built to carry PHEV, BEV, hybrid and combustion powertrains. EVs based on CMA seem unlikely to support innovative cabins.

"The first lines of CMA were laid in 2012," recalls Börje Grandin, director of electric propulsion systems at CEVT. "At the time, we were more willing to make compromises for the pure electric vehicles than for the hybrid and conventional cars."

Since then, the landscape has shifted, says Grandin. "In the future we'll probably change around where we do the compromises," he adds. "This is all over the industry right now. There's a lot of rethinking in engineering communities about how we do platforms, and what we prioritize."

Packaging an ICE has been the overriding concern in the past. "The front end of the architecture has traditionally been a fixed component because of all the load structures – everything is so critical and so expensive. But [with] electric architectures, it's the middle floor that's more important," says Grandin.

The move to BEVs will make it easier and cheaper to build a wide variety of cars, from rear-wheel-drive sports cars and sedans, to front-drive hatchbacks and crossovers, to all-wheel-drive SUVs and pickups, on the same modular platform. "When we talk about a rear-wheel-drive conventional architecture, we instantly start thinking about positioning the combustion engine," Grandin observes. "That affects the front end and the floor. But in an EV, rear drive only affects the rear of the car [and vice versa]. As a result, we can be more flexible with an EV architecture."

AUTOMATIC FOR THE PEOPLE

"Electric vehicles are driving change in the interior," says Han Hendriks, chief technology officer at Shanghai-based Yanfeng Automotive Interiors (YFAI). "Electric drivetrains are more standardized, offering less room for differentiation than combustion engines, so the interior becomes more important."

Hendriks adds that automotive startups are bringing new thinking. "Tesla and Waymo, Uber and others don't carry 100 years of heritage about what an interior should be like," he observes. "They are new and fresh and challenge us to be the same."

Similarly, autonomous technology is poised to unleash a wave of change, as the driving position ceases to dictate cabin layout. Instead, adaptable interiors will be needed. "If the driver is no longer driving, the occupants can move around and the interior needs to support that with work surfaces, more storage, and more space to relax and play and stretch your legs," Hendriks says.

YFAI's current thinking was embodied in its XiM18 show car, displayed at the Frankfurt Motor Show in September. It features a folding steering wheel plus seats and center consoles that can slide across a flat floor. Rears seats can be stowed, while the passenger seat swivels 180° to enable face-to-face conversations. Touchscreen controls migrate among different panels as occupants change position.

Autonomous cars will de-emphasize many of the factors deemed important in today's cars, Hendriks adds. "The interior will become the number one purchase decision driver in the future," he predicts.

YFAI imagines an autonomous vehicle where driving position no longer dictates the layout of the interior

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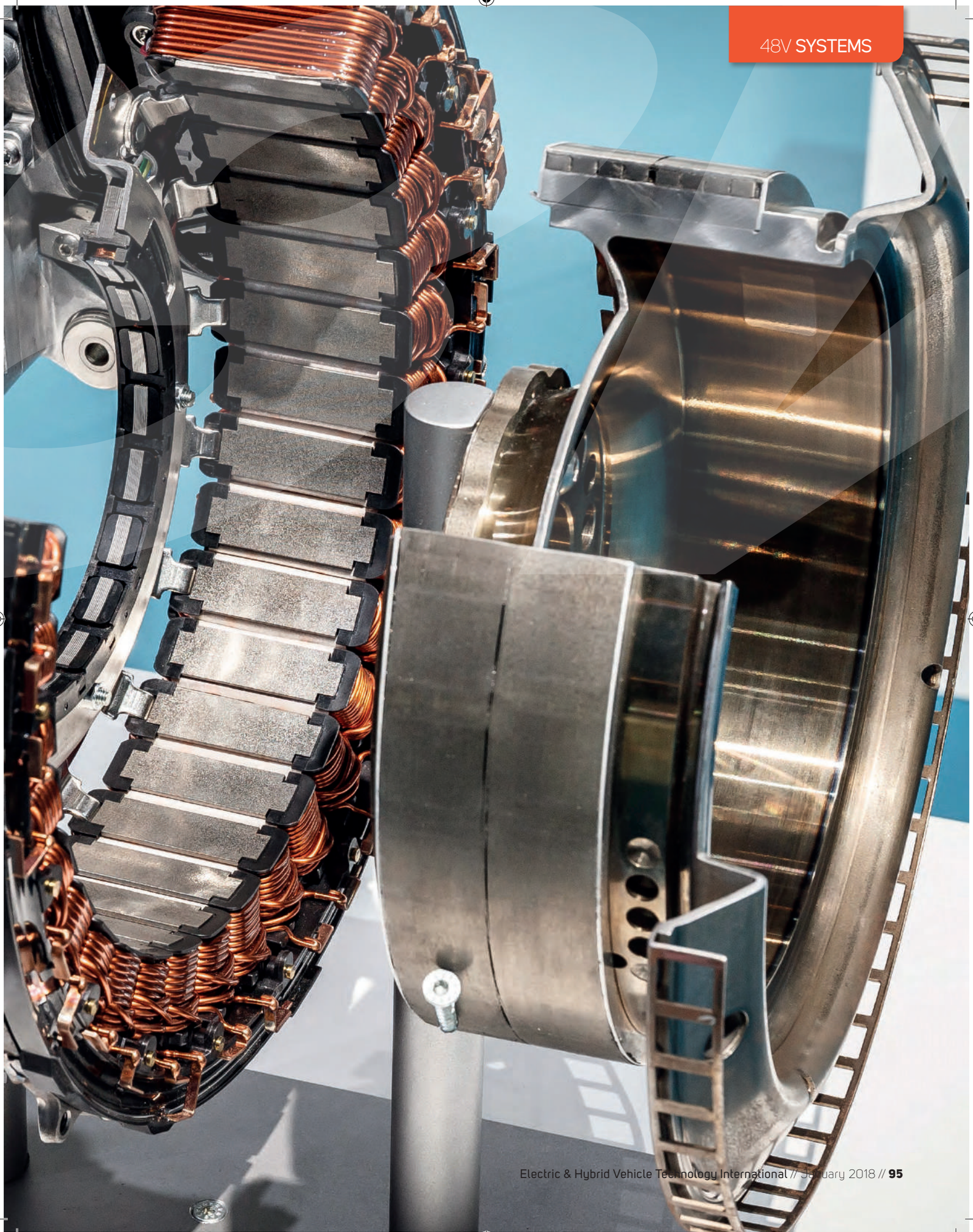
A walk on the mild side

Could the rise of 48V mild hybrid systems offer the benefits of full hybridization without some of the compromises?

WORDS: CHRIS PICKERING



"At present, we're focused primarily on efficiency and CO_2 with the 48V system"

Oliver Vollrath, powertrain project manager, Daimler

Predicting the future can be a tricky business. Technologies tend to ebb and flow, gradually shaping the automotive landscape. But there are two things we can say with absolute certainty: CO_2 targets will continue to come down, while the specification of the cars will continue to go up.

The former is very obviously a powertrain issue, but so too is the latter. Increasingly sophisticated ADAS and ever-greater levels of luxury mean that the electrical power consumption of vehicles is rising rapidly.

The answer may lie with 48V mild hybrid systems, which offer a very attractive compromise – most of the benefits of a full hybrid system at a fraction of the size, weight and cost. A report from UBS estimated that 48V gasoline systems could account for a quarter of all cars sold by 2025, outnumbering non-electrified diesels by that point.

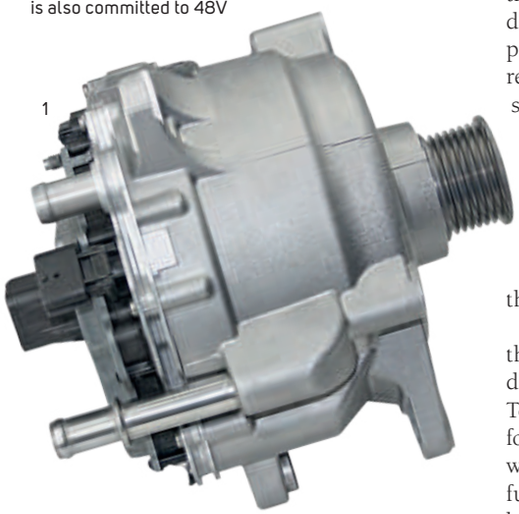
"We think that mild hybrid technology will develop massively from 2020, when OEMs need to achieve very stringent CAFE [Corporate Average Fuel Economy] targets," says Renault's powertrain planning director, Vincent Terrail. "It could be particularly beneficial in mid- to large-size vehicles. Here, the growing demands of emissions control systems, multiple sensors linked with ADAS, and other features, will make it mandatory to switch to 48V."

Small packages

Terrail and his colleagues are putting their money where their mouth is. Renault has recently launched its first 48V system as an option on the 1.5-liter diesel engine found in the Scenic and Grand Scenic people carriers.

1. Continental's 48V system is available as an option on the Renault Scenic and Grand Scenic

2. Driveline specialist ZF is also committed to 48V



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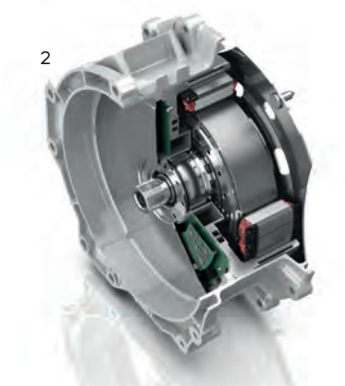

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Delphi 48V tech in a 1.6-liter diesel

The system uses a 10kW e-motor, allied to a 150Wh lithium-ion battery, which is small enough to fit in the spare wheel well. In total, it adds 49kg (108 lb), but knocks nearly 10% off the fuel consumption and 6g/km off the CO_2 figure.

Aside from harvesting and deploying energy, the belt-starter generator (BSG) also provides an enhanced stop-start function and assists the engine's aftertreatment strategy. The car draws heavily from the 48V battery as the particulate filter approaches the need for regeneration. Once the battery is empty, the system switches into an aggressive charging mode, increasing the load on the combustion engine, which raises the exhaust gas temperatures and aids regeneration.

At present, the system's propulsion capabilities are limited to the load point shifting, but they could extend further in the future.

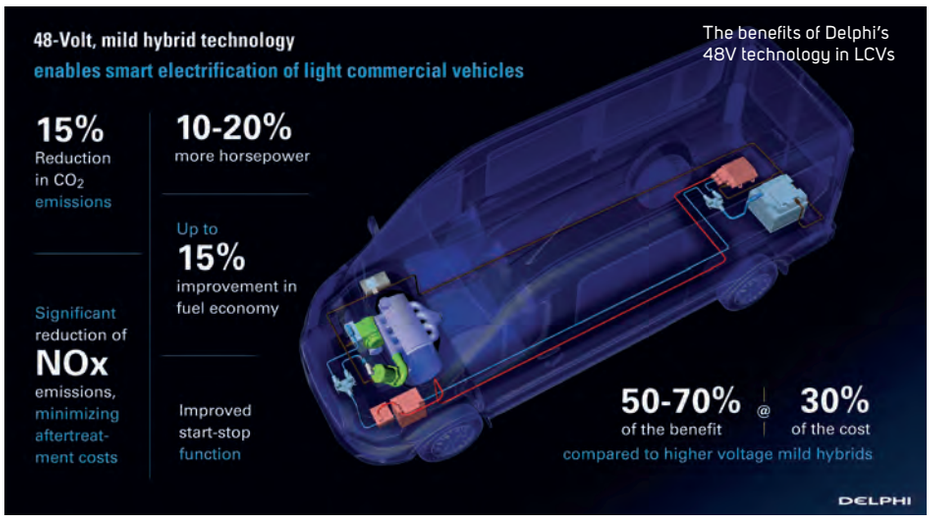
"If the 48V system was packaged inside the transmission, the e-motor could be linked directly to wheels to propel the car," explains Terrail. "With 10-25kW it could only be used for very low speeds and parking maneuvers. It would also allow us to implement a stop/start function during coasting, but if we want to have real e-drive at higher vehicle speeds [over 30km/h (19mph)], we would need to switch to a stronger e-motor and a higher voltage."

Power play

Mercedes-Benz has also turned to 48V. The new 3-liter M256 gasoline straight-six in the latest S-Class uses an integrated starter-generator (ISG) combined with an e-booster to aid the turbocharger. It's also the firm's first beltless engine, driving most of the ancillaries direct from the 48V system.

"This approach allows us to achieve a very high specific output without any turbo lag (thanks to the e-booster), as well as significant reductions in fuel consumption and CO_2 through the possibility of energy recovery," comments Oliver Vollrath, powertrain project manager at Daimler. "Furthermore, it means we can move high-energy parts like the air-conditioning compressor, exhauster, electric auxiliary compressor, water pump and electric refrigerant compressor from the 12V system to the 48V side. This is more energy-efficient and allows us to draw more power, enabling new functions in areas of ADAS and infotainment."

Much like his Renault counterpart, Vollrath expects widespread adoption of 48V systems over the next few years, but he points out that it's driven by a combination of factors: "As shown with our new family of modular



engines, we have powertrains that build a good base to fulfill the upcoming emissions standards without electrification. But there's a wider trend – it's not only CO_2, but also emissions and increased electrical power."

While mild hybrid systems have the potential to improve all these aspects, there are still trade-offs to be made. The dilemma facing OEMs currently is whether to use the load point shifting to reduce the CO_2 output or whether to look at other emissions.

"At present, we're focused primarily on efficiency and CO_2 with the 48V system," explains Vollrath. "It could also be used to tackle emissions, but we have other more efficient technologies that can do that. For CO_2 there aren't many technologies that offer the same cost-to-benefit ratio."

The same logic would apply equally well to a diesel engine, he points out. It's also likely that more devices on the car could be powered by a 48V system in the future, although he's very clear on the boundaries of the system: "I get asked if we could drive the whole car electrically, maybe for parking or creeping in traffic, but I don't believe that's the right way to do it. If you start to think about electric propulsion, then 48V will never be the optimal solution; if you want to drive parts of your daily route fully electric, then it's best to go for a plug-in."

A major considerations is packaging. The Daimler engineers set a target that the battery for their 48V system should be no bigger than its 12V counterpart. At this size, it's relatively easy to accommodate both systems in a regular vehicle platform. It also limits the weight of the 48V system – something that's aided by the smaller wire thicknesses made possible by the high-voltage/low-current architecture.

Overall, the M256 with its ISG and the associated power electronics is only around 5kg (11 lb) heavier than the outgoing M276 V6. While the electric machine adds mass, it is offset by the loss of the alternator and the starter motor. More importantly, it's one of the enabling technologies that means a six-cylinder engine could potentially replace a large-capacity V8.

Cost of doing business

The cost case for 48V is persuasive. It roughly quadruples the power-handling capability of the electrical system, yet it's reasonably affordable. Mary Gustanski, senior vice president and chief technology officer for Delphi Powertrain, estimates the cost of adapting an existing 12V architecture to dual-voltage at around US$150 per vehicle. The total cost of the mild hybrid system could then be as low as US$600, rising to around twice that for a high-spec luxury vehicle.

In comparison, she explains, upgrading the electrical architecture to accommodate a plug-in hybrid would be six to eight times greater: "Above 60V, the requirements become far more demanding. You have to put in high-voltage cabling, costly shielding and much more robust connectors. To give you an idea, a high-voltage connector is US$20; a low-voltage one is US$2."

"Until 2040 or 2050 we see 48V mild hybrids as the best value form of electrification"

Mary Gustanski, senior VP and chief technology officer, Delphi Powertrain

Overall, Gustanski estimates that mild hybrids could offer 70% of the fuel economy benefit of a full-hybrid powertrain for around 30% of the cost.

"Eventually we'll move to an EV world – but we're talking maybe 2040 or 2050," she says. "Until that point we see 48V mild hybrids as the best value form of electrification. The question is how best to utilize them? We think P2 architecture [where the e-machine is downstream of the clutch] is the next step. A 48V P4 [driving the wheels] would be an interesting concept – it could provide a greater degree of hybridization at a more reasonable cost. As motors become smaller and lighter, could we yield the required power with multiple 48V motors perhaps?"

There are also synergies with other technologies; Delphi's engineers have found that using a mild hybrid system enables them to considerably extend the operating range of the firm's cylinder deactivation system.

"We've got a VW Passat test vehicle with our GDI system. When we combined a 48V architecture with our Dynamic Split Fire System, we saw a fuel economy improvement of 19% straight out of the box," says Gustanski. "That's without optimizing the calibration. With more work to combine the two control systems, we think we can get even more."

The benefits of 48V could extend beyond the powertrain, says Markus Heiartz, program manager for hybrid modules at ZF: "Active chassis systems such as electric power steering, active rear-axle steering, active damping systems or electromechanical roll control could all benefit from a 48V system. It could also be used to support electric valve timing adjustment of the ICE or – one step further – an electromechanically actuated valvetrain."

Though best known as a driveline specialist, ZF has recently introduced a 48V ISG. Heiartz shares the OEM's view that mild hybrid systems will become "more or less mandatory" in the coming years. That's not to say these systems are without their challenges, though.

"Currently, the packaging is tricky, because we usually have to integrate our components into a space that's not designed for them," he explains. "In this respect, we are focusing on modular transmission construction kits that enable optional hybridization from the start."

Although there are incremental gains to be made in areas like power and energy density, the main aspect that the suppliers and OEMs are working on is cost reduction. Almost by definition, 48V systems are highly cost-sensitive (it is, after all, the main reason for using a 'mild' hybrid). The consensus, though, seems to be that we have reached a tipping point, where it is cost-effective to switch to this architecture. And it looks like it will be here to stay.

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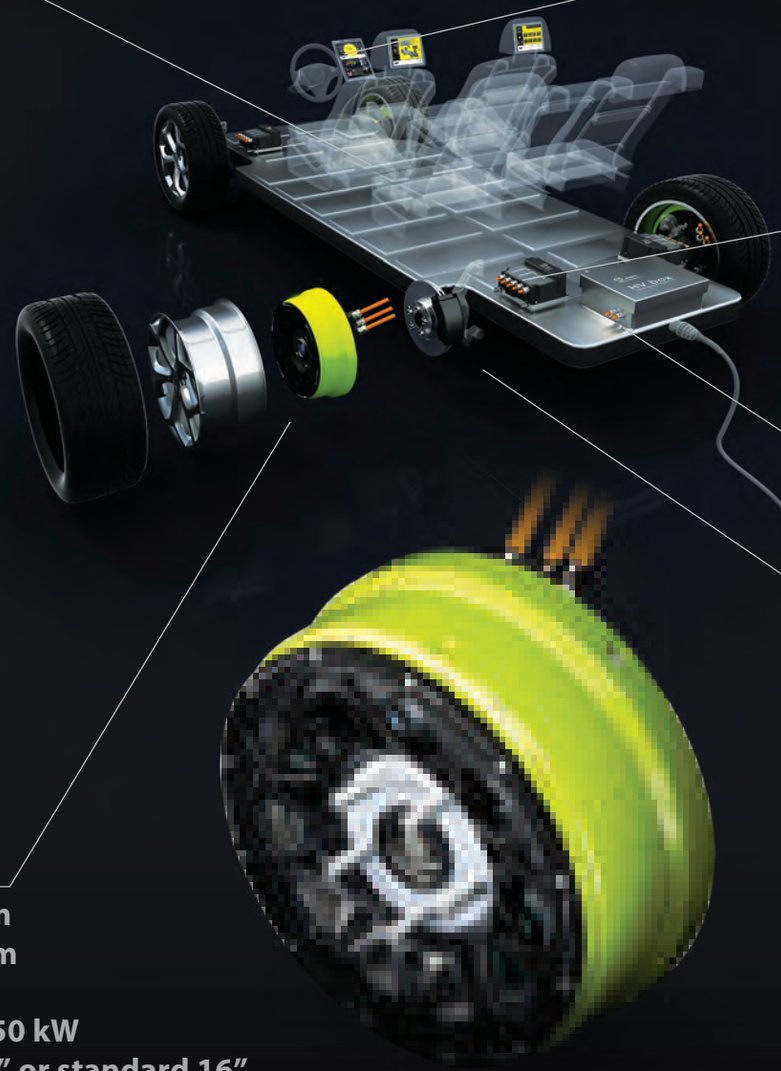

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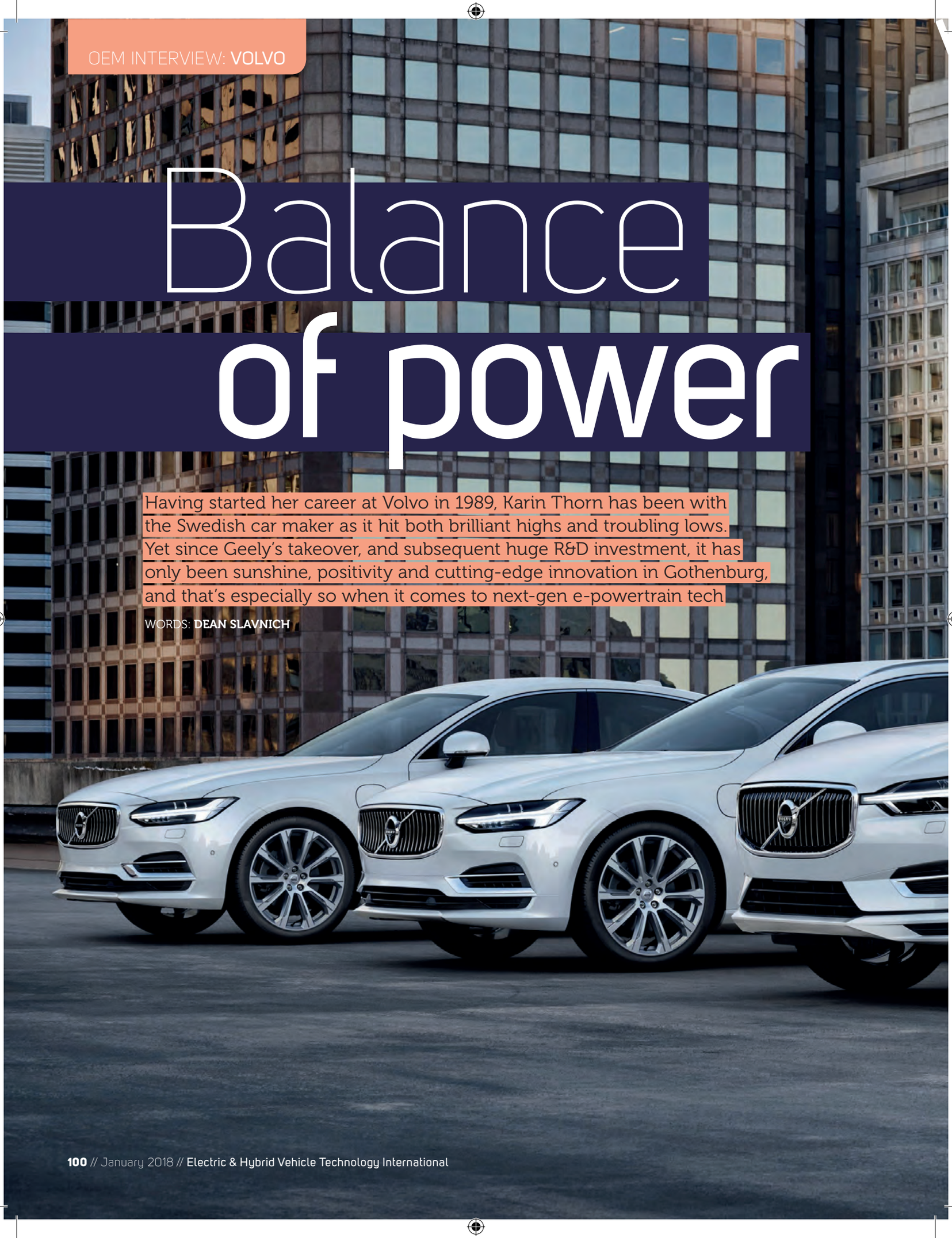
Balance of power

Having started her career at Volvo in 1989, Karin Thorn has been with the Swedish car maker as it hit both brilliant highs and troubling lows. Yet since Geely's takeover, and subsequent huge R&D investment, it has only been sunshine, positivity and cutting-edge innovation in Gothenburg, and that's especially so when it comes to next-gen e-powertrain tech

WORDS: **DEAN SLAVNICH**



"The range we get is determined by the size of battery and the type of battery technology we're using. Then there are other factors, like weight and the energy consumption of the vehicle. Working [with these factors] it's actually quite similar when working on the range of combustion vehicles"

Volvo's medium- and long-term future will be fully shaped by the electric powertrain

The best place to start is with that e-powertrain announcement earlier this year [in which Volvo confirmed all new models from 2019 will feature some form of electrification]. How do you think it was received globally?
As far as I know, we generated huge global interest. It was a big announcement.

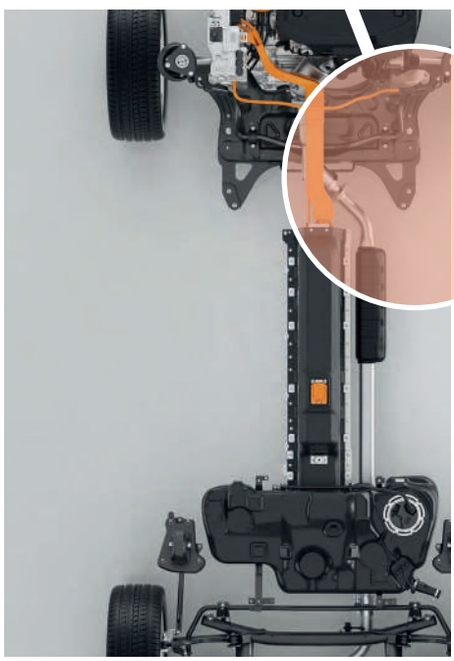
But won't all car makers have to adopt this electrification strategy anyway, what with the 2019/2020 targets being so tough?
For us, this is the best plan for Volvo as a company – offering good technology to our customers while meeting legislation in every market where we sell vehicles. Exactly what plans other brands might have, I can't comment. But for us, it's about good products with low emissions.

But does this plan really mark the end of the IC engine, as the Volvo press release stated?
It marks the end of pure IC engines. What we said is that from 2019 onward, all propulsion systems will come with some form of system electrification. So for the mild hybrids – 48V – they will have a combustion engine. Then we'll have plug-in hybrids [with IC engines] and pure battery vehicles. I guess it all depends what one means by the word 'end'. Over time, we will stop having pure combustion engines, and instead it will be combustion engines in combination with some electric machine/technology.

Right: The T5 Twin Engine development will make electrification accessible to a wider, more global audience for Volvo, with various products being able to use the state-of-the-art plug-in architecture

So you don't think future emissions legislation can be met with IC engine developments alone, like HCCI or variable valve compression technology?
There are many technical ways of improving fuel economy. What we are saying is that this combination [electric motor and IC engine/full electrification] gives us the best product and helps us improve fuel economy/CO_2. Of course, you can choose different technologies, and some brands are doing it differently, but we believe this is the best way.

From an engineering perspective, what pressure is the powertrain team under to make sure all very near-future Volvos feature electrification measures?
For the engineers working in propulsion engineering, their job has always been to make fantastic powertrains that have low emissions and good driveability along with good performance. That work continues today. The new programs are for battery electric vehicles, mild hybrid vehicles and plug-in hybrid vehicles, so there's a changeover to include electrical propulsion. But despite this, the basis is the same, so we focus on good fuel consumption or electrical range, low emissions, good driveability and good performance. Those aspects are the same.



As part of the wider powertrain program strategy, Volvo is aiming to launch five BEVs between 2019 and 2021. Is that an ambitious plan?
Five new battery electric vehicles is a good plan for us. It's a challenge, for sure, but it's something that we have the capability to do.

The first BEV will be a CMA product. But after that, what architecture will be used?
At this stage, we can't comment on the technical and engineering solutions of our battery electric vehicles.

But will the BEVs be standalone products, like the Leaf is for Nissan, or will they be derivatives of current products, like an all-electric XC40?
The full plans will be revealed at a later stage. I can confirm the XC40 will be a BEV, but all other details remain private.

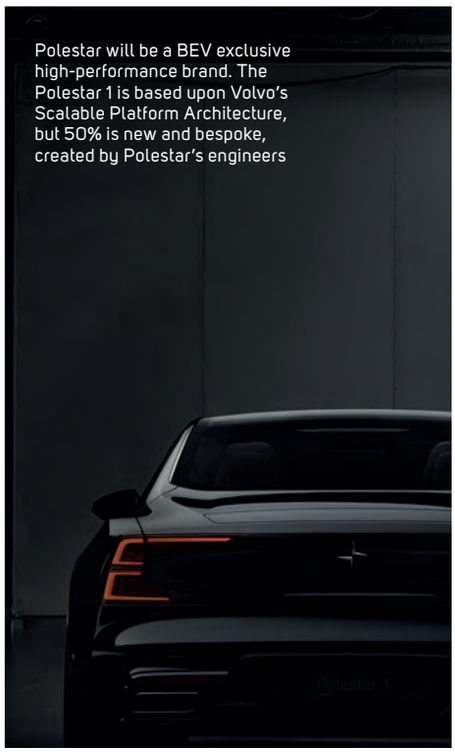
Why did you choose China as a location to build your first EV, meaning it's your primary choice over even Sweden?
China is an important market, but the technology we develop is actually global for all markets. We need to start somewhere, so it's China first [for production].

So this must be a decision made on cost alone?
I can't comment on that. The technology we develop and produce needs to work globally.

When you develop an EV, what's more important: realizing good real-world range, as in the case of, say, the Renault Zoe, or hitting supercar-like performance power outputs like Faraday and its FF91 model?
There's not one answer to that question. Probably what we will see with electric vehicles, just as we have seen with combustion vehicles, is that different customers will prioritize – and be prepared to pay for – different attributes. Of course, without knowing, different situations and positions will suit different products and brands, and that covers different ranges and different power outputs.

Do you think by 2030 a BEV will have the same range as a conventional 2.0 diesel XC60?
That's a very difficult question to answer. The range will improve, that's definite. But I can't give you an answer on the progress. When we start to talk about the future, and as far ahead as 2030, [any answers] will be pure speculation from my side and that's something I don't want to do.

Three of the 2019-2021 BEVs will be Volvo-badged, the other two Polestar. Do the powertrain engineering teams overlap between the brands, or are they separate, standalone units?
It's both. Some people work in Polestar and then cross over. But the base technology development is done within the propulsion engineering unit in Volvo Cars. The propulsion organization within Volvo Cars is much bigger, so the majority of the work is done there. But overall it's a mixture.



Polestar will be a BEV exclusive high-performance brand. The Polestar 1 is based upon Volvo's Scalable Platform Architecture, but 50% is new and bespoke, created by Polestar's engineers

"The diesel market is shrinking, and customers want to have other products. Our thinking is: we of course still want to have good fuel economy figures, and it's here where the 48V mild hybrid technology comes into play"

Volvo has gone on record to state it won't be creating a new diesel architecture. Instead its future is based on gasoline PHEVs and BEVs

The XC40 will eventually feature a full electric model

"We have chosen to have gasoline engines for our future plug-in hybrids, as seen in the T8 models. The reason for this choice is because we want it to be a global product. The USA and China are very important markets for us and we do not sell diesels there"

The standout figure of the Polestar 1 announcement was not the huge power outputs, but the 150km (93-mile) electric range. How easy was that to achieve?

The range we get is determined by the size of battery and the type of battery technology we're using. Then there are other factors, like weight and the energy consumption of the vehicle. Working [with these factors] it's actually quite similar when working on the range of combustion vehicles.

Polestar 1 comes off SPA, but 50% of components and subsystems are new to that specific car. Can you tell me what's changed?

We can't go into details yet on Polestar 1 and SPA. We start from the plug-in hybrid technology that we already have in the SPA vehicles and then we add further technology to achieve the attributes we wanted for Polestar 1. But the main thing is, we started from the base that we developed for the SPA architecture and the plug-in hybrid technology. That was the starting point and then we added more.

Is the battery developed in-house or with partners?

We work with suppliers for the battery technology and we then integrate that technology into our product. We don't have cell chemistry capability within my team; we buy that in.

Which suppliers are you working with?

We've not communicated that yet. That's something for a future announcement.

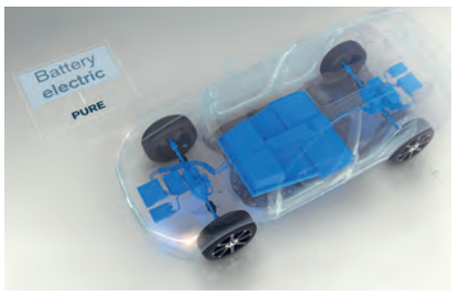
You've gone on record to say 48V technology is an alternative/ replacement for diesel engines. Can you expand on that statement?

Today, Volvo has both gasoline and diesel engines, and that's something we'll have for a while. What we've seen, though, is that the diesel market is shrinking, and customers want to have other products. Our thinking is: we of course still want to have good fuel economy figures, and it's here where the 48V mild hybrid technology comes into play, improving fuel economy of [gasoline] engines and overall driving range. There is a degree of how much electrification you can add on the 48V system, but it is less costly [than competing engine technologies]. For the near term, if a customer wants an alternative to diesel, then we can offer a gasoline engine with 48V technology. This combination gives very good fuel economy with also very good driveability.

So will 48V replace diesel technology?

I don't know! But we have developed it so that the customer has a choice. But we've also developed 48V technology for diesel engines.

Below and bottom: Volvo Cars' goal of having over one million electrified products on the road by 2025 might sound ambitious, but Thorn says it has the technology to make that a reality



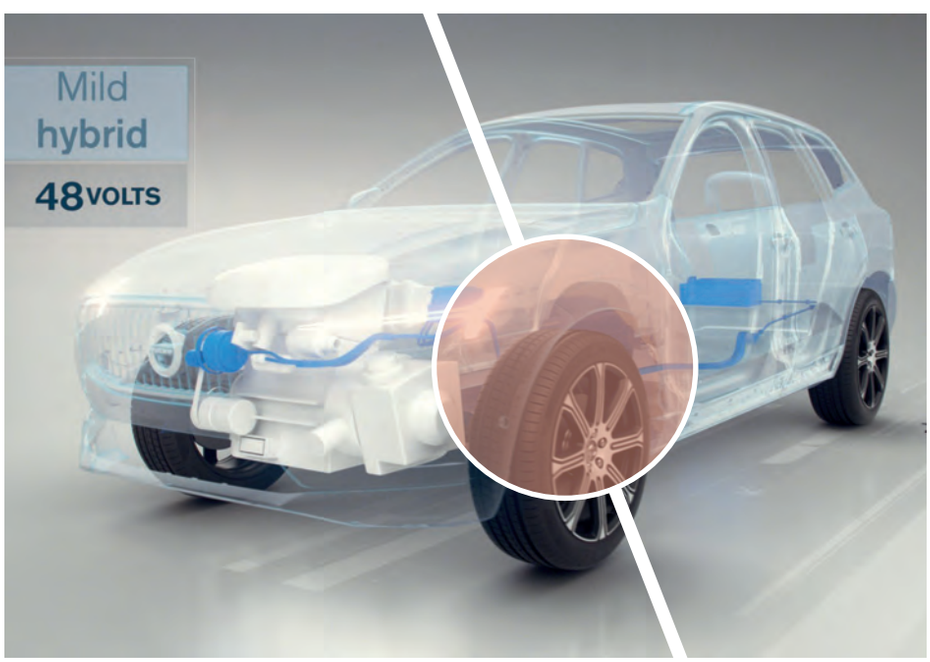
"It was first 42V and now 48V and discussions have been going on for a long time now. It's a question of timing and when the technology is ready, as well as the price point and customer demand"

The problem is 48V has been around for a long time. Why has it taken so long to get to this near-production point?
It's a good point – it was first 42V and now 48V and discussions have been going on for a long time now. It's a question of timing and when the technology is ready, as well as the price point and customer demand. For Volvo, the timing for this technology is 2019 and onward.

Along with PSA Peugeot Citroën, Volvo was one of the first with a diesel hybrid product. Is this technology now dead?
We have chosen to have gasoline engines for our future plug-in hybrids, as seen in the T8 models. The reason for this choice is because we want it to be a global product. The USA and China are very important markets for us and we do not sell diesels there.

On the road, and in the real world, diesel hybrids actually make sense. So does a bit of your engineering heart break at such a decision?
Perhaps. But like I said, we need to limit ourselves somewhere, so we decided to go for technology that we can sell all over the world.

Is diesel dead?
I don't know. I really don't know. For the time being, we sell diesels and we have good diesel products. If we'll have them in the longer-term future, I do not know. That said, our diesel architecture is quite new, but we have already communicated that we won't do a new architecture.



Volvo Cars' commitment to electrification across its range will see a Battery Electric 40 Series car from the Swedish OEM in the coming years

How much has Volvo advanced in terms of powertrain technology since Geely's takeover, and especially in comparison with the Ford/PAG ownership days?
It's a completely different situation. When we were part of Ford, we were part of a huge company with completely different possibilities to having different technologies. In terms of volumes within the Ford group, we had options for many different engines and architectures or derivatives. And the same applies to gearboxes and actually any other technologies. When we were sold from Ford, and became part of a much smaller group volume-wise, we needed to have a different strategy and new architectures. So we replaced all our different engine and powertrain architectures with one common architecture for gasoline and diesel products. That's worked extremely well for us and is now the foundation that we build upon for the future.

Will Lynk & Co also be getting battery-electric technology?
I can't comment on other brands. Those announcements need to be made by those specific brands.

Finally, is hydrogen fuel cell technology the end game for true sustainable automotive transportation?
When it comes to hydrogen fuel cell vehicles, we're monitoring what's happening in the world, but electrification is what we're working with and further developing. We believe that electrification is the right track for the future and that's where we're putting our full research, development, resources and efforts.

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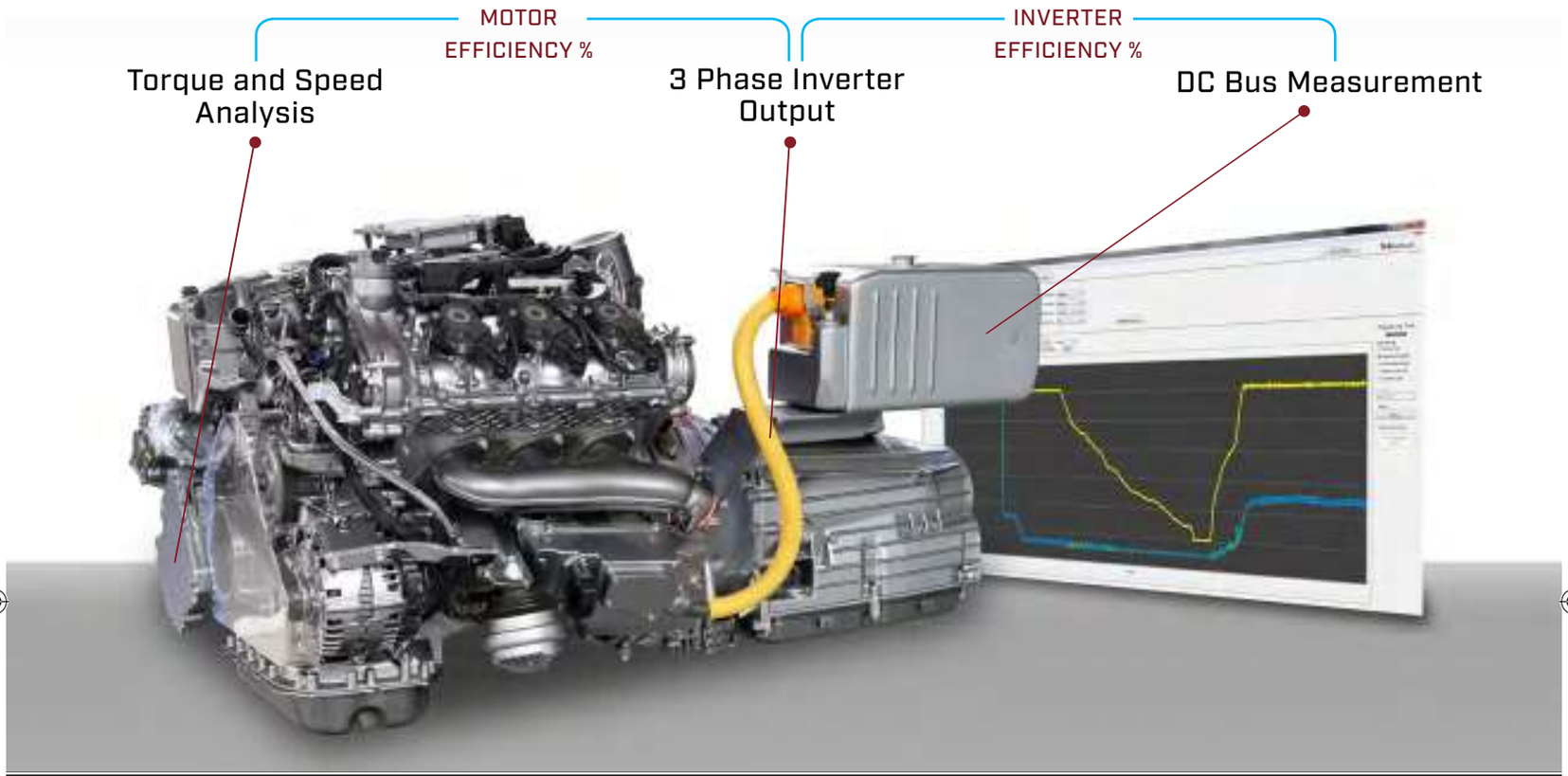

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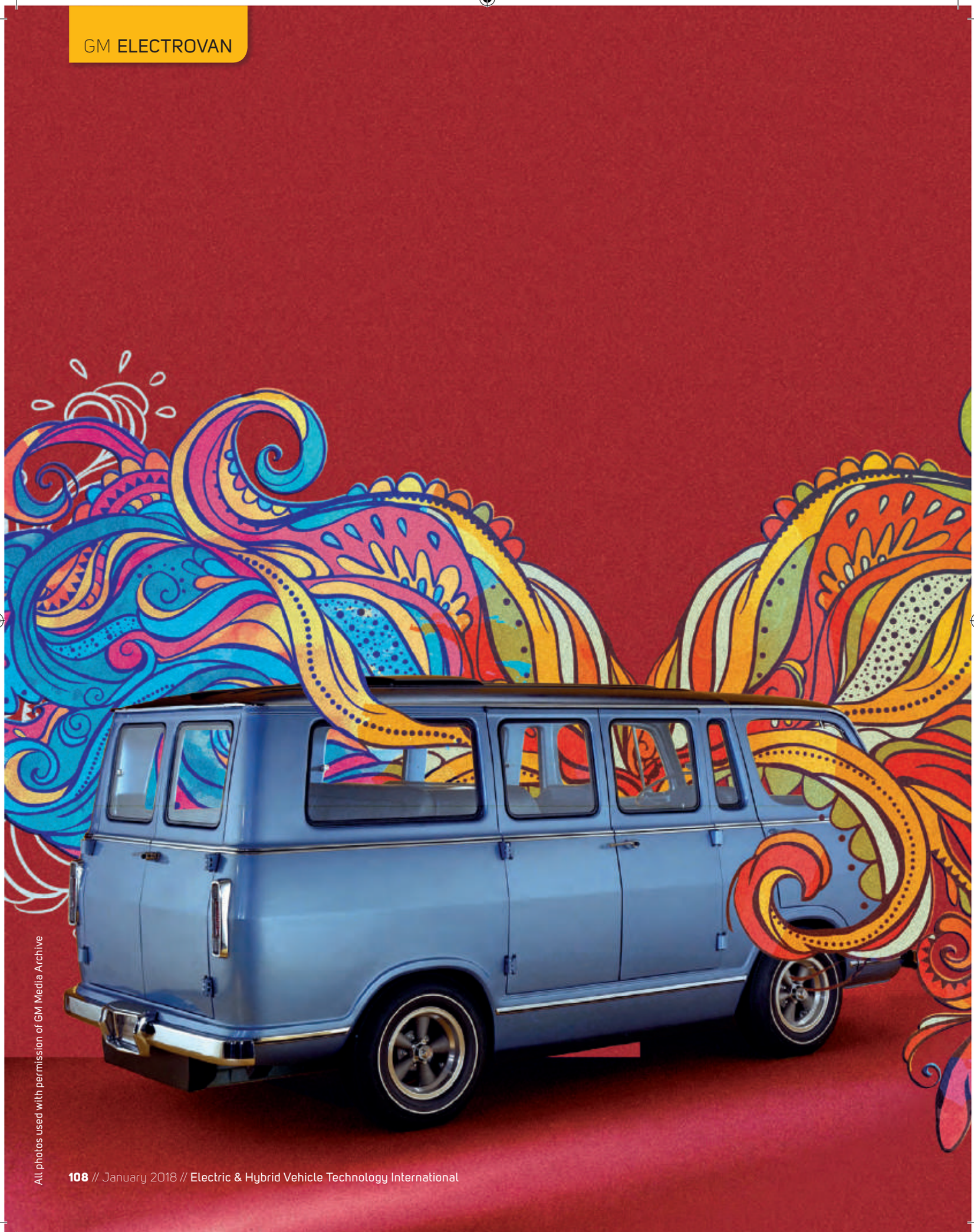

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History lessons

It's been more than 50 years since GM tested the world's first hydrogen-powered vehicle, but Floyd Wyczalek, project manager for fuel cell development on the Electrovan, has clear memories of working on the innovative venture

INTERVIEWED BY:
JOHN THORNTON AND MATT ROSS

The 1960s was a decade with no shortage of technological, political, social and cultural change. But amid all the upheaval, away from the headlines, General Motors (GM) was quietly going about its business with the testing of the Electrovan – the world's first hydrogen-powered fuel cell vehicle, and the first use of fuel cell technology derived from US President John F Kennedy's challenge to NASA to safely land a man on the moon by the end of the decade.

Electrovan was the brainchild of Dr Craig Marks, who headed up many of GM's advanced engineering projects. It was developed by a 200-person team over a two-year period and tested for 10 months before a driveable tech demonstrator was shown off to the media in the autumn of 1966. Due to its prohibitive cost (the platinum used in the fuel cell was reportedly enough to purchase an entire fleet of vans) and lack of supporting hydrogen infrastructure in place at that time, Electrovan was regarded by GM as strictly a test vehicle to explore hydrogen as an energy source for vehicle propulsion.

At the end of the project, Electrovan was stored in a warehouse in Pontiac, Michigan, for 31 years before being rediscovered in 2001 and rehoused at the GM Heritage Center (GMHC) in Sterling Heights for public displays. The vehicle has remained there ever since, and when Electrovan celebrated its 50th anniversary, GM marked the occasion by inviting Floyd Wyczalek, project manager of Electrovan's fuel cell development, to GMHC to recount the test period and, remarkably, to sit inside the vehicle for the very first time. Speaking with *E&H Vehicle*, Wyczalek, now 91, rolled back the years to discuss what it was like working on the groundbreaking project.

Dr Craig Marks (left), GM engineering staff, and Dr Charles E Winters of the Union Carbide Corporation inside the Electrovan. The powertrain had a significant impact on the vehicle's interior space

Can you remember how the Electrovan project was first set in motion?

GM adopted a corporate policy of ZEV [zero-emissions vehicles] in the early 1960s. In early 1964, the GM engineering staff division at the GM Technical Center [located in Warren, Michigan] responded by proposing a two-phase solution to support senior management's ZEV policy.

What did phase one entail?

Phase one was an Ag-Zn [silver-zinc] BEV platform to develop an oil-cooled 75kW three-phase induction motor compact enough to mount in a production vehicle, measuring 20cm [7.9in] in diameter by 25cm [9.8in] long, 13,000rpm, with a mass of 60kg [132 lb]. Dr Paul Agarwal, head of GM Research's electrical engineering department, coordinated development of the traction motor and IV [infinitely variable] solid-state motor control system. GM Delco Products built the units for our project. Neither component existed at the time. This was called Electrovair and was based on a converted rear engine production 1964 Corvair air-cooled IC piston engine platform.

What can you tell us about phase two?

Phase two was an H_2 [hydrogen] fuel cell-powered EV called Electrovan, which was based on a GMC Handivan platform. The Electrovair traction motor and IV motor controls were to be transferred directly into the Electrovan. Consequently, development effort could be focused exclusively on an H_2 fuel cell development compact enough to mount in the Electrovan. The fuel cells were a spin-off from NASA's Apollo lunar program. Fuel cells provided pure drinking water for the three-person lunar mission crew and electric power for the command module and two-person lunar lander. Water exhaust and electric power were also an ideal fit for GM's ZEV policy.

Was a different approach to testing required, compared with those that were designed for fossil fuel-powered vehicles?

Yes, our first challenge was to build a fuel cell powertrain simulator development test facility, which did not exist at that time. In addition, we needed to appoint and train a team of fuel cell powertrain simulator test engineers and technicians. Except for principle engineering staff leadership, most of the engineering team was not familiar with fuel cells. In a hands-on program with fuel cell engineers and technicians from Union Carbide, this joint team then began the process of designing and installing appropriate fuel cell test equipment, starting with an empty test cell.

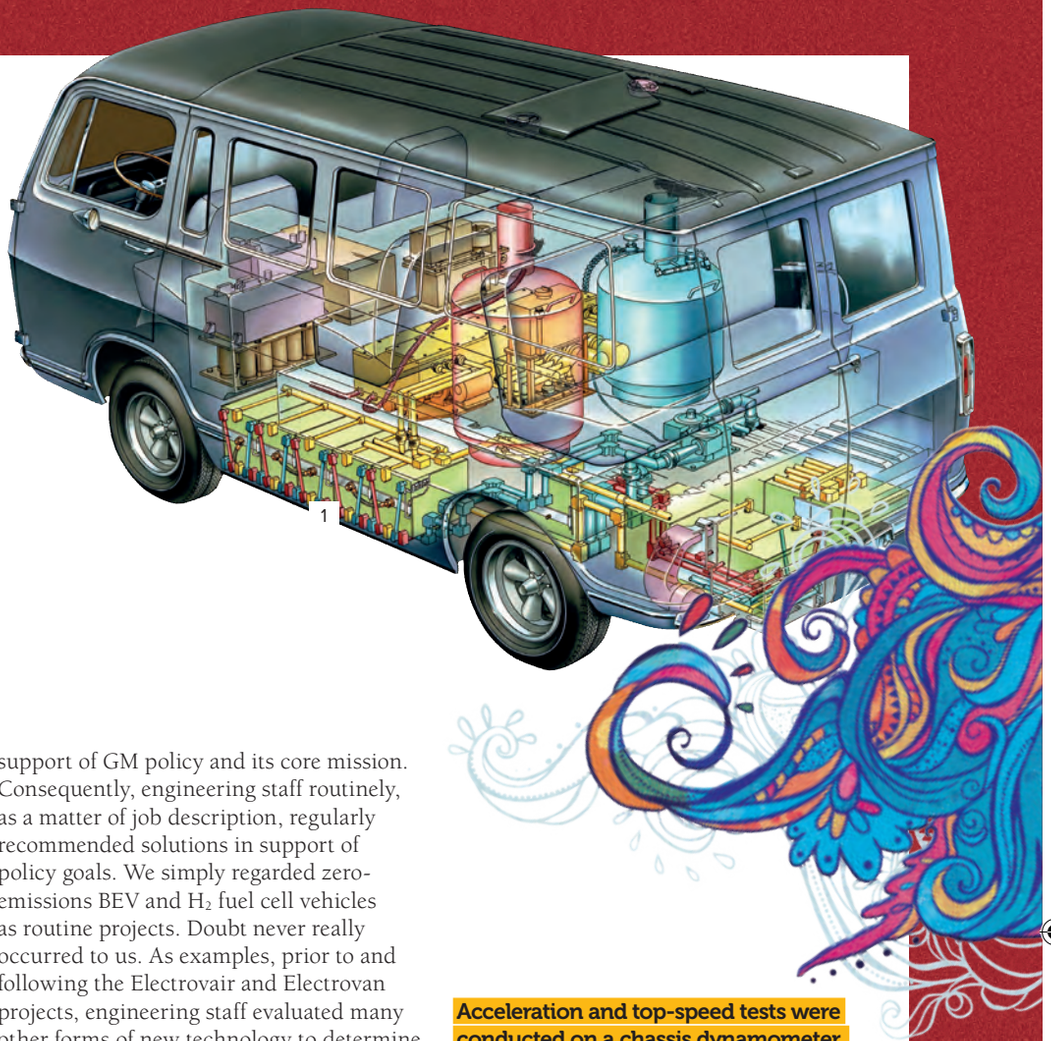
Which suppliers did you work with on the project?

Hydrogen and oxygen were available from Linde Group and Air Products, two independent companies. Linde installed a 6m-diameter [19.7ft] cryogenic liquid H_2 sphere at the GM Technical Center campus and Air Products installed a cryogenic liquid O_2 tank at the end of the engineering staff piston engine dynamometer wing. Furthermore, our fuel cell test facility was located at the very end of the dynamometer wing for safety considerations.

What were some of the project's biggest engineering challenges and how did you overcome them?

We had 32 series-connected fuel cells. Each fuel cell had four submodules consisting of four single cells in parallel plus 17 series submodules per 1kW fuel cell – 68 cells and 17V DC per module – for a total of 2,176 cells. The 32 series-connected fuel cell modules provided 540V DC – two phase +270V and -270V. Consequently, our second

challenge was to scale up from a 31-cell Apollo fuel cell module to 2,176 cells – a world-first effort that had never been accomplished previously. Furthermore, H_2 gas polypropylene plumbing to the last fuel cell module was more than several meters away from the gas input. Consequently, hydrodynamic fluid transport prevented uniform distribution of H_2 to each of the 2,176 cells simultaneously. The result was single-cell polarity reversals by adjacent cells that had activated first. The resident Union Carbide engineers and technicians solved this cell polarity reversal issue by rewiring each 1kW module with 68 individual cell conductors leading to a multiconnector mounted on top of each 1kW module. There was a total of 2,176 wiring connections for the 32 modules, which was another world first.



What were some of the most important tests that you performed on the vehicle?

The fuel cell simulator ran 24/7 for 30 days in a continuous durability test. It found that the KOH [potassium hydroxide] electrolyte was leaching and reacting with the fuel cell neoprene seals hydrocarbon plasticizer. The chemical reaction formed soap deposits within the polypropylene tubing serpentine circulation loops. Soap also plugged KOH passages within the GM Harrison radiator heat exchanger. Furthermore, there were some unseen soap deposits within individual fuel cell KOH passages.

Did you have a sense that you were working on something groundbreaking?

A key function of GM senior management level is to provide policy direction and set the core mission and direction for the company. In turn, the prime responsibility of staff divisions at the GM Technical Center is to recommend solutions in support of GM policy and its core mission. Consequently, engineering staff routinely, as a matter of job description, regularly recommended solutions in support of policy goals. We simply regarded zero-emissions BEV and H_2 fuel cell vehicles as routine projects. Doubt never really occurred to us. As examples, prior to and following the Electrovair and Electrovan projects, engineering staff evaluated many other forms of new technology to determine their readiness for commercial production. Project prototypes that demonstrated readiness were transferred directly to a manufacturing division for serial production consideration. For Electrovan, we concluded that potassium hydroxide hydrogen fuel cells demonstrated that a Bacon-type KOH fuel cell was not a viable option in an automotive application.

1. The GM Electrovan featured 32 series-connected fuel cells providing 540V DC

2. As a result of the hydrogen fuel cell drivetrain technology, the Electrovan had space for just a driver and two passengers

Acceleration and top-speed tests were conducted on a chassis dynamometer, while fuel cell durability was performed over several months in a test cell. What are your memories of that time?

Driving and durability tests were conducted at the chassis dynamometer wing to ensure driveability, determine a maximum speed of 70mph [113km/h], and 0-60mph [0-97km/h] acceleration of 30 seconds. Final practice driveability evaluations were then carried out on a north-south half-mile straight built along the eastern boundary of the GM Technical Center campus. Practice proof-of-principle demonstration loops were driven past the styling division dome before the international press ZEV H_2 fuel cell demo run on October 28, 1966.

Were you satisfied with the project?

Although the press demonstration proved successful, Electrovan was deactivated, reactants purged, and the van moved to the styling division dome interior display area for inspection and photograph by press. We concluded that Electrovan was not suitable for the passenger automotive application and confined it to long-term storage.

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The F-word

WORDS: **JOHN THORNTON**

Daimler's Mercedes-Benz GLC F-Cell marks a world-first combination of hydrogen and battery electric power

Having unveiled a preproduction model of the new Mercedes-Benz GLC F-Cell at the 2017 IAA International Motor Show in Frankfurt, Daimler very much sees the SUV as the next milestone on the road toward emissions-free driving. Bestowed with the EQ Power badge, the GLC F-Cell forms part of Daimler's CASE (Connected, Autonomous, Shared & Service, Electric) strategy for future mobility, in which the German OEM intends to bring out 10 BEVs between now and 2022.

But, in a world-first, the GLC F-Cell combines hydrogen fuel cell and battery technology in the form of a plug-in hybrid. The preproduction model carries 4.4kg of hydrogen in two carbon-fiber-encased tanks built into the vehicle floor, which propels the vehicle 437km (272 miles) before refueling is required. Furthermore, a 9kWh lithium-ion battery installed in the rear of the vehicle provides an additional 49km (30 miles). Together, the two energy sources drive an asynchronous electric motor to provide a system output of 200ps, 350Nm of torque and a combined 486km (302-mile) range.

According to Christian Mohrdieck, Daimler's fuel cell director, the decision to install such a unique powertrain in the GLC was simple: "It's one of our best sellers." He also explains that the development timeline (four to five years) "was pretty similar to that of an ICE vehicle", as

1

Daimler didn't want, or need, to develop a new vehicle platform to accommodate a fuel cell-battery powertrain.

"Existing IC engine platforms and vehicle architectures are well suited to accommodating a full-cell powertrain," he explains. "We don't need to develop special platforms, especially at this point in time when volumes are still moderate. Developing a new platform is very expensive, so it was much easier to package this powertrain into an existing architecture."

Fuel for thought

The full-cell system itself is completely new. Compared with the B-Class F-Cell, which has been on the market since 2010, the GLC F-Cell's overall drive system is said to offer around 40% more output. It's reportedly 30% more compact than its predecessor and can – for the first time – be housed entirely in the engine compartment. It's also installed on the usual mounting points, much like a standard engine. Furthermore, the use of platinum in the fuel cell has been reduced by 90% to conserve resources and lower system costs.

And like the conventionally powered GLC, this vehicle will be produced in Bremen, Germany. However the fuel cell stack itself was co-developed with Ford in the Automotive Fuel Cell Cooperation joint venture, in Vancouver, Canada, with production of the fuel cell system taking place at the Mercedes-Benz Fuel Cell production facility in nearby Burnaby, British Columbia.

Furthermore, both the fuel cell unit and the hydrogen storage system were developed by Daimler subsidiary NuCellSys in Kirchheim/Nabern in Baden-Württemberg, while Daimler's parent plant in Untertürkheim, also in Nabern, is responsible for fuel cell system assembly. Meanwhile, the hydrogen tank system is being produced at Daimler's Mannheim plant, and the lithium-ion battery comes from wholly owned Daimler subsidiary Accumotive, in Kamenz, Saxony.

According to Mohrdieck, the battery size was determined partly by the current lack of hydrogen fueling stations. "Infrastructure indeed had an impact on the size of the battery. The plug-in concept really takes into account that, at this point in time, and in the next two to three years, hydrogen-refueling infrastructure will remain sparse.

"With a fuel cell you don't have range anxiety, but you might have station anxiety, and I want to take station anxiety away from the people! The most frequent feedback I get is that infrastructure is not sufficient, so the GLC F-Cell is really our answer at this point in time."

Thus, the battery can be fully recharged in around 90 minutes from a standard household power socket, wallbox or public charging station, courtesy of 7.2kW onboard chargers. And, thanks to globally standardized 700 bar tank technology, the supply of hydrogen can be replenished within three minutes.

2

1. The GLC F-Cell's drive system is 30% smaller than its predecessor, and is installed on standard engine mounting points

2. Daimler neither wanted nor needed to develop a new platform for the fuel cell and battery hybrid

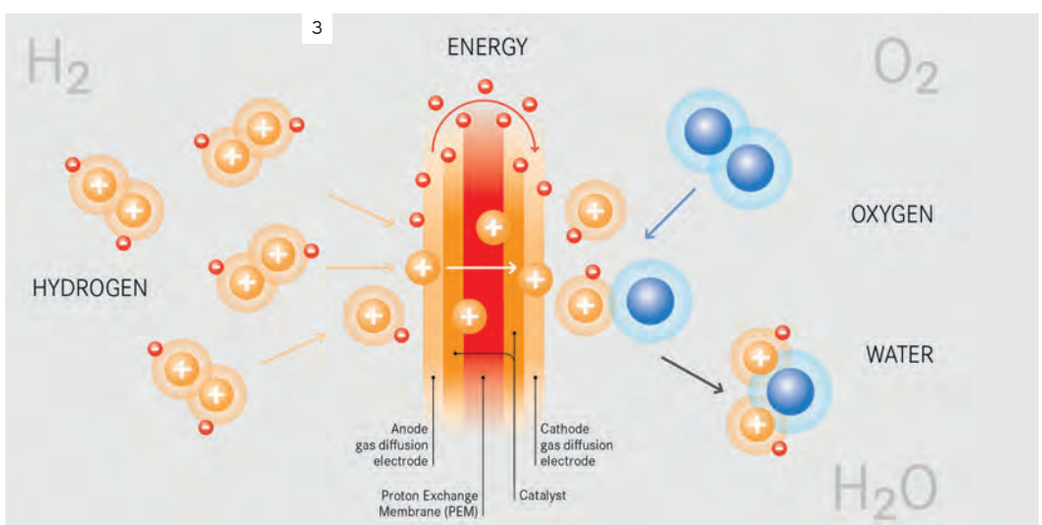
3. The Proton Exchange Membrane (PEM) fuel cell technology at the heart of the Mercedes GLC F-Cell

Power play

Like the GLC Plug-in Hybrid, the fuel cell variant comes with various operating modes and drive programs, all of which influence the interplay between the fuel cell and battery. The drive programs include Eco, Comfort and Sport, while the operating modes comprise Hybrid, F-Cell, Battery and Charge.

In Hybrid mode, the vehicle draws power from both energy sources, with power peaks handled by the battery while the fuel cell runs in the optimum efficiency range. In F-Cell mode, the state of charge of the high-voltage battery is kept constant by the energy from the fuel cell. In Battery mode, the GLC F-Cell runs all-electrically and is powered by the battery. In Charge mode, battery charging takes priority, for example to recharge the battery for the maximum overall range prior to refueling with hydrogen.

During development of the vehicle, the test program comprised more than 500 individual tests, which, in addition to the standard test regimen applied to all Mercedes-Benz vehicles, included special tests for the electric powertrain, the fuel cell, and the interplay of all powertrain components.



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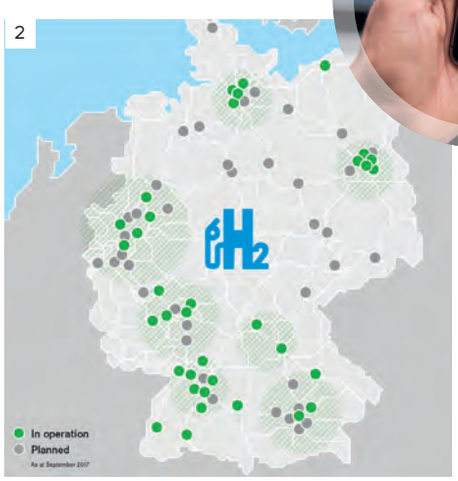
1. The battery size in the hybrid was partly determined by the lack of available hydrogen refueling structure

2. Currently, and for the next two to three years, Daimler expects hydrogen refueling infrastructure to remain relatively sparse

"Development of the fuel cell powertrain was like developing an engine from scratch," says Mohrdieck. "So, the testing phase was very important for us. With an IC engine, you'd run that for maybe 2,000,000km before you felt pretty sure that you'd found all the issues, such as wear and tear and degradation.

"But with a fuel cell, it's not just how it performs during operation time that's important, you also need to evaluate the events that occur during non-operation times. It's an electrochemical system, which means that the chemical processes continue to work in the stack after the vehicle has been switched off. Hence, we needed to have some soak times during testing, where the system just sat there. Maybe a layman would look at that and think nothing is happening, but something is always happening and we needed to find out what."

Event-triggered testing was also vital to the development of the car. "We have certain events that put extraordinary stress on the system, such as freeze-start, where we start the car in freezing conditions," explains Mohrdieck. "This is a very important mechanical and thermal stress on the fuel cell membrane, so we needed to understand the system behavior. About 15-20 years ago we didn't know how freeze-start in such a system could work, but we do know now."



2

Crash course

Special attention was also directed to the integration of safety-relevant and high-voltage components such as the hydrogen tanks, gas seals and valves. As such, the hydrogen tanks are installed in a crash-protected area between the vehicle axles and are protected additionally by a subframe wrapped around the tanks. During crash testing at the TFS, where 40 variants of the GLC F-Cell were evaluated, additional extensive measures were implemented, including a multistage valve system and special protective circuits for the high-voltage system.

With sales of the GLC F-Cell due to begin in selected markets in 2018, Mohrdieck says he has already started pre-development of the next generation. And while he's keen not to reveal how different the next iteration will be, one thing he's happy to confirm is Daimler's future fuel cell strategy.

"In my view, all future Daimler fuel cell powertrains will be hybrids," he says. "I would never recommend that we develop a pure fuel cell powertrain without any hybridization by a battery. Why? Hybridization, from a technical standpoint, results in lots of benefits. For sure, you have to discuss cost and find the best cost compromise, but technically speaking, I'd always opt for a hybrid fuel cell. For example, having a battery on board not only simplifies freeze-start, but it also prolongs the life of the fuel cell, thanks to minimizing the amount of time that it is operated at open circuit voltage, which is something that deteriorates the fuel cell."

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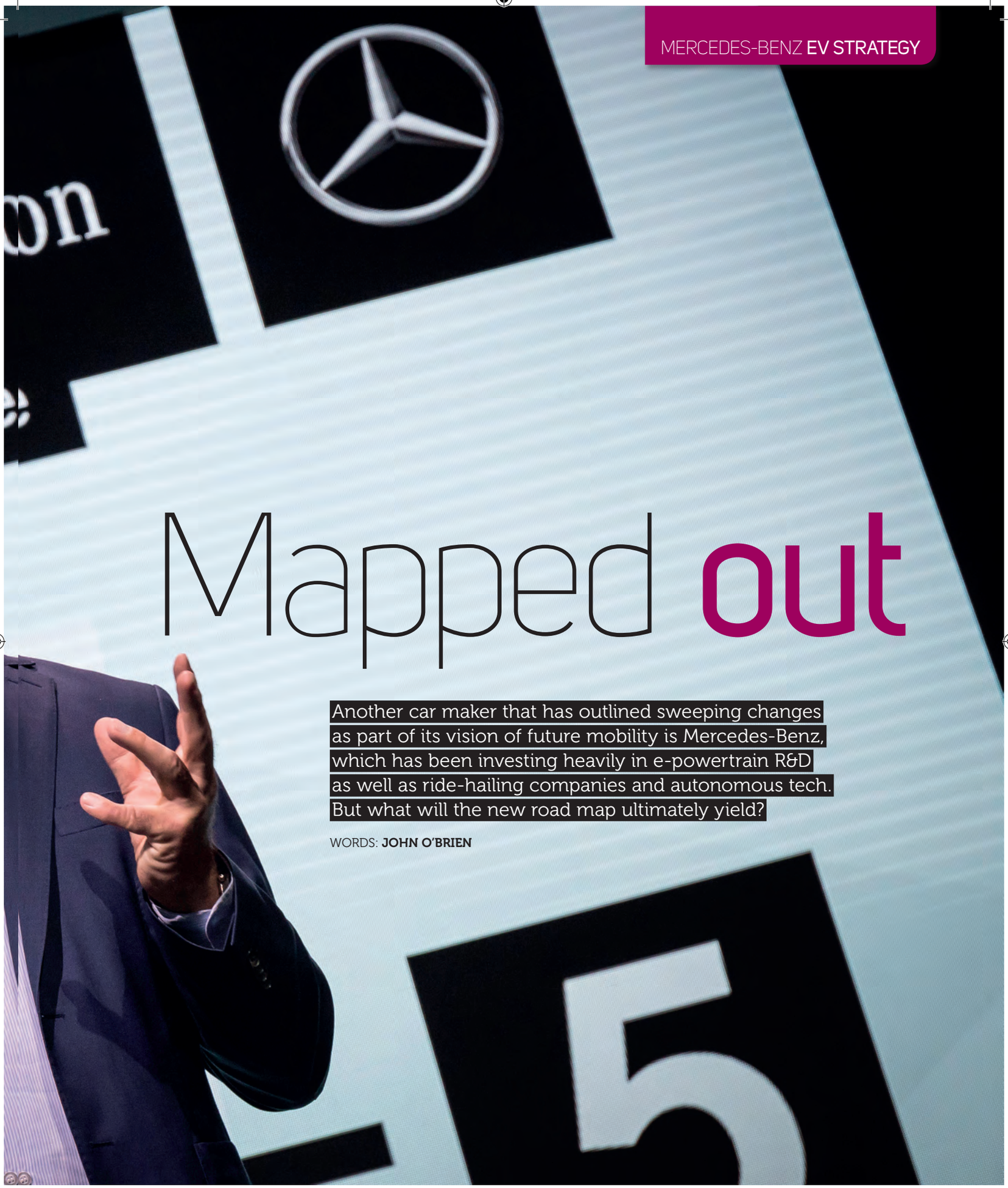
Mapped out

Another car maker that has outlined sweeping changes as part of its vision of future mobility is Mercedes-Benz, which has been investing heavily in e-powertrain R&D as well as ride-hailing companies and autonomous tech. But what will the new road map ultimately yield?

WORDS: **JOHN O'BRIEN**



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From fast-charging solutions to shared mobility services and Level 5 autonomy, Mercedes-Benz's vision of next-generation car ownership is beginning to take shape

"Mercedes-Benz is in a consortium with BMW, VW and Ford of Europe for high-powered charging systems, which will be 800V units that will deliver 350kW"

Since it built the Patent Motorcar in 1885, Mercedes-Benz has held a reputation for developing and launching some of the finest IC engines that money can buy. As such, the brand has come to represent the idea of automotive attention to detail, with a level of perceived quality that still resonates to this day.

But as the automotive industry continues to evolve, the German OEM – like so many others – is having to rethink its entire business structure. While the roll-out of fully electrified drivetrains is a given, it is the changing concept of the car itself that Wilko Stark, Mercedes-Benz head of strategy and the CASE program (Connected, Autonomous, Shared & Service and Electric Drive), believes offers unrivaled opportunities for growth and diversification.

"If you take Apple as an example, it is still making 90% of its profits with hardware, and just 10% comes from the software," he explains. "We are going to diversify into new services, but the medium and long term of our business is still selling vehicles.

"For all the predictions we have for unit sales, we don't see anything that would suggest a massive change within the next decade," he continues. "In 20 or 25 years' time, there may be some changes."

The journey to that future moment that Stark outlines will be aided in the short term by the collaborative Ionity project between several OEMs that aims to remedy any preconceptions of range anxiety.

"We are making big, big progress with the charging times," says Stark. "Mercedes-Benz is in a consortium with BMW, VW and Ford of Europe for high-powered charging systems, which will be 800V units that will deliver 350kW. This means our recharging times will be less than 25 minutes for a full charge. This is a huge step for the old European automotive industry, as the Tesla Supercharger is only 120kW."

The Ionity project will eventually see more than 400 fast-charging stations appear across Europe, with completion estimated for 2020. The project has already seen the installation of 20 stations set at 120km (75-mile) intervals through Austria, Germany and Norway.

"The project is up and running and fully on course," states Stark. "Setting up a company, especially one formed of multiple OEMs, takes serious time as there are trust issues, and we need approval from the EU, but to date it is all on target. It will prove that you can take an EV across Europe, completely hassle-free, and with 25-minute full-recharge times."

The Ionity project will eventually see more than 400 fast-charging stations installed across Europe by 2020

A tale of two cities

Yet the city center, an environment that has seen the focus of most OEM powertrain efforts thus far, will continue to be an area of great interest for automotive development. With the rise in autonomous vehicles in the medium term as governments continue to strive toward zero road casualties, Stark explains, "We are in development to come up with some sort of autonomous Robocab or Robotaxi that is designed and developed for inner cities, and will be 100% electric, because otherwise it won't be allowed in a lot of future cities."

"I think the big step toward Level 4 and Level 5 autonomy in inner cities will be around early 2020"

"This is what we're working on right now, and of course autonomous driving on the highway. Regarding highway driving, these technologies will also come in our next generation of cars such as the S-Class, but I think the big step toward Level 4 and Level 5 autonomy in inner cities will be around early 2020."

Yet immediate uptake in private ownership could be affected due to high cost. "From my perspective, going fully autonomous is going to be quite expensive in the beginning, so it definitely makes sense to use these cars in the first generation for mobility services and ride-hailing services," surmises Stark.

"It doesn't make any sense for the first generation of cars to be used by private investors, as they will likely be too expensive for fleets."

While the first generation of autonomous electric vehicles may currently prove to be too expensive for ride-hailing services to use, the synergies between the technology and the amenity mean it won't be long before the two collide.

"If your car is capable of driving autonomously, it's actually the same service as a taxi," says Stark. "In the future, we will likely all use ride-hailing services, and of course this can be exclusive, but it can also be shared, so therefore we are investing in other companies because it's quite important to have an intelligent algorithm, to have absolute perfect routing, as in the end it's about managing the overall traffic flow. This also [means we need] a lot of experience in IT, and therefore we are going to be building up in all sectors and services."

Despite partnering with Bosch to avoid a dependency on Google mapping, Mercedes-Benz will wait until it has achieved Level 5 autonomy before introducing its first fully autonomous vehicle, according to Stark. Nevertheless, he also believes that early introductions of self-driving concepts, as well as rudimentary car-sharing platforms, put the company in good stead.

"We're pretty good in terms of autonomous driving, which is displayed in some of our cars already, and we also have shared mobility through the Car2go app, so we have a lot of experience," he says.

"Now comes the next step of combining all these four dimensions together. It's about predicted mobility, and that's why we have come up with these concepts. We're not just a premium car manufacturer – in the future we will also be a mobility service provider."

But while the concept of ride-hailing and car-sharing has some suggesting the end of traditional car ownership, Stark believes that high-density cities are the perfect example of how the two future technologies won't be mutually exclusive.

"In San Francisco, for example, people still have their private cars, but use ride-hailing services as the city parking is very, very expensive and limited," he explains. "So we believe there will be a healthy mixture of exclusive ownership and shared mobility. Both worlds are already taking place, so we will see a good mixture of mobility services."

Multifaceted future

The conundrum for Mercedes-Benz, however, is how to ensure that it remains relevant once society moves away from a traditional ownership model. Beyond flooding the market, how does Mercedes-Benz ensure that its cars are there for users when needed?

"With mobility services, availability is absolutely crucial. People are not prepared to wait an additional two or three minutes," answers Stark. "Therefore, when we come up with a network, we also have to provide premium services and that means people do not have to wait too long for a car. Having a Mercedes, to us, represents a more relaxing and enjoyable experience than driving other cars, and we strongly believe that people will be prepared to pay that little bit more to take a Mercedes," Stark claims.

While CASE has clear objectives in both the medium and long term, the immediate future for Mercedes-Benz still calls for a development that blends the fundamentals of tomorrow's world with a product acceptable in today's marketplace – arguably a much harder task.

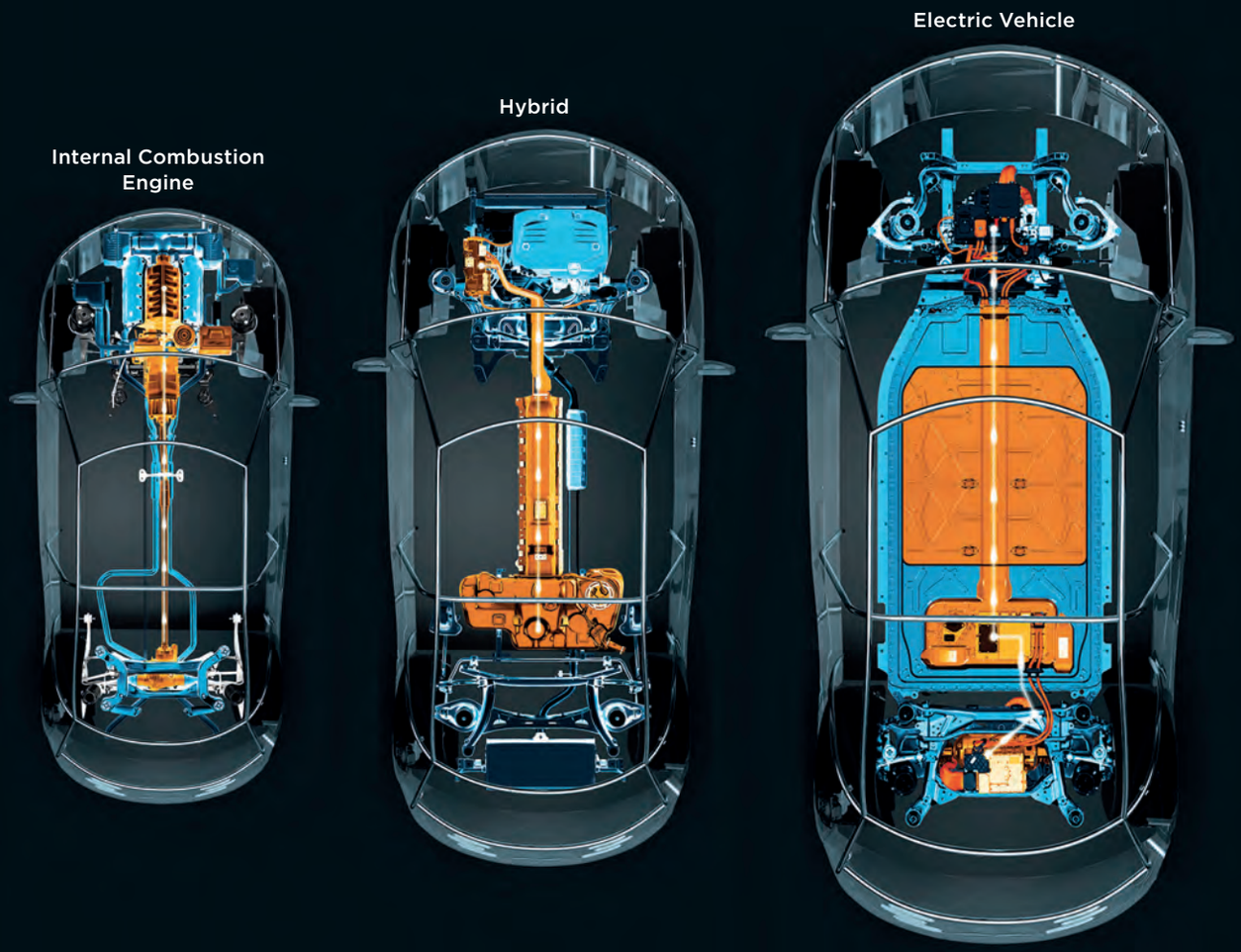
"I believe the whole line-up of EVs coming, particularly the next generation, by the end of 2020 will be absolutely fantastic – dedicated EVs with ranges of over 500km [310 miles], and [for us] they will be Mercedes-Benz's above all else," concludes Stark. "We believe it will become the benchmark among EVs."

1. Mercedes-Benz is currently developing an autonomous, electric 'Robotaxi' for inner cities in an effort to eliminate future road casualties

2. The availability of mobility services will be a crucial factor if society moves away from traditional, established models of car ownership

3. The Ionity network's 25-minute full-recharge time could enable electric vehicle owners to drive across Europe without range anxiety

POWERTRAIN REVOLUTION



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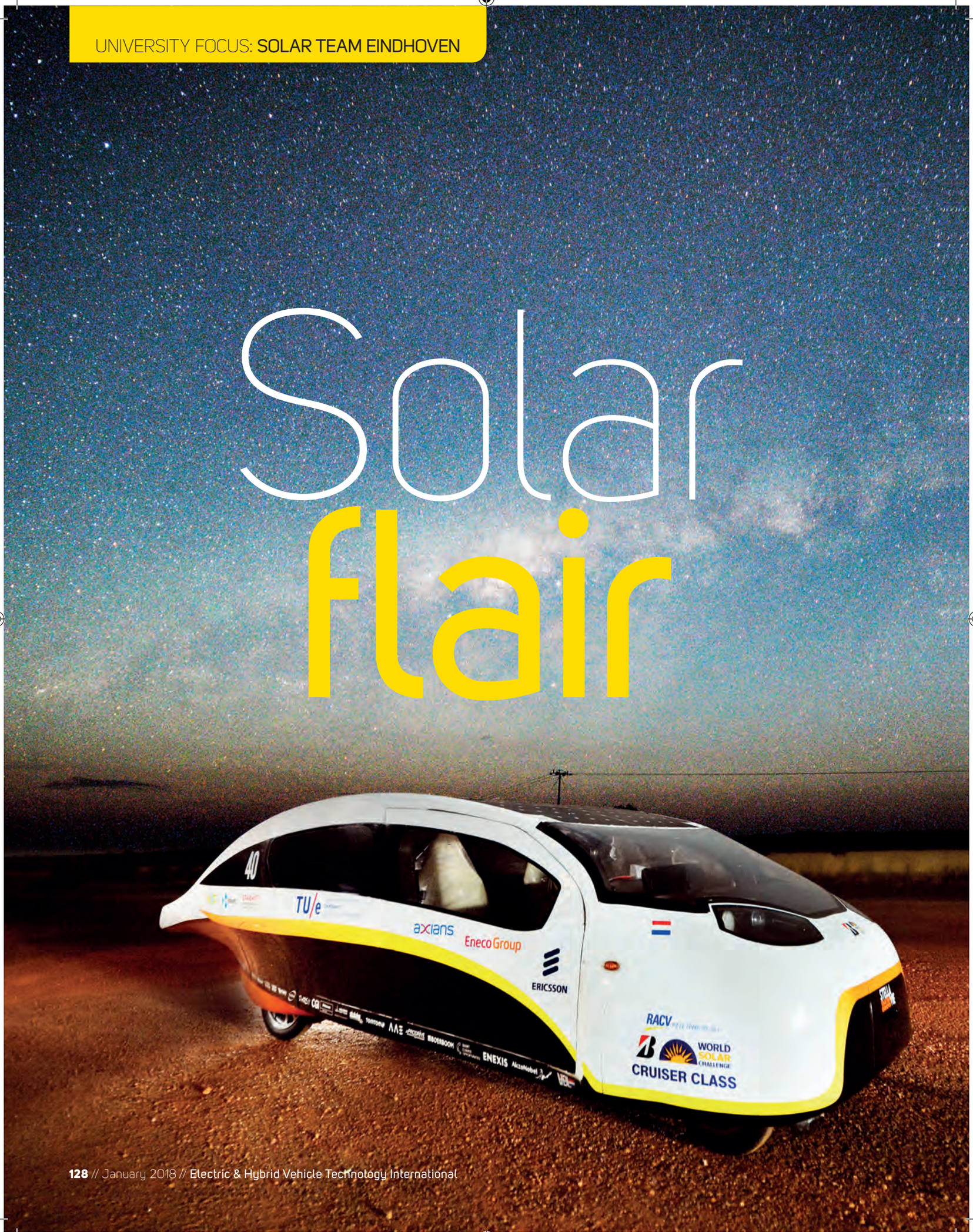
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WORLD SOLAR CHALLENGE
CRUISER CLASS

All photos: TU Eindhoven, Bart van Overbeeke; Map: Bridgestone World Solar Challenge 2017

WORDS: **MATT JOY**

Not content with leading its class at the World Solar Challenge, Solar Team Eindhoven has plans to turn its EV racer into production reality

The World Solar Challenge is possibly the most intense, yet slowest, forms of motorsport in the world. Competitors must focus on efficiency while traveling over 3,000km (1,860 miles) across central Australia, on public roads and at the mercy of the weather. If that weren't enough, however, Solar Team Eindhoven – a group of engineering students from the Technical University of Eindhoven – is choosing an even tougher route: competing in the Cruiser class means factors such as payload and practicality are taken into account as well as energy consumption. Yet the ultimate test of teamwork comes out on the road, as Cruiser cars must carry at least one passenger. Team Eindhoven's Stella Vie has seating for five.

The 2017 event will mark the third time Solar Team Eindhoven (STE) has participated in the world-famous challenge. But in that short period, the crew has already built itself a reputation, having taken victory in the Cruiser class in 2015 and in the first running of the separate category in 2013. Current team manager Wout Gubbels explains the

process of bringing the class of 2017 together: "Our team went through an application process from the university, so everyone could just write in if they were interested, and then they picked out the best people. We had a group of 23 university students, all full-timers, and we stopped our studies for a year and a half to work on this project. We're a group of electrical engineers, mechanical engineers, designers, and we've got industrial engineers, software engineers, and so on. It's a really mixed group."

Seating plans

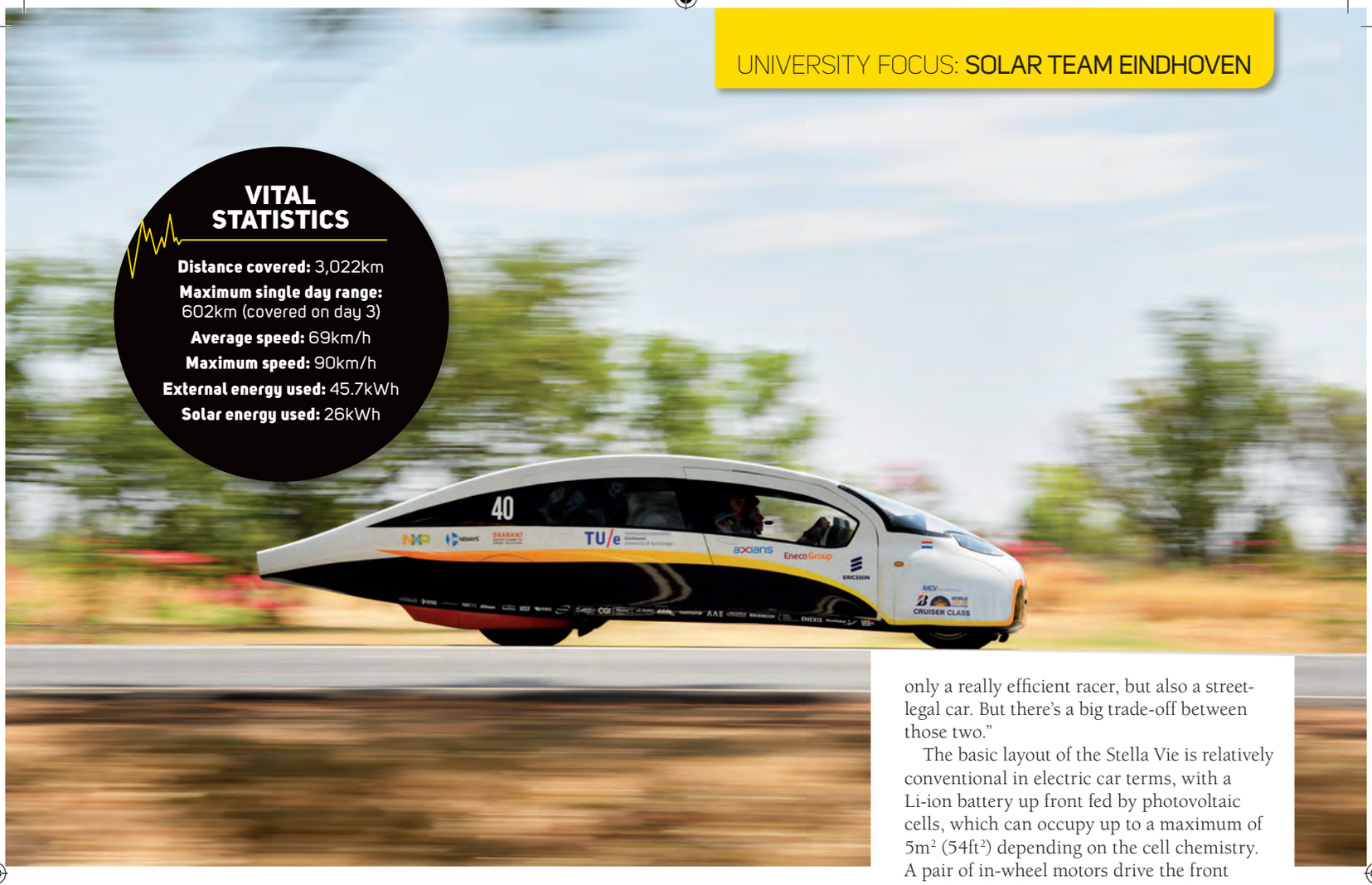
Coming from a country with an established reputation for sustainability and ecological responsibility, it should come as no surprise that STE continues to compete solely in the Cruiser class. This means a minimum of two seats, and scores are calculated based on the number of vehicle occupants you take with you over the course of the test route. Battery capacity and the number of external charges performed are also taken into account. "This determines 80% of the score," explains Karlijn Fransen, system architect of mechanical engineering for STE: "There's also 20% of the score that's judged by a jury, and it focuses on practicality. So, how much space there is, how easily you can get in and out of the car, and what features you have in your car."

"It's a trade-off between how practical your car will be, how sturdy everything will be, and how light and efficient it will be"

Wout Gubbels, team manager, STE

Top: Entrants to the World Solar Challenge Cruiser class must carry at least one passenger – Solar Team Eindhoven's Stella Vie has seating for five

Compared with the more extreme and efficiency-focused vehicles in the Challenger class, this makes STE's Stella Vie a more relevant vehicle to the real world, and subsequently a greater challenge to design and build. As the vehicle is closer to a conventional production car, the team had to weigh up the various requirements and not concentrate on a single goal, as Gubbels explains: "It's a trade-off between how practical your car will be, how sturdy everything will be, and how light and efficient it will be. If you put more luxury in it, it will get heavier and less efficient, but still we want to build a car that also inspires people and which is not



VITAL STATISTICS

Distance covered: 3,022km
Maximum single day range: 602km (covered on day 3)
Average speed: 69km/h
Maximum speed: 90km/h
External energy used: 45.7kWh
Solar energy used: 26kWh

Left: The Stella Vie's photovoltaic cells supply power to the vehicle's front-mounted lithium-ion battery, which powers a pair of in-wheel motors

Below: The Stella Vie makes extensive use of carbon fiber, with an overall weight of 380kg

only a really efficient racer, but also a street-legal car. But there's a big trade-off between those two."

The basic layout of the Stella Vie is relatively conventional in electric car terms, with a Li-ion battery up front fed by photovoltaic cells, which can occupy up to a maximum of 5m² (54ft²) depending on the cell chemistry. A pair of in-wheel motors drive the front wheels and deliver regeneration under braking. More radical designs were considered. "We thought about making it four-wheel drive at first, to give it more power and be able to get up steeper mountains," says Gubbels. "In the end, we decided not to do that, because two motors are more efficient, and I guess front-wheel steering was just easier, because all the electronics are in the front. That makes it a lot easier for us to design it. And as we have in-wheel motors anyway, it doesn't really matter with the steering system if you put them in the front or rear wheels, so that was just easier to design. We thought about making the solar panel moveable; instead of [putting a storage box on the roof, putting] one under the car so you don't block the solar panels. Those kinds of crazy things. And then you get to the final concept which we have right now."

Like many of its competitors, the Stella Vie relies heavily on carbon fiber for its structure and body panels, resulting in a highly impressive overall weight of 380kg (838 lb). "So the weight of our car is less than the weight of the persons that can be seated inside," says Fransen. STE believes the Stella Vie is the first solar car to be capable of carrying five occupants. The vehicle also showcases some impressive technology designed to improve efficiency. The energy

Left: The success of the Stella Vie and its forerunners has led to development of a real-world vehicle

Below: STE has recorded multiple World Solar Challenge victories

management system has been designed from scratch and is linked to the navigation system, so the car can calculate a route that will give the maximum amount of sunshine and therefore the most energy. "It loads in weather data, so based on the prospected weather, it can show which route will be best for you," says Gubbels. "And using that, it gives you the best way to go."

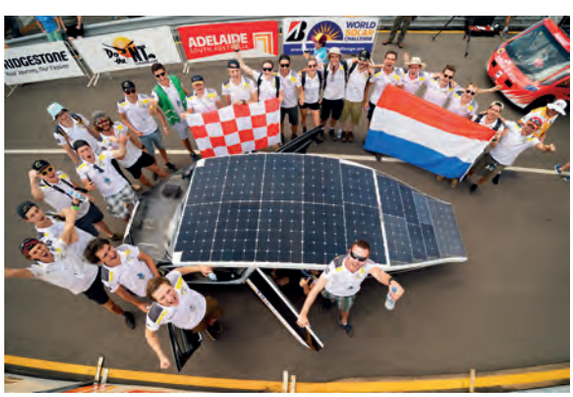
Class act

Inevitably, the thinking and innovation that went into the Stella Vie and its predecessors – and their suitability for real-world usage – led to the creation of a startup called Lightyear. The company's first product is the Lightyear One, as Gubbels explains: "Our theme was always focused on making a car that would inspire people to see what is possible with stable mobility. And a few guys from the previous teams have said, 'Well, we've done it in this challenge, so why not do it in real life and make a consumer version out of it?' They just started brainstorming, and then formed a startup, mainly consisting of old sorority members. They started designing and gathering funds, and now they're doing pretty well – they already have the first purchases lined up, so I'm really curious how that will end up, and if it will be a success."

The Lightyear One is billed as an 'energy-positive family car' – even in the comparatively mild conditions of the Netherlands, the car has the potential to generate enough energy for 10,000 to 20,000km (6,200 to 12,400 miles), which could exceed typical usage – and by syncing with a smartphone, it can determine if any surplus energy should be fed back into the owner's home or remain in the vehicle for the following day. "It's really about the ecosystem around the car as well, because it's so efficient that it would generate more energy than it uses," says Gubbels. "You can use it as a source of energy to power your house, like an external solar panel."

> "Battery capacity and number of charges determines 80% of the score. There is also 20% that's judged by a jury, and it focuses on practicality"
>
> Karlijn Fransen, system architect of mechanical engineering, STE

Delivery of 10 Signature cars – each with an expected price of €119,000 (US$140,500) – is anticipated in 2019, with a further production run of 100 units to follow in 2020. It's clear that the heat of competition in the World Solar Challenge is beginning to deliver tangible progress and vehicles directly derived from the purpose-built racers. In the case of the Lightyear One and its siblings, it also demonstrates the higher ecological goals being targeted by these enthusiastic and dedicated students.



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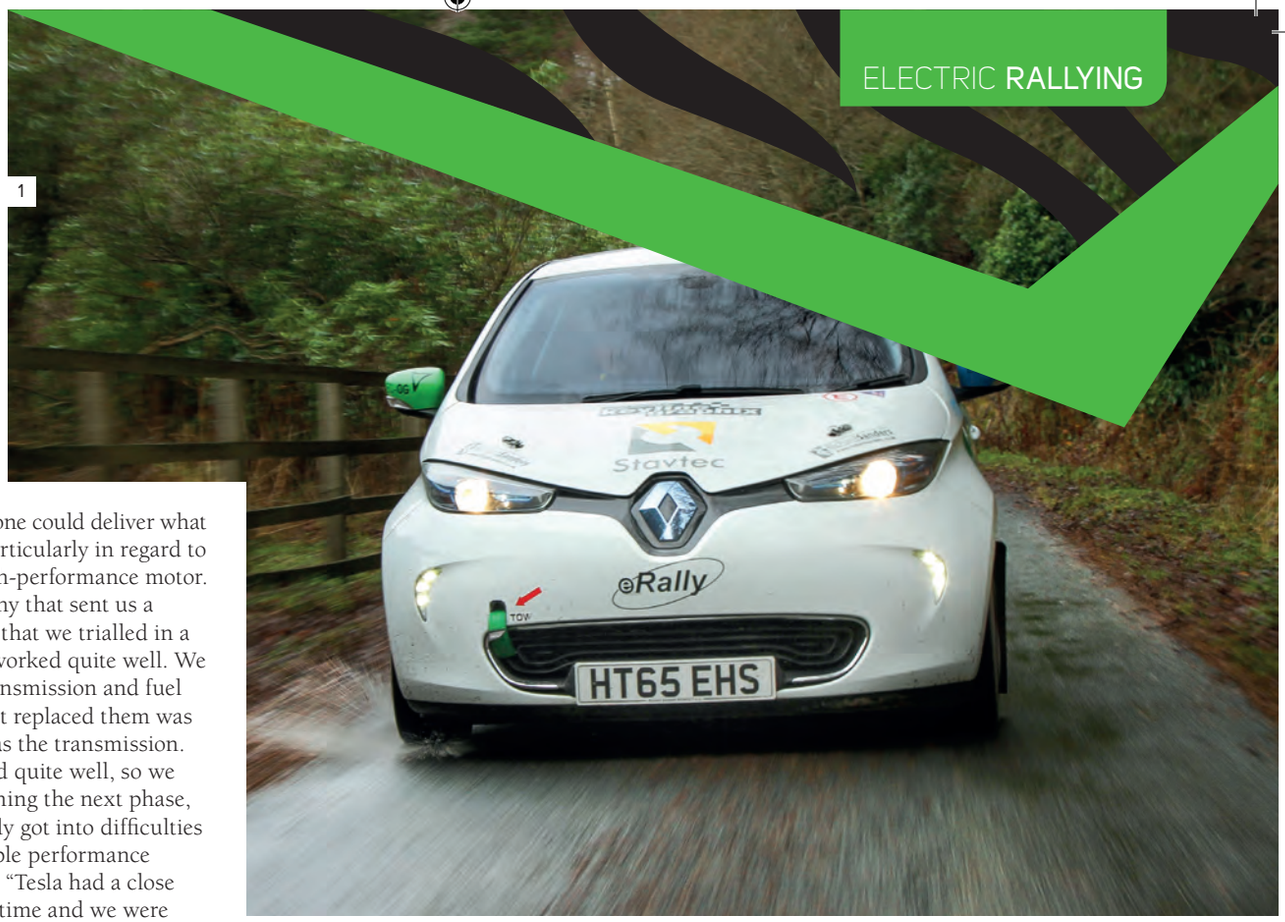
British racing green

As electrification in motorsport continues to grow in prominence, the UK's eRally aims to put EVs through decidedly unforgiving terrain with its Renault Zoe competition car

WORDS: **JOHN O'BRIEN**

Much like the rest of the motorsport industry, junior rallying is increasingly feeling the pinch of increasing regulation and scrutiny. In short, the long-term status of the championship format hinges on creating a sustainable future. The UK's eRally is making inroads toward a future format, through the development of its all-electric Renault Zoe prototype rally car, which made its debut in early October at The Adgespeed Stages near Wigan, England. The eRally Zoe packs similar dimensions and performance figures to an IC-engined Nissan Micra, Peugeot 107 or Citroën C1, the stalwarts of junior series.

"It was the Tesla Roadster that first got me thinking of the idea of a high-performance electric vehicle," explains Ellya Gold, founder of eRally. "It was at that point that we realized the technologies involved would be viable for motorsport, particularly rallying. We started researching various batteries and motors but ultimately hit a brick



1. The eRally weighs around 1,500kg, and produces 220Nm of torque from its standard 65kW synchronous motor

2. The Zoe's single-speed transmission has been retained in the competition car, eliminating the need for a gearbox and clutch

wall. We found that no one could deliver what they said they could, particularly in regard to providing us with a high-performance motor. We did find one company that sent us a proof-of-concept motor that we trialled in a Ford Focus estate that worked quite well. We removed the engine, transmission and fuel tank, and the motor that replaced them was about the same weight as the transmission.

"The Focus performed quite well, so we decided to start researching the next phase, and that's when we really got into difficulties in trying to find a suitable performance motor," continues Gold. "Tesla had a close guard on its tech at the time and we were making ground on a motor used in an electric Mini, before we found out Volvo had bought the rights to it, effectively sealing that route off too! We gave up for a while, and one day [co-driver Jean Hay] and I were competing in our Mitsubishi Evo at the Scottish Rally when we saw a Zoe parked in a side street, which kick-started the idea."

Revisions to the car, which is to be pitched to competitors as costing around £10,000 (US$12,500), are restricted to competition tires, lightweight wheels and bespoke dampers from GAZ Shocks.

The car was conceived with the idea of promoting alternative power in a competitive environment and in the interests of reliability and ease of maintenance, the Zoe's factory-specification 22kWh lithium-ion battery and Continental-supplied 65kW synchronous motor remain unchanged.

Interior design

The major changes to the car's interior come in the form of improving safety and adhere to MSA and FIA regulations. The multipoint custom cage, Gold admits, is perhaps on the excessive side in terms of engineering, but wanted to offer junior drivers, and their parents, a safe environment in which to compete. "We've also selected SPA Design gas extinguishers in there too, as you can't really be spraying AFFF over an electrical fire," adds Gold.

Despite the added roll cage and safety equipment, the stripped interior has resulted in the competition car weighing 100kg less than the road car, tipping the scales at around 1,500kg. While this is marginally up against its potential C1, 107 and Micra rivals (all of which weigh around 1,000kg) the added benefits of the EV drivetrain mean that there is a great parity between drivetrain choices, with the Zoe offering up double the torque (around 220Nm). And despite the single-speed transmission, which removes the need for a gearbox and clutch, Gold believes the Zoe is simply a sign of things to come for younger drivers.

"The future of road cars is heading that way anyway," he states. "In 5 to 10 years you are going to struggle to find a manual gearbox in a road car. A manual adds to the experience of driving a rally car, but our experience with the EV has been great as it is huge fun to drive. For the young drivers coming out of karting, they're more likely to just jump straight in with left foot braking!"

> "For the young drivers coming out of karting, they're more likely to just jump straight in with left foot braking"
>
> Ellya Gold, founder, eRally

1

1. Jean Hay and Ellya Gold with the prototype

Going the distance

With the potential to offer quicker stage time, perhaps the biggest concern for competitors would be with the car's range on its unchanged 22kWh battery pack. Gold states that this gives the competition car a range of around 40km (25 miles) when driven flat-out, which should cover most stages on the J1000 calendar.

"We're working with three other Scottish companies that are specialists in battery management systems and battery packs," explains Gold. "We're looking into having a battery pack fitted to the service vehicle, which can then be used to recharge the Zoe. With the juniors, they tend to do two stages then come back to service for 15-20 minutes. So during the free time they have in the service area, the car can be recharging."

Unlike other categories that use modified road cars, the eRally Zoe has retained the 40kW regenerative brake functionality of the standard Renault, which helps eek out additional range from the battery. While this is impressive, the pace of EV development is rapid and advances are emerging regularly for the team.

"We use the 21kWh battery at present, but Renault has just upgraded the standard car's system, which would theoretically give us around 50 competition miles in total. The Zoe has only been on the market for three years, in which time Renault has doubled the capacity of the battery without adding any weight. Ultimately, we look at it as safeguarding the future of the sport. There's increasing regulation in regard to emissions and so on, and we don't want motorsport to be legislated out of existence. We're aiming to future-proof the sport and encourage as many others to get involved with EV motorsport as we possibly can."

DESIGNATED DRIVER

The man behind the wheel of the eRally's debut in October was 23-year-old Cameron Davies (above left), winner of the 2010 UK Young Rally Driver of the Year award from *E&H Vehicle*'s sister publication, *Professional Motorsport World*. Having raced the electric Zoe around The Adgespeed Stages, Davies reveals how the vehicle held up, and what he and the team have learned.

What did you make of the eRally?
The driving of the car is different to a vehicle with an engine and gearbox, where you're using the gears to help you. The Zoe has just one long gear, and it has so much torque and it takes you right the way up. The biggest thing was the regeneration on the car, and driving with that in mind. Driving a normal rally car, as soon as you come off the power, it keeps rolling and you've got to press on the brakes as hard as you can. With the regen it was having to drive smarter, so you're waiting for it to help you brake a bit more, so you're on the brakes less.

Talk us through the car's debut
There were about 60 cars [in the event], and on the second stage we managed to set 26th fastest, to our surprise to be honest. We were a little worried about the car making the event on a charge – we had a normal slow charger in service, running off the mains, so we were plugging in during services. But obviously, because of the type of event, and the fact that you're on the power all the time, it's hard to get a lot of regen from the car because you want to be off the brakes as much as you can and not slowing down.

A touch of rally range anxiety?
When you're queuing up at the start line, that does go through your mind. But once you get going, you just focus on getting the best time possible. I was assured by the team, who had done their calculations – they were a little bit worried, but thankfully didn't tell me about that until the end of the rally – that we'd make it. We crossed the finish with two miles of range left. The dashboard was lit up like a Christmas tree. It was judged perfectly.

Was there anything about racing the vehicle that surprised you?
I was surprised by the handling of the car – with the batteries and the center of gravity being so low. Another thing that I didn't expect was that, although I knew it had torque all the way from the bottom, it was about dealing with that through the corners. Usually you'd rev the car up through the corners so you have the torque coming through, but it was a surprise just how instant it was midway through a corner.

Did the car run smoothly?
Really smoothly. There's always some hiccups, especially being the first, but it ran like clockwork. Being an EV, the mechanics were over the moon because there was nothing to really look at. You haven't got the engine and gearbox to look at, there's no oil to check, there's only really the brakes. There's things to check on a road car, but servicing was bliss. The car ran faultlessly. We plugged in, checked the wheel nuts, that was it. It was almost worryingly smooth because you expect something to break!

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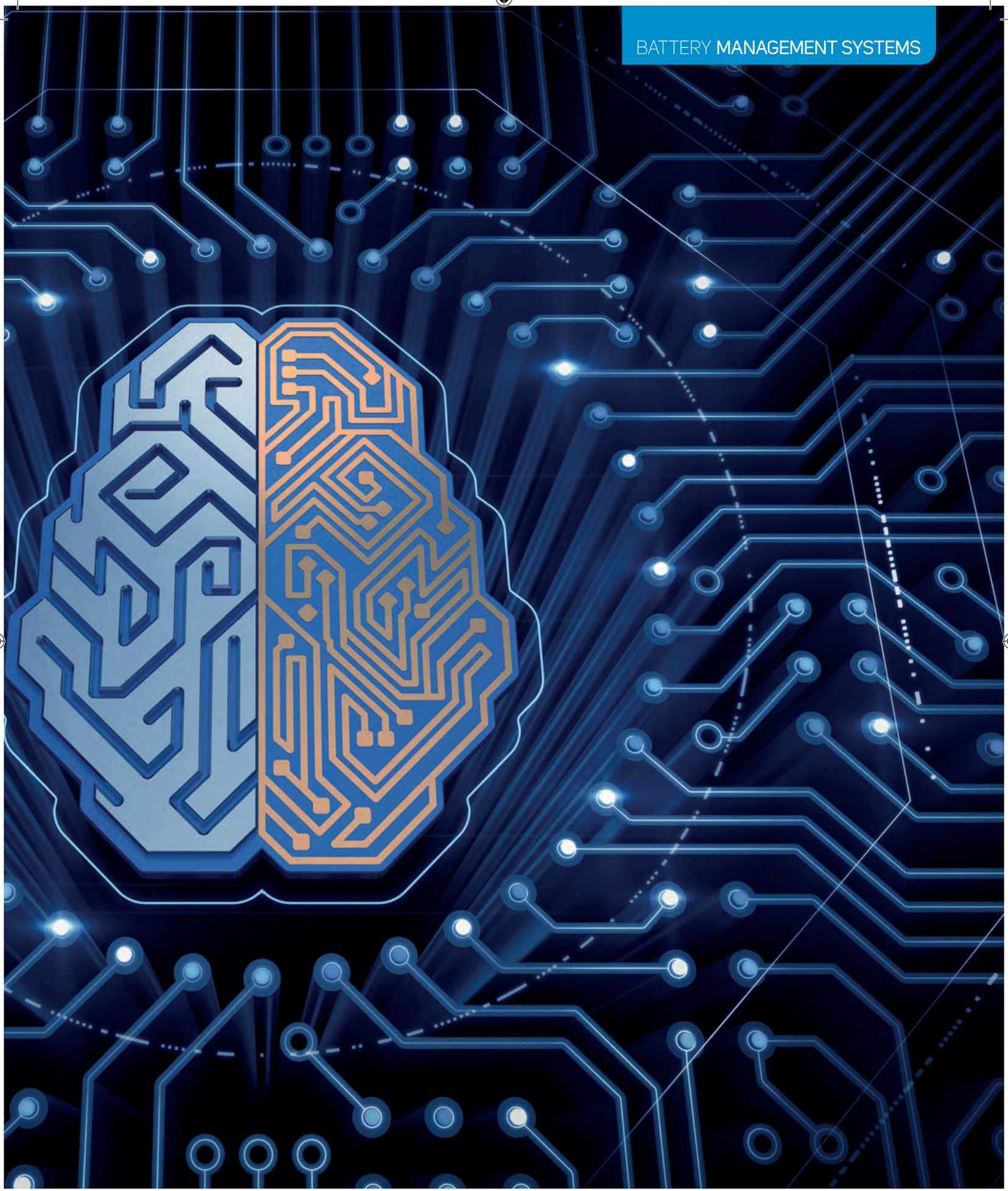
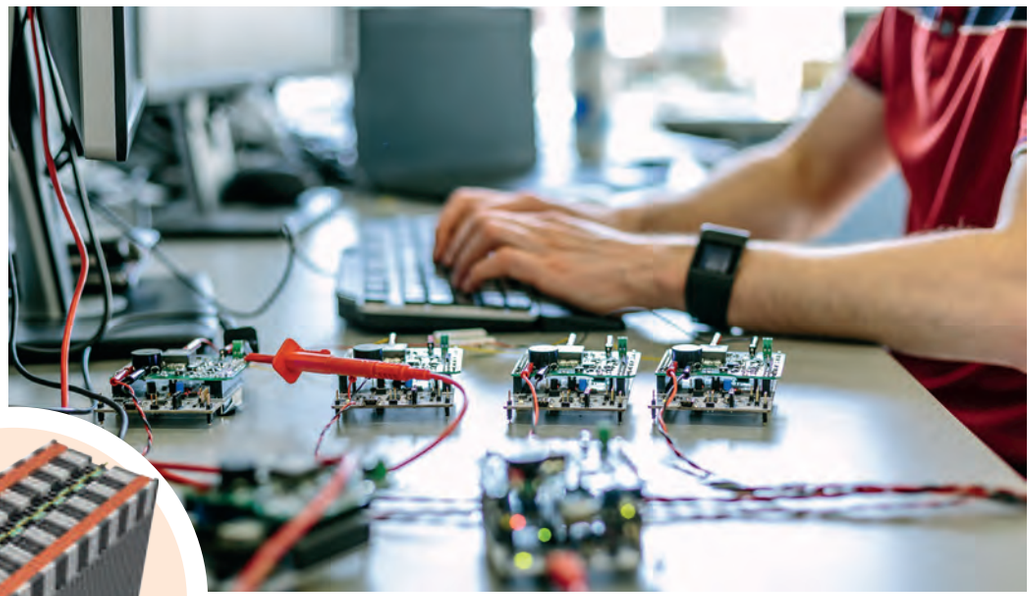
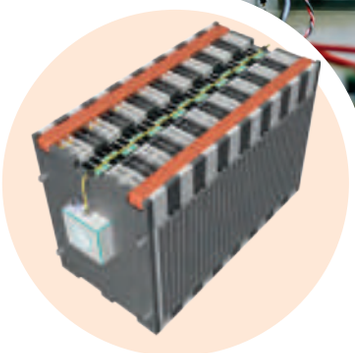
WORDS: **CHRIS PICKERING**







Above: Oxford University's Energy and Power Group is investigating the potential of remote battery monitoring

Left: A Dukosi pack, featuring a near-field wireless link

The cells inside a modern battery pack are little short of miraculous. They deliver previously unheard of levels of power and energy density in a lightweight, relatively affordable package. But it's the battery management system (BMS) that's the real brains behind the operation, protecting the sometimes volatile cells from harm and ensuring the pack works as efficiently as possible.

Historically, most automotive BMSs could trace their roots back to technology developed for consumer electronics. However, the demands are very different. Hybrid or electric vehicles using regenerative braking can switch between very high levels of charge or discharge in an instant. They also have to operate in all conditions, from Scandinavian winters to Middle Eastern summers.

The most fundamental difference, however, is scale. While a laptop may have three or four cells, operating at 12V, an automotive pack can have hundreds or even thousands, running at anything up to 800V. Far from being a simple case of upsizing, this impacts every aspect of the design. And with electrified vehicles continuing to grow in terms of complexity, it's pushing the development of some increasingly specialized solutions.

Off center

To monitor the cells, the BMS requires input from a network of sensors, which spread out like nerve endings through the battery pack. Feeding all this data back into a central brain typically requires a lot of wiring and connectors, not to mention a considerable amount of communications bandwidth and plenty of number-crunching power. With this in mind, there is now a growing interest in the concept of decentralized BMSs, which handle a greater proportion of the processing at modular or even cellular level.

Integrated circuit specialist Dukosi is one of the companies leading the charge. Its system uses an application-specific integrated circuit embedded into every cell. These combine an onboard sensor capability – measuring voltage, current and temperature – with a powerful 32bit microcontroller. The end result is a module that not only collects data, but can also run complex algorithms such as Kalman filters within the cell itself.

"The project was inspired by a feasibility study we did into the idea of embedding a BMS sensor within a lithium-ion cell," explains Dukosi's chief technical officer, Joel Sylvester. "It got us thinking about the systems engineering approach to BMSs that you might take if you started with a clean sheet of paper. This convinced us there was a possibility for real disruption."

One of the benefits of decentralization is that it eliminates a potential bottleneck in the communications system. The Dukosi design handles most of the real-time processing on the cell and only sends high-level data such as state of charge (SoC), state of health (SoH) and warning signals back to the central control module. This means the sampling rates are no longer constrained by the bandwidth of the communications system.

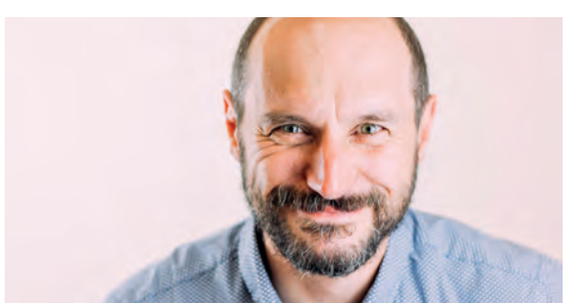
"There's some really interesting modeling that you can do with the precision and richness of data that this approach provides," says Sylvester. "Having data for every single cell will allow you to manage the trade-off between, say, usable capacity and battery lifecycle far more precisely."

Dukosi uses a near-field wireless link to connect the cells to the controller via a simple twisted-pair cable antenna that runs across the top of the battery pack. This approach was designed to combine the repeatability of a wiring harness with the inherent isolation of a wireless system, but it could bring other benefits too, Sylvester explains.

"The intention is to embed the chip at the cell's point of manufacture," he says. "With the sampling rates turned right down, this means a single antenna could be used to test and track tens of thousands of cells in one go as they come off the production line. The cells

"Having data for every single cell will allow you to manage the trade-off between, say, usable capacity and battery lifecycle far more precisely"

Joel Sylvester, chief technical officer, Dukosi



don't even need to be connected at the time, so they could be monitored while they're sat in boxes waiting for shipping or potentially during transport. The same applies if they come to be used for a second-life application. Storing the lifetime history on each cell eliminates the need for grading."

Cloud computing

Wirelessly connecting the various elements of the BMS may just be the start. A number of companies are exploring handling aspects of the monitoring process remotely.

"When you're looking at the SoH of a battery, the change in capacity or internal resistance from one day to the next is going to be minimal," explains Dr David Howey from Oxford University's Energy and Power Group. "You're more interested in the shift over months or years, so selectively squirting a bit of data up to the cloud every few days makes sense. It means you don't have to carry out the processing locally and it allows you to combine data from lots of vehicles to fine-tune the prediction."

Dr Dennis Doerffel, chief technology officer of REAP Systems, shares a similar view: "What we're seeing now – particularly following the introduction of ISO 26262 – is that people are trying to separate out the general functions of the BMS from the safety-critical aspects. I think it's likely that we'll see the really clever stuff carried out on an external server. That way it could be updated cheaply and easily without impacting the safety-critical code."

One of the more exotic concepts under discussion is the use of neural networks. In many respects, these are an ideal fit for the complex, multidimensional relationships that impact SoC and SoH estimation. At present, however, the technology is still in its infancy and it's virtually impossible to track what's actually happening inside the network. Until that obstacle is overcome it effectively rules out neural networks – and most other forms of artificial intelligence – from safety-critical aspects, but there is no reason why they couldn't be employed elsewhere in the BMS.

Above: Experts at REAP have observed attempts to separate more general BMS functions from safety-critical aspects

Left: REAP developed a series hybrid powertrain for a bus for the Korean Rail Research Institute

Lithium-ion cells look set to dominate the automotive landscape for the next few years at least, but any major changes to the chemistry could have a disruptive effect on the BMS. Lithium iron phosphate, for instance, has an extremely consistent output voltage across the main portion of its charge range. This makes it virtually impossible to estimate SoC based on cell voltage, so more complex predictive models would need to be employed. This has already been seen to a certain extent with conventional cell chemistries, thanks to the increasing computing power now on offer, but it's a trend that looks set to continue.

"One thing that could be a game-changer is solid electrolytes with metal anodes," says Howey. "If that could be made to work, it could offer twice the energy density. The tools we have in place for things like SoC estimation would still apply, but we'd be thinking a lot more about the mechanical effects. You can already improve SoC estimation by monitoring the swelling of Li-ion cells, but that would be far more critical with a solid-state electrolyte."

Potential wins

Perhaps the biggest BMS gains are not to be had from the hardware or software, but from the insight that goes into them, though. The marriage of electrochemistry and control technology is relatively new, Howey points out.

"The technology that goes into internal combustion engine management is a great example of deep understanding of the processes, combined with very good control engineering," he says. "There isn't the same level of experience with BMSs yet, but we're heading in the right direction."

"What we're seeing now – particularly following the introduction of ISO 26262 – is that people are trying to separate out the general functions of the BMS from the safety-critical aspects

Dr Dennis Doerffel, chief technology officer, REAP Systems

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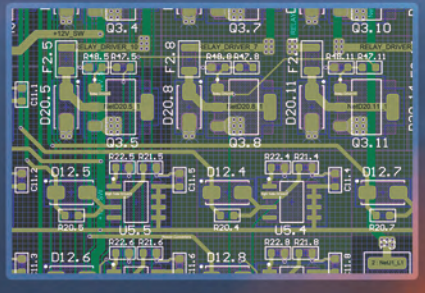

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Charging ahead

Electric & Hybrid Vehicle Technology Expo Europe moves to a city pioneering the future of e-mobility

Electric & Hybrid Vehicle Technology Expo and The Battery Show Europe, May 15-17, 2018, Hanover, Germany

Renowned as Europe's most advanced forum for H/EV technology, this year's Electric & Hybrid Vehicle Technology Expo gets a location to match its magnitude as the trade fair moves to the world's largest exhibition grounds in Hanover, Germany, a hub for automotive manufacturing and production.

The Hanover Messegelände will host more than 300 exhibitors in its vast, modern space, which is strategically situated on the doorstep of some of Germany's leading automotive manufacturers. The city of Hanover is one of Germany's thriving locations for automobile construction, with 10 million vehicles built in the state of Lower Saxony every year. And with this growth, demand is increasing for suppliers of batteries and other e-mobility components.

This is where Electric & Hybrid Vehicle Technology Expo Europe steps in. Co-located with The Battery Show Europe, the two events offer an unparalleled opportunity to source the latest products and services from leading automotive companies both in the region and from further afield.

Well connected regionally, nationally and internationally, Hanover is a true hub for the event's anticipated 5,000+ attendees, who will be arriving from more than 50 countries – a status that complements the industry's shift toward fostering increased opportunities for globalization and international collaboration.

In previous years, and at its North American sister event, Electric & Hybrid Vehicle Technology Expo has enjoyed unprecedented levels of success, and 2018 is set to build on this history. The expo is firmly established as a meeting point for the e-mobility industry's leading companies and representatives. It features a showcase of manufacturing solutions and live demos from across the entire supply chain, including electrical powertrains and components, battery management systems, materials and equipment. TE Connectivity Germany's Uwe Hauck has praised the opportunities for valuable discussion at the event: "We really enjoyed the quality of the conversations with both technical experts and decision makers."

The breadth and inclusiveness of the expo also impresses, with Huber+Suhner's Max Göldi commenting on the overwhelming number of knowledgeable people in attendance: "It's different from standard exhibitions," he says. "All the engineers and people from that market are here."

The exhibition is free to attend and passes are available online at www.evtechexpo.eu

EXHIBITING COMPANIES INCLUDE: CONTINENTAL, VALEO, HUBER+SUHNER, LEONI, HONEYWELL, SIEMENS, OMNIGEAR, MAHLE, JOHN DEERE, TE CONNECTIVITY

DRIVING E-MOBILITY IN HANOVER

Electric & Hybrid Vehicle Technology Expo Europe is moving to Hanover, Lower Saxony, a city pioneering the future of e-mobility.

Supporting this is Automotive Nord's eponymous initiative that works with the states of Lower Saxony, Bremen and Hamburg to pool the interests and activities of the automotive and mobility industries, with regional automotive clusters and employers' associations. This provides a foundation for unrestricted industry growth and development. Its objective is to promote Germany's automotive companies, boost their competitiveness through technology and innovation, and provide platforms for information exchange and communication.

With 120,000 employees and 700 automotive supplier companies in Lower Saxony, the region is the production home to global players including Volkswagen, Continental, Johnson Controls, Robert Bosch, ZF Lemförder and Wabco.

As an innovator and catalyst for mobility of the future, Hanover's ambitions align closely with the content of Electric & Hybrid Vehicle Technology Expo Europe. With a shared focus on collaboration and development, Hanover is the ideal exhibition host, making the expo the ideal place to meet potential partners and customers.

electric & hybrid vehicle technology expo europe 2018

Co-located with THE BATTERY SHOW EUROPE 2018

15 – 17 May 2018 // Hanover, Germany

Europe's largest trade fair for H/EV and advanced battery technology

300+ exhibitors // 5,000+ attendees

Confirmed participation from:

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"We are overwhelmed with how many people are here, very knowledgeable people. It's very different to standard exhibitions. All the engineers and people from that market are here."

Max Göldi, LF Market Manager Industry, HUBER+SUHNER

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JOHN DEERE ELECTRONIC SOLUTIONS

The PD400 modular inverter from John Deere Electronic Solutions provides space savings and flexibility to system designers needing a solution for high-voltage/high-power hybrid electric vehicles. The company's all-in-one system eliminates the need for multiple interfaces while meeting exact system requirements. This enables system designers to optimize design integration and machine performance in the often extreme conditions of off-highway and heavy-duty applications. The PD400 modular design can be configured with a single or dual inverter for maximum design flexibility in addition to offering common electronic control architecture that supports a full suite of advanced motor control software.
John Deere will exhibit on stand 425

TE CONNECTIVITY

Technology giant TE Connectivity will highlight its next generation of EV charging cables and inlets. Recharging the traction battery of an electric vehicle or hybrid car is a crucial element of powertrain electrification. Charging cables in particular have a direct influence on the acceptance of electrified driving because vehicle availability depends on the cable. TE's third generation of charging cables offers robust design, while its new CCS inlet types meet OEM requirements for fast charging, bringing charge time for plug-in hybrid and battery electric vehicles down to just a few minutes. As well as new cables and inlets, TE Connectivity will showcase a broad product portfolio including power distribution technologies, interconnection systems and e-motor sensors.
TE Connectivity will exhibit on stand 359

HENKEL

German chemical and consumer goods company Henkel will highlight its electronic automotive solutions. The company will display an extensive range of material technologies that are facilitating advances in automotive electronics innovation. Its interactive stand will take visitors on a journey through Henkel materials integration into battery technologies for new energy vehicles, advanced driver assistance systems, automotive lighting and powertrain technologies, and chassis and interior systems. Henkel prides itself on formulating reliable materials that meet challenging expectations for advanced vehicle performance, and its holistic understanding of entire automotive electronics systems enables the company to deliver material combinations aligned for maximum performance, reliability and efficiency.
Henkel will exhibit on stand 452

ELECTRIC & HYBRID VEHICLE TECHNOLOGY CONFERENCE

After the outstanding 2017 launch of the European Electric & Hybrid Vehicle Technology Conference, co-located with The Battery Show Conference, which together attracted more than 550 delegates, 80+ speakers and over 4,000 exhibition visitors, the event returns this year with an expanded program.

Having moved to Hanover, the expert-led agenda promises to deliver insight into key business and technical challenges while framing the commercial opportunities currently facing global OEMs, Tier 1s, battery manufacturers, components providers and their supply chains locally and globally. Attendees will hear constructive, technical and strategic insights, enabling them to tackle the issues at the center of an automotive sector under pressure to drive increased electrification to meet impending emissions targets. The speaker panels, on-stage interviews, keynote talks and workshops will demonstrate both the innovations available today and potential solutions coming down the road in the future.

New for 2018: Building on the highly successful multitrack format of last year, the 2018 event will include more diverse session formats, audience interactive features, and a day of pre-conference workshops on Monday, May 14, 2018, followed by an expanded conference agenda with three tracks over the course of three days.

Key topics include:

- EV and hybrid future market trends
- Implications of autonomous vehicles for the EV automotive supply chain
- Next-generation powertrain technologies
- Charging and infrastructure and the impact on electric vehicle design
- 48V systems integration and components for mild hybrids
- Thermal management in the electric vehicle
- Transferring hybrid and EV technology from the racetrack to the road
- The latest electric and hybrid propulsion powertrain technologies from the aerospace industry
- Cost-efficiency of hybrid and electric deployments for fleets
- The latest technologies driving mass deployment of hybrid and electric buses
- Electric vehicles for off-road construction, agriculture and mining

Speakers at previous Electric & Hybrid Vehicle Technology Conferences included representatives from: BMW, Daimler, Ford, GM, Porsche, Toyota, BorgWarner, Tesla, Valeo, EU Commission, EuroBat, Jaguar Land Rover, Johnson Controls International, Volkswagen, Samsung, LG Chem, Siemens, Mercedes-Benz, Renault-Nissan, PSA Group, Continental, Cummins, Airbus and Google.

View the initial agenda online at www.evtechexpo.eu/conference

Save up to €500 by securing the Super Early Bird rates for the Electric & Hybrid Vehicle Technology Conference, available online until Friday, January 26, 2018.

Super Early Bird: One-day pass €695; Two-day pass €1,095; Three-day pass €1,495; and pre-conference workshops €595.

CO-LOCATED EVENT: THE BATTERY SHOW EUROPE

Also taking place on May 15-17 in Hanover is The Battery Show Europe – an exhibition and conference showcasing advanced battery technology for automotive industries.

The event is co-located with Electric & Hybrid Vehicle Technology Expo, bringing together suppliers and buyers in one place. And with battery gigafactories opening across Europe, now is an opportune moment for two events that represent and serve the battery and automotive industries.

Major names including Voltabox, Siemens, Paraclete Energy and 3M will be unveiling their latest industry solutions and staging live demonstrations on the show floor. The event marks an unmissable opportunity to get to the heart of sector activity, network with industry peers and stay informed about current industry developments.

electric & hybrid vehicle technology conference | europe 2018

THE BATTERY SHOW CONFERENCE EUROPE 2018

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Key topics include:

- Future H/EV market trends
- Next-generation powertrain technologies
- 48V systems integration and components for mild hybrids
- Cost-efficiency of hybrid and electric deployments for fleets

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From the inside

Left: A mass-production air-cooled in-wheel motor with an integrated disc brake for modular light electric vehicles, developed by Elaphe and EU-Live consortium partners (PSA Peugeot Citroën, Peugeot Scooters, Brembo, Continental, Samsung SDI and others)

Right: Superseding Elaphe's in-wheel BMW X6, which demonstrated 0-100km/h in under 4.8 seconds, the in-wheel-driven Audi R8 aims to do so in under 3 seconds

In-wheel motor platforms have the potential to shift industry focus from the powertrain to innovations in packaging, user experience, automation, safety features and optimization of the EV supply chain

WORDS: **KARL VADASZFFY**

Although the idea of an in-wheel motor platform was proposed by Ferdinand Porsche as far back as the turn of the 19th century, the underlying technology at that time was in its infancy. Elaphe Propulsion Technologies' active development of in-wheel propulsion over the past two decades, through the development of direct-drive propulsion systems for over 15 different vehicle platforms, has matured in-wheel technology to the extent that it is now enabling a fundamental shift in mobility.

In-wheel propulsion eliminates the entire conventional drivetrain, simplifying and shortening the whole process of engineering a car, from concept to series. Transmissions, gearboxes, driveshafts and the associated space constraints are now becoming obsolete.

"We're focused on bringing reliable, modular and high-performance propulsion platforms for the next generation of user-focused EVs to market," says Dr Gorazd Gotovac, Elaphe CTO. "Research from our founders, some dating back over 25 years, has shown that an in-wheel powertrain best suits the needs of a modern, autonomous and connected car."

Model growth

Elaphe began as a startup company, financing its growth by building custom powertrains. A development phase of more than 10 years saw the firm create new analytical models to arrive at an optimal electromagnetic design, and today, as a result of this intensive learning curve, Elaphe is able to perform extensive testing, validation and industrialization of its electric motors and powertrains.

Challenges along the way included dealing with harsh external environmental conditions and their variation. "People rarely realize the effort that goes into designing and validating a car component that works in the toughest of conditions, everywhere in the world – among others, in temperatures from -40°C to +85°C [-40°F to +185°F]," says Gotovac. He explains that the company's rapid growth created an opportunity for investment in thermal cycling and thermal shocking equipment, which "rapidly accelerated the development of our products' reliability in all weather conditions".

A major modern trend is reducing the footprint of underlying technology, instead utilizing more space to enhance the user experience, continues Gotovac: "We think the user experience in a car will dramatically change. Its transformation through different levels of vehicle autonomy and digitalization needs to be supported by a transformation in the underlying technology that performs the base functionality."

To enable car designers to build the vehicle around the user's needs, Gotovac believes the powertrain should become almost invisible to the user, with the focus instead on what he terms "the front-end functionality". He adds, "In-wheel motors share space with existing components in the wheel, moving out of the way of a safety- and user-focused chassis."

In-wheel motors contain only one moving part each, so little servicing and maintenance are required. In addition, they enable unparalleled agility in all conditions, with multiple-wheel independent control using Elaphe's propulsion control unit algorithms, the full potential of which is realized with increasing automation of vehicles.

Furthermore, manufacturers benefit from the modularity of such a powertrain platform for use in multiple vehicle bases, a reduction in the number of components, and a fall in development and production costs.

It is possible to integrate the propulsion into a new vehicle or retrofit an existing ICE car, and the technology enables independent four-wheel control, a custom interface, visual displays with 3D graphics, homologation, fast charging and intelligent traction control, the latter being one of the most efficient technologies for energy regeneration.

As in-wheel powertrains are an alternative solution, Gotovac recognizes that customers want assurance that the technology is safe and reliable, which means demonstrating that "technically the components can withstand the same durability and performance standards as other solutions, that they are compatible with some already-developed systems, that the components can be produced at an acceptable cost, and that organizationally we can support customers in such a large transformation of the vehicle."

Real-world applications

Elaphe is not content with just developing and demonstrating new technology, but is venturing into the validation and production of its technology on a mass scale. Driving its growth and inspiration for the refinement of in-wheel technology is an ever-evolving portfolio of projects, usually focusing on paradigm-changing mobility concepts – using modular, agile powertrain technology, making it far less complex than that of a run-of-the-mill car, and thus closer to the market than one might expect.

For example, Elaphe is working on the commercialization of advanced technologies for the new era of mobility. One joint project, co-funded by the European Community – which involves, among others, Brembo, Continental, Samsung SDI, Virtual Vehicle, PSA and Peugeot Scooters – is dubbed EU-Live, and aims to develop modular building blocks for the unified light electric vehicle platform of the next decade.

In addition, with the support of the EU, Elaphe is on a path to bring its most powerful in-wheel drive to date into mass production, showcasing the technology in the Audi R8 and BMW X6 testing platforms.

Gotovac argues that "one doesn't need to be a visionary to see that the mass electrification of cars is inevitable". But as battery technology, cost and production capacity improve, the priorities in the powertrain are shifting, and "some of the traditionally most important development drivers will become less so."

For example, he suggests that the electric powertrain is already so efficient that further investment in efficiency improvement will be of limited benefit. And since some electric city cars currently exceed the performance of many one-time sports cars, there is little room left for performance improvement.

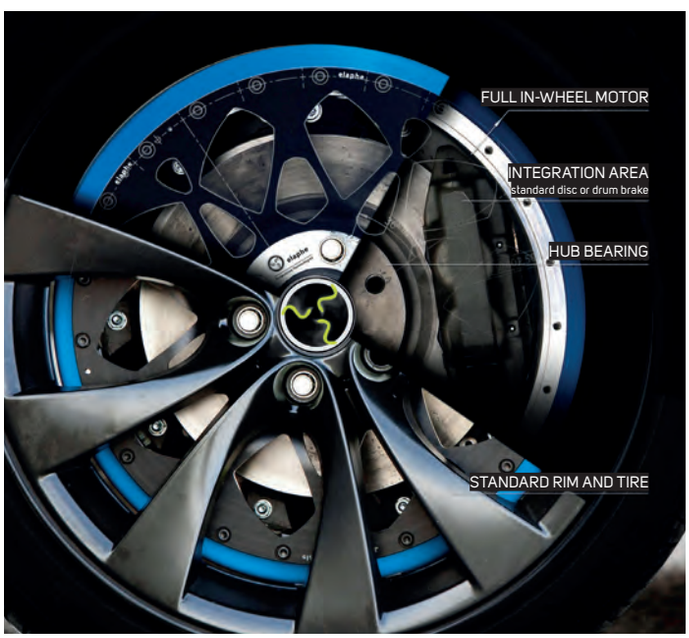
Gotovac believes that more can be achieved with packaging and functionality to contribute to the vision of the new user-centered car paradigm, "and that's what I think will be the direction of the automotive industry with regard to innovations in powertrain development and architecture."

The development of custom direct-drive powertrain solutions within demanding space and environmental constraints enables OEMs, vehicle developers and premium suppliers far more innovation in packaging, design, safety and lightweighting than ever before.

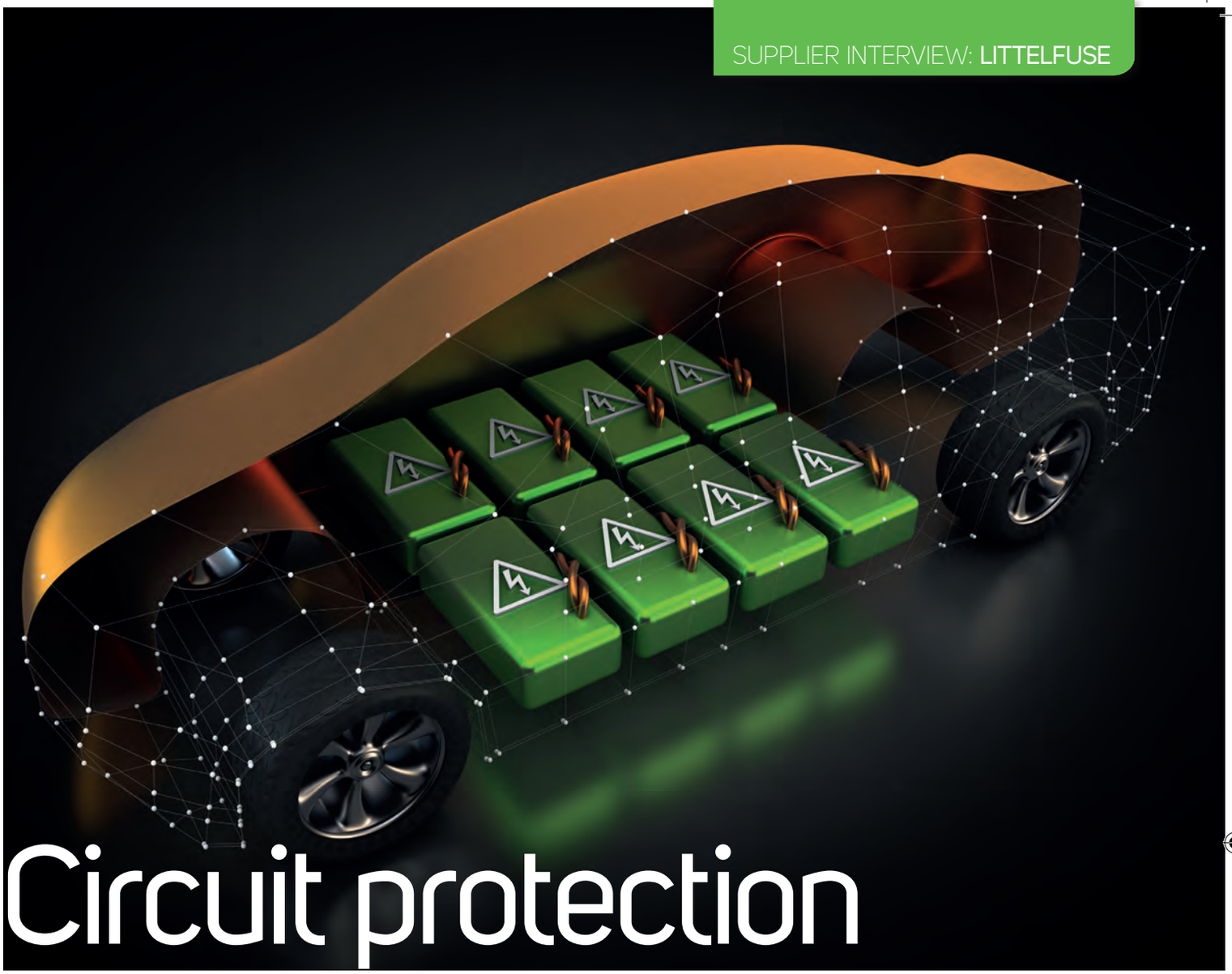
However, while custom development is an important part of its activities, Elaphe is also on a mission to provide its customers with an industrialized, complete solution for in-wheel propulsion. That is why Elaphe's plug-and-play platform (in-wheel traction motors, power electronics, power distribution, and intelligent, connected, multiple-motor propulsion control unit) can be the main building block for many new applications and players in the automotive arena, especially in the field of autonomous vehicles.

"People rarely realize the effort that goes into designing and validating a car component that works in the toughest of conditions"

Dr Gorazd Gotovac, CTO, Elaphe Propulsion Technologies



In support of Elaphe's mission to offer vehicle developers a full, industrialized propulsion solution, the L1500 in-wheel motor is one of the highest-performance gearless motors in the world. The compact and lightweight motor is built around a standard bearing and disc brake. The L1500 is in the final stages of design validation for mass production and is available to early adopters for vehicle development projects. Its industrialization is co-funded by the European Union's COSME program



Circuit protection challenges

Robust circuit protection devices are required to protect the BMS from electrostatic discharges, overvoltage and overcurrent conditions that threaten automotive performance and driver safety

As voltages in automotive systems increase, so too does the need for safety-guaranteed circuit protection

WORDS: **KARL VADASZFFY**

The market for vehicles containing electric, battery-powered drive systems with voltages equal to or higher than 48V is expected to grow by double-digits in the coming years – from four million vehicles in 2017, to over 14 million in 2022. Public and government demands for improved air quality, with a particular emphasis on lower emissions and zero-emission vehicles, is a key driving factor, as is the growing number of electric loads in vehicles, which require higher voltages and more powerful electric systems. To successfully fulfill this industry step-change, greater levels of vehicle efficiency are needed.

Carlos Castro is an electrical engineering specialist with PhDs from the University of Granada, Spain, and the University of Dortmund, Germany, and has a leading role in automotive electronics at Littelfuse, a developer and manufacturer of circuit protection. He believes that lithium-ion batteries will be the foundation for future EVs because of their power density and charging lifetime, but to support their use, "major efforts in monitoring and protection are required".

The latest generations of EVs, he says, are approaching the stage where the battery is no longer a blocking point for an increase in popularity with consumers. "There is now a really significant reduction in cost, and the EVs coming on the market at the end of this year and early next year claim to offer up to 500km [310 miles] of range capability," he says.

Electronic fuses for vehicle systems must be carefully selected in line with the requirements of the specific application, and must also be subjected to automotive standards in component reliability

Furthermore, Castro is quick to point out that improvements in battery technology and its cost will lead to higher volumes, resulting in a better cost situation and the possibility of integrating even more effective technologies in electric vehicles.

"One of today's challenges," he explains, "is that there is no standard for the BMS and, therefore, we see very different approaches, which could make it difficult to maximize economy of scale."

Safety first

Battery management systems in EVs demand strategically selected and located protection components for overvoltage and overcurrent protection – for instance, electronic fuses for use in vehicle systems, such as BMS sense line protection, need to be carefully selected and should be able to pass reliability testing following automotive quality standards.

"The voltage range that is required depends on battery configuration," Castro says. "The fuse should have a low temperature de-rating, long-term stability is required, the fuse must be able to cope with temperature cycles and vibrations, and small form factor is essential."

The BMS, he goes on to explain, is a critical application in terms of safety and reliability: "Each module of batteries will have different cell monitoring subsystems to monitor the voltage of those cells, to ensure that proper balancing of the cells is achieved.

"Microcontrollers control each of those modules. Proper balancing can help achieve the highest energy efficiency of a battery and extend its lifetime."

In addition, the BMS is an especially critical system with regard to circuit protection, Castro says, because it is a high-voltage, high-energy system, so it is necessary to achieve the proper protection and isolation: "Electric vehicles are still entering the market and some people are reluctant to drive a car when they are sitting on a 900V battery, even though it is much safer than sitting on a tank of gasoline. That is why, for Tier 1s and OEMs, it is critical that nothing happens with those systems." To ensure this, the number of protection devices used in a BMS can reach 700 fuses, which results in the challenge of having to work with such a high number of fuses to protect cells against overcurrent.

"The fuse should have a low temperature de-rating, long-term stability is required, the fuse must be able to cope with temperature cycles and vibrations, and small form factor is essential"

Carlos Castro, electrical engineering specialist, Littelfuse

Meeting customer needs

Different customer requirements, Castro adds, depend on which architecture they choose. In decentralized architecture, long wires are used to connect systems. In the event of an accident, there is the risk of having a short-circuit under high-voltage conditions in the module, which is why high-voltage fuses are used. The benefit of this architecture is that components can be replaced separately, making it the cheaper and easier option.

On the other hand, with centralized architecture, components are integrated into one module, which is particularly important for hybrids due to the lack of space resulting from the presence of the combustion engine and transmission. In the event of an accident, there is a very low risk of having a short-circuit under high-voltage conditions, so low-voltage fuses are chosen, reducing cost. However, with this option, if a component needs to be changed, the entire module has to be replaced.

What is important, Castro adds, is to ensure optimal protection component selection while adhering to automotive safety standards: "Today, regulations are driving the market. In response, major countries are setting extremely ambitious goals on the percentage of hybrid-electric or full-EV vehicles they want to see on the road in terms of new vehicles, and other countries are matching these ambitious goals. The UK, France, Belgium and China have driven a shift in how automotive companies opposition themselves against one another to have ambitious targets themselves."

In the future, Castro stresses that, although most forecasts still show EVs and HEVs will make up a low percentage of the vehicles on the road, there will be faster growth than expected. This is especially down to events such as Dieselgate in Germany, which change the minds of politicians and sway public opinion, as well as improvements in infrastructure. "More countries are involved and more charging stations are beginning to emerge. Companies now realize there is a business case behind electric vehicles. And I believe these are some of the things that could alter the landscape of the automotive market in the coming years."

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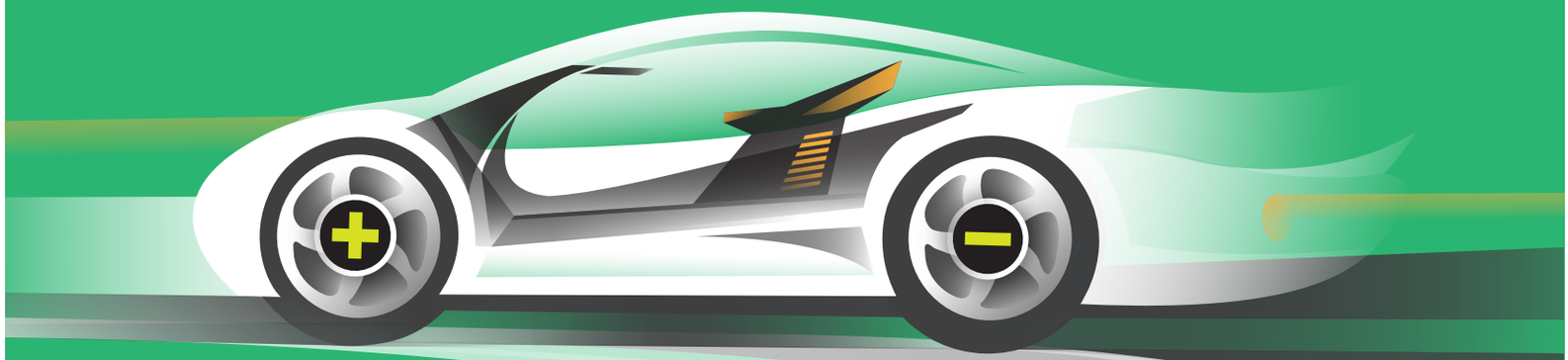

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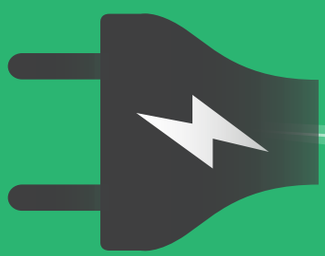

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Predictive methodology

The mission of a technology company's founder continues to influence its approach to advancing innovation, both in the automotive sector and beyond

Left: Guided by the vision of Omron's founder, Kazuma Tateisi, the tech company is creating a range of automation solutions for the factory of the future

Right: Omron's solutions, such as Human Vision Sensing (facial detection) and the Project Zero 2.0 wrist blood pressure monitor prototype, are the result of Tateisi's Seed-Innovation to Need-Impetus Cyclic Evolution future prediction theory (SINIC), developed in 1970. It remains at the heart of the company's management philosophy today

"Dr Kazuma Tateisi was a deep thinker with a profound vision," explains Robb Black, CEO of Omron Automation Americas. "He wanted to change the world by using technology to build a more harmonious society."

Tateisi proposed a predictive methodology for realizing this goal with the Seed-Innovation to Need-Impetus Cyclic Evolution (SINIC) theory, which he presented to the International Future Research Conference in 1970 and which subsequently became the core of Omron's management philosophy.

The SINIC theory approach advocates using machines to create sustainable abundance so people can work more efficiently and lead longer, healthier, more fulfilled lives. Black admits that this may be something of an idyllic goal for a multi-billion-dollar corporation with deep roots in industrial automation and consumer manufacturing.

"It speaks to our optimism, not just as Omron employees, but as human beings," he says. "Even though the planet faces a number of challenges, we believe technology can and should play a role in bringing about a better world."

Of course, to change the world, you need to have a plan. In 2011 Omron launched Value Generation 2.0 (VG2.0), which directed the company's 37,000 employees to pursue the innovations that will help people solve a host of social issues, including workforce decline, population aging, environmental degradation and climate change.

"VG2.0 involves everyone at Omron, but especially our automation, automotive, electronic components and healthcare business units," explains Nigel Blakeway, managing executive officer of Omron Corporation. "It provides a framework for using our core sensing and control capabilities to generate value. Over time, it has been updated to include artificial intelligence, the Internet of Things, robotics and other advances."

This blend of existing and emerging technologies is producing results. For example, Omron has developed the industry's first machine automation controller with onboard artificial intelligence (AI). Placing machine learning AI at the cell level creates real-time integration between the programmable logic controller function, the processing function, and any connected output devices, motors, safeguards and robots.

Relocating AI functions from back-end servers and the cloud also facilitates advanced processing in flexible manufacturing and small-batch customization. This repositioning of computing resources reduces network congestion and enables production lines to self-correct in microseconds. And integrating these technologies with predictive analytics at the point-of-use helps semi-skilled operators to make informed decisions while avoiding equipment stoppages and workplace accidents.

Omron's healthcare business is on an equally bold mission: eliminating heart attacks and strokes. Key to this Going for Zero initiative is a wearable miniaturized blood pressure monitor that provides patients with a better way to monitor blood pressure and seamlessly communicate real-time readings to doctors. It is equivalent in accuracy to traditional home monitors and is clinically validated and FDA cleared.

This product and other Omron blood pressure monitors connect via the Omron Connect smartphone application, enabling physicians to monitor vital signs and adjust clinical care as needed.

In addition, Omron, in partnership with Alivecor, is introducing the first combined blood pressure and ECG monitor and mobile app package. "This is an exciting development for managing hypertension and atrial fibrillation and moving us closer to our goal of eliminating heart attacks and strokes," explains Rob Schneider, vice president of sales and marketing.

These innovations are allowing Omron to close the gap between the real and digital worlds. The company's automotive group is developing other smart devices that can be monitored within intelligent ecosystems. Ecosystems with AI and cognitive self-learning programs are already using sensory data, pattern recognition and even natural language commands to monitor events and act on an individual's behalf when circumstances warrant.

"Automation technology is advancing rapidly as interest in autonomous vehicles continues to build," explains Blakeway. "Soon, systems for lane-keeping, emergency stops and limited self-driving will be standard on most vehicles. These innovations are key to making our roads safer."

New vehicles will leave the factory with connectivity, sensor arrays and fast-compute capabilities. Such features will allow transportation experts to treat vehicles like nodes in an Internet of Things network and use sophisticated controls to manage traffic in real time. Ultimately, roads will become ecosystems of connected autonomous devices, able to support faster, safer commutes even as usage increases.

In addition to the development of sophisticated relays, switches, sensors and connectors for OEMs in many industries, Omron is adding intelligence into everyday things. Its product portfolio includes image sensors such as the Human Vision Sensor, which OEMs can use to detect the age, gender, position and expression of occupants in a variety of defined areas or spaces. The sensor is particularly useful for managing building environments, collecting marketing data and even reliably controlling access to age-sensitive products dispensed through vending machines or self-service POS systems.

Omron is also releasing a new sensor that will help building scientists maximize energy savings while optimizing indoor air quality. The sensor can detect the minute particles that are especially dangerous to occupants in increasingly airtight structures. Adding it to a purifier or monitoring system could provide valuable data on changes in air quality that might have an effect on occupant health.

As most individuals spend 90% of their time indoors, Omron has long focused on delivering technology that enhances safety and comfort. Its devices are widely used to monitor temperature, humidity, illumination, movement, ambient noise, ultraviolet light and absolute pressure levels. In seismically active areas, Omron earthquake secondary damage sensors are being used to detect vibrations and minimize secondary damage by shutting down public utilities, data center operations and other critical infrastructure.

Tateisi believed that progress would be meaningless if it did not improve the lives of everyday people. And creating this harmony and balance between people and machines remains one of the company's core principles.

"Omron continues to drive technical innovation and efficiency," says Blakeway. "But technology is just a means to achieving our goal of a better society and a better Earth for future generations."

Smart battery management

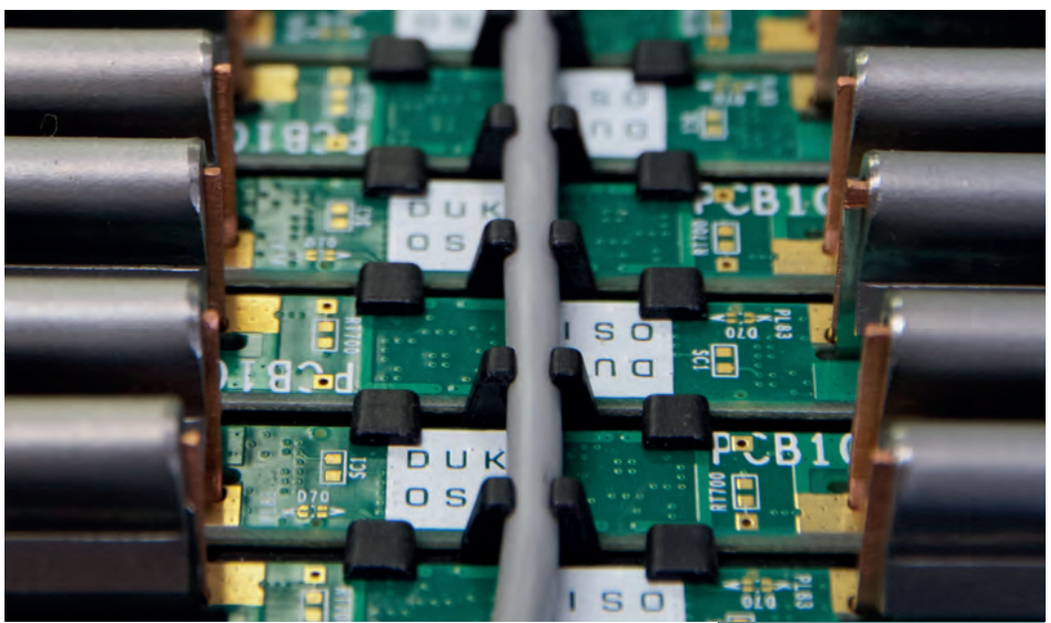
A range of breakthrough battery technologies could help pack developers and vehicle manufacturers with development of the next generation of electrification

Reducing the weight, increasing the energy density and enabling second use of batteries is on almost every electrified vehicle developer's near-term roadmap. AGM Batteries has been working to pull relevant emerging technologies together at the cell level. The cell-monitoring system ASIC, from Dukosi has been integrated to generate smart cells. The latest cell-level addition is nanoplasmonic sensing (NPS), which is being developed by Insplorion. It looks like pack developers and vehicle OEMs will have much more scope to fully utilize new generation automotive batteries.

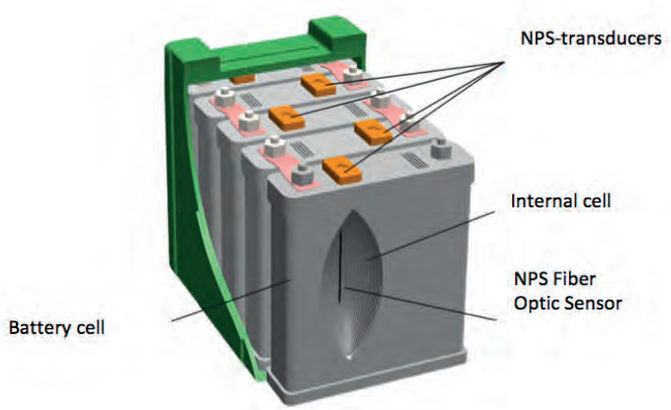
Although some serious improvements have been made in internal combustion engine efficiency, vehicle manufacturers are almost all moving ahead with electrified powertrains, necessary to achieve immediate targets, with even more extensive levels of electrification to follow in line with future global requirements.

Batteries are the main barrier for transitioning from ICE to electrified powertrains. The primary issues are economic: current total cost of ownership of EVs is far greater than that of ICE vehicles, primarily due to the high initial price of EVs and the high cost of batteries. There are also practical barriers: the limited driving range, perceived battery safety hazards and a limited charging infrastructure lead to uncertainty among consumers.

Both issues are related to the inefficient way that batteries are currently controlled. Vehicle manufacturers use large safety margins within their battery management systems (BMS) to prevent battery damage because voltammetry – the primary measurement and monitoring method – fails to provide the battery management system with the accurate information required.



NPS sensor technology enables enhanced battery usage as well as providing improved cell health data



NPS has the potential to significantly reduce several inherent problems related to inefficient use of batteries. It measures the battery health and charge directly inside each battery cell. NPS is an optical technique based on localized surface plasmon resonance (LSPR), wherein nano features (for example, gold nanoparticles) are used as sensing elements. The sensor is sensitive to changes in the refractive index in the volume within a few tens of nanometers from the nanoparticles. This enables sensitive *in situ* tracking of various surface processes such as adsorption/desorption phenomena, specific molecular interactions, structural changes as well as temperature shifts.

A sensor inside the battery cell measures changes in chemical and physical composition, which holds much more relevant information about the state of the battery than voltametric measurements, the current state-of-the-art technology. Consequently, Insplorion's sensor gives better data to the BMS, enabling much more efficient use of the battery during both discharge and charging. The cell-integrated sensors can also detect early warning signs of potential catastrophic failure.

More direct and precise sensing of the battery allows better control of how the energy and power is used, enabling more efficient usage of the battery energy, extending the

driving range, decreasing charging time, improving the safety and performance of electric vehicles.

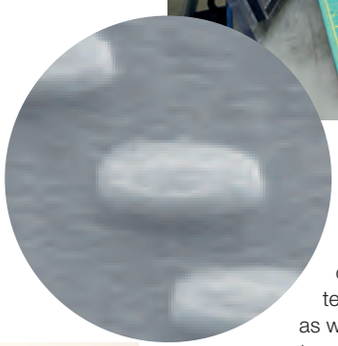
AGM has collaborated with Insplorion in developing the techniques and process for embedding the sensor directly into the electrode stack of a fully formed lithium pouch cell and replicating state-of-charge (SoC) measurement as previously shown in the laboratories at Insplorion and Uppsala University in Sweden. The pilot project demonstrated that Insplorion's technology works as predicted and has uncovered potential for far greater battery pack SoC and state-of-health determination across every sector.

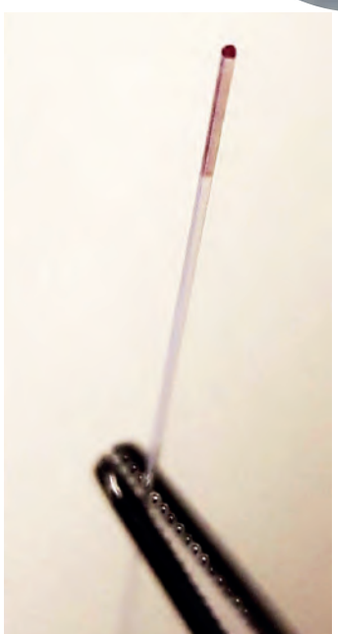
AGM and Insplorion, alongside other expert partner companies, are building on the successful pilot project and planning a follow-on to develop the integrated NPS sensor, improving robustness and optimum sensor placement inside the electrode stack, while engineering and miniaturizing the associated electronics for full compatibility with existing BMS technology and the AGM-Dukosi smart cell technology described in a previous article (*E&H Vehicle*, July 2016, p210).

Insplorion has been developing the NPS using traditional BMS hardware in order to demonstrate functionality on a current platform, but the truly exciting breakthrough happens when Insplorion's NPS is combined with the AGM-Dukosi smart cell. Dukosi's technology makes cells smart by embedding a custom chip with patented RF communications, processing individual cell models, providing health, performance and life-long data insights. The integrated system versatility is demonstrated by the on-cell device reading, storing and reporting actual (not derived) SoC measurement directly from the electrode stack within the cell.

AGM Batteries' lithium cell manufacturing facility and skill set enables the company to quickly prototype then scale-up growing numbers of electro-chemistries, including new variant Li-ion and Na-ion chemistries. The flexible, versatile nature of cell development at AGM assists rapid TRL/MRL progression of associated technologies as well as products such as Insplorion's NPS and Dukosi's smart cell technology – not only with conventional Li-ion, but also with a range of emerging chemistries that are key to future-proofing and successful commercialization.

Cell development at AGM Batteries assists the rapid progression of associated technologies as well as smart cell technology products





Nanoparticles on an optical fiber enhance the signal from chemical changes, such as Li-ion concentration

"Our collaboration with AGM has matured our battery sensor project from academic trials to commercial prototype stage rapidly, which has been essential to our project," says Insplorion's CEO Patrik Dahlqvist. "The joint opportunities that we now see with combining Dukosi's smart cell management with our optical sensor inside can truly be a game-changer."

The project builds on collaborative work that is already underway at AGM to help develop, scale-up and commercialize NPS technology for volume manufacture at AGM's 4,000m^2 production facilities in Caithness, Scotland.

"AGM has formed a close and collaborative relationship with our friends at Insplorion and we're very excited about the massive potential that NPS has," adds Colin Arnold, plant manager of AGM. "We're delighted that we have been able to make the link between Insplorion and Dukosi, our partners in highly innovative smart cell development. We're looking forward to using our proven lithium cell development and scaling-up expertise to help Insplorion and Dukosi combine technologies to truly transform battery and cell management."

"The Dukosi cell monitoring system ASIC, possesses the computational power to compute best-in-class SoC estimation models, but ultimately no model will measure the SoC directly," explains Joel Sylvester, chief technology officer at Dukosi. "By integrating Insplorion's NPS technology into a cell, alongside Dukosi's ASIC and software, we will have a direct measurement of SoC in a totally self-contained system that pack manufacturers can build into any configuration."

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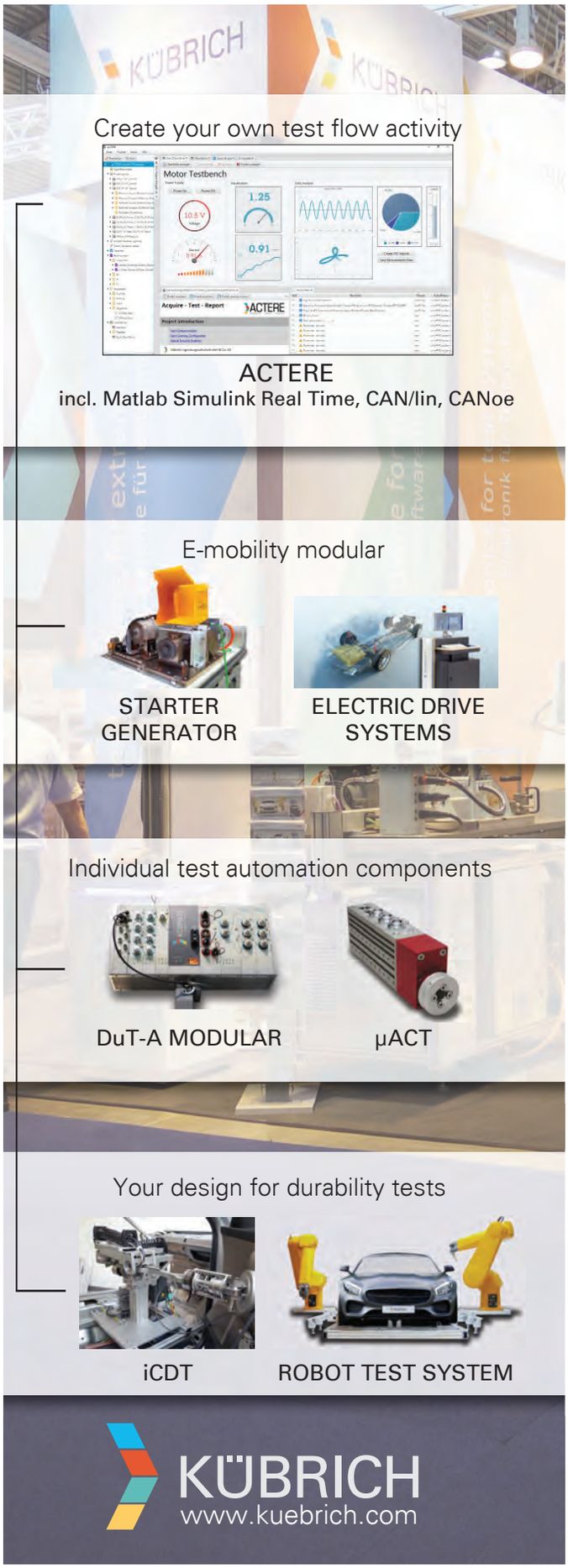

High-efficiency analysis

During development and test of EV drive systems, engineers require measurement instrumentation that will provide reliable, repeatable and accurate efficiency data

EV traction motors are now producing current levels in excess of 600A per phase at the output of the inverter and around 1kA through the DC bus. As power analyzers will generally measure up to a maximum of 60A internally, such high levels of current will require the test engineer to employ external methods of current measurement. This poses a challenge as the external transducer and associated interfacing to the analyzer will exhibit their own error contribution to the measurement of power.

Newtons4th (N4L) offers a range of current measurement options to accompany its power analysis instrumentation, including resistive shunt arrays, zero-flux transducers, Rogowski coils and current clamps using Hall-effect topologies. Each transducer type is accompanied by advantages and disadvantages.

N4L's resistive arrays offer nominal accuracies of 0.1% and a bandwidth of DC ~1MHz. Phase accuracy of 0.005° is also achieved. Resistive arrays do, however, require the conductor to be broken and then physically connected to the shunt, which can be inconvenient.

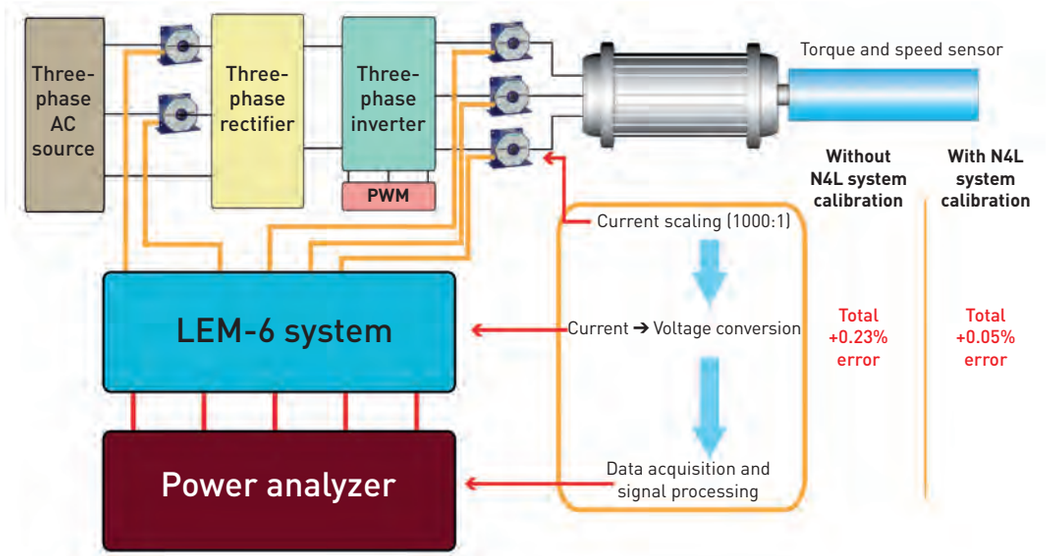

Figure 1: An example test system current measurement signal chain, illustrating reduced error when using N4L calibration

Zero-flux transducers such as the LEM ITN/IT range offer good accuracy with respect to both magnitude (0.08%) and phase (0.01°) as well as a non-contact measurement, eliminating any common mode issues. They feature bandwidths of DC to 600kHz, which is appropriate for this application.

Figure 2: Six transducers series connected to a test rig capable of up to 500A$_{rms}$

However, zero-flux transducers still require the conductor to be opened.

Rogowski coils can offer an alternative solution, which works well when the power factor is high (magnitude accuracy is 0.5%, phase accuracy is ±1°). They feature wide bandwidth (1MHz), decouple any common mode noise and are also convenient as they will clip around any conductor. Rogowskis should not be utilized if the highest accuracies are required, as they can be affected by surrounding magnetic fields and the position of the conductor within the coil.

AC-responding current clamps can offer acceptable accuracies (0.5%, 0.5°) and bandwidths up to 15kHz. They meet the demands of certain motors, depending on the switching frequencies of the inverter. While they are convenient, a resistive shunt or zero-flux transducer will offer better accuracies and adequate bandwidth, essential if there is ripple current near the switching frequency of the inverter. AC clamps offer the lowest cost per amperage as a measurement solution.

AC+DC responding current clamps extend the capabilities of AC-responding clamps to include DC measurement at the expense of accuracy, featuring a magnitude accuracy of 1% and phase accuracy of 2°.

All the transducers mentioned are connected to the power analyzer and combine with the voltage measurement channels to perform power (watts) analysis of the traction motor. This enables engineers to analyze efficiency, power input, power output, noise, ripple current and many other performance parameters.

The reader will observe that nominal accuracies of external transducers can contribute to the total measurement error. If these transducers are system calibrated, the error contribution can be significantly reduced.

N4L power analyzers will typically provide watts accuracies of better

Figure 3: The LEM-6 interface from Newtons4th will facilitate a simple connection of the N4L power analyzer to any LEM IT/ITN current transducer

than 0.05% at frequencies up to 850Hz. If an uncalibrated transducer is added to the signal chain, the overall accuracy will be degraded. If the output of the transducer is stable, it can be calibrated with the power analyzer to improve overall accuracy of the test system.

System calibration is a process in which the power analyzer, current transducers and any interfacing electronics are connected as a single measurement chain. An ISO17025-accredited calibrator is then used to apply reference signals to the system and the chain is calibrated as a single entity.

Without system calibration, test engineers must calculate the additive uncertainties the external transducers bring with them using root sum squared techniques or similar. Customers or competitors may also raise questions regarding the validity of measurements without suitable system traceability.

System calibration provides test engineers with a number of benefits, including increased accuracy, simplified uncertainty budgeting and ISO17025 traceability.

N4L has an on-site UKAS ISO17025-accredited laboratory (number 7949), able to perform voltage, current, phase and watts calibration of the complete signal chain. An example test system current measurement signal chain is shown in Figure 1.

While a resistive shunt will provide excellent accuracy and very wide bandwidth, a zero-flux transducer is, on balance, the best solution for inverter measurement due to galvanic isolation from the device under test, which negates any common mode issues at the input of the power analyzer.

N4L has developed a high-performance interface unit for the LEM series of IT and ITN transducers, which simplifies connection of the LEM zero-flux current transducers to the power analyzers. To maximize the performance of the LEM transducers, an extremely stable power supply is required along with an accurate and linear shunt, which converts the output of the transducer into a voltage ready for signal processing. Each input channel is isolated and provides a highly regulated DC power supply to each transducer. Thus, transducer performance is maximized.

This interface completes the signal chain and is included in the system calibration process, providing traceable accurate power measurement up to 1,000A_{rms} per phase. Higher current solutions are also possible. An example of the calibration process is shown in Figure 2, whereby six transducers are series connected to a test rig capable of generating up to 500A_{rms}.

Measurement performance after system calibration is seen in Figure 4, where current was gradually reduced over time. Six channels were compared for performance and excellent channel-to-channel repeatability can be observed.

A signal chain is only as strong as its weakest link and it is vital that the power analyzer is highly accurate over its complete operating range. N4L has been developing power analyzers for over 20 years. In this time the company has developed various innovative measurement techniques that optimize both real-time processing and the analog bandwidth of the measurement system. Each power analyzer leaving the factory in Leicester, UK, is subjected to a comprehensive calibration process including high frequency calibration using custom-designed N4L calibrators, as well as calibration using commercially available calibrators including the Fluke 6105A and Agilent 3458A.

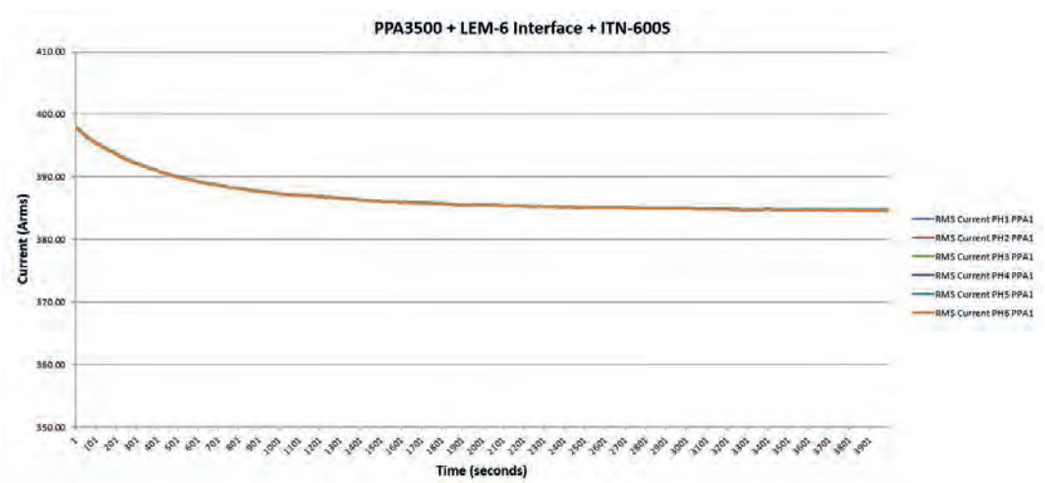

Figure 4: Current over time in a system calibrated with Newtons4th's high-performance interface unit for the LEM series

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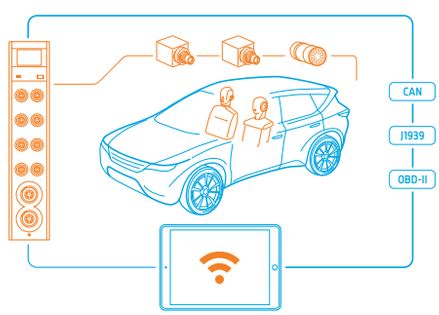

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Smart CVT technology

New beltless variator CVT technology for conventional and electrified applications can assist car makers in fuel economy improvements and drivetrain optimization

With the potential for higher system efficiencies and fuel savings compared with competitive belt technologies, Dana's VariGlide beltless variator is a smart CVT technology for auto manufacturers that are seeking 2025 fuel economy solutions and optimized electrification drivetrain technologies.

The VariGlide variator is a modular, coaxial traction device leveraging the principal of elastrohydrodynamic lubrication. When the contact patch experiences high pressures, the fluid behaves like an elastic solid, enabling reliable torque transfer through the device. Speed ratio is controlled by modulating the relative contact diameters between an input and output ring. The system uses a stable, low-energy skew shifting system to select and maintain desired speed ratio.

VariGlide architecture is unique, robust and simple. Resembling a planetary gear configuration and using traditional bearing-based technologies, the variator is designed as an easily assembled, bolt-in module, which minimizes integration complexity and maximizes assembly robustness. Leveraging bearing-based technology ensures that the life of the unit is predictable for numerous duty cycles and environments, including extreme conditions such as towing. More than 70,000 hours of durability testing have been accumulated.

Developed to resolve challenges associated with traditional belt-based CVTs, the VariGlide variator is easy to control, insensitive to slip-induced damage, and compatible with front-, rear- and all-wheel-drive configurations. The difference relative to belt CVTs is the simple coaxial architecture and the absence of a high-pressure hydraulic pump, which results in high parasitic losses. The VariGlide beltless variator uses an efficient, passive, mechanical cam-based clamping mechanism providing instant response to torque that results in optimum clamping, eliminating the risk of slippage.

Requiring no belts or pulleys, Dana's VariGlide planetary variator is a compact, coaxial, passively clamped device that sets new standards in continuously variable transmission (CVT) fuel economy, and will assist OEMs with drivetrain optimization

With the flexibility to power split in several different configurations, the variator provides a highly efficient transmission solution. The ability to shift rapidly provides added flexibility supporting both seamless and simulated mode shifts as desired by vehicle manufacturers and end customers. With more than 300 power path permutations identified, OEMs can customize and optimize transmission solutions depending on application, market and driveability requirements. This provides packaging, weight and cost benefits, while the bearing-like architecture improves NVH.

With the market shift toward electrification, VariGlide technology has the potential to optimize electric motor operation and maximize total system energy recuperation. By expanding ratio range without the need for a multimode system and subsequent mode shift, the VariGlide variator provides NVH benefits where perceptible mode shifts are not acceptable. For dedicated hybrid transmissions, P2, P4 and battery electric vehicles, VariGlide technology is generating considerable interest from OEMs and Tier 1 suppliers.

At Dana's 45,000ft^2 Texas technology center, customer prototypes are designed, built and tested. This advanced, state-of-the-art facility houses design, analysis, simulation, controls and manufacturing engineers dedicated to refining VariGlide technology for volume production. The on-site test equipment features low-inertia motors with engine firing pulse simulation capabilities to test for real-world system-level conditions. A cold chamber and AWD chassis dynamometer are also available.

This advance leverages more than 700 US and international patents and patent applications. With expertise in automotive innovation and market delivery, Dana's VariGlide technology will have a significant impact on the future of CVTs.

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Battery pack design

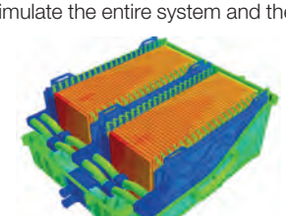
Simulating an electrified powertrain enables sophisticated modeling of battery packs and cooling systems, making it possible to test component design under realistic conditions

Conventional combustion engines alone will not be enough to reach the emissions goals set by the Paris Agreement. New innovative technology is required to achieve these future targets and vehicle electrification could play a key role. This means developing new powertrain designs, with new components such as electric motors, power electronics and battery packs.

The design of the battery pack and its cooling system is complex. First it is necessary to select the cell chemistry and shape to fit the end application. Then, the pack must be sized according to the system power/energy requirements. These provide a good initial understanding of the project, and enable a more detailed analysis of the pack's thermal behavior, which significantly impacts overall performance and aging. It is critical to ensure the pack is operated in favorable and uniform temperature conditions to prevent cell performance heterogeneity.

The pack can then be integrated into the desired powertrain – which has been previously sized according to the energy/power requirements and desired architecture (full, mild or micro-hybrid, or even full electric). In addition, the energy/power trade-off between the battery pack and the other components must be understood to define the optimum drive performance and comfort for the passengers.

One way to achieve this is to simulate the entire system and the detailed components. Here, the starting point is to build the electrified powertrain in LMS Amesim in order to start sizing the appropriate battery to match the power requirements. The pack's electrochemical performance is typically modeled with an equivalent circuit model and configurations can quickly be evaluated. Once a pack has been sized more precisely, it becomes clearer how many cells are required, and analysis of the cell arrangement within the pack, and the cooling system, can start.



STAR-CCM+ detailed 3D pack model

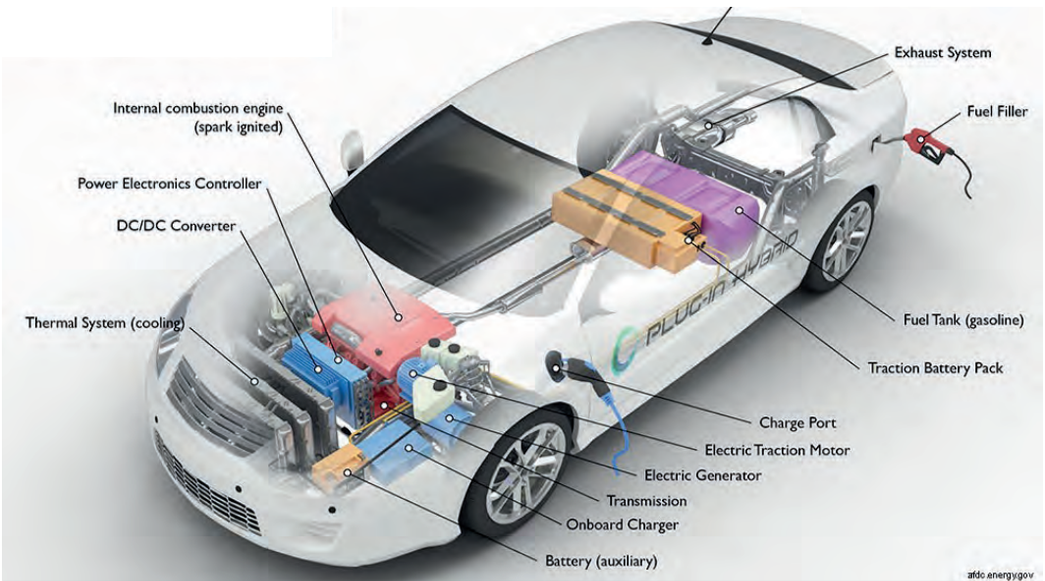
That task requires examination of the problem in more detail, and use of 3D analysis to assess different configuration for cell arrangements and the impact on the temperature behavior – which an appropriately sized cooling system should control, using STAR-CCM+.

Here the pack pre-sizing from LMS Amesim is used to build a 3D representation with all the pack components. Cell electrochemical performance is handled by an equivalent circuit model, used to compute the cell heat generation, which STAR-CCM+ can then turn into temperature distributions. The ability to automatically explore several designs speeds up the design phase of matching the pack and cooling system to requirements for temperature levels and variations, as well as overall pack weight – including cells and all components.

Once a virtual prototype has been achieved, it can be used on various drive cycle conditions to refine the model through exchanging key metrics such as heat generation, voltage and temperature.

The refined full-system model can also be used to validate the pack virtual prototype. In such cases, a co-simulation between LMS Amesim and STAR-CCM+ can be established. The system model of the powertrain is executed under a given drive cycle, climate conditions and activation of the air-conditioning. The battery component is replaced by the co-simulation of the detailed 3D pack model. The system model computes the behavior of all other components and their mutual interactions, and can provide realistic boundary conditions to the STAR-CCM+ simulation of the pack – such as the available coolant temperature and coolant flow rate. This allows for the validation of the 3D virtual prototype under realistic conditions, and assesses whether further changes to the design are needed.

This approach is a unique methodology that can also be deployed in the design of electric machines and help promote innovation in the deployment of efficient and affordable electrified powertrains to the market.



Multidisciplinary simulation allows representation of real-world physics to enable system and component analysis and design

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SiC vehicle components

Now established in the automotive industry, silicon-carbide components are becoming the go-to choice for system performance in plug-in and battery electric vehicles

Over the past few years, a general consensus has emerged within the automotive industry that electrification will shape the mobility of the future. Silicon carbide (SiC) has now established itself as a material of choice to increase the performance of the systems embedded in plug-in hybrid and battery electric vehicles. Already, the first onboard charger systems using SiC diodes are ramping up at a large scale.

The intrinsic physical properties of SiC enable the development of power chips that are smaller, faster and more efficient than traditional silicon components. Besides, this technology has now reached the degree of maturity necessary to enter the automotive market: the latest generation of trench MOSFETs has overcome the issues associated with gate oxide quality. They offer a level of reliability that meets the stringent targets set by the automotive industry.

However, the manufacturing landscape of SiC components is currently not as cost efficient as for silicon-based devices. Firstly, the manufacturing process of SiC substrates is much more complex and prone to higher defect densities and lower yield. Secondly, even if recent improvements have been significant, state-of-the-art front-end processing relies today on 6in wafers, which is still far off the economy of scales realized for traditional silicon (12in wafer size). Therefore, the market introduction of SiC is expected to be progressive and tightly correlated to the benefits provided at system level.

The high-voltage battery will likely remain the most expensive component of the hybrid and BEVs in the coming 10 years. This is even truer for high-autonomy BEVs, which may contain up to 100kWh battery capacity in order to achieve a driving range of 400km or more. A high-efficiency inverter results in fewer thermal losses and in a better use of the energy of the battery. As a result, it enables optimization of the battery size and weight at constant mileage.

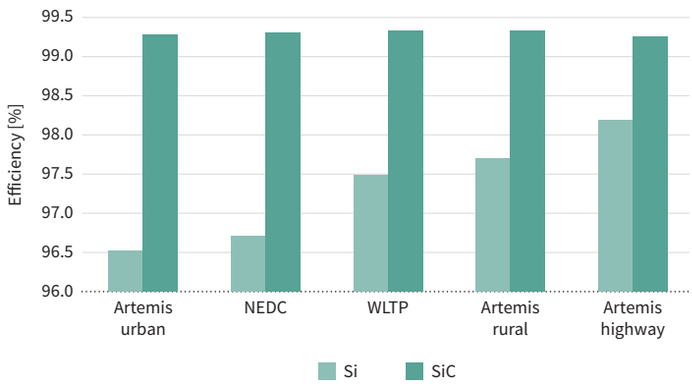

Figure 1: Inverter efficiency comparison for HybridPACK drive in Si and SiC versions

Figure 1 shows an efficiency comparison between a Si and a SiC inverter for different driving cycles: NEDC and WLTP cycles; and driving cycles that aim to simulate close-to-reality conditions (Artemis cycles). A SiC-based inverter can achieve efficiency levels above 99%. Taking into account regeneration, a SiC inverter can increase the driving range of a BEV by 5-10%.

The efficiency improvement is linked first to the fast switching capability of a SiC MOSFET, which may reduce switching losses by 80% compared with IGBT. Even if this potential cannot be fully used in current system implementations due to EMC constraints and parasitic effects, the absence of recovery losses or trail effects at turn-off leads to a significant reduction of dynamic losses. Furthermore, SiC MOSFETs have a resistance-like output characteristic. This makes them particularly efficient in light load conditions. Light load operation represents the most frequent operating condition of the inverter. It is therefore predominant in the derivation of the average efficiency of the system. Figure 2 shows, for example, that an inverter operates at 20% load (or less) for more than 80% of the time.

It is expected that SiC inverters will first deploy in premium BEV platforms, which are characterized by demanding performance requirements, such as power ratings above 200kW and 850V system voltages in order to enable fast charging. This is exactly the field where the benefits of the SiC technology are maximized.

To ease the introduction of SiC inverters, Infineon is developing a full SiC power module based on the scalable HybridPACK drive package suitable for power up to 300kW (Figure 3).

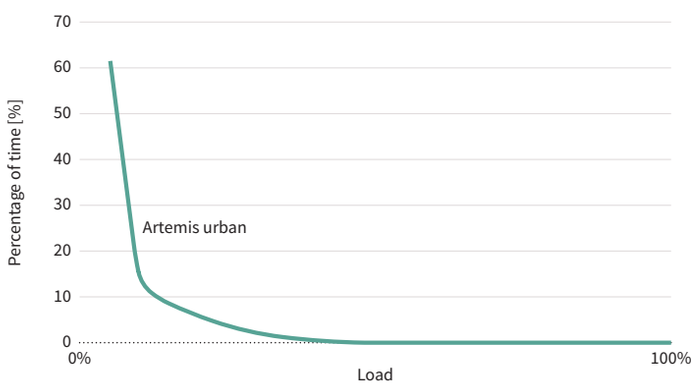

Figure 2: Inverter operation levels in realistic urban driving conditions

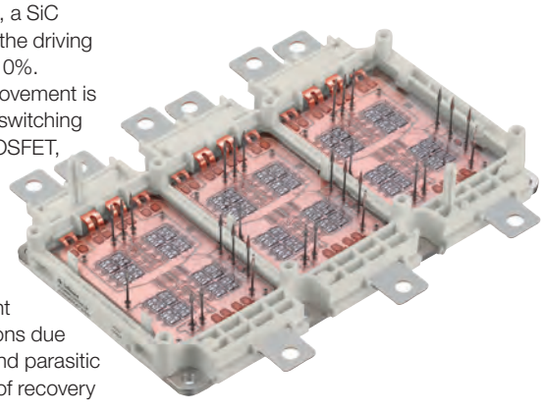

Figure 3: HybridPACK drive CoolSiC

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(e.g. for sensor applications)

Bondjet BJ955/959
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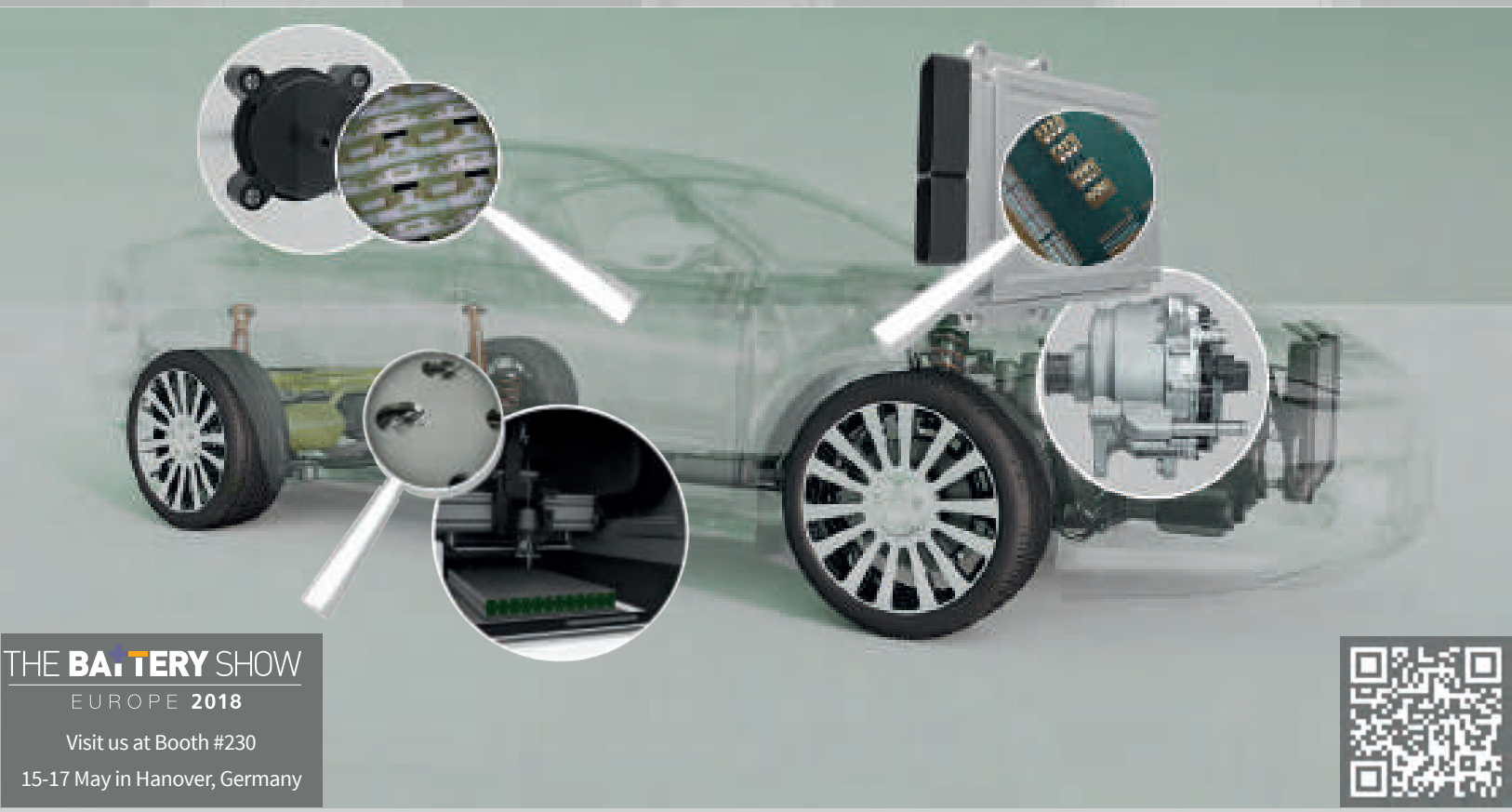

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Hybrid fuel cell powertrain

A demonstration hybrid fuel cell vehicle, developed by a consortium of companies, offers attractive powertrain costs, short refueling times and long driving ranges

The major challenges for future road transportation and the global automotive industry are enabling individual mobility and reducing energy consumption as well as decarbonization. Electric vehicles with battery and fuel cell technology will be a key enabler to meet these challenges. Both technologies offer a complete zero-emissions powertrain approach from tank to wheel, and green electricity from well to wheel. Battery electric vehicles are more suitable for smaller vehicles and short-range (urban) usage, whereas larger vehicles with long driving range and high power demands benefit from the advantages offered by fuel cell technology. So far, the automotive industry has focused on pure battery versus pure fuel cell approaches with a very small battery (<2kWh).

In contrast to these concepts, the transnational project KeyTech4EV – a consortium led by AVL – follows a more innovative approach to hybridization and is currently developing a demonstration fuel cell car. Besides AVL's input, the project also involves ElringKlinger (fuel cell stack), Hörbiger Ventilwerke (hydrogen injector/ejector unit), Magna Steyr & HyCentA Research (hydrogen tank system), Graz University of Technology (stack testing and durability), Vienna University of Technology (stack diagnostics) and IESTA (thermal management).

The KeyTech4EV powertrain concept is a combination of battery and fuel cell technologies in a single dedicated hybridized powertrain architecture, benefitting from all possible synergies available. As such, this conceptual approach is capable of achieving vehicle ranges of more than 600km (370 miles) per fueling and short refilling times of about three minutes. At the same time, overall powertrain costs are reduced in comparison to those of pure fuel cell and battery EVs.

Integration of AVL fuel cell technology helps the KeyTech4EV hybrid vehicle demonstrator achieve the project's targets

To meet the performance and cost targets of the onboard hydrogen storage, the tank system is simplified by optimizing the system layout and functional integration of single components or features into integrated components. This results in a reduction of the tank weight, number of parts, and therefore system assembly time and cost.

Innovative technologies are implemented into the vehicle, with particular focus on maximizing the energy efficiency of the electrified powertrain. For this, all main components of the hybrid powertrain – for example, the fuel cell system, e-drive, power electronics and controls – are developed based on the extensive engineering knowledge of AVL. In order to increase the efficiency of the fuel cell system, the implementation of improved balance of plant (BoP) components is a prerequisite. A reduced power consumption of the BoP components is achieved by integrating a special air compressor and a passive hydrogen recirculation unit (injector/ejector system) into the respective fuel cell system. As a result, the overall fuel cell stack size is reduced, while maintaining a high gross power output. As an additional measure to increase the energy efficiency of the demonstrator, the e-drive is balanced to reduce the number of components, conversion losses, and system weight.

To ensure high vehicle efficiency, along with increased range, and better performance and driveability, it is necessary to implement functional and sophisticated vehicle and system controls and calibration. Therefore, the knowledge of the current state-of-health and the functionality of these components (especially that of the fuel cell stack) is important. The demonstrator vehicle benefits from a non-intrusive online monitoring and diagnosis approach in combination with regular fuel cell vehicle sensors.

The KeyTech4EV project's approach toward a hybridized fuel cell vehicle overcomes the current barriers of electromobility as the driveability performance and targets of the series version of the selected vehicle platform – including the vehicle's climbing performance – can be met.

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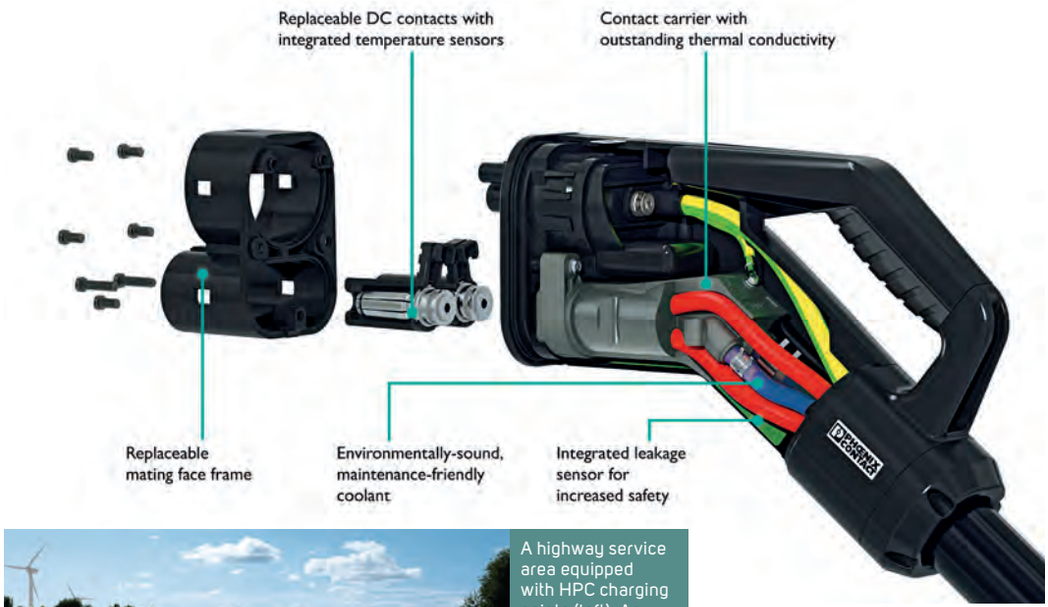
High-speed charging

A rapid, high-performance vehicle charging system features intelligent cooling, and will play an important role in the greater uptake of electromobility that suits everyday use

Drivers and electric vehicle manufacturers are demanding ever shorter charging times, as these contribute considerably to a vehicle's suitability for everyday use and to the acceptance of electromobility in society. With its High Power Charging (HPC) system, Phoenix Contact has developed a technology that charges a battery for a range of 100km in just three to five minutes. The heart of this technology is a high-performance charging connector with intelligent cooling that enables a charging current of up to 500A.

Until now, charging currents of up to 200A were technically possible with the Combined Charging System (CCS). Considerably higher currents are necessary, however, to achieve markedly short charging times. Conventional charging technology would result in dangerous levels of overheating – or would require larger, cumbersome cable diameters.

Phoenix Contact's HPC technology is based on an active cooling system that makes charging currents of up to 500A possible, without compromising on safety or manageability. Using the maximum system voltage of 1,000V, this means a charging power of 500,000W. For the coolant, an environmentally sound and maintenance-friendly water-glycol mixture is used. This cools both the charging cable and the DC power contacts in the vehicle connector. The contact carrier also acts as a heatsink, thanks to its outstanding thermal conductivity. Integrated temperature sensors measure the development of heat in real time – directly at every DC contact and in the cable. A controller evaluates this data and regulates the cooling output accordingly. This prevents overheating and, at the same time, increases the energy efficiency of the cooling system.



A highway service area equipped with HPC charging points (left). An internal view of Phoenix Contact's HPC connector (shown above) reveals the high-speed charging technology's key components and features

Based on the established CCS for Europe and North America, the HPC vehicle connector is completely CCS-compatible. Furthermore, it is easy to maintain, as the mating face frame and the DC contacts can be easily exchanged, in the event of damage, without needing to drain the coolant. Thanks to integrated temperature sensors and a leakage sensor, the charging process is especially safe.

The HPC system includes several components in its delivery scope. In addition to the vehicle connector and charging cable, it includes a cooling unit coordinated with the charging station dimensions, as well as a standard controller for the cooling system. Moreover, a special cable entry with strain relief is offered for connecting the cooled charging cable to the charging station.

Typical applications of the HPC system are public or commercial charging parks, for example in highway rest areas, where the driver of an EV has only a limited amount of time. Here, the cooling system and the controller are usually centrally located. While separate, the decentralized charging points are supplied with coolant and only have individual heat exchangers. However, it is also possible to install the HPC system in standalone charging stations, in which the cooling system and controller are integrated. The system's modular design provides a high degree of flexibility for developing an individual HPC infrastructure.

Of course, besides ultra-fast charging technology, there are further requirements to be fulfilled within the coming years to make such an infrastructure work. For example, energy providers and charging park operators will develop new supply concepts for the high energy demand of HPC applications, also considering renewable energies. Furthermore, car manufacturers will release new models whose batteries are compatible with charging currents of up to 500A. However, with its HPC system, Phoenix Contact lays the cornerstone for particularly short charging times on the highway, which is one key factor for the breakthrough of electromobility.

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Integrated development

Adopting a holistic scenario-planning approach to powertrain electrification can lead to smarter organization – and can help clients work towards smarter electrification

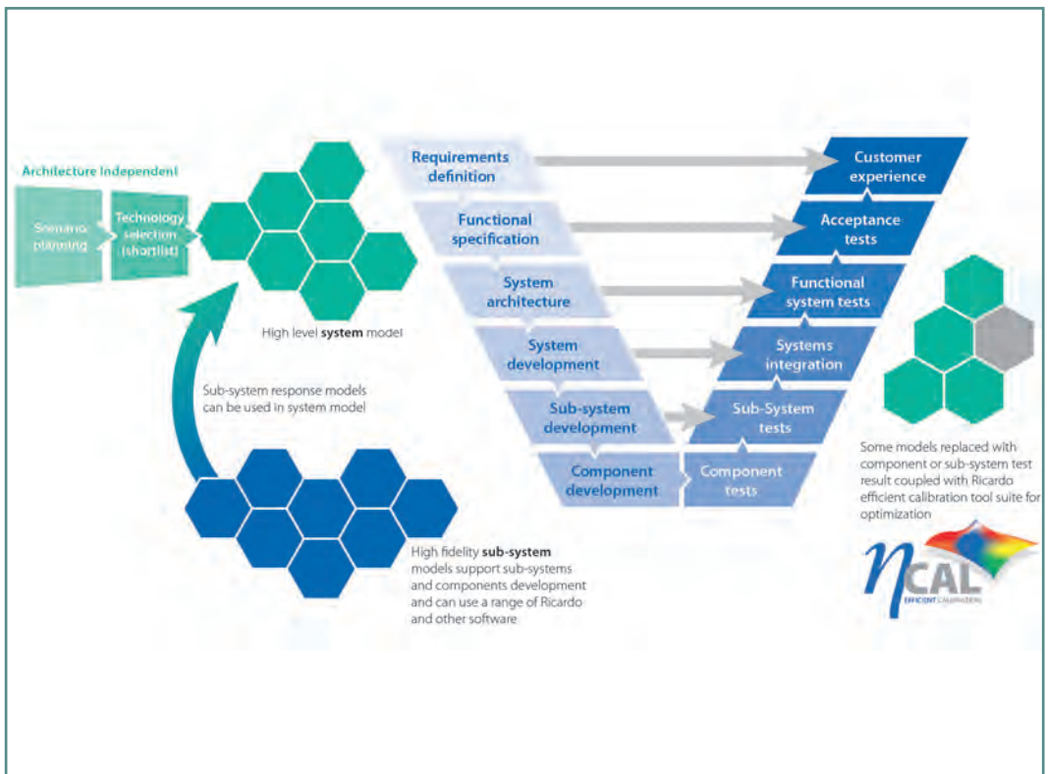
Long-term success in response to the drivers for electrification will be determined by selecting an appropriate strategic technology direction, and also by incorporating the requisite toolsets and skills into an organization in an effective manner.

Ricardo helps its clients with strategic planning. Deciding what electrified products to pursue, and mapping technology development trajectories, are areas in which Ricardo Strategic Consulting's (RSC) Technology Strategy team provides support. The Technology Strategy team has a long history of assisting clients in building strategic and technology roadmaps, enabling an understanding of industry landscapes, and facilitating planning a technology direction. Ricardo also continues to innovate. For example, RSC is currently working on a scenario-planning process, one that was originally developed to help organizations make flexible, robust long-term plans, for application to technology selection. This starts by creating plausible future worlds, uses workshops with technical specialists to capture products and services that would be successful in these future environments, before focusing on a robust shortlist of technologies to test in simulation activities.

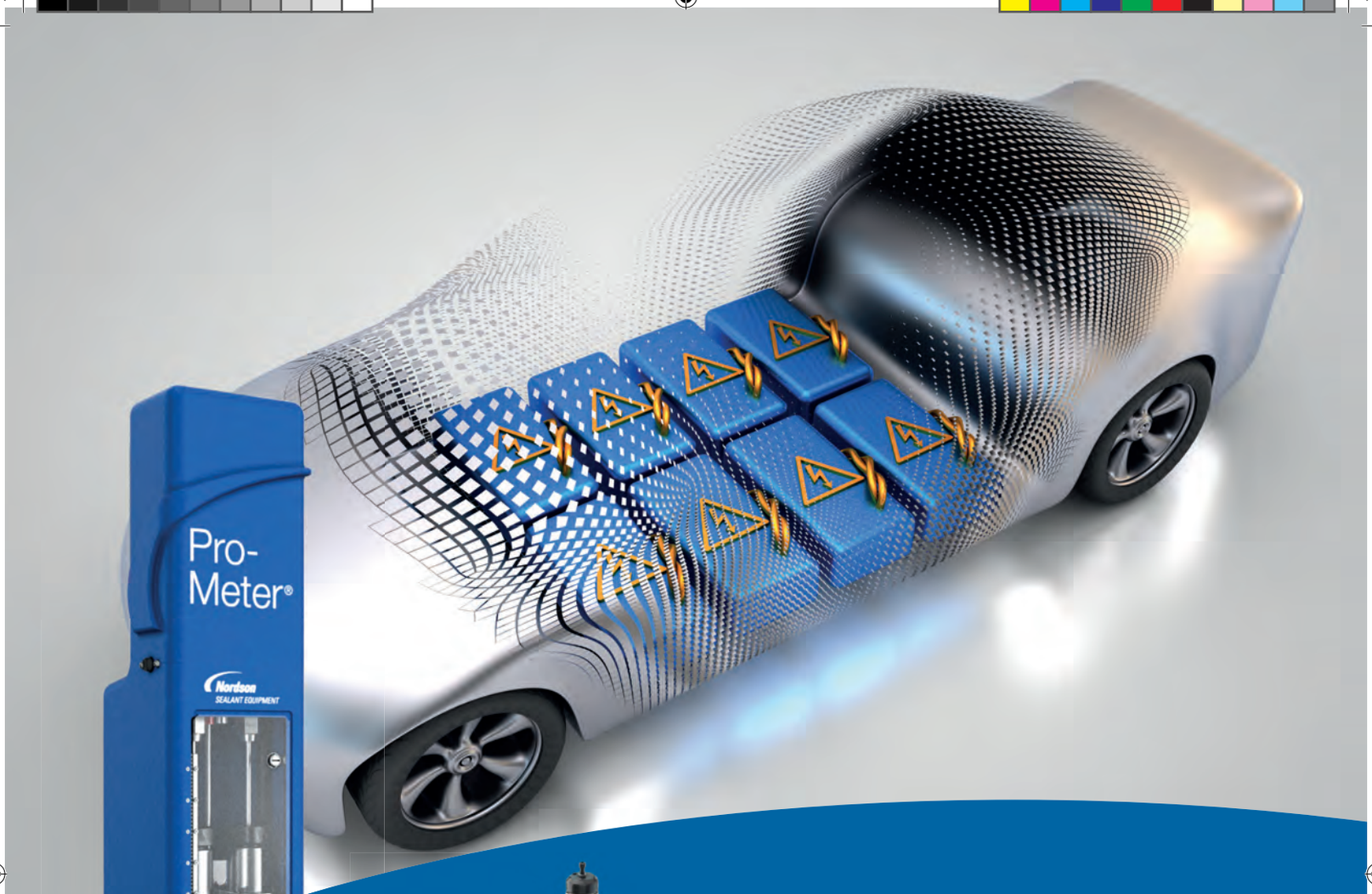
Ricardo is also developing an integrated, holistic approach to powertrain electrification. The company believes future product development must be not only flexible, but also highly integrated.

The first pillar of Ricardo's R-Intellect (Integrated Electrification) approach centers on improving system engineering. In many organizations, powertrain development remains a resolutely siloed activity, with engineering effort focused on functional specialism. The behavior of a vehicle – acceleration, braking, and so on – is governed by myriad subsystem behaviors, and, crucially, by their interactions. With increasing electrification, the complexity of subsystem interactions increases. For example, effective braking in a mild or full hybrid vehicle involves effectively blending traditional braking and regenerative braking. Ricardo refers to the product development discipline that optimizes these subsystems collectively as 'functional system engineering'. The company believes that growing a functional engineering capability is critical to the successful and efficient integration of electrified powertrain product development. Thus, Ricardo's R-Intellect tool provides an additional layer above traditional organizational delineations (for example, engine, transmission, chassis), enabling an organization to strengthen its functional system engineering activities.

The second pillar centers on simulation architecture. In parallel with functional system engineering, Ricardo has developed integrated simulation tools. Ricardo's integrated model-based development (IMBD) environment provides a framework for the exchange of data and information between analysis and simulation operations, and offers a hierarchy of tools that can be applied through the development 'V-cycle' (Figure 1). As each new product program is initiated, an experienced team defines the optimum modeling approach for each step of the process. Crucially, the IMBD environment manages subsystem models flexibly. As the development cycle progresses, subsystem modeling data used in high-level system models can be replaced by actual test results.



Ricardo Integrated Model Based Development (IMBD): A high-level system model that is continuously refined through product development by increasingly detailed sub-system modeling and results gathered from testing



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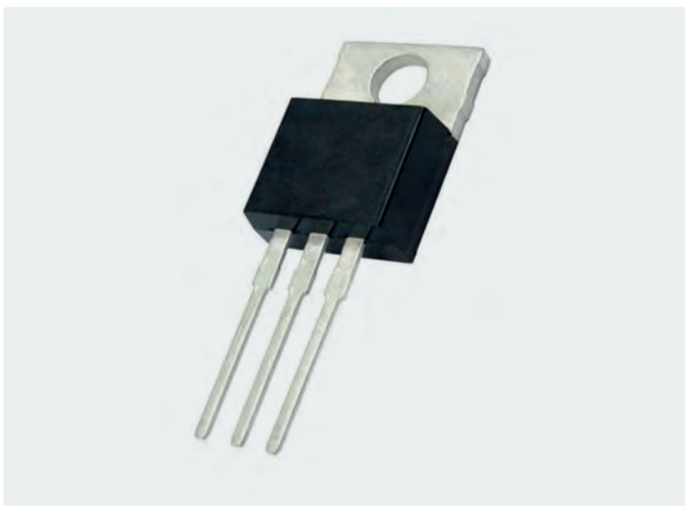
Semiconductor materials

Wide bandgap semiconductors have a pivotal role to play in hybrid and electric vehicle designs, and on greater uptake of electrified motoring

Concerns about the environment, limited oil reserves and international legislation are all giving considerable impetus to the migration away from ICE-based automobiles, but market penetration of the alternatives to this are still relatively low. Greater uptake of electric and hybrid-electric vehicles is very much dependent on advances within the powertrain over the course of the next few years. The major obstacles that automotive manufacturers face when it comes to making EV technology more appealing are the range that vehicles can travel between recharges and the price premium currently associated with them. Both of these issues stem directly from the powertrain – in particular the power inverter element.

The heightened price tags that come with EVs are mainly down to the financial outlay needed from the car manufacturer for power inverters. By ramping up the power efficiency levels that power inverters can support, these items can be made more compact and cost-effective. It is expected that the emergence of both gallium nitride (GaN) and silicon carbide (SiC) will enable new performance benchmarks to be set, way beyond what conventional silicon (Si) is capable of. These wide bandgap semiconductor materials are equipped to deliver much higher switching speeds and enhanced power conversion capabilities than Si devices, as well as supporting larger breakdown voltages. All this is thanks to the greater electron mobility and smaller on-resistance figures they possess. An additional benefit is that they will also enable power inverters that are more lightweight. As a consequence, vehicles that use them will be able to cover further distances before they need to be recharged (since less strain will be placed on their battery resources when providing vehicle propulsion).

Above: The GS6650x series of GaN-based transistors from GaN Systems
Below: ON Semiconductor's NTP8G202N GaN cascode transistor



Because their power losses are lower, the associated thermal management that GaN/SiC devices require is significantly less. As a result, the heatsinks used do not need to be as big as they previously would have been. Again, this has effects in terms of both the cost and weight (which also translate into improvements in the vehicle's average range and a curbing of its overall expense).

Helping in the progression toward greater EV proliferation, the devices comprised within the GeneSiC GA100SICseries integrate SiC rectifiers with ultra-low IGBTs. As they use SiC-based Schottky diodes, rather than conventional Si-based freewheeling ones, these components can deliver industry-leading switching characteristics.

GaN Systems' GS6650x series transistor devices eliminate the need for space-consuming bus bars in EV designs. The company's proprietary Island Technology means that these 650V-rated GaN-based components can draw current off the chip vertically, thereby lowering inductance losses and providing stronger Figure of Merit (FoM) values. Accordingly, engineers are no longer forced to make such big compromises when it comes to balancing the saturation voltage with switching losses.

For use in next-generation EV motor drives, the NTP8G202N from ON Semiconductor is a 600V transistor with an on-resistance of just 290mΩ (typical) when operating at 10V. This compact device, which is housed in a TO-220 package for easier integration, enables faster switching speeds and higher degrees of power efficiency to be derived from the power system it is incorporated into.

Thanks to the accelerated switching speeds and elevated voltages they support, power discretes based on wide bandgap materials are now enabling the deployment of more efficient powertrains in electric vehicles. Innovative new components, such as those described here, will be instrumental in ensuring greater market acceptance of EVs in the coming decades, and will have a huge impact on the long-term future of the automotive industry.

MOSFET inverters

A new line of inverters can deliver the current levels needed to power 48V applications without associated space requirements and mounting complexity

Safe and convenient battery-powered electrification and automatization of vehicles and auxiliary functions continues to be a key focus for the automotive sector. The power levels required may vary between a few and several hundred kilowatts. While for high-power applications, operating voltages of 300-900V are the only choice, the lower end of the spectrum is best addressed by low-voltage applications of 12, 24 or 48V.

At voltages below 60V, many functions can be provided without the need for high-voltage systems – and the associated cost of added isolation and protection features. In China, more than 400,000 electrified vehicles are built each year, with many of them operating below 60V. Applications for other industries, such as battery-powered pumps, winches or even boats, are also on their way.

Driven by adoption within the automotive industry, 48V systems are migrating into neighboring industrial applications, which are taking advantage of the growing number of available components for a 48V drivetrain. But power is an issue. Today's 48V automotive designs typically top out at 10kW output power. However, many applications need between 15kW and 40kW of power to move their application. This can be achieved by a separate motor plus inverter – a bulky solution, but the technology is available.

Figure 1: SKAI3 inverter with standard case

To become attractive, solutions must become smaller. This means reduction in the size of individual elements – motor and inverter.

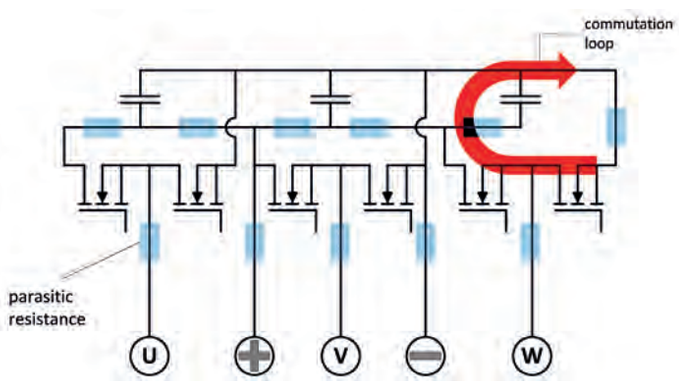


Figure 2: Critical design-elements for MOSFET inverters

Ideally, the two elements form a single integrated piece, minimizing both space requirements and mounting complexity.

In the 48V power range, inverters are very often larger than the motors. A key issue is to reduce the size of the inverter, so it can be brought closer to the motor, ideally through direct attachment.

So why not take the existing inverter building blocks and put them together as needed to meet space requirements? The main answer is that, for MOSFET inverters, it is not enough to put individual components together, especially when power above 10kW or currents above 250A_{rms} are needed. The combination of high currents and low voltages requires good control of the electrical parasitics. The lack of MOSFET modules – as compared with standard IGBT modules – indicates the need for higher integration in MOSFET inverters. With MOSFET resistances below 1mΩ, the power distribution of the inverter must become shorter, using high-cross-section bars and cables to effectively reduce the conduction losses. But switching losses cannot be addressed by increased investment in silicon and copper.

The key element is the parasitic induction in the commutation loop of the inverter formed between the bus capacitors and the switches. Physically minimizing this loop will also minimize it electrically – bringing the bus capacitors as close to the switches as possible is the best way to reduce parasitic induction (Figure 2).

As a result, the application needs and design needs of the inverter go in the same direction. A smaller inverter becomes more efficient and can be integrated more easily.

With the new SKAI3 MOSFET inverters (Figure 1) Semikron has addressed this need. Built from an optimized power core – consisting of the power switches, bus capacitance, power distribution and gate driver – the complete inverter can deliver more than 500A_{rms} at an overall volume of less than 1.7 liters. The inverters are available for 48V (<60V), 48V (<72V) and 80V (<119V). A future extension for battery voltages of 144V (<180V) is planned by the company.

The SKAI3 is designed for easy mechanical integration in compact drive systems. By utilizing a case, protection for standard side-by-side mounting is provided, but the system is also available without a protective cover, similar to a MOSFET module, enabling optimized and compact integration in a customized design.

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Supervisory controllers

A sophisticated new electric and hybrid vehicle supervisory ECU offers ASIL D-level functional safety and system cost savings

Electric and hybrid vehicle systems require sophisticated supervisory control to deliver superior overall performance. Pi Innovo has developed the M560 OpenECU controller, utilizing ASIL D-level processes to meet the key functional safety requirements needed for drive-by-wire high-voltage vehicle systems.

Since the M560 is designed to be used in almost any EV or HEV system, Pi Innovo provides documentation describing how the M560 controller should be applied as a Safety Element out of Context (SEooC), in a system, and for system hazards, for which it wasn't originally designed. By satisfying these requirements, vehicle system engineers can address ASIL D hazards, which is the likely situation for overall vehicle control units.

The M560 controller provides robust communication options. The 112 pins of flexible I/O are well suited to EV and PHEV system architectures, while the integrated EVSE interface control covers all global charging standards (J1772 [CCS], China GB/T and CHAdeMO). This enables potential savings and one less controller in the overall system. The four CANbuses work in the most complex of system architectures, while the production-proven OpenECU model-based control development platform supports communication protocols such as UDS and J1939. Vehicle manufacturers can interface with the M560's OpenECU platform using their preferred service diagnostic tools, through the regulatory compliant OBD data management infrastructure. Additional auxiliary I/O is well matched to the sensors and actuators, such as system contactors and plug-in charge doors that hybrid and electric vehicle systems use.

A version of the M560 can also be applied in 24V systems for pure electric vehicles, where a regulated supply is available, so it can be used for transit buses and other commercial vehicles operating at this system voltage. Much of the I/O that M560 offers is customizable, making it ideal for development programs where the system architecture is evolving.

Customization is possible and costs can be reduced thanks to the system's fully scalable architecture. Functionality that is not required can be removed from the module prior to the program moving to production. For modest annual volumes, the integrated EVSE interface circuitry can be removed, if it is not applicable for the vehicle in question. Thanks to Pi Innovo's partnership with electronics manufacturer TTM Technologies, higher volume and custom variants of the M560 controller can be produced and delivered to OEMs with the quality and professionalism that is expected of a world-class Tier 1 supplier.

Pi Innovo can supply Simulink model-based vehicle supervisory control strategies to help accelerate system development, which are suitable for basic vehicle operations, or as a starting-off point for full production functionality. Later in 2018, additional model-based control strategies will add more features, bringing Pi Innovo's application offering one step closer to a full production solution. The OpenECU technology roadmap also includes support for Ethernet connectivity, and features that facilitate integration with ADAS and fully autonomous driving solutions.

Due to its customizable I/O, advanced microprocessor, safety oriented architecture and user-friendly OpenECU Simulink application interface, the M560 is a versatile supervisory ECU designed for rapid controls prototyping development to volume production applications.

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High-voltage distribution

A range of reliable, customizable and modular units ensures safe power distribution between all high-voltage components in any electric vehicle

Special and commercial vehicles, including trucks, buses and construction vehicles, are moving to the forefront of electric mobility. Local environmental regulations, as well as the need for greater efficiency and profitability, have driven development of these vehicles. However, a number of key challenges are apparent, including high board power and charging currents, stringent materials requirements, safety concerns and harsh operating environments.

Huber+Suhner, a leading global manufacturer of components and systems for electrical and optical connectivity, has developed highly reliable high-voltage distribution units (HVDU) to tackle these challenges. The HVDUs are designed and manufactured to meet the demands of the customer to ensure an easy assembly process. As standard, HVDUs are EMC protected, have low electrical resistance, meet the IP6K9K and IP67 ingress protection standards and contain an interlock protection system, which turns off the high-voltage battery when the lid is opened. Additional safety features can also be incorporated, such as an isolation monitor, which detects any drop in resistance and shuts down the high-voltage system accordingly, or actively discharges the threat to protect service staff.

Depending on the requirements of the customer, the units can be equipped with capacitors, fuses, an insulation monitor, an inertia switch, an active discharging unit and contactors. Furthermore, the dimensions of the lightweight aluminum housing are variable according to customer needs. The HVDU is supplied with a voltage rating of 850V (DC) and an operating voltage of 400-1,000V (DC). It processes a power range of 50-800kW and fits cable sizes from 2.5-95mm^2. With an ambient temperature range from -40°C to 85°C, the unit meets all current automotive standards.

A modular HVDU (MHVDU) is also available. This variant enables the customer to assemble an HVDU by selecting from a wide portfolio of standardized components. This results in a simplified and harmonized solution designed for individual requirements. The final dimension of the housing is dependent on the selected elements. Thanks to its modular combination of standardized components, the Huber+Suhner, MHVDU can be developed at short notice and reasonable pricing.

For those who require an even higher level of customization of components and functionality, the company offers the customized HVDU (CHVDU). This version is completely custom-made to meet the specifications of the customer, whether that is in terms of the components required or the final shape of the unit.

Huber+Suhner's solutions are in use today in cars, trucks, buses and specialized vehicles such as snow groomers, providing safe interconnections between all high-voltage components in the vehicle, including motors, inverters, batteries, chargers, DC/DC converters and compressors.

Above: Huber+Suhner offers a range of reliable, modular and customizable high-voltage distribution units

Left: Systems are suitable for any EV where high-voltage distribution is required within the onboard systems

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INQUIRY NO. 513

Efficient system modeling

Model-based development enables early-process testing, optimization studies, integration of multi-domain systems and application of multiple system expertise in a single model

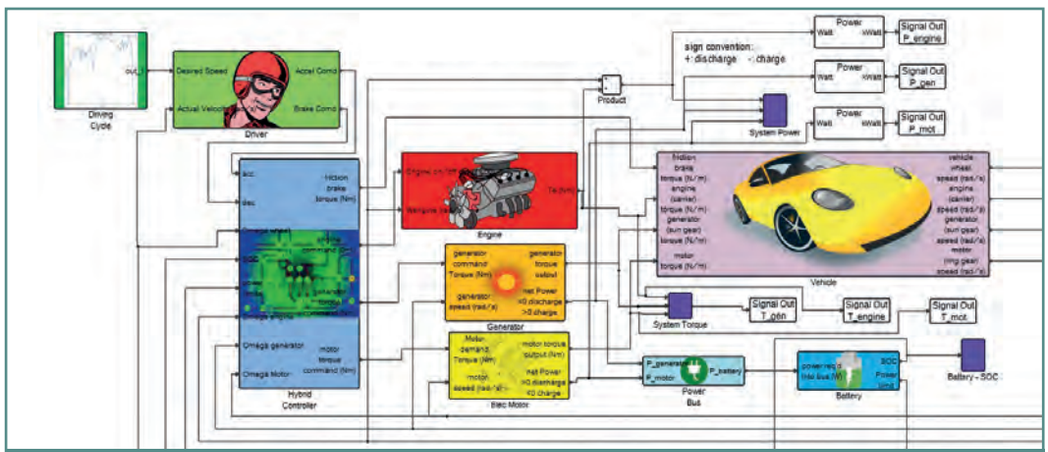
The electrification of vehicles is poised to transform the transportation industry, but reaching the goals for the next generation of vehicles will require advancement in many technologies. How can these increasingly complex systems – integrating battery and energy management equipment, electric drive and safety systems – be built to time and budget constraints, while meeting customer requirements for performance, reliability and quality?

Model-based development is a process that helps to manage and reduce the risk of creating complex systems. This process relies on simulation models and flows from abstract to the specific, which means that design starts at a high level with system-level requirements, and flows from functional to detailed system models and component models, and back up to implementation through testing.

This approach pays dividends by providing many benefits, such as testing designs earlier in the design process, performing optimization studies with parametric models, integrating multi-domain systems in an open environment, or leveraging the knowledge of different systems into one model.

Depending on the stage of design, engineers may require different levels of model fidelity and use either 1D or 3D simulation tools, or both. For example, system models can help in the design process of electrified vehicles with supervisory control for fuel economy and electric machine design and controls. These two aspects of vehicle development are interdependent, as both a supervisory controller and the motor controllers must all work efficiently to achieve the highest levels of performance.

For the supervisory control design for hybrid vehicles, a key goal is to determine how best to use power sources – the ICE and one or more motor/generators – to efficiently use fuel and electric energy stored in the battery at desired levels of performance. Early on in the design process, designers may create system simulation models of the complete vehicle, including simplified vehicle loads and abstracted components, to represent how the vehicle behaves during a drive cycle. This can be used to evaluate vehicle topology, perform component sizing, and set subsystem requirements.



An example of model-based development, shown here in relation to the complex systems in a hybrid vehicle powertrain

While some components are simplified, they must contain enough detail for longer drive cycles used to evaluate powertrain efficiency – as compared with detailed (for example, FE, multibody, CFD) 3D models, which may provide more accuracy but require longer solving time.

A controller and motor is built within SolidThinking Activate to study the motor behavior and design the controller as desired.

The electric drive is a key component of the electrified powertrain, and the challenges of designing these systems are application specific. Two strategic subsystems in the hybrid simulation model are the motor controller and the electric machine. The motor controller has a large effect on the motor behavior. To control the motor, field-oriented (vector) control is often used, providing a robust method to control the torque efficiently.

Different types of representations can be integrated in an Activate system. The 'Park' motor model simplified equations offer quick estimation, but fidelity is lower compared to using a tool such as Flux where it is possible to capture non-linear effects including saturation and losses, with a full co-simulation of a finite element electromagnetic model for detailed motor design. An interesting alternative to study the motor and controller behavior is using Flux to generate an equivalent reduced order model which can be represented by look-up tables in Activate: once the tables are generated from Flux, it is much faster while still providing accurate results, which may be helpful for analyses with long drives cycles. Representing complex products may require additional system integration with other tools to provide greater model fidelity. SolidThinking Activate supports native co-simulation with other Altair tools – including MotionSolve for multibody system simulation and external tools such as VI-Grade CarRealTime for real-time chassis simulation – and supports the Functional Mock-up Interface (FMI) where over 100 tools such as MapleSim, DSH+, CarSim and others are available to create multi-domain system models.

Altair's broad and deep solution spans detailed 3D domains and now includes 0D/1D math and system to help leverage the right tools to meet the challenge in designing electric machines in complex systems. Integration of these tools and others enables the model-based design process to bring together the multi-domain teams needed to build the next generation of electrified vehicles.

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INQUIRY NO. 514

Driving 48V applications

As research and development continue to advance 48V technology, innovative solutions are emerging to address the anticipated high volumes of testing

As fuel regulations continue to tighten and emissions targets increase, automotive manufacturers are turning to high-efficiency electronic components to replace traditional, less efficient systems. As well as performance, vehicle manufacturers are packing in more power-hungry electronic convenience features with their launch strategies. Needless to say, with onboard electrical systems demanding more power, the go-to 12V automotive electrical system has reached its serviceable 3kW limit.

The solution is the newly introduced LV148 automotive standard, already in use by manufacturers in Europe, which integrates a much-needed 48V bus with the 12V system. Packaged in three components – a starter generator, DC/DC converter and a high-voltage battery – this augment in power is what automotive manufacturers need to design power-hungry technologies into their hybrids to meet stringent CO_2 targets and fuel economy regulations (Figure 1). Once the 48V system is in place, manufacturers will be quick to layer more electronics on board, including computers, cameras, infotainment, and radar and lidar sensors. For the supply chain, this provides big challenges for testing and opportunities to design new tech.

To assist automotive R&D and help test engineers tackle the predicted high volumes of 48V applications, Chroma provides two innovative solutions. The first is a new 100V DC power supply, 62150H-100P, with a constant power envelope feature that supports wider voltage ranges up to 100V and output of up to 15kW. The second is Chroma's 17020/A170202 battery simulator, used in place of the battery to provide more versatile testing for products such as motor drivers or DC/DC converters. The 17020/A170202 is a regenerative hardware and software package that delivers dynamic current charge and discharge simulation.

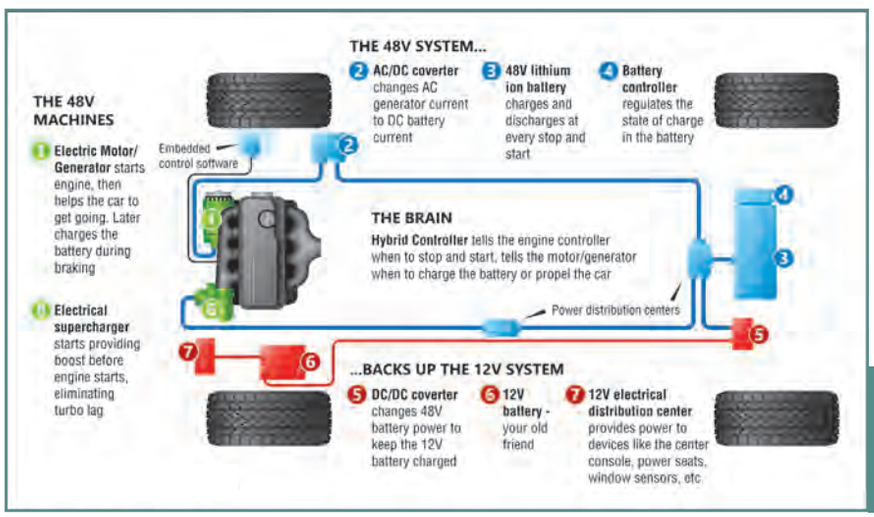

Image: HIS Automotive and Delphi Automotive

Figure 1: A typical 48V system using regenerative braking and stop/start

Designed to support LV148 standards, the 62150H-100P is well-equipped to test new 48V stop/start vehicle electrical systems, as well as implemented features such as regenerative braking and electronic power assistance. The 62150H-100P can provide plenty of output power (up to 150kW) when set up in parallel. Chroma's constant power envelope provides a wide voltage and current range that allows the unit to operate at full power at different voltage set points (Figure 2). It has active current sharing and fast transient response functions with active PFC to put low energy consumption and high conversion efficiency into effect.

The direct current power supply's voltage slew rate control is from 0.001V/ms to 5V/ms and can integrate with an automatic programming mode to meet the needs of 48V automotive electronic system testing. The company also incorporates the ISO 16750-2, VW 80000 and GS 95024-2 international automotive electronics standards into the GUI, Softpanel, to help speed up the development and testing stages.

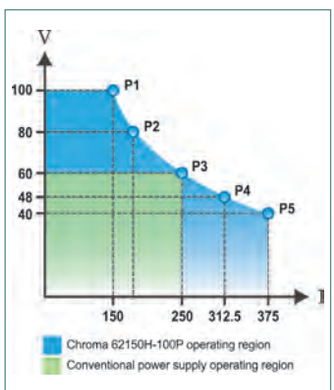

Figure 2: Power supply operating with Chroma's Constant Power Envelope

The 17020 (hardware) and A170202 (software) is a regenerative battery simulator test system ideal for battery connected devices of 48V systems. When a connected device is under development, the 17020 can simulate the battery to verify if the device is functioning as designed.

In addition, the 17020 can control the SoC status of different batteries. Users can upload required battery curves to the software to test the DUT for charge and discharge status. The 17020 can also perform battery and DUT collocation evaluation tests in advance that apply to the motor driver for vehicle stop/start systems, light EV electronic controllers, car-mounted chargers, and so on.

As for 48V applications, emission-reducing features such as e-boosting and ADAS lead the way. However, the 48V bus will power active chassis systems, electric superchargers and turbos, air-conditioning compressors, regenerative braking and adjustable suspensions, as well as other heavy load components.

Innovating electrification

Continued development of connected vehicles depends on smooth signal, data and energy flows – and the interconnection technology and sensors to provide them

Networking electronic systems within the car and connecting the vehicle to its environment and the internet is the future for safe, comfortable and efficient driving. Already, modern vehicles are rolling networks built around the flows of signals, data and electric energy. This trend will further accelerate as automated driving, electrification and connected car technology advance.

As a leading specialist in interconnection technology and sensors, TE Connectivity (TE) is developing high-performance products, especially designed for automotive applications. Decades of innovation in this field have led to a comprehensive TE portfolio that is appreciated by car makers, Tier 1 suppliers and cabling experts around the globe. TE solutions span everything from connecting the finest of stranded wires with as little as 0.13mm² cross-section up to traction power interconnection technology and automotive contactors. TE also provides the sensors that deliver crucial information on processes, states, positions and speeds. The company and its solutions are renowned for meeting and exceeding the most demanding requirements toward ruggedness, precision, reliability, top-notch electrical and mechanical performance, leading-edge miniaturization, production to the most exacting quality standards, and continuous product innovation. Applications cover everything from contacting a single sensor, to the modular and scalable MATEnet interconnection system, implemented as a backbone for using high-bandwidth automotive-grade Ethernet technology.

Connected vehicles of the future will depend on smooth signal, data and energy flows. With a broad product portfolio, TE Connectivity offers auto makers, Tier 1 suppliers and cabling experts the benefit of its extensive industry experience

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One key advantage of electric energy in the vehicle is that it can be used in such a large number of different ways. This versatility has led to a multitude of powertrain architectures with different voltage levels and functional content. Varying dual-voltage architectures (12V DC/48V DC and 12V DC/400V DC hybrid cars) and pure battery electric-powered vehicles all require new and specific interconnection solutions.

TE develops interconnection technology for the whole choice of complex energy flows within the differing voltage levels. High-voltage contactors and relays complete the connectors.

One of the main challenges of contacting high voltages is the danger of arcing and contact welding. The design of the new TE automotive contactor EVC 250-800 provides a safe solution for up to 900V DC in hybrid and electric applications. Smart AMP+ HVA connector systems with optimized shielding, safety, creepage and clearance distances ensure the free flow of power to its destination.

Recharging the traction battery of an electric or hybrid car is a crucial element of powertrain electrification. Charging cables in particular have a direct influence on the acceptance of electrified driving because the vehicle availability depends on the cable.

TE's third generation of charging cables, which features compliance with IEC 62752, offers an even more robust design in terms of mechanical influences and sealing requirements. TE's next-generation CCS inlet types meet OEM requirements for fast-charging inlets, enabling the batteries of plug-in hybrid and battery electric vehicles to charge in just a few minutes. Together with the charging inlet portfolio, TE offers a complete charging system, which sustains the development of hybrid and electric vehicle technology. Both new-generation charging products will launch in 2018.

TE Connectivity is contributing to the creation of a safer, sustainable, productive and connected future. Connectivity technology for the vehicle powertrain reaches into every corner of the company's engineering history and is integral to its broad portfolio of products and capabilities.

Products and solutions from global TE laboratories, test centers and factories help to faster revolutionize the control architecture, sensing, and safe power distribution of the highly efficient powertrains that will be part of the connected vehicle. To provide this service, TE relies on advanced materials, deep contact physics expertise, miniaturization know-how, and new power and data architectures to help auto manufacturers achieve their desired solutions.

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INQUIRY NO. 516

Precision battery tests

A higher degree of measurement precision will lead to new discoveries and characterization metrics in the energy storage industry, and will have a major impact on the EV market

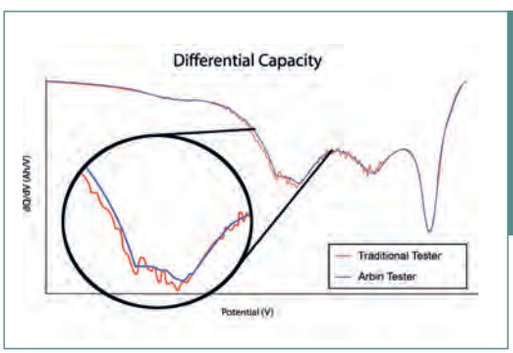
Arbin Instruments, the Ford Motor Company and Sandia National Lab recently completed an ARPA-E project to develop a high-precision battery test station. The goal of the project was to develop a testing system capable of 50ppm coulombic efficiency precision that will enable users to see degradation mechanisms more clearly on a full-scale cell under real-world conditions.

The need for this type of equipment was highlighted in a recently published paper entitled *The Importance of Coulombic Efficiency Measurements in R&D Efforts to Obtain Long-Lived Li-ion Batteries*, published by Dr Jeff Dahn et al, describing how the results obtained from ultra-high precision test equipment uncover key battery life trends that can be missed or overlooked using conventional test equipment. The need for high-precision test equipment drove Arbin to develop testing systems capable of 50ppm coulombic efficiency precision for systems ranging from 100mA to 5A for cell development, up to 200A for full-scale testing.

The technological breakthroughs that were developed during the project earned Arbin the R&D100 Award for Green Technology. Arbin's laboratory battery testing (LBT) series commercializes technology developed from this project and provides customers with an economical testing solution for applications requiring high-precision measurement and fast data sampling. Most other battery testing systems do not correctly specify their precision and/or have relatively poor precision, weakening the conclusions drawn from results. Important trends and electrochemical indicators may remain unnoticed, lost in the measurement noise.

Arbin's new technology offers users 0.01% precision and 24bit measurement resolution. Along with the ability to collect 2,000 datapoints per second with a time resolution of 100µs, the new LBT series hardware provides accurate capacity calculations to monitor long-term battery life. Arbin's hope is that these higher degrees of measurement precision will lead to new discoveries and characterization metrics across the energy storage industry for all organizations, not only those looking at coulombic efficiency as their key indicator.

The graph below illustrates the difference between Arbin's differential capacity and that of another leading manufacturer. The two distinct dips in the plot may be missed using an inferior tester. While many companies try to sell the same antiquated equipment, Arbin has been hard at work improving its designs to meet future industry demands. Arbin learned a lot during the three-year ARPA-E project and has implemented this new technology in its LBT and HPT product series. The HPT systems represent a premium product, but LBT is claimed to be superior to all other standard testers on the market.



An illustration of the improved precision showing the differential capacity as measured by an Arbin LBT system (blue) compared to a traditional testing system (red)

Arbin's high-precision test station with built-in temperature chambers

Building on the success and feedback of the new LBT hardware, Arbin will now provide a standard two-year warranty on all new hardware purchases. Arbin's engineering team has always been confident in the reliability and longevity of its products, with some of the first manufactured test stations still in use. Since 1991 customers have received responsive support through a network of offices around the world, and the new two-year warranty will provide customers with continued access to the support team, paired with a lifetime of phone and email support for as long as an Arbin test station is owned.

These major hardware and software improvements can be paired with Arbin's new lifecycle chamber, which is designed to provide an accurate and stable temperature. Regulating cell temperature fluctuation is an important factor for accurately measuring coulombic efficiency. The lifecycle chamber's integrated solution controls the temperature of cells from 10-60ºC (50-140°F).

Arbin understands the vital role energy storage plays in everyday life and its importance to the future.

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INQUIRY NO. 517

Compact BMS for LEVs

A new battery management system for light electric vehicles is ideal for a range of applications, and offers engineers and designers a compact, cost-effective solution

The demand for high-quality, safe, cost-efficient and compact battery management systems (BMSs) for the growing light electric vehicle (LEV) market continues to rise rapidly. With the new c-BMS from Lithium Balance, battery engineers will have even better opportunities to meet this demand. The c-BMS manages up to 24 battery cells, which makes it ideal for 48V or 72V LEV applications, such as golf or utility service vehicles and industrial machines such as forklifts, AGVs or cleaning machines.

One of the key benefits of the c-BMS, when it is applied into a typical LEV application, is that it is extremely compact (measuring 150 x 70mm) and therefore easy to install in any small battery pack. In addition, the c-BMS is designed for ISO26262 compliance and has an ASIL C rating for all safety critical circuits – the power supply and measurements of cell voltages, pack temperature and current.

The c-BMS, with its compact and cost-efficient design, will further improve the cost/benefit of replacing lead-acid batteries with lithium technology in LEVs and therefore contribute in bringing safer LEVs – with greater range and performance – into the market. In golf carts, which often operate in high temperatures, the c-BMS, with its high degree of accuracy for cell voltage and temperature, is particularly appreciated.

Turkish company Imecar Elektronik develops and converts electric-powered vehicles and manufactures EV battery packs for customers in Europe, Russia and the USA. CEO Mark Lander has observed great demand for turning public and commercial transportation toward electric buses and vans. One of his company's customers is a golf and utility service car manufacturer that wanted to transfer from lead-acid to lithium batteries to increase the range of an airport vehicle.

The BMS Creator PC software tool makes it possible for engineers to design a battery to suit the application

The project's main constraints were to fit 12-16kWh of lithium batteries into the compartment available for lead-acid batteries in the existing vehicle design, and to design a solution that would tolerate the high temperatures experienced on the tarmac of Turkish airports. Imecar Elektronik decided on the c-BMS for its lithium-ion pack, due to its compactness and low cost. Other key benefits for the company were the accuracy of the voltage and current measurements and SOC estimation, the automatic balancing function and the temperature range tolerated.

Imecar Elektronik chose the Lithium Balance c-BMS for the Li-ion battery pack (left) used in its customer's golf and utility service vehicles (above)

Imecar has placed the c-BMS on top of the battery cell modules and inside the battery pack. "The c-BMS hardware is a solid rock," explains Lander, who looks forward to seeing the upcoming software versions, as Lithium Balance continues to release greater levels of functionality for the c-BMS platform.

The c-BMS is easily configured for optimal performance through CAN, UDS or with Lithium Balance's BMS Creator PC software. BMS Creator is a PC toolbox that enables the battery engineer to design a unique battery, specifically optimized for the performance and battery cell chemistry selected to address the requirements of the application.

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INQUIRY NO. 518

Temperature management

New 48V concepts and intelligent cooling will play an increasingly important role in vehicles featuring internal combustion engines, hybrid powertrains and full-electric drives

The automotive industry is banking on the electric drive and is constantly surpassing itself in offering new models to the market. Electrification of the ICE is of equal importance. Electric motors for auxiliary systems are used for pumping, cooling and compressing in ICEs. In mild-hybrid vehicles, with up to 25kW of peak power, 48V systems provide additional power when accelerating and recuperate energy when coasting. There are entirely new concepts in development, such as the electric transfer case by Magna Powertrain, which increases a four-wheel-drive vehicle's fuel efficiency to levels higher than for models with two-wheel drive.

The electrification of the ICE offers further benefits in terms of fuel efficiency, such as the approximately 2% saving in the WLTP cycle by using a 950W electric main water pump, which Magna Powertrain was the first to bring to market for the 48V onboard electric system. The benefits are obvious: the electric-powered auxiliary systems are decoupled from the ICE and independent of its RPM, and are only switched on when really needed. The engine warms up faster and produces fewer emissions when starting, as the optimal temperature window for the combustion process and exhaust-gas aftertreatment is reached faster.

The increased use of electric motors in vehicles with ICEs or concepts featuring mild hybrid technology is closely related to the 48V onboard electrical system. For recuperation it is necessary to transfer as much braking energy as quickly as possible from the electric engine, which is operating as the generator, back to the battery. The same applies to accelerating in mild-hybrid vehicles, where the electric motor needs to measurably support the ICE or is expected to operate as the starter for re-engaging the engine in fractions of a second, depending on the configuration.

The Thermal Management Module was designed to handle even very sophisticated regulation strategies

Above: A Magna primary electronic water pump

Left: A Magna electronic water pump used as a secondary cooling source

The Magna electric supercharger also operates on 48V. It can supply up to 7kW for short boosts and offers substantial improvements in performance over previous turbochargers and compressors. Other 48V drives are found in transmissions and traction drive products by Magna Powertrain. However, the 12V onboard electrical system will not be tossed overboard, but will maintain its important role in many vehicles globally; here Magna Powertrain continues to support OEMs with innovative products such as electric water pumps up to 600W.

Better performance for the ICE and electric drives inevitably means higher temperatures. In this regard, thermal management plays a key role. There are many functions affected by this in the engine – for example, crankshaft- or belt-integrated starter generators, electric AC compressors and electric superchargers. Heat-sensitive areas in the powertrain can be cooled using small electric coolant pumps or fans.

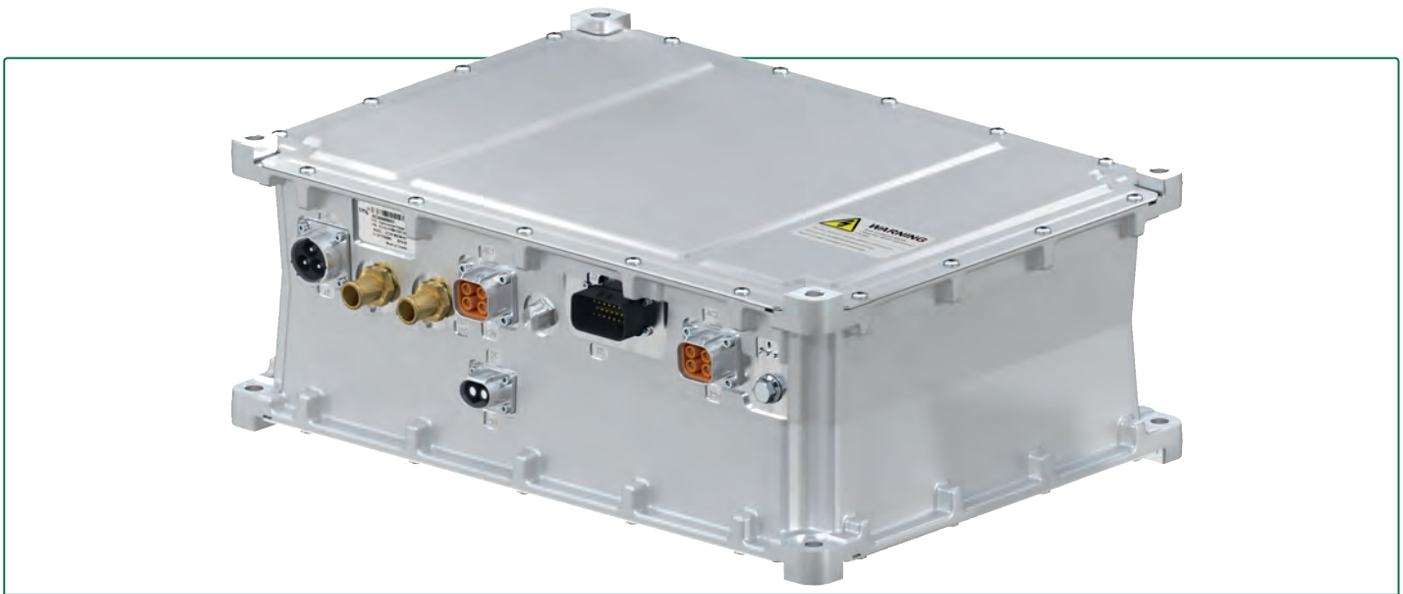
Smart thermal management prevents components from overloading. The Magna 48V electric water pump can withstand temperatures up to 130°C (266°F), for example, and intelligent control continually reduces its output above 110°C (230°F). Magna developed the Thermal Management Module (TMM) to handle even sophisticated regulation strategies. This module can continually regulate flow in the cooling and heating circuits from zero to the maximum possible depending on the driving situation.

Effective temperature management is also vital to attain the savings goals set by legislation: from 2021 a maximum of 95g/km of CO_2 will apply in the European Union. It is a question of applying a holistic approach. We cannot expect to tap all efficiency potentials just by optimizing the temperature in individual systems. It will only be possible when we view the entire system of ICE, powertrain and electrical units and develop a common regulation strategy that coordinates temperature sensors, engines and software optimally.

This depends upon thorough, comprehensive knowledge of the systems, something that Magna Powertrain, with its many years of experience in electrification, is capable of. Thermal management will continue to grow in importance, even with full EVs where the electric motors and batteries also require temperature management to ensure optimal efficiency and performance. It calls for new concepts of intelligent cooling systems. Magna, as the system supplier for the entire powertrain, has also developed customized solutions using electric pumps and TMMs.

Bidirectional solutions

A compact bidirectional unit combines multiple functionalities, providing efficient battery charging and auxiliary power supply during electric and hybrid vehicle operation



TM4 has developed a bidirectional charger capable of charging an electric vehicle's battery, as well as serving as an auxiliary power supply during vehicle operation

Since the inception of electric vehicles (and even earlier), chargers have played a key role – recharging the battery and ensuring that it is always operating safely and maintained in a good condition to deliver the best performance. Chargers, vehicles and batteries were all simple enough in the early stages of the technology, but as battery systems and charging safety requirements have become more complex, the need for more sophisticated charging solutions has emerged. Electrification of commercial vehicles accelerated the transition from alternator-powered auxiliaries, to components that operated at higher voltages and fed directly from the EV's high-voltage battery using DC-to-AC inverters. Additionally, onboard chargers with bidirectional functionalities have recently become of interest to fleet operators and vehicle manufacturers thanks to their compatibility with V2G (vehicle-to-grid) applications. These applications are expected to be standardized in the future – as power utilities and consumers look at various ways to optimize energy consumption during peak demand hours in order to reduce loads on the power grid and avoid purchasing electricity when the rates are at their highest.

TM4 has always been at the forefront of electric and hybrid powertrain development. The company's expertise in the field has enabled the development of a compact bidirectional charger that provides not only battery charging functionality but also auxiliary power supply during vehicle operation – using the same power electronic modules to supply a configurable voltage and frequency output to auxiliary devices.

In charger mode, the TM4 BCI20 converts AC to DC power to efficiently charge the electric vehicle's battery. It is designed to use the full current range from the AC mains supply, as defined in SAE J1772, for a maximum charge power of 18kW on 240V AC.

When the vehicle is in use, the unit becomes a dual inverter, which converts stored onboard energy from the electric vehicle battery to AC power. Its two independent three-phase outputs of 9kVA can each be used to power various loads, including pumps, HVACs, and so on. The charger, combined with two inverter outputs, simplifies vehicle integration and saves weight and space by combining multiple functionalities in one box.

The BCI20 satisfies the IP67 rating for reliable operation in harsh underhood vehicle environments. Its aluminum enclosure is sealed against dust, sand and water. It is compact and lightweight, and allows for a flexible installation in multiple mounting locations within the vehicle.

Over time, TM4 will expand this new series of products and offer the North American and European markets single-phase and three-phase bidirectional charger-inverters, available in 450V DC or 750V DC voltage ranges.

TM4 is currently supplying its powertrains to several automotive manufacturers and technical centers in North America, Europe and Asia. Production takes place at TM4's Canadian facilities in Boucherville and at its Chinese joint-venture, Prestolite E-Propulsion Systems, in Beijing. Both are equipped with high-volume, flexible and automated production lines, and a large range of dynamometers and test cells, making it possible to conduct full validation and certification of electric and hybrid powertrains.

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INQUIRY NO. 520

Recording NVH data

A popular NVH recorder for validation and engineering or on-the-go in-production testing now includes CAN data, providing a solution for assessing electric and hybrid vehicles

Electric and hybrid vehicle testing presents engineers with challenges that are unique for those systems. For example, without the usual internal combustion engine noise, the vehicle's noise floor drops considerably, making previously unheard squeaks and rattles noticeable. This also makes noise and vibration a challenge when hybrids shift from electric motor to the internal combustion engine.

NVH engineers need the ability to quickly record and characterize vehicles with maximum confidence because so much development testing involves before and after comparisons or competitor-vehicle benchmarking where testers only have sporadic vehicle access for a short period of time. In response to that need, the workflow and setup of Sonoscout have been optimized and simplified to enable testing over a lunch break. Autonomous measurement-triggering capabilities and on-site measurement verification ensure that the test will not need to be rescheduled and repeated later.

The Sonoscout system, established as the go-to system for quickly and reliably recording NVH data, combines an iPad app (and integrated CAN interface) with a battery-powered data acquisition front-end based on Brüel & Kjær's modular LAN-XI hardware, updated to enhance the wireless connection. Due to the improved connection, the iPad can be placed anywhere within the car.

A binaural recording headset, headrest mount for standard measurement microphones, head and torso simulator (HATS) – such as Brüel & Kjær's new High-frequency HATS (with a frequency range up to 20kHz) or Head Acoustics' digital HATS – enable cabin sounds to be immediately captured and validated in real time. Playback connectivity via Bluetooth enables these recordings to be audited through the binaural headset, the car's own audio system, or additional headphones plugged directly into the iPad.

Operation and analysis can be performed with the fingertips thanks to the Sonoscout recorder's multi-touch control

Sonoscout can cut down on setup time, provides a mass of relevant data and insures against the need to retest it thanks to its new native CANbus interface that enables the logging of all CAN data, such as engine and motor RPM, speed, load, charge level and throttle position.

Sonoscout records all CAN parameters on the go; users can revisit any CAN data for post-processing, eliminating the risk of having to schedule a retest to obtain, for example, load percent and speed when transitioning from electric motor to ICE. This also saves time otherwise spent on mounting tachos, and goes beyond that to enable the acquisition of electric motor data such as RPM.

Immediately after recording, data can be quickly and easily validated, enabling immediate comparison of up to four different vehicles and test conditions. Data can be exported to a PC using easy-to-use tools for transfer in five common file formats, including custom sound design systems, such as VSound.

In addition to recording, the Sonoscout app has onboard analysis that enables users to make decisions on the spot. Measurements can be checked against targets using the same sound quality metrics found in PULSE Reflex post-processing software. Once users are satisfied, it is even possible to generate a report using Microsoft Office apps.

A virtual front-end feature in Sonoscout makes it possible for users to try the full analysis functionality using demonstration data before purchasing any hardware, as Sonoscout can be downloaded from the App Store.

Connection to the vehicle CANbus via OBD-II connector logs parameters such as engine and motor RPM, speed, load/torque percent, charge level and throttle position. This can reduce setup time and insures against the need to retest

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INQUIRY NO. 521

Pressure management

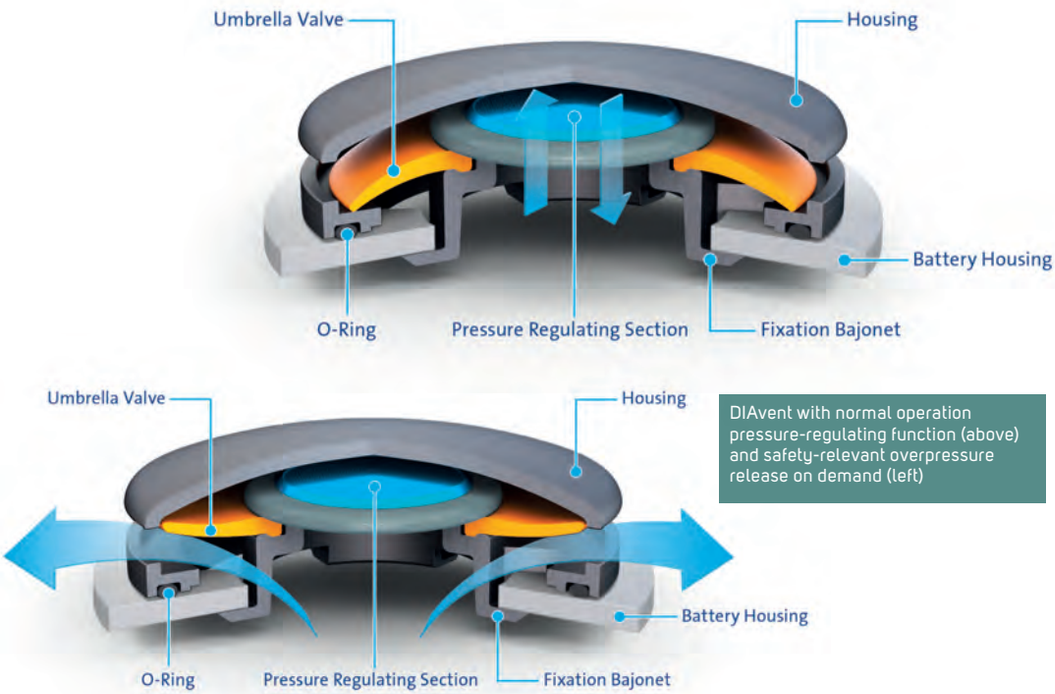
A pressure management system consisting of a multilayer nonwoven combined with an umbrella membrane provides several advantages over microporous film solutions

The large-scale batteries used in electric and hybrid vehicle applications require smart pressure management. Freudenberg Sealing Technologies has introduced DIAvent, an innovative solution made of a patented multilayer nonwoven fabric combined with an umbrella membrane. Together, these structures can handle pressure under any battery operating condition, intelligently and reliably.

DIAvent provides extremely high gas permeation in normal operation and a reversible emergency degassing function. At the same time, it meets the requirements for water tightness according to protection category IP67 and higher.

DIAvent offers a number of advantages over existing pressure compensation systems. These systems either achieve normal or emergency operation with two different components or they are irreversibly destroyed in the event of emergency operation. However, in the DIAvent, the functions are combined into just one component, while it is guaranteed that the emergency operation is reversible.

To develop this innovation, a critical challenge had to be overcome: on the one hand there was the need for high, surface-related air permeability, and on the other, a high degree of tightness when the system is in contact with water. Freudenberg has achieved this with its nonwoven combination, consisting of a highly permeable, filtering and hydrophobic external layer and a downstream water-blocking inner layer. The outer layer protects against penetration of water – in water columns of up to 100mm. It is only when higher pressures are present and the water passes through the outer layer that the inner layer activates and completely blocks the entry of water into the housing.



DIAvent with normal operation pressure-regulating function (above) and safety-relevant overpressure release on demand (left)

In comparison with microporous films, the nonwoven combination stands out for its ruggedness and high performance, which is not greatly affected by the unavoidable contamination seen over the part's operating life. In addition, the nonwoven can be processed in such a way that no residual water can collect on the nonwoven layer and reduce the air throughput.

Nonwovens are also a better choice than microporous foil due to their mechanical robustness (for example, creeping does not occur). It is only the substantial air throughput that enables the functional integration of emergency venting in the same installation space as is required by applications employing microporous films.

The DIAvent has a ring-shaped umbrella valve for the reduction in overpressure during an emergency degassing. Using its outer lip, it seals the outer area from the inner, but opens up reliably when there are slight housing overpressures. One important technical benefit is that the valve closes reversibly after a reduction in the overpressure. After an emergency degassing, interior operation is reliably protected – a damaged battery can be salvaged safely.

In addition, the umbrella valve can actively support the pressure compensation function during normal operation. This accelerates the exchange of gases from the interior to the exterior, making it possible to compensate for very fast overpressure fluctuations. This is beneficial for future developments for two reasons: fast battery charging accelerates the heating processes, and large housings are much more sensitive to internal overpressure. As a result, compensation for overpressure represents a greater challenge than the reduction of under-pressures. In this respect, this combination of functions can contribute to and support lightweight design trends.

The DIAvent developed by Freudenberg therefore represents a novel and innovative approach that meets the requirements of future battery systems. It can also be used in electronic systems without an emergency function – for example in transformers, electric motors, transmissions and headlights, which need a pressure compensation function with simultaneous water tightness.

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To learn more about Freudenberg Sealing Technologies, visit:
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INQUIRY NO. 522

High-performance testing

Industry experience and expert collaboration enables a test system developer to offer instruments that are accurate, flexible and customizable, and which operate at high speed

Recognized as a pioneer in the modern battery testing industry, Maccor started operations in Tulsa, Oklahoma, in 1986, dedicated to the development of high-performance battery test systems. With a nucleus of engineers experienced in emerging battery technologies and computer control systems, the company has enjoyed continued and rapid growth.

In the past, the only commercial products available for the evaluation of battery performance had been designed and built specifically for lead acid vehicle battery applications. These were relatively high-power units without any high degree of accuracy, had limited test programming capabilities, and collected data relatively slowly. In the mid-1980s, when there was a resurgence in new battery technologies, it quickly became obvious that the available battery test systems were inadequate.

Maccor's founders conceived of an entirely different design for a battery test system. The result was a system that provided extremely accurate results, collected test data at high speed, would test large numbers of batteries at the same time, and that could be programmed to perform virtually any test sequence required.

Over the past 30 years, Maccor's innovative technology has enabled the company to become the industry standard for most companies that are involved in the research, development, quality control and evaluation of cells and batteries for a wide range of products and cell chemistries. This solid foundation provides Maccor with the knowledge, experience and resources for the future. Today, the company has earned a greater than 80% share of the US business in its product area, and has a major share of the European market, as well as an expanding market in Asia. With more than 2,000 systems in regular operation in over 50 countries, there is no doubt that Maccor is a true leader in the battery test industry.

Maccor is a USA-based developer of high-performance battery test systems that offer high levels of accuracy and customization

Maccor designs all its own hardware and software. Most systems are customized to meet a customer's specific requirements, and from time to time customers also request customized features in the software. Over the years, this has provided Maccor with a wealth of knowledge and experience in the design and performance of these systems. This experience is being used to develop systems for the future, with even higher levels of performance, additional advanced features and capabilities utilizing new computer technology.

Maccor is confident that it offers the widest range of features and capabilities of any manufacturer for this type of equipment. If the company's standard equipment doesn't meet a customer's exact needs, Maccor can customize equipment to specific requirements.

In early 2014, Maccor announced an exclusive agreement with the Scientific Instruments business unit of Ametek Advanced Measurement Technology. Scientific Instruments comprises the Princeton Applied Research, Solartron Analytical and Signal Recovery businesses of Ametek. This agreement enables Princeton Applied Research or Solartron Analytical impedance analyzers to be integrated with a Maccor test system to perform EIS experiments *in situ*. These integrated solutions result in: higher productivity by switching automatically between Maccor's test equipment and Ametek's electrical impedance instrument; greater data integrity with more reliable and reproducible test results; and reduced idle time and in-test waiting caused by operators having to move test devices from one instrument to the other.

Recently, Maccor and Voltaiq announced a marketing agreement. Voltaiq is a leading supplier of data analytics whose vision is to provide the leading informatics platform and expertise for optimizing energy device performance throughout the product lifetime. The Voltaiq Battery Intelligence software platform integrates seamlessly with Maccor's leading test equipment, providing a completed end-to-end solution for battery testing, analysis and optimization.

In 2009, Maccor moved to a newer and larger facility due to the increased demand in sales volumes. In 2015, the facility was expanded due to additional increases in demand and sales volumes.

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INQUIRY NO. 523

High BMS accuracy

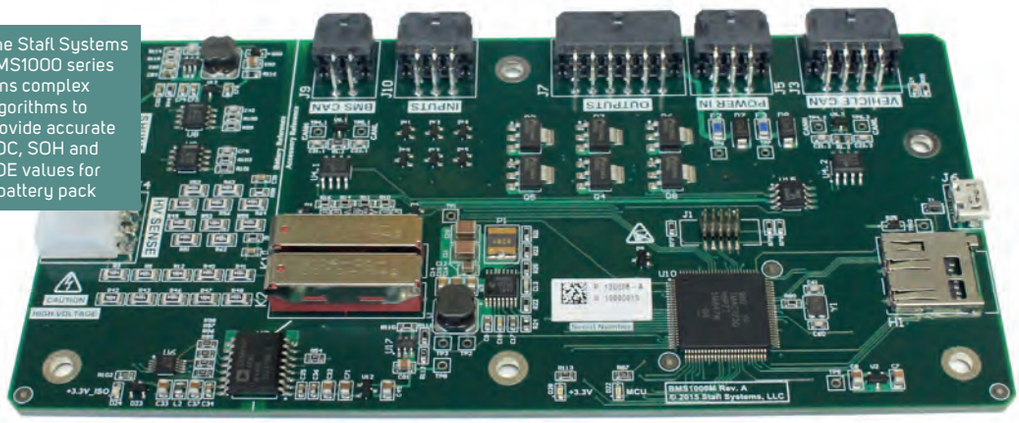
The accuracy of the SOC, SOH and SOE calculations provided by a battery management system are increasingly becoming a critical differentiating factor for many applications

The accuracy of the state of charge (SOC) calculation for a battery pack throughout its life is becoming a defining feature of a battery management system (BMS). Until now, a standard SOC accuracy error of 5-10% has been tolerated. However, as weight, volume and cost pressures reduce the capacity margin that is integrated in battery packs, achieving accuracy closer to 1% is critical.

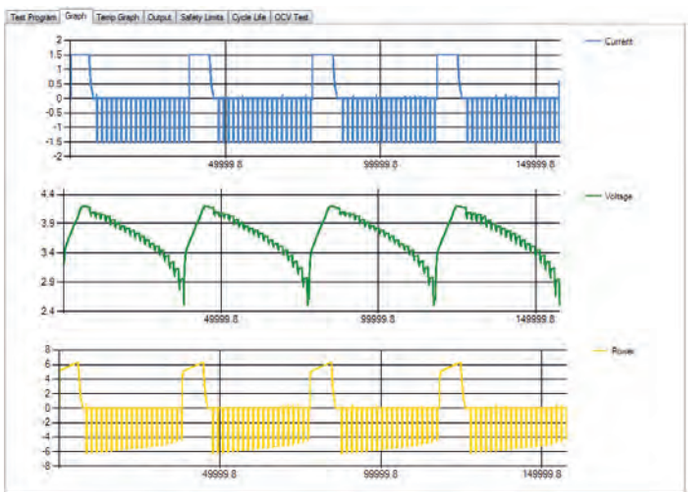
To achieve 1% accuracy of SOC, standard coulomb counting and open circuit voltage lookup table methods are insufficient. A more detailed, internal model of the cell that includes temperature dependence and impedance effects is required. The cell model itself is well known; indeed many academic papers describe complex lithium-ion cell models in great detail. The difficulty is generating the sheer volume of data required to ensure that the model matches reality.

Most battery management systems use data provided by the cell manufacturer in data sheets or technical specifications to drive their algorithms. This data often lacks the necessary detail and is occasionally optimistic about real-world cell performance, meaning that the performance experienced in the field may not meet the performance level expected in the design.

To address this issue, San Francisco-based Stafl Systems has developed an automatic cell characterization system that generates valuable cell test data across a number of temperature and discharge rate profiles. By independently testing a number of sample cells, this system can generate the data needed for a highly accurate SOC calculation for a new battery pack design. Using this system, Stafl Systems offers a cell characterization service to its BMS customers to enable packs using this system to approach 1% SOC accuracy.



The Stafl Systems BMS1000 series runs complex algorithms to provide accurate SOC, SOH and SOE values for a battery pack



An automatic battery cell tester generates the valuable multiparameter data that is necessary for successful application of highly accurate BMS algorithms

While generating enough initial data is important in achieving accuracy at the beginning of the life of a battery pack, the pack's performance will change with use and age. Therefore, an accurate SOC algorithm must continue to adapt to the real-world performance of the pack. In order to do this, Stafl Systems' BMS products use a built-in learning algorithm that measures and adjusts the predicted pack performance to match the actual measured pack behavior. This learning mechanism, coupled with a state of health (SOH) and a cell impedance growth algorithm, generates pack performance data that enables the user to confidently get the most out of the battery pack for their application.

Highly accurate SOC and SOH calculations are important, but there is another calculated value that can be very helpful for an application – the safe operating envelope (SOE). An SOE algorithm continuously broadcasts the maximum charge and discharge current that the pack can accept at any given time, due to the internal state of the cells. This varies with SOC, SOH and temperature. This calculated value allows the application system controller or vehicle control unit to ensure that it operates the pack within this envelope, avoiding potential safety faults leading to pack shutdown. This also avoids the need to include complex battery modeling code within the application controller, freeing up a program's development team to focus on other critical tasks.

To meet these requirements, Stafl Systems, through its BMS1000 series, offers a high performance, scalable BMS solution that can accurately generate the operational information needed to ensure the safe and reliable operation of a lithium-ion battery pack.

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To learn more about Stafl Systems, visit: ***www.ukimediaevents.com/info/ev***
INQUIRY NO. 524

Battery safety standards

The changing requirements for batteries in commercial and industrial electric vehicles must be met to increase manufacturer, operator and customer confidence

Commercial electric vehicles are becoming more prevalent in everyday life. Valence Technology now sees customers using its safe, proven lithium-ion batteries in varied applications such as refuse collection vehicles, port terminal tractors, electric buses, large lift trucks and aircraft tugs. Some of these applications are driven by the need to reduce carbon emissions and to limit noise pollution. Each market has developed, and applications now call for specific safety testing and certifications.

The United Nations Economic Commission for Europe Regulation No. 100, often referred to as ECE R100, addresses the safety requirements specific to the electric powertrain of road vehicles that utilize battery rechargeable systems. The original R100 regulation was first published in 1996, but was revised in 2011 to keep pace with new technologies. However, the scope of this was limited and Revision 2 of the regulation was published in 2013 with a broader scope that now includes the Rechargeable Energy Storage System (RESS) – in most cases the rechargeable battery pack. This regulation became mandatory for new or modified vehicles homologated in Europe from July 2016 and is intended to regulate the lithium energy storage systems contained in such vehicles.

Faun are set to launch a new Refuse Collection electric vehicle, powered by Valence safe energy, in early 2018

Valence adherence to battery standards inspires confidence in it's products, as shown in Kalmar Motor's range of hybrid tugs

The tests required for R100 Revision 2 certification include: vibration testing; thermal shock and cycling; fire resistance (immersion in fuel fire); and over-temperature; over-charge and over-discharge. Additionally, there are tests for mechanical shock and integrity of the battery pack and short-circuit scenarios. Valence submitted modules for testing for all applicable tests in conjunction with IDIADA testing and homologation services. All tests were successfully passed without the inclusion of a Valence BMS, which provides system-level protection in addition to the inherent safety provided by an individual module. Given the severity of the testing involved in this new regulation, the operators and general public will have more confidence than ever before in the safety of the batteries used to power these vehicles.

IEC 62619 is a standard designed for rechargeable batteries used in stationary, marine and motive applications such as lift-trucks and automated guided vehicles (AGVs). These include yet another set of vibration, short circuit, impact, drop test, thermal abuse, over-charge and over-discharge tests, and adds propagation testing for thermal runaway. These tests enable vehicle manufacturers and operators to ensure that the vehicles working in their facilities conform to the highest safety standards. Valence is now compliant with all tests in this rigorous standard, which will enable customers manufacturing lift-trucks, aircraft tugs and AGVs to make use of the company's products with high levels of confidence.

UL 2580 is now required by many applications operating in the USA and serves as a safety standard for batteries in electric vehicles. Increasingly, customers within industrial, motive and other applications are specifying this standard as a prerequisite to any prospective battery supplier. Valence's new 24XP series was designed with UL 2580 in mind and can readily be a recognized component assembled into a full battery pack.

In addition to these standards, Valence includes charging protocols such as CCS and CHAdeMO for fast charging along with communication protocols such as CANOpen and SAE J1939, which combine to increase the safety of normal battery use. Battery systems fitted with remote monitoring enable operators or OEMs to view key parameters from the vehicles at all stages of their daily activities to ensure that each application performs efficiently and with the utmost safety at all times. Valence offers a Master Battery Server (MBS) to provide these functions along with critical features such as system redundancy.

As many diesel- or petrol-fueled applications move toward lithium battery-based forms of energy, there continues to be an increase in specific legislation focused on safety. Meeting these regulations will aid customer confidence and ensure that safe, reliable solutions continue to be selected for vehicles used in everyday life.

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INQUIRY NO. 525

Advancing electrification

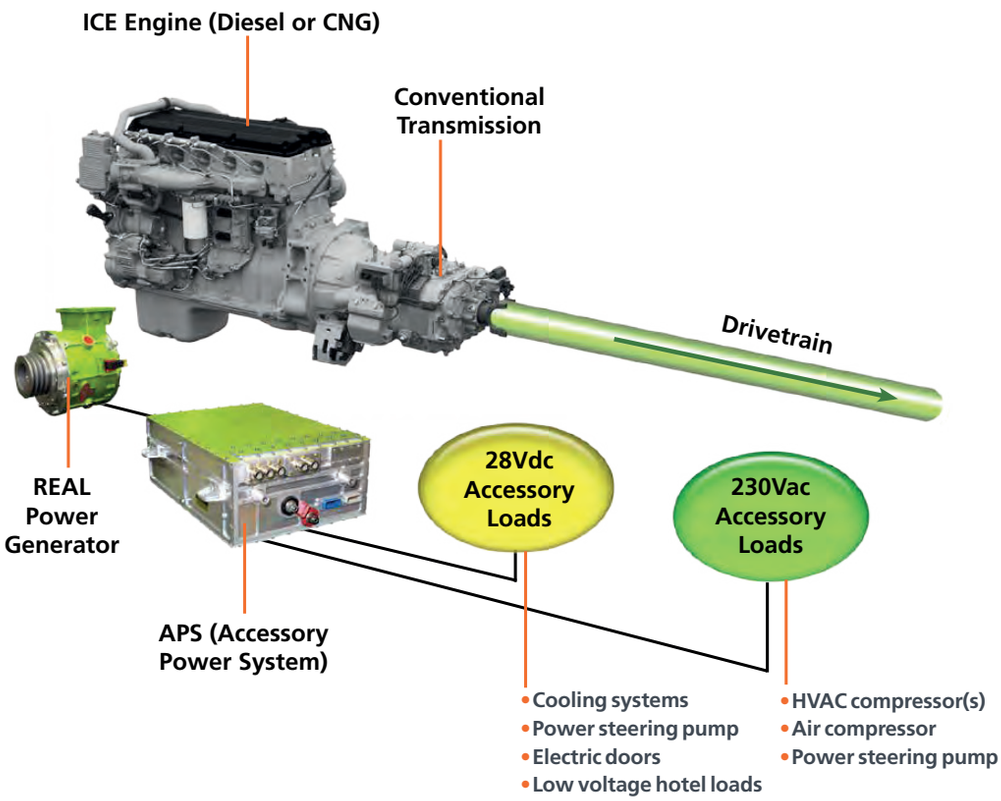
A simple, compact vehicle accessory system can now be applied to conventional powertrains, offering operational and maintenance benefits for cost-conscious applications

Using proven technology derived from more than 8,000 in-service hybrid propulsion and power systems, BAE Systems introduces REAL (reduced engine accessory load), the company's latest 'more-electric' advance addressing a much broader industry segment – electrified accessory systems for conventional powertrain vehicles.

As the transit market seeks low- and zero-emission solutions to keep up with emissions targets, BAE Systems is stepping up with an array of options. Full zero-emissions solutions include hydrogen fuel cell-electric and battery-electric powertrains; low-emission solutions include an 'electric-range' hybrid, and a hybrid with fully electrified vehicle accessories.

The addition of the REAL product line will round out the product portfolio for CNG and diesel powertrains. The zero-emissions solutions maximize the potential environmental benefit; hybrid-electric provides substantially reduced emissions and reduced GHG operation on a workhorse or 'go-anywhere platform'; and REAL is available for the cost-conscious operator desiring the operational and maintenance benefits of electrified vehicle accessory systems, while still retaining conventional engine/transmission propulsion. An electrification system for conventional powertrains supports environmental objectives while achieving financial goals.

Transit operators, as well as over-the-road coach or commercial truck fleets, are considering REAL, a simple, compact system capable of reducing both scheduled and unscheduled maintenance costs; decreasing external and internal noise, vibration and harshness; and increasing up-time due to accessory service and maintenance. Another advantage of moving to an electric accessory system is that the high-pressure hydraulic oil can be removed from the engine compartment and the associated potential for a compartment fire is greatly diminished.



BAE Systems' REAL (reduced engine accessory loads) product line provides 'more electric' benefits for cost-conscious vehicle powertrain applications

The REAL system makes use of proven components. The vehicle accessories are powered by BAE Systems' Accessory Power System (APS), which is currently used on more than 4,000 hybrid transit buses, replacing the conventional powertrain's A/C compressor and 28V high-current alternator with a single, compact, high-voltage permanent magnet generator. The APS integrates all power management functionality and supplies power for all vehicle accessories including: the 28V DC supply which would previously have been provided by the alternators; high-voltage three-phase power capable of powering A/C compressors; air compressors; electric engine cooling and electric power steering.

Future REAL variants will include an optional energy storage module which will provide vehicle applications with higher fuel efficiency, anti-idle and stop/start capabilities.

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INQUIRY NO. 526

High-voltage connectors

A substantial connector portfolio has been further extended, with new products offering the benefits of high-voltage, AK automotive connectors

Responding to the continuing growth in the hybrid-electric/plug-in hybrid-electric sector, Delphi, a leading global supplier of technologies for the automotive and commercial vehicle market, has strengthened its broad high-voltage connector portfolio, adding new devices that are compatible with the increasingly important AK interface industry standard. By leveraging in-depth field experience and feedback from numerous global OEMs, Delphi's new AK class 4 and class 1 connectors, and AK pass-through connectors, not only maintain full compliance with the AK standard, they also deliver a number of key performance enhancements.

Backed by local contacts from both Delphi and global distribution partner TTI, customers operating in this fiercely competitive market can also rely on extensive product development, manufacturing and logistics support.

The AK class 4 with a 90° cable exit

Delphi's two-way AK connector

Pioneered by leading German OEMs, the AK standard is now used in an ever-wider array of high-power automotive applications. Complementing Delphi's existing portfolio, the company's new AK connector solutions are rated at 850V DC/600V AC and can address even more severe environments, meeting or exceeding vibration severity 3 and temperature severity 4 up to 140°C, according to the LV214 standard.

Enhanced vibration behavior is achieved as a result of Delphi's new patented cable squeezer, which tightens the cable at the back of the connector and dramatically reduces vibrations at the terminal contact point. The increased temperature rating of up to 140°C further helps to address the growing number of hybrid-electric and plug-in hybrid-electric applications, where the presence of an IC engine significantly increases the temperature and vibrations compared with pure-electric vehicles.

In addition, product development undertaken in close collaboration with leading wire harness suppliers has resulted in a considerable improvement in the ease with which the connectors can be assembled. This simplified design philosophy, which employs fewer components, means that productivity is boosted and rework is minimized. The new parts are also fully interoperable and compatible with other leading vendors of AK products.

Designed for power conversion applications, particularly DC batteries and inverters, the new two-way AK class 4 series meets the AK footprint definition and features a 100-250A current range. For easier cable routing, the product is available in a 90° cable exit version. Delphi's field-proven pin and sleeve terminal system is utilized, along with ergonomic lever-assist mating. Full compliance with LV214/215 automotive performance specifications is provided. For auxiliary device applications such as onboard chargers, heaters and air-conditioning units, Delphi's new HV280 AK class 1 female connectors support a current range of 10-40A and are available in both two- and three-way formats. Similar to the AK class 4, the Delphi AK class 1 female connector can handle voltages of up to 850V DC and 600V AC. Alongside excellent thermal and vibration performance, benefits include enhanced shielding. The parts are also designed in full accordance with the LV214 (Version: 2010) specification.

The AK pass-through 3W (three way)

Completing the new product line-up, Delphi's AK pass-through connectors help meet the growing demand for robust screw-type connections within harsh operating environments. Available in one-, two- and three-way formats, a 70-250A current range is combined with the recognized AK footprint, it offers improved shielding, mechanical and thermal robustness, and compliance with LV214/215.

The performance advantages that are offered by the new Delphi parts are enhanced by logistics, service and support from TTI. With a global reach and presence that mirrors Delphi's own, TTI facilitates a highly responsive supply chain that can match the exacting demands of the modern automotive industry. Local inventories are combined with dedicated teams that work side-by-side with Delphi and the customer. As a result, OEMs seeking to maintain and extend competitive advantage in the EV/HEV sector can rely on minimal lead times, rapid reaction to fluctuations in demand and production levels, and an overall reduction in their total cost of ownership.

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INQUIRY NO. 527

Inverter selection

Often a low priority when designing electrified powertrains, inverter selection can have a significant impact on a project's performance and cost targets

In the hunt for ever-greater levels of efficiency, traditional IC engines are subject to high levels of innovation focused on downsizing and forced induction. While this does not appear to have a parallel with the ever-increasing levels of powertrain electrification, a focus on system performance – conceiving the battery, inverter and electric machine together – can have an equally dramatic effect on weight, size, performance and cost.

A traditional route to conceiving an electrified powertrain will tend to specify the system components in the order of electric machine, battery, then inverter. In this sequence the most complex unit, responsible for optimizing bidirectional energy flow between battery and electric machine, as well as integration with safety-critical vehicle operating systems, is given the lowest priority – possibly because of the belief that an inverter is just an inverter. However, inverter selection should be given greater consideration at the time of specifying the battery and motor, as the inverter will have an equally significant impact on whether or not the system's performance and cost targets are achieved.

Continental Engineering Services (CES), a subsidiary of Continental, is experienced in the parallel development of electric machines, power electronics and batteries, specifically engineered for use in the automotive and motorsport markets. As a consequence, CES is well-placed to understand the key parameters that must be considered in the specification, development and application of a successful HV traction system, with the inverter as the key enabler to unlock system potential.

Prior to the commencement of either an inverter selection, or the development of a new bespoke product, basic primary parameters need to be understood: input voltage range; output voltage range (matched to the electric machine); output power and current; drive cycle (to ensure thermal performance); and working temperature range. In the next stage, secondary information will be required, including maximum electrical frequency (used to select the optimum PWM frequency to control switching losses) and further battery characteristics (to optimize DC link capacitance to reduce DC ripple current losses). Even at this level, it is apparent that the information presented on data sheets or sales flyers is insufficient for comparing inverters.

Continental's 48V DC/DC converter provides a stable power supply even if the engine is switched off, for example during advanced stop/start and coasting

The Power Electronics system features an inverter and a DC/DC converter

Having carefully selected or designed an inverter, only by using advanced, state-of-the-art, machine control techniques can optimum performance be realized. Given a nameplate inverter electrical rating, it is a common misconception that all similarly rated inverters will drive electrical machines in the same manner. CES uses a proprietary AC controller, featuring space vector modulation with advanced discontinuous and over-commutation techniques, implemented on a system-by-system basis. At no point is any table look-up of torque versus machine current used, as this technique cannot be used for top-end, high-performance systems capable of extracting the maximum torque/amp. Live, closed-loop models of both inverter and machine loss are run in the inverter, enabling the realization of operating efficiencies of >97%, along with high levels of delivered torque accuracy (typically <1% torque error when applied to salient machines, where torque is not proportional to any measurable physical variable).

Finally, from a safety aspect, vehicle level implementations require inverters to meet ISO26262 ASIL-D, necessitating dualization of current sensing within the inverter using different sensing techniques, and the ability to continue to function even in the case of a complete loss of 12V ignition.

Continental and CES have a wide range of inverters available for motorsport, prototype vehicles and homologated road car applications, capable of achieving all of the above and more, not only as a pure current switching device, but as the primary system enabler, and importantly, the first choice when conceiving electrification requirements.

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INQUIRY NO. 528

Sophisticated components

High efficiency in e-mobility relies on good components. Cooperation, extensive knowledge and collaboration are key to the delivery of innovative new technologies

The pursuit of greater efficiency in e-mobility has generated a drive to improve the efficiency of all components – from engine rotors, to wiring and powertrain. As a long-term partner of the automotive industry, the Wieland Group uses its unique and broad access to key technologies to develop highly sophisticated e-mobility components. As an example, reliable substance-locking connections enable highly efficient solutions for the electric machine, the powertrain and the battery. Such development is based on extensive expertise in forming and laser welding. Other components are rotors, rotor bars, shunts and connector rings. The development usually takes place in partnership with auto manufacturers, which rely on Wieland's knowledge and position in the market.

The Wieland copper rotor design for induction motors is a proprietary patented setup that resists to much higher speeds than alternative solutions. Thanks to the high conductivity of copper, the rotor achieves higher efficiency than aluminum and is ready for serial production in large quantities.

With IAV Automotive Engineering, Wieland carried out the modular electric drive unit project, where the copper rotor was a key element for development of a highly efficient engine. The project's objective was to create a compact drive module for electric axles – including induction machine, transmission and differential, as well as a power electronic unit.

The solution was designed with a modular setup (to suit a range of speeds and transmission ratios), integrated power electronics and mechatronic module, an optimized electric motor design, and was focused on high efficiency thanks to use of IAVs electric motor synthesis tool. The solution included an induction machine with fabricated copper rotor, a stator cooling jacket, and direct spray oil cooling of end windings. The mechanical properties were defined by IAV's application parameters of 8,000rpm, as well as by rotor resistance and torque-slip characteristics.

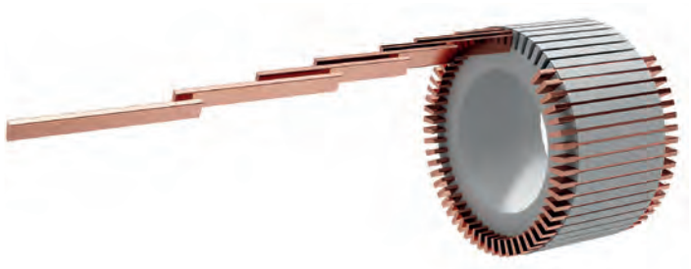
Thanks to the expertise of the two partners, the outcome of the project is an entirely optimized system for the powertrain. The system, including gearbox and power electronics, achieves maximum reach at minimum weight, and is ready for series production for the automotive industry.

In addition to the induction motor, Wieland has developed a solution to improve the reliability of the permanent magnet motor in the electric machine. Connector rings connect stator windings with the high-voltage parts. The technology is the most robust and solid way of connecting every single inductor in compact conditions. The connector rings are individually designed for a specific project and benefit from Wieland's assistance from prototype through to series production.

Due to the limited storage capacity of EV batteries, the energy consumption of vehicles has to be as efficient as possible. Precision shunt resistors play a decisive role in this process, as they enable precise and reliable determination of the actual battery level and better battery management. Development of the shunt resistors is based on an electron beam-welded copper manganese strip, which enables extremely accurate measurement of the electronic systems with consistency over a wide temperature range, and provides the connection to the power electronics of the stator in the powertrain.

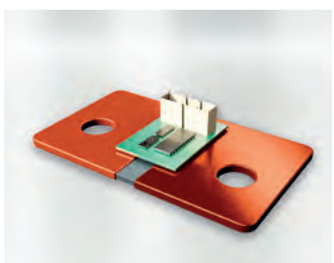
Another contributing factor to improvements in battery design are special bimetals used as bus bars between the anode and cathode. Specially developed laser cladding enables the combination of the properties of different metals in one composite material – a superior solution thanks to the excellent contact resistance. The procedure provides high degrees of freedom, flexibility and dimension.

Wieland continues development of additional high-performance components – using the company's key technologies, experience with the specific requirements of the automotive industry, as well as innovation. The company is ready to shape opportunities in e-mobility with its partners.



The Wieland copper rotor design for induction motors is a patented solution

Individually designed connector rings



Wieland's precision shunt resistor

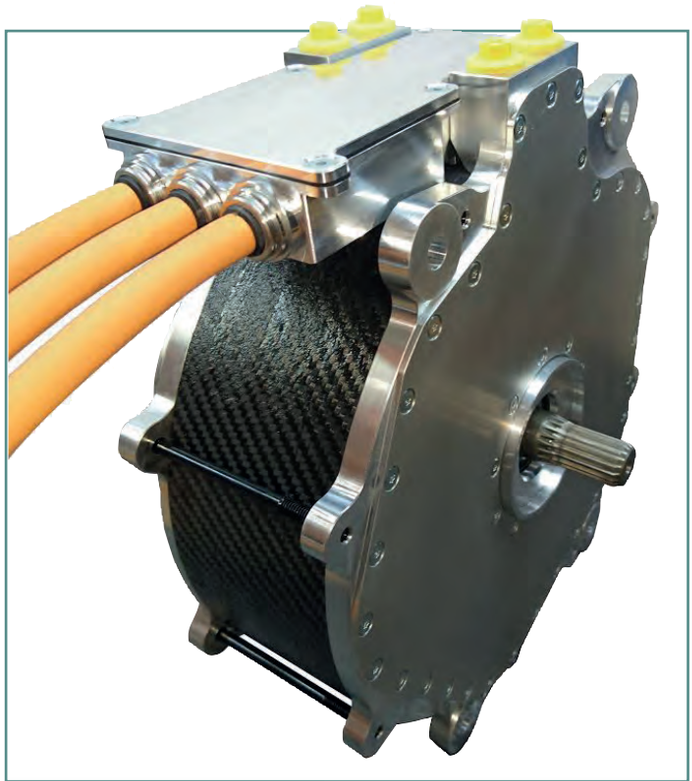
Aluminum and copper bimetallic bus bars for use between the anode and cathode

Axial flux innovation

A new generation of axial flux motors offers higher power and torque for a given volume, and is suitable for integration into hybrid modules and range-extender applications

Founded by electric motor expert Dr Michael Lampérth (the inventor of the Evo motor), Phi-Power was established with the goal of commercializing a new family of high-performance axial flux motors. Drawing on more than 30 years of combined experience in axial flux technology, including many years at Imperial College London, the company's engineering team is using state-of-the art design and manufacturing tools to develop motors with impressive performance. Compared with earlier generations, the new design offers 50% higher power and torque for a given volume. This is achieved by a new electromagnetic design with lower losses, a new cooling layout and lighter housings.

The strength of this technology has been demonstrated in a race motor, designed and built by Phi-Power, which was debuted in Formula E. This motor design uses a carbon-fiber housing, developed to have the strength to contain the rotor in case of an accident. Carbon fiber also offers significant weight reduction potential compared with aluminum. The motor has a peak power output of up to 200kW with a weight under 19kg.



The axial flux high-performance motor for electrical racing provides 200kW peak power and weighs 19kg

Phi Power's new Phi301 motor produces up to 500Nm of torque

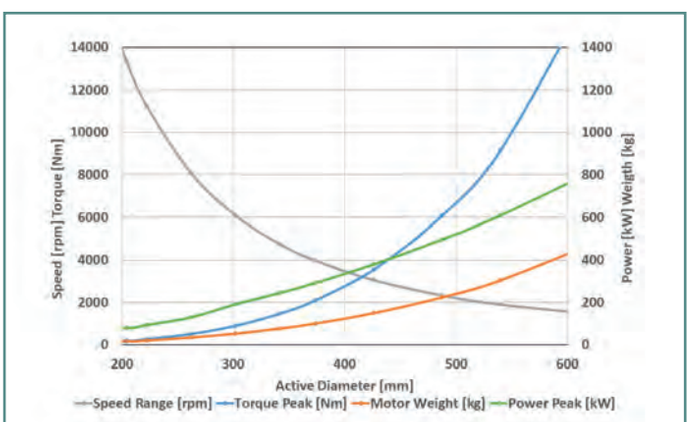
Phi-Power offers a range of motors, from 45kW to 0.5MW nominal output and speeds from 12,000rpm down to 2,200rpm. All motors are available with bespoke winding configurations to match customer requirements.

Phi-Power motors are liquid cooled using water glycol and can easily be integrated in a vehicle, potentially sharing the cooling circuit with the inverter. Phi-Power also offers motors with matched inverters, although the machines can be controlled by most commercially available VFDs on the market.

Axial flux motors offer excellent power-to-weight ratios at relatively low speed. This not only reduces the cost of electric machines, but also enables the use of lower gear speeds, single-speed gears and, often, direct-drive solutions.

The axial flux topology dictates that the available torque of an AF machine is proportional to the third power of the diameter of the machine; hence a small increase in diameter yields a large increase in torque. As diameter also impacts operating speed, the axial flux machine offers better power-to-weight ratios for small diameters and develops an excellent torque-to-weight ratio for larger diameters.

Short length is a key feature of axial flux motors. This makes them ideal for integration into hybrid power systems such as P2 hybrid modules and range-extender applications. Phi-Power offers bespoke design services to develop machines customized to meet customer space constraints.



Axial flux performance characteristics is proportional to machine diameter

Li-ion battery production

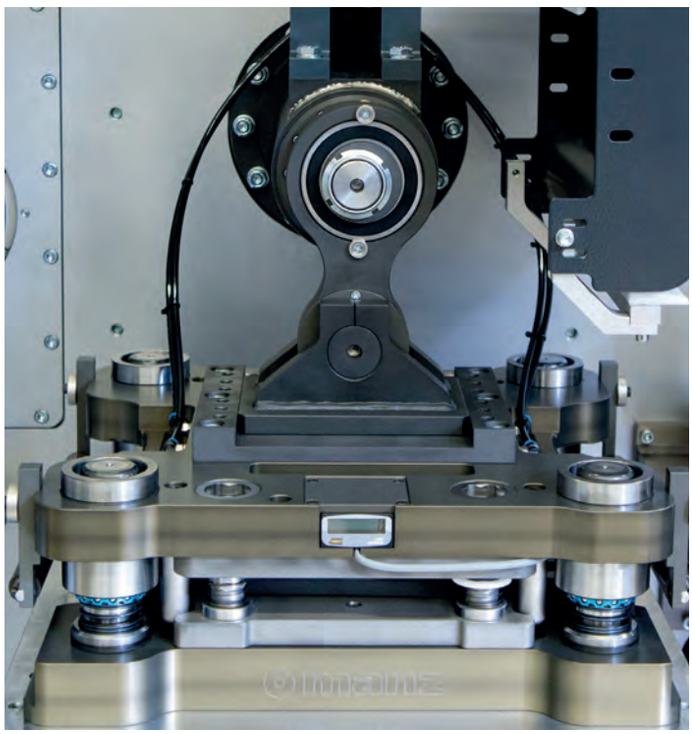
With a history of innovation in production equipment for lithium-ion batteries, a supplier's portfolio offers a range of solutions for competitive manufacturing of all current cell formats

Based in Reutlingen, Germany, Manz is a leading supplier of production equipment for lithium-ion battery cells, modules and packs. Manz has been setting global standards in this field for more than 30 years. With its comprehensive technology portfolio for manufacturing all current cell formats – from wound button cells to stacked pouch cells – the company offers equipment and solutions for competitive lithium-ion battery production.

Manz is constantly innovating processes and equipment for the benefit of its customers. With Manz systems, customers can raise their productivity and profitability and simultaneously increase the quality and safety of their battery cells. The company recently launched three cutting-edge solutions for increasing the efficiency of cell manufacturing.

With the FLS 1800, Manz has developed a flexible laser platform that is designed for different laser processes in the manufacture of lithium-ion cells as well as modules and packs. With the standardized machine platform, customers can in just a few steps assemble powerful laser equipment that is matched to individual requirements and processes. It combines the advantages of a standard system with those of a customized solution.

Regardless of whether it is used as a standalone system with manual workpiece loading, or as part of a fully integrated production line, the FLS 1800 offers a high degree of flexibility and performance in the manufacture of lithium-ion batteries. Thanks to its configurable laser processing unit, the FLS 1800 is just as suitable for laser cutting, drilling or partial removal of materials and coatings as it is for high-precision laser welding – for example, for reflective materials or bi-metals with very different properties, which can be processed with high weld-seam strength and stable, repetition-accurate welding depths.



The Highspeed Notching Platform offers industry-leading material speeds, and is suitable for a variety of notching processes, using mechanical cutting (left) or laser cutting (below)

In 1995 Manz Italy (formerly Arcotronics) developed the notching process that prevailed as the standard in the years that followed and is used today by all battery manufacturers. This knowledge has flowed into the development of a new machine generation.

The Highspeed Notching Platform notches electrodes and electrode webs for hard-case and pouch geometries at an excellent price-performance ratio, and operates at one of the highest material speeds currently available. It is suitable for a variety of notching processes – from constant pitch to progressive and double progressive pitch – using mechanical or laser cutting. This makes the Highspeed Notching Platform the ideal choice for the production of high-quality hard-case batteries or pouch cells. Thanks to the integrated in-line measurement systems, users of the Manz system can rely on 100% error-free raw material.

The Modular Stacking Machine is more than just a stacker. It covers all process steps for manufacturing stacked cells – from the reel material to the completely assembled and tested cell stack.

The single sheet stacking of electrodes and separators is an alternative to winding, particularly when producing powerful hard-case or pouch cells used in plug-in hybrid drive solutions or stationary energy storage, for example. As a fully automated production line, the Modular Stacking Machine realizes optimally coordinated processes and thus enables direct interlinking of all critical processes. After every important process step, integrated inspection systems recognize any faulty items that may have been created, which are directly ejected. This prevents further processing of faulty material, with correspondingly positive effects on earnings and consistently high product quality in the cell.

The system guarantees 100% traceability for all materials installed in the cell. This ensures that the Modular Stacking Machine meets all specifications of European and North American OEMs.

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INQUIRY NO. 531

Sealed ring connectors

An innovative new range of M6/M8 sealed ring connectors supports the shift to 48V, offering OEMs a way to achieve emissions reduction through mild hybridization

International automotive and transportation industry supplier Delphi has introduced a new M6/M8 sealed ring connector range designed specifically to meet the demands of 48V applications. Unique to the market and available from global automotive distribution partner Power and Signal, Delphi's latest connector innovation offers an efficient solution for OEMs seeking to realize reductions in CO_2 emissions through implementation of mild hybrid powertrain technologies such as stop/start, e-boost and energy recuperation.

Driven primarily by a number of leading German OEMs, adoption of 48V is very quickly gathering momentum, and the reasons behind this trend are clear. Positioned between traditional 12V solutions and the much higher voltages required for full and plug-in hybrids and pure EVs, OEMs can reap considerable CO_2 reductions without having to undertake extensive and costly design and architecture changes. Furthermore, while attention is inevitably focused on the automotive sector, Delphi is witnessing a similar growth in interest in 48V from the CV industries too; quite simply, designers of buses, coaches and other commercial applications find themselves under exactly the same pressure as their counterparts in consumer markets.

As far as interconnection is concerned, opting for 48V negates the need for the high-performance EMI shielding and user protection that are essential in full and plug-in hybrids and EVs operating at 240V and beyond. However, while 48V promises more straightforward implementation than higher voltage architectures, the design of Delphi's new M6/M8 sealed ring connectors reflects the fact that 48V vehicle applications still present design challenges. Leveraging over 20 years of experience in hybrid interconnection, Delphi has delivered a product that is suited to a wide array of 48V applications, including electrical centers, power distribution boxes, stop/start systems, e-turbos, active suspension units and belt-driven starter generator (BSG) units. High standards of sealing (IP6K8, IPXK9) are achieved via a wire seal and holder, and co-molded housing and cover, providing excellent protection against the threat of corrosion.

Scheduled for production in 2018, the Delphi sealed connector range is suited to multiple 48V applications

Furthermore, many 48V systems are located in close proximity to engines and/or gearboxes. Consequently, the new products have also been developed to provide vibration resistance (AK LV-214 standard, Level 4), as well as security and ease of use of a screw connection. Voltage rating is <60V DC, with a current rating of up to 200A (at 140°C, 50mm^2).

Another key benefit of 48V adoption is the ability to retain existing wire gauges. Delphi's new M6/M8 sealed ring connectors accept 16-50mm^2 wire sections, support crimping or welding of the terminal, and meet M6/M8 wrench tool standards. Design flexibility is further extended by the option of an M8 sealed interface busbar connector that is fully protected against oil, pressure and temperature. It is therefore ideally suited to gearbox interface applications, a common feature of 48V designs.

Serial production of the M6/M8 sealed ring connector range is scheduled to start in early 2018.

Alongside targeted product development, manufacturers are also looking for dedicated support. Over a number of years, the Power and Signal Group focused exclusively on the automotive and transportation market, and with over 35 years' experience as a specialized distributor of Delphi's automotive connector portfolio, has established and maintained close working links with all its key customers in this sector. In practical terms, this can include value-added services such as immediate product availability via extensive inventories, and a willingness to supply small volumes of assembled products and harnesses for the prototyping and development phases.

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INQUIRY NO. 532

Battery data transmission

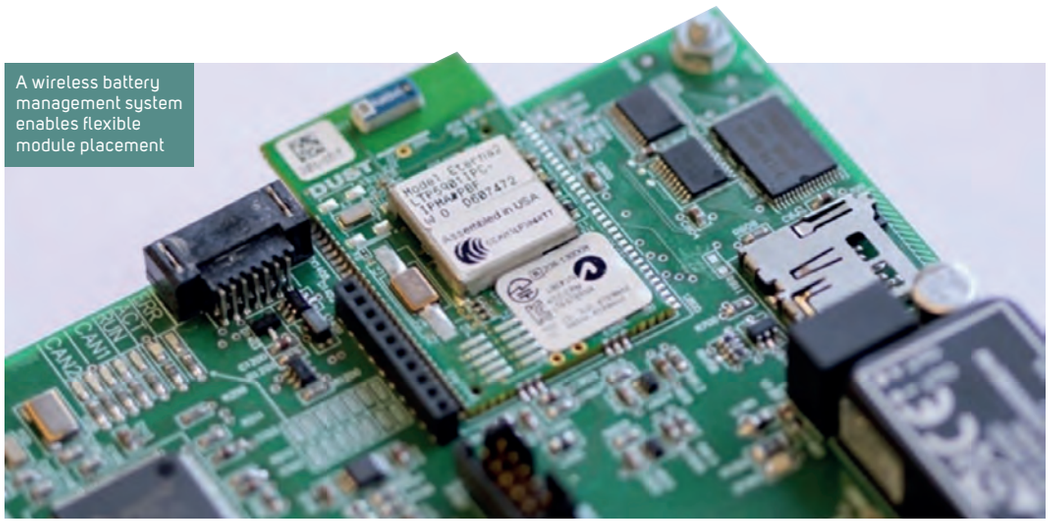
Different methods of communication within a battery system have strengths and weaknesses, and will have an impact on the requirements for wiring the BMS

A battery pack consists of a number of cells connected in series in order to reach a specific system voltage. Sensitive operating ranges for cell voltage and cell temperature require continuous monitoring by a dedicated device. Real-time error detection requires high cell data refresh rates and reliable transmission. The wiring for collecting data from the measuring devices to a master unit is therefore complex and error-prone.

Possible topologies are point-to-point connections or network solutions such as star, mesh or bus. All topologies can be realized by the technologies discussed in this article. Galvanic isolation between modules is essential.

The most commonly used technology is wired communications as it is very easy to implement. Standard protocols are, for example, isoSPI and CAN with a maximum data rate of 1Mbps. Faster protocols are not used due to high costs of implementation. The data rate depends strongly on the number of participants and the cable length. A long cable also negatively affects power consumption and signal absorption. High labor costs and a high chance for failure caused by environmental influences, such as heat, moisture and mechanical exposures, show that alternatives are necessary.

Relevant radio technologies in battery systems are Bluetooth and wi-fi, allowing for data rates of up to 2Mbps. The operating frequency ranges between 2.4GHz and around 5GHz. Long transmission distances and the radial spread of electromagnetic waves lead to a more flexible placement of the battery modules. This flexibility is accompanied by high power consumption and a high potential for electromagnetic interferences. A countermeasure can be the use of shielding materials for the battery casing. Error detection protocols can reduce data loss.



A wireless battery management system enables flexible module placement

	Wire	Radio	Light	Sound
Implementation	isoSPI, CAN	Bluetooth, wi-fi	IrDA (SIR, FIR, MIR)	Chirp, Infosound
Manufacturing	--	0	0	0
Power consumption	+	0	+	0
Bandwidth	1Mbps	2Mbps	1Gbps	100bps
Range	++	+	-	0
Vulnerability to failure	-	--	++	++
Mechanical	--	++	+	0
Reflection, absorption, transitivity	0	++	+	0
Environmental influences	0	0	++	-

Personal rating of communications systems in a battery management system

Although sound was already used to transmit short data words, it has never been used in battery systems, due to the limitation in bandwidth of approximately 50-100bps. Uses for this could be emergency notifications or heartbeat signals. Protocols such as 'chirp' are using audible sound to transmit data, while others like 'Infosound' are using the ultrasonic spectrum with a range of 18.4-20.8kHz. The battery could shield parasitic frequencies, but vibrations of the battery itself need to be considered. Transmitting over long distances consumes more power. The short distances inside a battery means less power is required, which is sufficient for our purpose.

Data transmission via infrared light is an easy and inexpensive form of wireless communications. The IrDA protocol ensures very low failure rates and has been extensively used and tested for many years. The implementation can be transferred to battery systems with little or no changes. The reduction of the protocol stack to fit customary needs reduces latency times and overheads. The physical layer provides data rates from 9,600bps up to 1Gbps with a wavelength of 850-900nm and is therefore protected from interferences of visible light. Dedicated space for propagation of light and customized plastics, which absorb or reflect specific wavelengths, can be used to guide the communication as well as reducing interference from other light sources. Precisely guiding the light allows for low-power modes with only a few µA of continuous power consumption.

All things considered, the biggest advantage of any wireless communications is cable reduction, which reduces weight, materials, labor costs and error sources. As galvanic isolation is physically provided in wireless systems, PCB design can be simplified. Target data rates can be achieved, and security issues can be addressed by combining parts of different communications methods.

Two-speed transmission

A new compact coaxial design of multispeed drivetrain technology can be easily integrated, and can deliver improved efficiency and high agility with twin-clutch torque vectoring

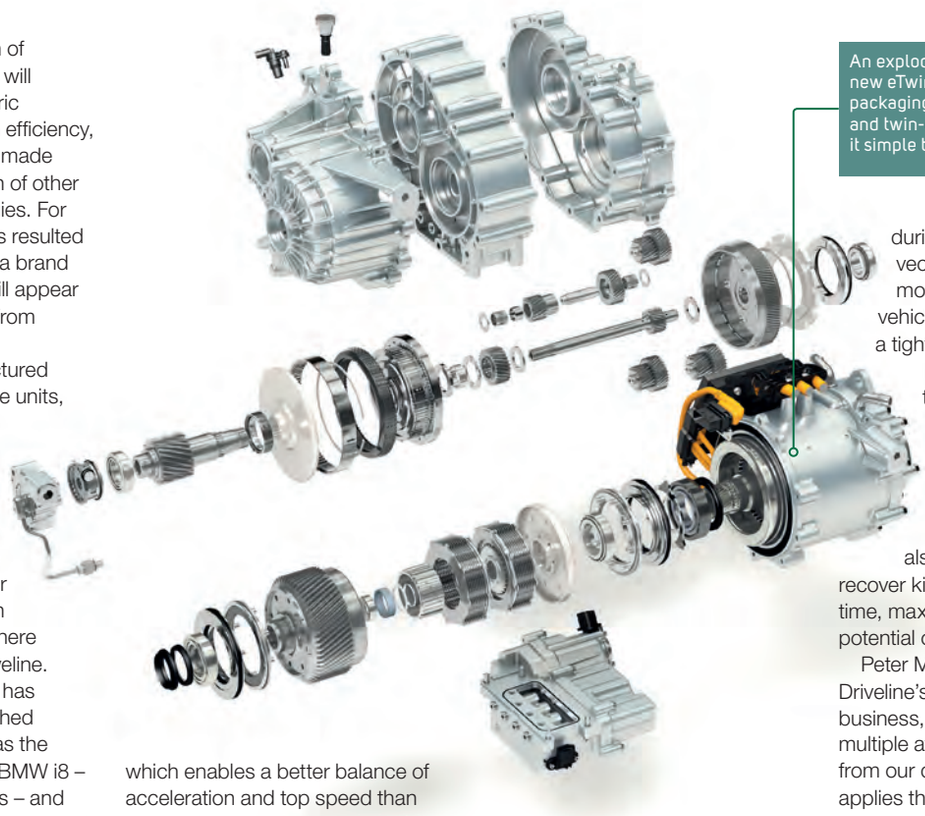
The next generation of electrified drivelines will enable new kinds of electric vehicles, with advances in efficiency, packaging and dynamics made possible by the integration of other state-of-the-art technologies. For GKN, this progression has resulted in the eTwinsterX system, a brand new coaxial e-axle that will appear in demonstrator vehicles from early in 2018.

GKN has now manufactured more than 400,000 e-drive units, and with eTwinsterX the company aims to deliver enhanced capabilities from these integrated systems. The new e-axle can be used either for the primary drive in full EVs, or for the secondary drive on plug-in hybrid vehicles, where it creates a 'split-axle' driveline. This kind of hybrid format has already been well established by GKN in vehicles such as the Porsche 918 Spyder and BMW i8 – with front axle applications – and the Volvo XC90 T8 Twin Engine and BMW 2 Series Active Tourer models.

Three key benefits of the new eTwinsterX system are evidenced by its packaging, its transmission design, and its twin-clutch differential. The unit is as compact as possible, with tightly packaged powertrain elements that share a common housing, and a coaxial format with the electric motor wrapped around the driveshaft element. The system's size also provides benefits when trying to accommodate an e-drive unit within a chassis, and can enable integration into existing vehicle platforms, enabling 'bolt on' all-wheel-drive hybridization without major design modifications.

The new eTwinsterX employs a unique 2-speed transmission, which enables a better balance of acceleration and top speed than conventional single-speed electric drive units. It meets the emerging trend toward high-revving – but lower-torque – electric motors, by making high torque available from the start in first gear, and delivering full electric power up to the maximum vehicle speed with the second gear. An optimized shifting strategy keeps the motor operating close to its efficiency 'sweet spot', meaning that it can deliver greater maximum driving range – what GKN refers to as 'more miles per watt'.

In addition to the improved efficiency, the 2-speed transmission also unlocks higher performance. The company tested single-speed and 2-speed e-axles back-to-back in the same vehicle using the same e-motor, and found that the 2-speed system delivered an improvement of 36% in 0-50km/h (0-31mph) acceleration, and a 22% improvement in 0-100km/h (0-62mph).



An exploded view of GKN Driveline's new eTwinster X. The compact packaging, transmission design and twin-clutch differential makes it simple to integrate into a chassis

Power from the e-axle is transmitted through GKN's familiar Twinster torque vectoring technology, which uses a unique twin-clutch system in place of a complex conventional differential. It provides intelligent control of the vehicle dynamics by managing the distribution of torque to individual wheels. Fully electric drivelines produce high levels of instant torque, and by precisely controlling its transmission between the wheels, GKN's system aims to ensure more stable take-off, acceleration and cornering. For example, by enabling overspeeding of the outside wheel during a corner, torque vectoring can induce a yaw-moment, helping to steer the vehicle more safely toward a tighter cornering radius.

In the eTwinsterX unit, the twin-clutch system can also produce a negative torque effect to slow the vehicle, and provides a limited-slip differential function. It can also stabilize the vehicle and recover kinetic energy at the same time, maximizing the recuperation potential of the e-drive system.

Peter Moelgg, CEO of GKN Driveline's AWD and e-drive business, says, "eTwinsterX takes multiple award-winning elements from our driveline portfolio and applies the principles in a single state-of-the-art electrified system. GKN is unique in being able to deliver an integrated e-motor, 2-speed electrified transmission and torque vectoring within a complete e-axle system."

Potential applications for the new e-axle range from city cars to luxury plug-in hybrid SUVs, whether front-wheel drive, rear-wheel drive, or all-wheel drive. The technologies within the unit also mean that it is the first e-axle in the world that has full off-road capabilities. The system will be put through live trials including GKN's extensive winter testing program in early 2018.

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SAIETTA

LEADERS IN THE DESIGN, MANUFACTURE AND INTEGRATION OF VEHICLE ELECTRIC TRACTION MOTORS

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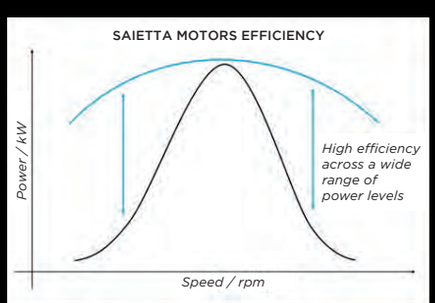
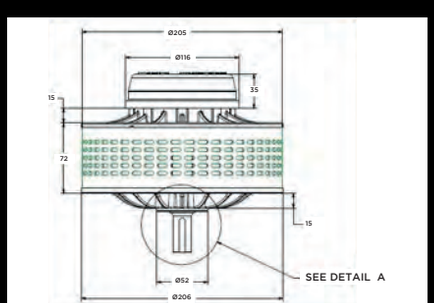
- World speed record for electric powered aircraft
- First 100% electric flight across the English Channel
- Powered 80%+ of electric racebikes globally since 2009, winning 80%+ podiums

Saietta motors optimised for vehicles

HIGH EFFICIENCY & POWER	LIGHT WEIGHT	COMPACT	COST EFFECTIVE
Super premium efficiency **93% +** ↕ **SAIETTA MOTORS 93% +**	Unique architecture delivers leading power-to-weight ratio	↓	Production in special economic zone in India = cost advantage
Premium efficiency **93%**			
High efficiency **88%**			
Standard efficiency **85%**			





WEBSITE: **saiettagroup.com** / ENQUIRIES: **sales@saietta.com**

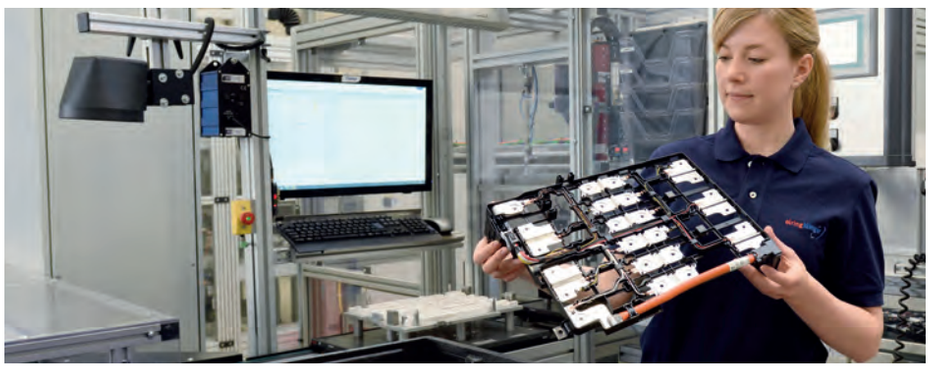
Focus on electromobility

As the automotive industry continues to reshape the way we think about mobility, suppliers such as ElringKlinger face a whole raft of challenges. ElringKlinger has focused its expertise and energy on two solutions in the electric drive market: batteries and fuel cells.

"Looking ahead, both concepts – batteries and fuel cells – have their own specific characteristics and advantages. They can also be combined to harness their respective strengths," says CEO Dr Stefan Wolf in support of the company's strategy.

ElringKlinger began series production of various components for lithium-ion batteries as far back as eight years ago. As well as cell contact systems and module connectors, the list includes the development of complete battery modules and systems and integrated energy storage units. ElringKlinger's core area of expertise – combining different components into a single assembly using a highly reliable process – has proved invaluable in the case of battery modules. The cell contact system features integrated voltage and temperature monitoring. This solution is based on a 48V module built to withstand overall system voltages of up to 800V.

ElringKlinger launched its first fuel cell technology project at the turn of the century. In this context, the company's USPs are its own stacks, a series of patented designs for metallic bipolar plates, and a portfolio of plastic media modules – all of which make it possible to simplify the fuel cell system. The company's core areas of expertise in metalworking, plastics processing, and tooling technology are matched by its unrivaled materials know-how. Thanks to automated series production processes in the areas of metal forming and plastic injection molding – including automated stacking, high-tech joining and coating technology, and an in-house tool and mold construction facility – ElringKlinger is the ideal choice of partner for companies involved in the industrialization of fuel cell products.



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Lightweight protection for automotive electronics

Electronic content in vehicles continues to increase as manufacturers dive deeper into the development of driver-assist systems and various levels of automation. As the industry relies more heavily on electronics, it is imperative that components and systems operate reliably – driver and passenger safety demands it. To survive harsh automotive environments (for example, extreme temperatures, humidity, corrosive fluids and gases, and others), many components require an added layer of protection. But that protective solution must be robust, yet not add significant mass or dimension, and cannot interfere with signal transmissions.

Ultra-thin and lightweight, Parylene conformal coatings offer excellent moisture, chemical and dielectric barrier capabilities to protect automotive components. The coatings also offer superior thermal and UV stability and, for elastomeric components, a low coefficient of friction. Applied as a vapor, there is no liquid phase in the coating process, thus there are no subsequent meniscus, pooling or bridging effects. The molecular growth of Parylene not only ensures an even, ultra-thin, lightweight conformal coating, it also enables the coating to penetrate into every crevice, providing complete encapsulation of the substrate. Parylene coatings afford automotive electronics a level of protection that is unmatched by many conformal coating materials.

Parylene coatings are RoHS and REACH compliant and have proven to provide metallic whisker mitigation in lead-free solder applications. Parylenes are ideal for protecting sensors, circuit boards, MEMS, LEDs, elastomers and other surfaces and components that need reliable, long-life performance in harsh automotive environments.

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INQUIRY NO. 536

Bidirectional high dynamic test bench energy system

Reliable and powerful test equipment along the whole supply chain from R&D to end-of-line testing is mandatory for today's automotive industry. In particular, verification tests in drivetrain applications for HEVs and EVs require safe-to-operate test equipment with high reproducibility over a wide range.

The Heinzinger ERS test bench energy system is a high dynamic, bidirectional system with active energy recovery to the grid, specially designed for such applications.

With its unique features, the Heinzinger ERS supports battery simulation for power electronic and electric motor tests, as well as tests for hybrid and drive batteries. With a voltage and current range up to 1,200V DC/1,200A DC and range of power stages from ±50kW up to ±750KW, nearly every electric powertrain or fuel-cell application can be supported.

The ERS is available in a one- or two-channel version. An upgrade from a one-channel version to a two-channel version is possible at a later point in time. To increase the maximum output current, it is possible to connect the two output channels in parallel. Safe and efficient operation of the regenerative power supply is guaranteed by electrical isolation between the mains grid and the DC side via bidirectional switch mode power stages and HF transformers. A broad range of options, in combination with Heinzinger's engineering and aftersales support, completes the company's offered service.

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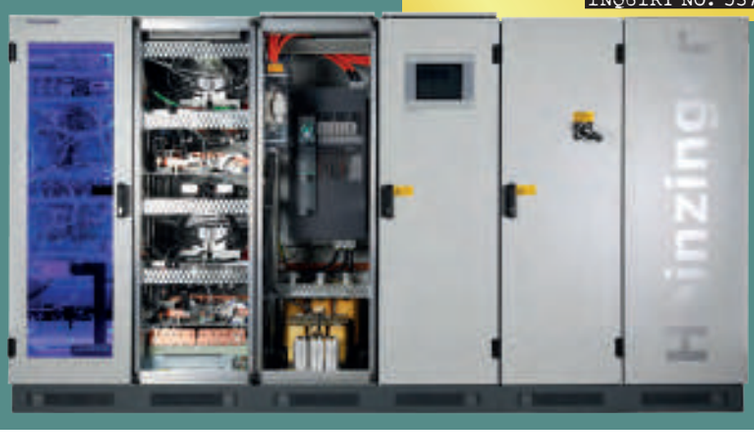


Semiconductor power module strategies

The world of individual mobility is facing a transition process that is unprecedented in the history of the automotive industry. Electrification, new trends and technologies will determine future car designs. Automotive OEMs and suppliers are forced to reconsider their whole value chain and core competencies. Growth assumptions for BEV and BHEV in global and regional markets indicate that it is high time to prepare for volume ramp-ups of electrified drivetrains.

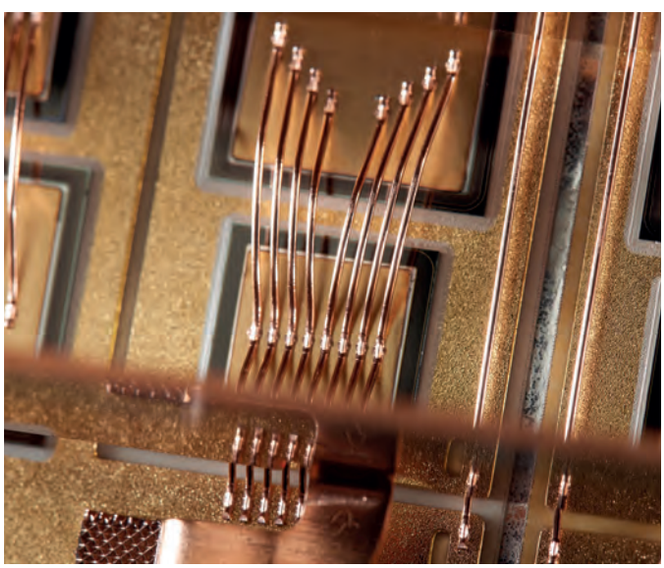
The future portfolio of traction equipment is not expected to consist of a singular layout or technology. Different drivetrains – with pure electric axles, plug-in hybrids and hybridized gearboxes combined with combustion engines – will offer a broad choice for customers.

Thanks to the presence of an electric drive, electric vehicle drivetrains comprise multi-chip semiconductor power modules densely integrated with electric machines. Competitive power modules require several features.

Advanced bonding-and-joining technology is called for, to provide superior reliability. Pressure-sintering processes and DBB (Danfoss Bond Buffer) technology with copper-wire bonding are mature and cost-efficient elements which are ready to be applied to millions of vehicles.

Similarly, excellent semiconductor cooling with advanced direct liquid-cooling technologies is also needed. For example, ShowerPower designs offer superior and more reliable performance compared with current double-sided cooling attempts.

It is also important to have a series-qualified and reliable power module platform, capable of serving a full range of current and voltage requirements to help customers leverage economic scale effects. Multiple semiconductor sourcing by an independent module manufacturer will improve the design flexibility and reliability of the supply chain, especially in a rapidly growing market.



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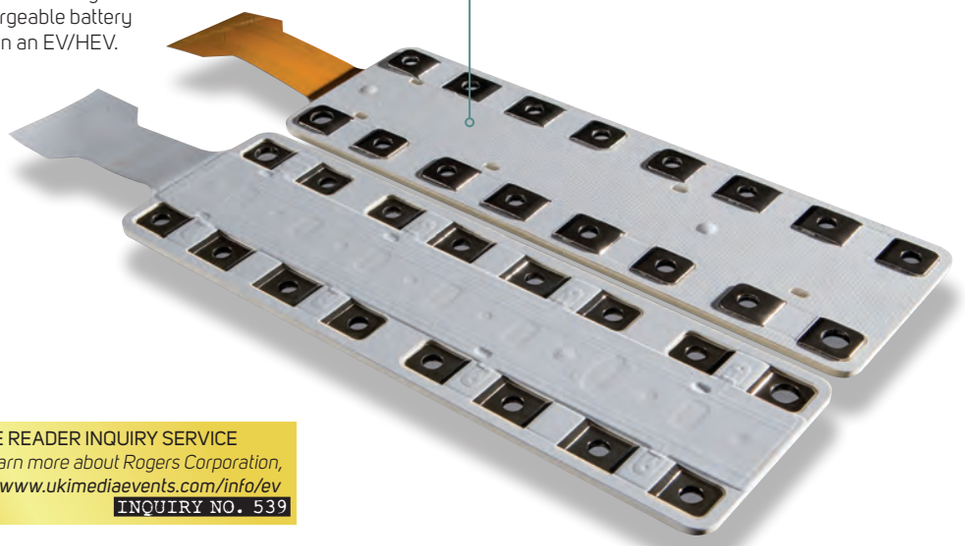
INQUIRY NO. 538

Powering EV/HEVs with laminated bus bars

The energy requirements of an EV/HEV can vary widely, with the largest amounts of electrical energy required by the inverter and electric drive motor. An EV motor has a wide range of power levels, from lower voltage operation at slow speeds to higher power use when accelerating or climbing steep grades. Low-inductance bus bars can help achieve low-loss transfer of energy with high energy efficiency from a battery pack, by minimizing energy losses in the power transmission path from an EV's high-power battery pack to the inverter and electric drive motor.

In contrast to power cables, bus bars not only transfer current from one point to another, but also make it possible to achieve power distribution with high power density, by mounting active components for power conversion, such as IGBT semiconductors, and passive circuit elements, such as capacitors and EMI filters for noise reduction. In most cases, circuit elements can be incorporated onto a laminated bus bar prior to its installation in an EV or HEV, or as part of the bus bar's manufacturing process. Incorporating capacitors into bus bars for motor drives can improve performance, while also conserving circuit volume.

Rogers Corporation has extensive experience in the design and manufacture of bus bar solutions for EV/HEV applications. As an example, the Rolinx Hybrid from Rogers is a laminated bus bar that combines power and signal paths in a compact assembly suitable for power distribution and signal connections within and from the large rechargeable battery pack in an EV/HEV.



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INQUIRY NO. 539

Thermal management in lithium-ion applications

Latent Heat Systems (LHS) from Outlast are helping global manufacturers to develop high-performing, cost-effective, next-generation battery packs. Larger power demands and growing cell density of lithium-ion battery packs result in high operating temperatures, especially under peak loads. Reducing detrimental thermal effects through the use of LHS materials that absorb and store thermal energy has proven highly effective. With their high latent heat, ease of processing and impressive reliability, LHS materials are becoming the forerunner in effective, simple and economical thermal management designs for power-intensive Li-ion battery applications.

LHS thermal management materials provide energy absorption and heat dissipation characteristics for passive thermal control, maintaining homogenous temperatures across cells and reducing battery overheating during fast charging/discharge cycles. This leads to less battery degradation, increased charge density and increased battery life.

Additionally, Outlast LHS materials are highly flame-retardant, providing for safer overall pack designs by eliminating the potential for thermal runaway and propagation.

Outlast Technologies is an expert in passive thermal control and safety of lithium-ion battery systems, and is experienced at optimizing its solutions to achieve a cost-effective, performance and safety solution for their application.

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Thermal management solutions

The Lord Corporation specializes in developing world-class thermal management solutions for demanding applications. The company's CoolTherm materials blend its highly responsive technical expertise with a leading portfolio of heat transfer technologies to deliver tailored products for managing heat issues and increasing power density. Battery pack solutions enable proper heat flow during charge/discharge cycles, while options for power electronics ensure high thermal conductivity at low viscosity to remove hot spots. Proven Lord technology will decrease operating temperature by up to 50°C (122°F) or increase power output by up to 30% for motors, and a variety of products designed for chargers ensure magnetics remain cool – with less than a 6°C (43°F) temperature difference between the core and heat sink during charging. The company is keen to share its expertise in potting and encapsulation materials, adhesives, gap fillers, gels and greases, and its solutions span various chemistries – silicones, epoxies, acrylics and urethanes – and are designed to make customers' products perform better.

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Hybrid vehicle traction inverter

The WTI-Traction Inverter series from Curtiss-Wright Industrial's family brand of Arens Controls offers state-of-the-art technology and innovative design for hybrid and pure-electric applications.

Operating with AC induction, permanent-magnet synchronous (PMS) and interior permanent-magnet (IPM) type motor technologies, the WTI-Traction Inverter's major components – IGBTs, capacitors, filters and circuit boards – are all automotive-grade and certified to AEC-Q100, Q101 and Q200 to ensure electrical reliability and an impressive power-cycle rating exceeding 7 million.

High levels of self-protection are achieved with both current and transistor temperature measuring locally to the IGBTs, rather than remote components. This delivers fast and accurate measurements, offering effective protection against adverse high-current conditions.

Advanced motor control algorithms using field-oriented control with space-vector modulation, combined with a 2-10kHz variable switching frequency, means high operating efficiency and increased operation time. A fundamental frequency up to 1,000Hz enables WTI-Traction Inverters to drive high pole-pair, high-speed motors, which are popular in hybrid applications. A torque motor-control mode is also available for hybrid applications, speed mode for pure-electric applications, or DC bus voltage mode, in which the inverter can moderate adverse and damaging voltages from regenerative braking, and so on.

WTI-Traction Inverters offer a versatile connection to master control systems by either standard J1939 or customer-specific CANbus protocols. A customizable discrete interface also enables the support of digital, analog and solenoid-drive control options.

Other features include rugged, die-cast aluminum construction; 360-600V DC supply and 160-530KVA peak power; heavy-duty, automotive-grade components throughout; IP67/69K protection against ingress of liquids and dust; and rapid discharge of internal high voltages at shutdown.

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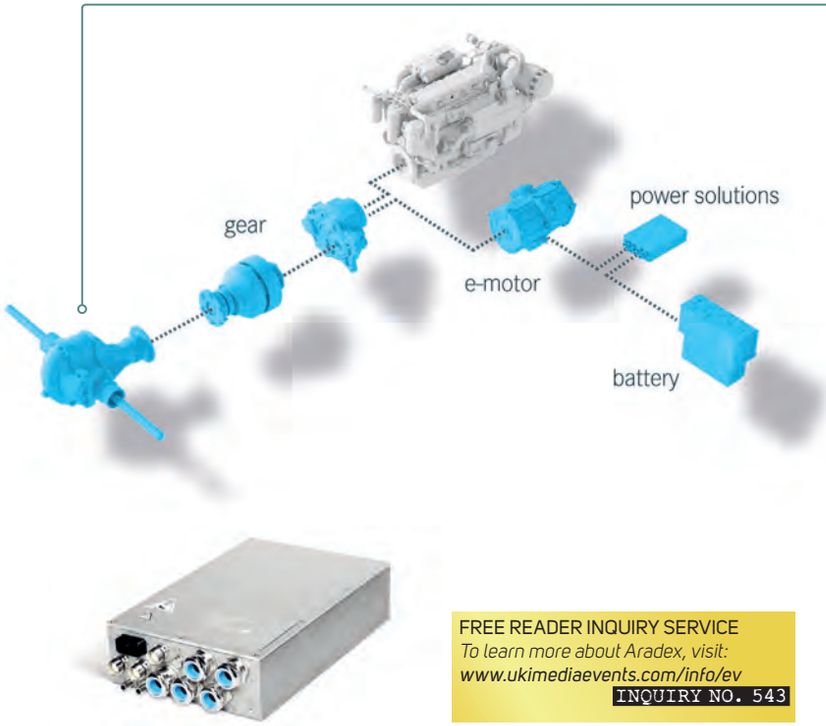

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Electrical efficiency

The German automobile and utility vehicle industry will invest more than €40bn (US$46.9bn) in alternative drives by 2020. For Aradex, as a specialist in drivetrain synthesis, this gives an opportunity to provide a holistic, systematic and agile powertrain process. Knowing the effects of all the active drivetrain components and analyzing their interaction is the basis for optimization. Configurations featuring all-electric drive components, vehicles and topologies provide system solutions for both hybrid and pure-electric drivetrains, enabling flexible drive designs.

This is where Aradex starts its system-oriented drivetrain synthesis, which focuses on maximum efficiency based on the factors of technology, performance and cost. Aradex's experience in a variety of electric drivetrains, as well as the development and integration of innovative control and power electronics, accelerates progress in electromobility. These solutions aim to increase the quality and productivity in industrial and mobile applications – including all necessary analyses.

Aradex uses the Vectopower power electronics as a core to innovatively connect and coordinate all drive components in an optimal way. In flexible and scalable applications, comprehensive system engineering can take account of interactions and save development time. Motors, gears and controls complete this system orientation, which is continuously updated with new developments – such as a traction motor which produces up to 400kW. Vectopower contains the corresponding electronics to provide mobility concepts with the freedom to activate the machine, communicate with the vehicle control, and diagnose the drive.

Hybrid efficiency

The automotive industry is currently experiencing an unprecedented transition. A wide range of propulsion architectures with differing degrees of electrification, from 48V mild hybrids to pure electric vehicles, is gaining traction in the market. The growing diversification presents numerous challenges for auto makers and suppliers alike. With its extensive portfolio of innovative 48V technologies, such as the eBooster electrically driven compressor and the integrated Belt Alternator Starter (iBAS), BorgWarner supports its customers in designing the car of the future.

Equipping vehicles with a 48V power supply delivers most of the benefits of a conventional high-voltage hybrid system – at only 30% of the cost. This makes 48V systems a key milestone on the road to meeting consumer demands regarding performance, features and fuel efficiency. BorgWarner's eBooster technology makes full use of the additional power. By driving the compressor turbine with an electric motor, the system complements traditional turbocharging systems and provides improved transient behavior at low engine speeds, while enhancing fuel efficiency and reducing emissions.

To increase efficiency even further, BorgWarner has developed the iBAS. This innovative solution featuring integrated power electronics optimally supports stop/start systems with fast, quiet engine restarts. In addition, the iBAS also enables hybrid functionalities such as regenerative braking and engine torque assist. Combining these two cutting-edge technologies allows for potential fuel economy gains of up to 20%.

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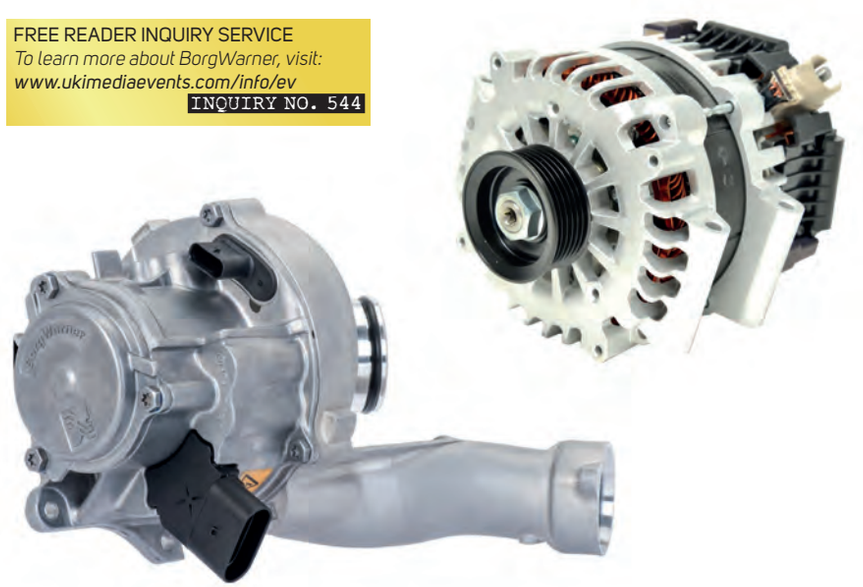
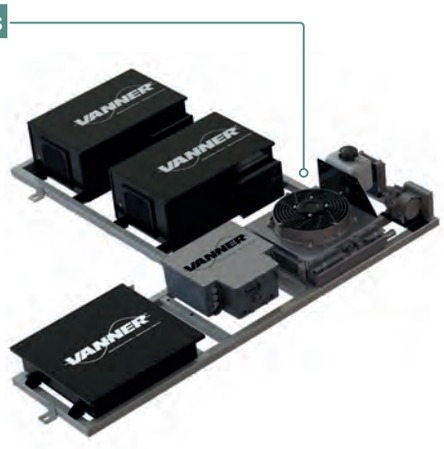


Total accessory electrification for buses

The complete electrification of bus accessory components is now achievable through Vanner's Increased Accessory Power II (IAP II) system. IAP II is a customizable distribution platform that provides power to operate electrical accessories such as air conditioning, air compressors and power steering systems for hybrid, EV and fuel cell buses.

IAP II can completely decouple accessories from the engine, significantly reducing parasitic loads and maintenance costs. A high-voltage distribution module (HVDM) provides intelligent high-voltage power control. A single HBA or dual HBAs can be used to convert high-voltage DC for the 24V DC system. Vanner's proprietary state-of-charge (SOC) modeling offers dynamic



24V DC system charging, and an inverter converts high-voltage DC to high-voltage AC for powering electric accessory systems while eliminating the need for a costly A/C system integral inverter.

Transit authorities realize that full bus electrification improves fuel economy, reduces emissions and lowers maintenance costs. IAP II further improves efficiency by removing parasitic loads from the engine and distributing electrical power through the entire bus.

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Thermal interface materials

Fujipoly Europe specializes in the supply of thermal interface materials (TIMs) for cooling of electronic systems, as well as elastomeric connectors and rubber extrusions for the automotive industry. Fujipoly's parent company, Fuji Polymer Industries Co., was established in 1978 as a manufacturer for secondary processing of industrial silicone rubber products. Thanks to the technical knowledge within the Fujipoly global group, Fujipoly Europe has the ability to meet current and future technical challenges.

The company's business relies not only on supplying its standard range of products, but also on its ability to work with customers to create customized materials suitable for their application. Fujipoly understands the time pressures on projects when prototypes are required urgently, and has invested in finishing machines that require no tooling. This enables the company to respond rapidly to customers' prototype requirements.

Fujipoly manufactures within the UK, and also from multiple Fujipoly locations. This enables the company to meet the local supply needs of its customers with regard to cost and speed of manufacture. Fujipoly's business continuity plan ensures that it is able to manufacture parts at several locations to guarantee the supply chain.

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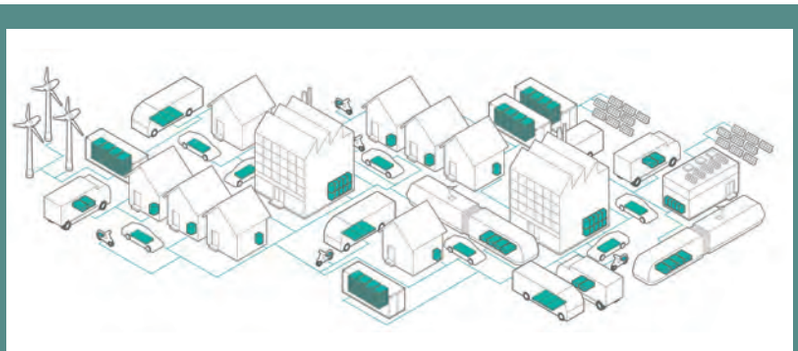

Making sense of batteries

Dukosi is bringing a disruptive lithium-ion individual battery cell monitoring technology to market by way of a custom ASIC with near-field wireless communication products.

This novel cell-monitoring technology complements existing and new battery management systems, offering product lifecycle cost and performance benefits across the entire battery supply chain, from cell manufacture, pack integration and in-service applications, through to end-of-life recycling processes.

Individual battery cell provenance is recorded and archived for future access, providing a complete, traceable history of manufacturing processes, utilization data and in-service performance.

Cost and reliability benefits may be realized through the elimination of complex wiring, connectors and interfacing components.

Secure data is acquired at each individual battery cell, this leads to more accurate measurement of key parameters, while the wireless component featured is able to support a series of data-driven services remote from the installation.

Bespoke software and algorithms are embedded in the high-performance ASIC that simplifies systems architecture and moves measurement and calculations downstream to the source. Dukosi's new battery technology is fully adaptable and can support smart and intelligent data-driven applications across a number of different market sectors including automotive, grid energy/renewables, industrial and marine.

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INQUIRY NO. 547

Enhanced measurement system

With its newly developed shunt-based IVT-S measurement technology, Isabellenhütte is responding to a market that now favors specified functions in current measurement systems. The main focus is on achieving dielectric strength that is as far as possible in line with the intended application. High dielectric strength must be guaranteed in battery-powered vehicles, for example.

To this end, Isabellenhütte is now introducing the IVT-S. The measurement system has a maximum dielectric strength of 1,000V. Its functional range includes the measurement of current and voltage. Isabellenhütte thus meets today's market requirements of traction battery systems or stationary, electrical energy storage devices. These lithium-ion batteries generate high energy density, at which higher voltages can be applied with smaller currents. Therefore the sensor's dielectric strength also has to be correspondingly high – a key quality feature that distinguishes the IVT-S from competing products. In applications such as fast-charging battery systems, this performance feature is extremely important.

The IVT-S uses a range of components. A 16-bit A/D converter guarantees the precise transformation of the voltage drop into digital signals. Data is transmitted via a CAN 2.0 interface. Through this module, internally developed current-counting firmware is provided with information on charge and discharge volumes. In addition, Isabellenhütte provides a CAN description file in DBC format that helps IVT-S users to swiftly integrate the application.

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INQUIRY NO. 548

Test systems for climate chambers

Kübrich has more than 15 years of experience with door slam systems for fatigue and durability testing in climate chamber usage (-40°C to +85°C (-40°C to +185°F), end-of-line test solutions, and test solutions for the complete e-mobility vehicle generation.

Thanks to its Actere software, Kübrich has come up with a turnkey test system individually designed for laboratories or test facilities. The company has developed a complete actuator and robot program for endurance and durability tests focused on climate chamber usage. All Kübrich systems are designed to simulate lifecycle testing, enabling up to 1 million cycles.

Testing of e-mobility components such as starter generators, e-drive motors and complete e-drive units have become a major part of Kübrich's operation, as well as component testing for development of autonomous drive systems (e.g. electronic steering, self-parking and electric driven aerodynamic components). All components interfaced with the Actere testing software allow users to create their own test sequences, displays and reports.

The DuT (device under test) module enables a wide range of measurement possibilities and simulations via CANbus or LINbus, and for climate chamber usage. With the company's latest development – a new starter generator test stand for 48V systems – Kübrich continues to innovate.

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INQUIRY NO. 549

High-voltage automotive battery stack monitoring

Analog Devices, which recently acquired Linear Technology Corporation, features the LTC6811 high-voltage battery stack monitor, a drop-in replacement for the LTC6804 with higher performance and a 25% lower price. The LTC6811 is a complete battery measuring IC for hybrid/electric vehicles that incorporates a deep-buried Zener voltage reference, high-voltage multiplexers, 16-bit delta-sigma ADCs, and a 1Mbps isolated serial interface. An LTC6811 can measure up to 12 series-connected battery cell voltages with better than 0.04% accuracy. With eight programmable third-order, low-pass filter settings, the LTC6811 provides outstanding noise reduction. In the fastest ADC mode, all cells can be measured within 290µs.

For large battery packs, multiple LTC6811s can be interconnected and operated simultaneously, using Linear Technology's proprietary two-wire isoSPI interface. This built-in interface provides electrically isolated, high-RF noise-immune communication for data rates up to 1Mbps. Using twisted-pair cabling, many LTC6811s can be connected in a chain to one host processor, enabling the measurement of hundreds of cells in high-voltage battery stacks.

The LTC6811 is offered in a small (8 x 12mm) surface mount SSOP package. Priced at US$8.19 each in 1,000-piece quantities, samples and demonstration boards are available on Linear Technology's website.

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To learn more about Linear Technology Corporation, visit: ***www.ukimediaevents.com/info/ev***
INQUIRY NO. 550

Extensive testing capabilities

Based in northern France, Critt M2A is an independent research and development center and currently specializes in four main automotive testing areas – NVH, engine, turbocharger and electrical testing.

The company's electrical department is equipped with 96 single battery cells and five battery module test systems, which can assess the electrical and thermal behavior of batteries used in the automotive, motorsport, railway and aeronautic industries.

To continue its growth, Critt M2A will expand and invest in new test facilities for electric and hybrid vehicles. A battery simulator will be installed on engine and turbo benches to anticipate the future evolution of the internal combustion engine.

Critt M2A will be equipped with six battery pack test systems – up to 750kW – to characterize the complete EV battery range (available end of 2018). Furthermore, to work on the overall energy management of the vehicle, a 4WD test bench will be installed in early 2019 and will enable tests on electric, hybrid and ICE powertrains.

Thanks to its extensive testing capabilities and expert support, Critt M2A has a flexible structure that can fully adapt to each specific customer request, while working under the highest levels of confidentiality.

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INQUIRY NO. 551

Hybrid system and electric machines

Transfluid's hybrid system is easily integrated with traditional propulsion systems, ensuring efficient green power and fuel economy. The hybrid system may be used in three ways: electric propulsion with zero emissions and silent operation; combustion engine propulsion while using the electric machine as a generator recharging the batteries; or 'booster' mode enabling, during acceleration, the electric motor to assist the combustion engine in providing extra torque.

Any operation is directed via Transfluid's proprietary electronic controller, MPCB-R5, which communicates with all other equipment through CANbus protocol, making the system a simple plug-and-play solution.

The HM module series was developed to provide a standard, simple, quality solution. Designed to be inserted between the engine SAE flywheel and the transmission SAE input, the HM module provides a seamless solution, easier to install and simpler to operate than other specific applications, and ideal for ground-support equipment and small mining and construction machines.

The electric machine can be mounted in various positions for the best fit in the engine compartment, and the module only requires a small space between the engine and the transmission – not just for new designs, but for retrofits as well.

Transfluid has also developed its own electric machines, mounted both on the hybrid groups and on the electric propulsion systems (EPS). The latter combines the electric motor with a gearbox, also manufactured by Transfluid. Primary EPS applications can be found in the airport vehicle sector and the road train sector, among others.

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INQUIRY NO. 552

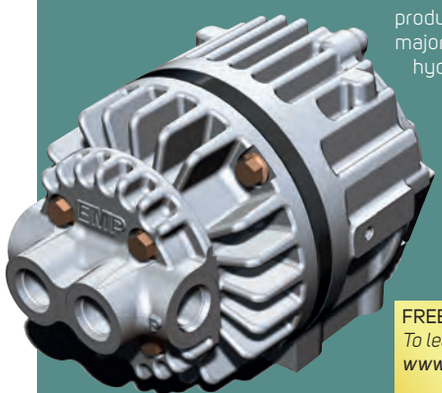
Traction/generator motor cooling

The engineering and manufacturing company that transformed the bus transit market a decade ago with its electric multi-fan cooling solution – Mini-Hybrid – is now aiming to do the same for electric and hybrid vehicle electronics cooling, including traction motors. Northern Michigan's EMP has launched a new electric oil pump (eOP) product line-up designed to provide the lubrication and oil cooling demanded by today's electric traction and generator motors.

Jason Cousineau, EMP's lead engineer for this revolutionary product, notes that the electric pumps represent a breakthrough in performance, durability and efficiency compared with other pump technologies. All EMP oil pump modes have high-efficiency, long-life brushless DC motor and drive technology available in both 12V DC and 24V DC. The pumps are positive displacement types, utilizing gerotor pumping element technology for quieter, more efficient operation. With discharge pressures up to 100psi, the pumps will handle a variety of fluid transfer applications including lubrication, cooling, scavenge and general fluid management.

The eOP product line-up recently expanded to include a new higher flow capacity model that doubles the flow capacity of the already existing OP40 pump to 8.0 gallons per minute. A two-stage pump model has also been introduced for dry sump lube and cooling applications.

EMP is a leader in complex precision machining and advanced thermal and oil management technologies and has been manufacturing electric oil pumps since 2010. Based in Escanaba, Michigan, EMP's products are used globally by major diesel engine OEMs and hydraulics manufacturers.



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INQUIRY NO. 554

Double inverters for electric buses

Manufacturer Proterra is a pioneer in the segment of electromobility. In the USA, it builds new vehicles instead of modifying old ones. Fully charged in just 10 minutes, Proterra e-buses, featuring sophisticated charging-management systems and efficient use of stored electrical energy, are attracting a lot of attention. For the drive of auxiliary units, Proterra uses double inverters from Lenze Schmidhauser's Mobile system, which are specifically designed for mobile use.

Lenze Schmidhauser is a leading manufacturer of drive solutions for mobile use. The company is focusing on the Mobile system of modular products specially designed for commercial vehicles. This system comprises double inverters, DC/DC converters, and various combination modules. Manufacturers can use these products to quickly and easily put together, from a catalog, a tailor-made system for the drive control of auxiliary equipment such as steering pump, air compressor and HVAC system, and the power supply of the onboard electrical system. The company's Mobile product range is off-the-shelf available and in volume production at present. The Mobile DCU 30/30 double inverter is designed to convert the direct current from the vehicle's batteries into alternating current on a frequency-controlled basis. The alternating current is then used to drive the power steering pump and the two electric motors for the air compressor.

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INQUIRY NO. 555

Thermal management of electric vehicles

Fränkische Industrial Pipes (FIP), an international development partner of OEMs and Tier 1 suppliers, has played an important role in electromobility for many years. The company's broad range of medium conducting systems, corrugated conduits and protective hoses also includes efficient systems for battery temperature conditioning. The Li-ion batteries used in electromobility applications boast an efficiency under 100% – the rest is emitted as heat. These highly sensitive batteries do not tolerate very high or low temperatures, and their service life depends on a constant operating temperature between 15°C and 35°C (59°F and 95°F). This means that batteries require appropriate cooling or heating to avoid performance decrease or damage.

FIP develops and manufactures battery temperature control systems according to customers' requirements, matching the battery and efficiently ensuring long service life of batteries in EVs. The structural components of the system are weight-saving, flexible, modular in various installation situations, and are adapted to meet the demands of the OEM. Compared with rubber or metal solutions, FIP's system offers better performance in terms of impact resistance and flexural strength, and the structural design makes it lightweight. It prevents corrosion and is easy to assemble. The system also has lower sensitivity to hydrolysis and features good mechanical properties attributed to the use of polyamide. Thanks to the flexibility available, even complex geometries can be produced. Space-optimized connectors and various connector systems with integrated temperature sensors complement the product portfolio of the ducting system.

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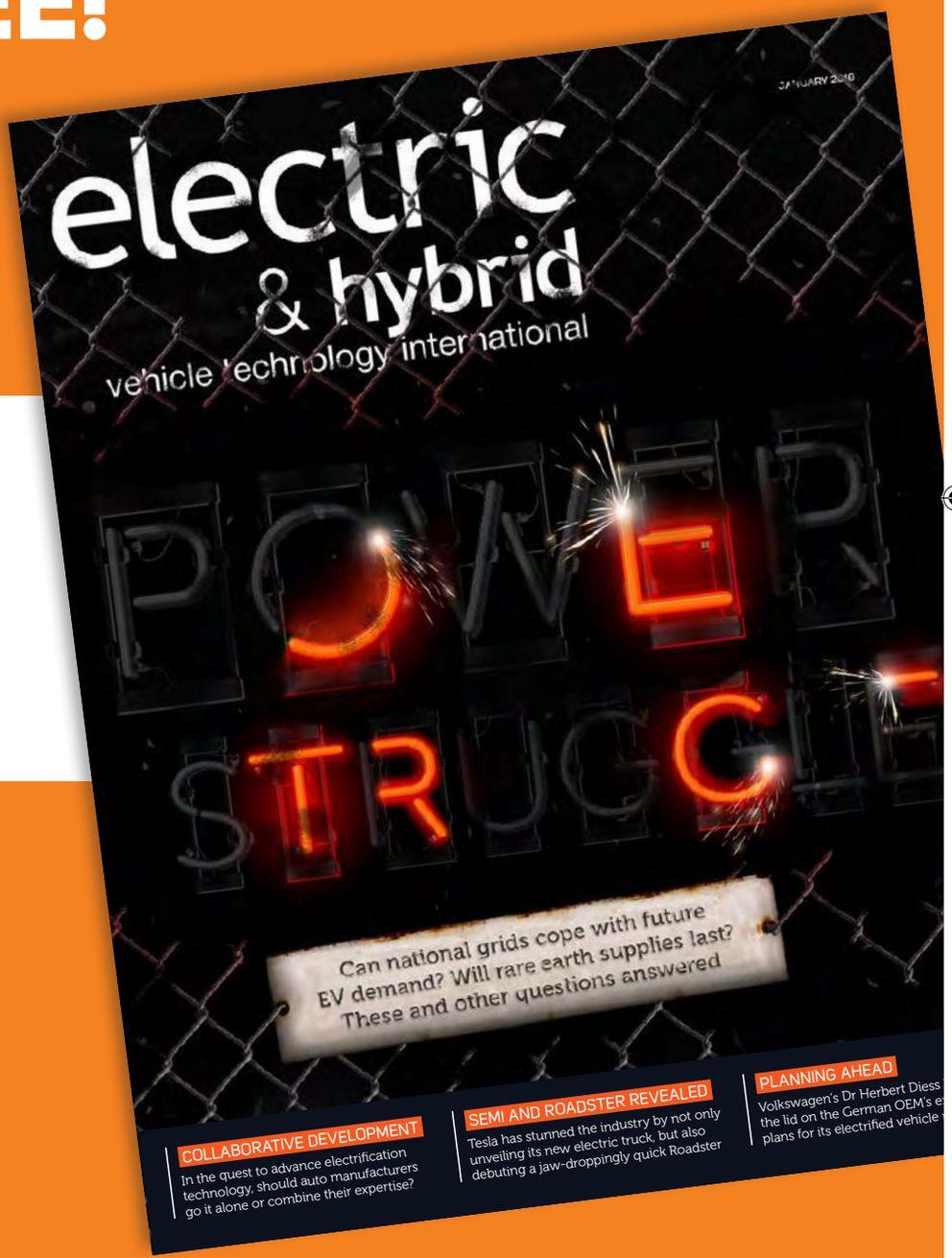

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TRACK BUSWAY

Elon Musk launched the Semi and Roadster in November in similar vein to how Apple unveils a new iPhone. But what are Tesla and its boss not telling the media?

Show **business**

You've got to hand it to Elon Musk. If nothing else, he knows how to put on a show.

The reveal of the Tesla Semi – the company's first venture in the trucking world – was just brilliant. It could actually shake up that industry more than the Model S did with the automotive world.

Yet if the Tesla Semi was a brilliant showpiece, then what followed was pure genius. As the extravaganza was coming to its logical conclusion, Musk played his second ace card of the evening. The Semi's trailer doors swung open and the stage went dark, revealing two bright white headlights from inside the truck. Beastie Boys' *Sabotage* kicked in over the sound system, and out rolled Tesla's second-gen Roadster. Simple, but so very effective.

The crowd responded with euphoria, and Musk himself could not contain his delight, feeding off the audience and grinning at the symbolic birth of his new car before those assembled eyes.

And he should be pleased with himself; the Tesla boss might just have pulled off the oldest trick in the book: deflection.

WORDS: **DEAN SLAVNICH**

In recent times, the Californian company has had it hard. While most OEMs face challenges, Tesla is struggling to overcome some enormous problems that threaten to drag the organization down.

Forget the Semi and Roadster for a moment; it's the Model 3 that's vital to Tesla's immediate and mid-term future. And with this pivotal product, the company is in manufacturing hell.

Launched in July – also to great pomp and fanfare – the Model 3 was Tesla's 'EV for the masses'. By the end of this year, production should have been close to 20,000 units per month. But, in the last quarter, only 260 or so examples of this 'fate-deciding car' have rolled out from Tesla's base. Manufacturing bottlenecks have bogged the company down, to the point that Model 3 production targets have had to be revised.

There have been other issues too. Quality glitches on those rare Model 3 runners, and even on the S. And then there have been 'those' reports of unrest at the company's production site in Fremont.

All in all, Tesla, which has never returned a yearly profit, has come to a critical juncture. So Musk is going big to fix the problems: spending around US$1bn a quarter, primarily to set up a Model 3 site, quick snap.

But even throwing huge amounts of money at the issue isn't guaranteed to make these problems go away any time soon. So what Musk needed to do was to get Tesla back in bed with the press, own social media for a few days, appease investors, and most importantly give his company something to rally behind.

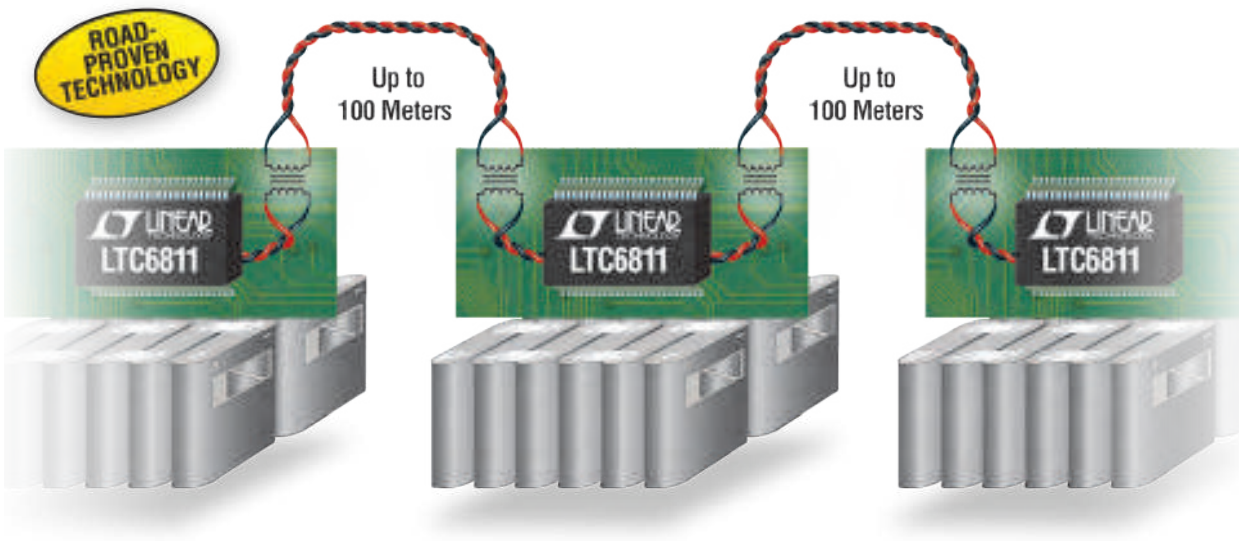
And that's exactly what we got on November 16, as the latest additions to the Tesla family took center stage.

I could be wrong; I might be being overly cynical. And let me say here and now I'm a huge Tesla fan. I just love the way the company is tearing up the auto rulebook. And no doubt the development and subsequent launch of both new vehicles have been planned for some time. But I still sense that there was much more at stake during this particular unveiling than the reaction to these new products.

Here's the thing: we don't even know where the Semi and Roadster will be built, and I suspect few do even within Tesla.

But those concerns were not apparent that night, because like everybody else, I couldn't help but smile as the Roadster emerged from the Semi. No wonder Musk's grin was so infectious. He'd pulled off a winner, and he knew it. A showman he might be, but a brilliant leader he is first and foremost.

1.2mV Accurate, Noise Immune Battery Stack Monitor



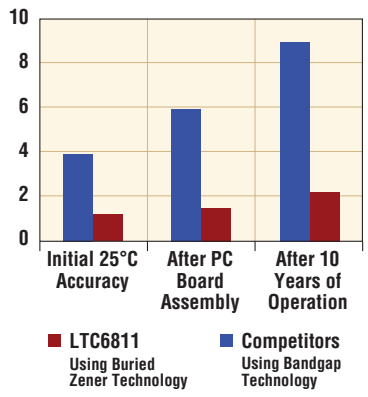
Maximize Battery Pack Safety, Life, Capacity & Driving Range

Safely extract the potential of large battery packs via precise monitoring of every cell. The LTC®6811 Battery Monitor measures cell voltage with less than 0.04% error, guaranteed. Measurement stability over time, temperature and operating conditions is achieved with a buried Zener voltage reference, similar to those in precision instrumentation. A programmable 3rd order noise filter keeps noise from corrupting cell measurements, and a 2-wire isoSPI™ interface provides a cost-effective, noise immune, 100 meter interconnection for multiple LTC6811s.

Features

- Total Measurement Error <1.2mV
- Long Term Stability Assured with Laboratory-Grade Voltage Reference
- isoSPI, Isolated 2-Wire Interconnection up to 100 Meters
- 290µs to Measure All Cells
- Passive Cell Balancing
- 4µA Sleep Mode Supply Current
- AEC-Q100
- Engineered for ISO 26262 Compliance

Measurement Error (mV) when Measuring a 3.3V Cell



Info & Free Samples

www.linear.com/product/LTC6811

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