electric & hybrid vehicle technology international
January 2019
UKi Media & Events

electric & hybrid
vehicle technology international

January 2019

Automobili Pininfarina
PF0

The **EXCLUSIVE** development story behind the new luxury electric hypercar

SOLID STATE OF AFFAIRS
Having promised a step-change for EV ranges, solid-state batteries have yet to find a route to widespread application

ELECTRIFYING THE OIL INDUSTRY
Major petroleum companies are embracing electrification, investing heavily in charging technology and station infrastructure

THE RETURN OF FISKER
E&H Vehicle speaks to Henrik Fisker about breakthrough battery technology, new business models and affordable EVs

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The pressure cycling test bench for climatic components tests at -40 to +140 degrees Celsius.

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Poppe + Potthoff Maschinenbau GmbH
An der Helme 26
99734 Nordhausen | Germany
Phone: +49.36 31.46 22 10 22
E-mail: salesppm@poppe-potthoff.com
www.e-mobility-pruefstand.de

THE PRECISION-MAKERS

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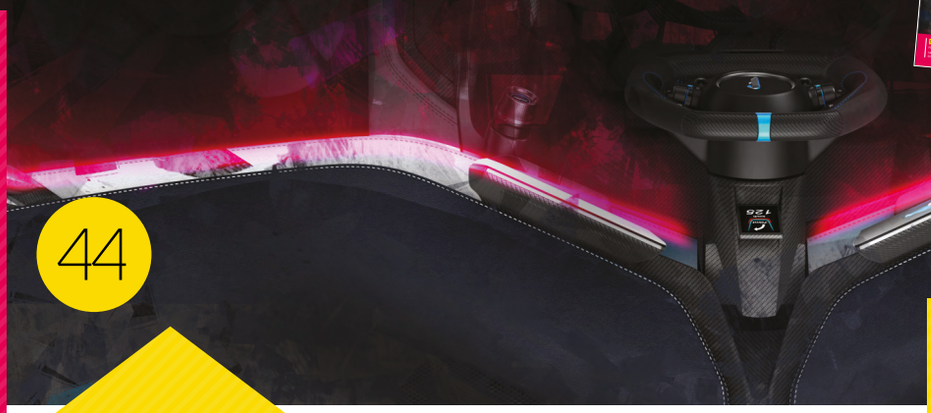

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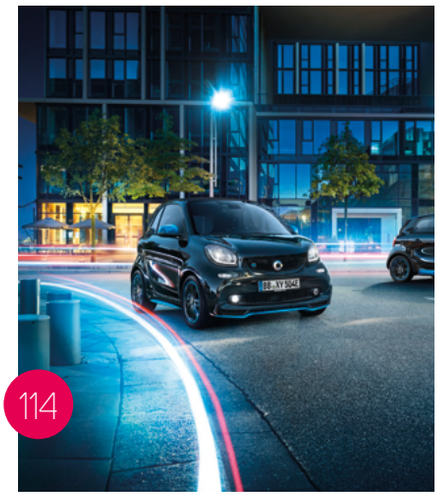

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PRODUCTS & SERVICES

EDITOR'S NOTE

Back in 2014, I joined UKi Media & Events as deputy editor on this very title. Though I must confess I can't remember exactly which article it was for, I conducted an interview during which the subject of advances in battery technology came up. We were discussing competing chemistries when I was told that, of course, everything would change when solid-state batteries became a practical, feasible reality. Having heard only a little about the idea of solid electrodes and electrolytes (in place of the liquids or polymers used more commonly) in next-generation battery technology, I asked how much of a big deal it could possibly be – though I sincerely hope I phrased it a little more eloquently than that. It's a game changer, I was told. It could change everything.

Yet here we find ourselves, nearly five years later. The technology still promises to offer new levels of battery performance – and, crucially, vehicle range – but we have yet to see it implemented in production vehicles. As with so many things (I'm looking at you, inductive charging), widespread application is yet to prove feasible. But it *is* coming, so we're told. Several OEMs – established and startups – are relying on the technology to finally offer the kind of vehicle ranges that will prove so vital to widespread consumer uptake. I don't know if I'd class myself as a 'typical' vehicle buyer, but I've no doubt that many would be as happy as I would to switch to fully electric if three barriers could be overcome. When vehicles can offer the kind of battery capacities that will cover my average weekly commute with room to spare; when I can charge my car with relative convenience; and when I can do so in just a few minutes – that's when you'll find me down at an EV showroom, eager to sign on the dotted line. But it is something of a chicken-and-egg situation. I currently can't charge a vehicle at home (if you don't have a driveway, you're basically out of luck), which means I would need to find a public charging point. But doing so would mean finding a way to occupy myself for several hours while I take on enough charge to manage another week.

We've looked at a few of these issues (and more) in this issue of *E&H Vehicle*. On page 52, you'll find an investigation of solid-state battery development, and perhaps some answers as to why we're still waiting to see the technology roll out. Turn to page 72 and you'll read how support for both charging rates and station availability is getting a boost from an unexpected source – petroleum companies. And on page 44, you'll find details of development on the Automobili Pininfarina PF0 – the car I'd like to buy when all these pieces fall into place. Sadly, short of an unexpected windfall or unlikely lottery win, the latter seems like it might be slightly out of my reach.

But, give it a couple more years, and perhaps ranges, charging rates and plug-in availability could hit that tipping point where someone 'typical' like me can start to seriously entertain the idea. What's more, there'll be even more EVs available by then. During 2019, we'll see the Jaguar I-Pace, Mercedes EQC, Audi e-tron, Kia e-Niro, Porsche Taycan and others finally driving out of showrooms. OEMs like BMW and Volkswagen are also on the verge of rolling out exciting (and expansive) portfolios of pure-electric cars with the kinds of ranges that make me pretty optimistic. Maybe I should hold off on the PF0 – for now. Enjoy the issue.

Matt Ross

Editorial
Editor: Matt Ross
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Design
Art director: Craig Marshall
Art editor: Ben White
Design team: Andy Bass, Anna Davie, Louise Green, Patrick MacKenzie, Karin Rees, James Sutcliffe, Nicola Turner, Julie Welby

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Advertising
Sales and marketing director: Simon Edmands
Sales manager: Ed Marshall

CEO: Tony Robinson
Managing director: Graham Johnson
Editorial director: Anthony James

How to contact us
Electric & Hybrid Vehicle Technology International
Abinger House, Church Street, Dorking, Surrey, RH4 1DF, UK
+44 1306 743744
electric@ukimediaevents.com
electrichybridvehicletechnology.com

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DRAG ACT

Chevrolet's eCOPO Camaro Concept offers a vision of how electric powertrains could slot into the vibrant OE performance parts market

WORDS: **GRAHAM HEEPS**

During a stroll around the Las Vegas halls of the 2017 SEMA aftermarket show, Russ O'Blenes, GM's director of performance variants, parts and motorsport, stumbled upon Shock and Awe. This Pontiac Firebird-based, electric drag race car was the brainchild of teacher Patrick McCue and his automotive technology program at Bothell High School near Seattle, Washington. Working with the respected Hancock & Lane (H&L) drag race team, more than a dozen students had participated in its development and assembly.

"When I talked to Pat, I saw the link to GM's commitment to engaging young minds in STEM education," says O'Blenes. "It also represents our goal of a world with zero emissions, with the next generation of engineers and scientists who will help us get there."

Seeing Shock and Awe fed into thoughts that O'Blenes and his colleagues had been having as to the right place to engage in electric motorsport.

"Formula E's cool, but this [drag racing] is the perfect opportunity to do fast learning on

Tipping the scales at 1,580kg (3,480 lb), the eCOPO is around 91kg (200 lb) heavier than a supercharged COPO Camaro. At 136kg (300 lb), the motor assembly is lighter than gasoline equivalents but the 318kg (700 lb) battery packs add mass

VITAL STATISTICS

Motors: 2x BorgWarner HVH250-115. Total 700bhp (710ps), 840Nm

Inverters: 2x Rinehart Motion Systems PM250DX

Battery pack: 4x 48-cell modules in series. Total 800V, 32kWh

Cells: Xalt Energy pouch-type

Transmission: Turbo 400 3-speed auto

Quarter-mile: 9 seconds (estimate)

battery technology, for example. The 32kWh in our battery pack is a perfect number: you can do three runs without charging, or do a fast recharge in-between and run all weekend.

"What else is interesting is that although you would have to make a big initial investment, there's almost no maintenance," says O'Blenes, himself an accomplished drag racer. "The electric motors are designed to run forever, and the battery life would be very long, given how a race car cycle would be. Racers in the Comp or Stock classes are [already] spending US$60,000-80,000 on a motor that will make 50 passes before it needs rebuilding. People just don't want to add up how much we spend on racing – we're all in denial!"

Crate engine concept

GM hatched a plan to draw on the experience of its own engineers, as well as McCue, Hancock & Lane, and other outside partners, to create a concept electric drag racer for the 2018 SEMA Show. The result – built and owned by the McCue/H&L team – is the eCOPO Camaro Concept, which marries a dual-motor stack and a four-module Li-ion battery pack to a conventional drag-race transmission and driveline in a regular COPO rolling chassis. COPO stands for Central Office Production Order; Chevrolet has offered 69 of the special-order performance Camaros for sale each year since 1969.

The goal from the start was to mimic the plug-and-play setup of Chevrolet's successful Performance Parts program, which offers crate engines and associated systems under the Connect & Cruise banner to amateur racers and street-car builders.

"I'm not saying it's happening tomorrow, but I wanted to get ahead of the game," says O'Blenes. "Crate engines are our bread and butter, so we had that mindset from the beginning. What's neat is that everything has a modular design. The eCOPO package has two motors in it, but you can build it with one, two or three, for 350, 700 or 1,050bhp [355, 710 or 1,065ps]. It gives flexibility for how we might do stuff in the future."

The electric crate motor concept shown at SEMA was designed and built at GM. It comprises two BorgWarner (ex-Delco Remy) HVH 250-115 motors, each making around 420Nm of torque for a combined 840Nm, and two Rinehart Motion Systems PM250DX propulsion inverters.

The motor stack bolts to the COPO's regular Turbo 400, 3-speed automatic gearbox using the same bell housing mounting pattern and crankshaft flange as the gasoline-powered, LS-family crate engines. That was partly to fit the vision of plug-in power, but also for performance reasons in this specialized drag-race application.

"One advantage is that you get the torque multiplication of the converter," says O'Blenes.

Two of the eCOPO's battery modules are located in the trunk. Two more modules are located in the back seat. Each module contains 48V Xalt Energy pouch power cells

"You lose some efficiency from the hydraulic losses, but also in terms of getting down the track, it's better. You really want to be able to hit the tire hard and this setup has a two-step [rev limiter launch control], just like in a regular engine, so you can set the exact power and RPM you want to leave [the start line] at."

Power cells

Design and construction of the battery pack was a major challenge for the four-and-a-half-month eCOPO program. The pack is split into four, with two modules in the back seat (one either side of the driveshaft) and two in the trunk. Each module contains 48 Xalt Energy pouch power cells for around 1,400A at full power. Like the motors, the pack's modular design would enable the pack to be scaled to different vehicles.

"The main simulation we did for eCOPO was on the battery," says O'Blenes. "Unfortunately, when you get into these types of discharge rates, the cell choices are pretty small. Availability is even more of a challenge. It seems that everybody's making energy cells, but no one's making power cells! These were literally the last 225 cells [of their type] in the world and it was a struggle to get them."

The team turned to GM's internal resources for cell choices and for sign-off on system safety: "It was critical that we had good oversight of how the contactor worked, the e-stops and electrical isolation," he adds. Starting with a battery box design from EV hot rod pioneer, Bloodshed Motors, the integration of cells and BMS was a joint effort by GM, McCue/H&L and Hybrid Design Services in Troy, Michigan, which has been a Tier 2 for GM through LG and had experience in the motorsport niche. O'Blenes notes that without the input of the various external partners, the project would not have been completed so quickly.

Each module contains 48 pouch cells and an integrated BMS to monitor cell voltages and temperatures. In turn, each BMS is connected via CAN to a 'watchdog' that monitors the BMSs, motors and inverters to ensure safety of the overall electrical system.

The four modules supply 200V each and are connected in series to give 800V, more than twice the voltage of the production Volt and Bolt battery packs. The arrangement is said to support more efficient power transfer to the electric motors and faster recharging, which is important for the limited time between elimination rounds in drag racing. Each pack has its own fuse, plus a main fuse in the custom-designed contactor box.

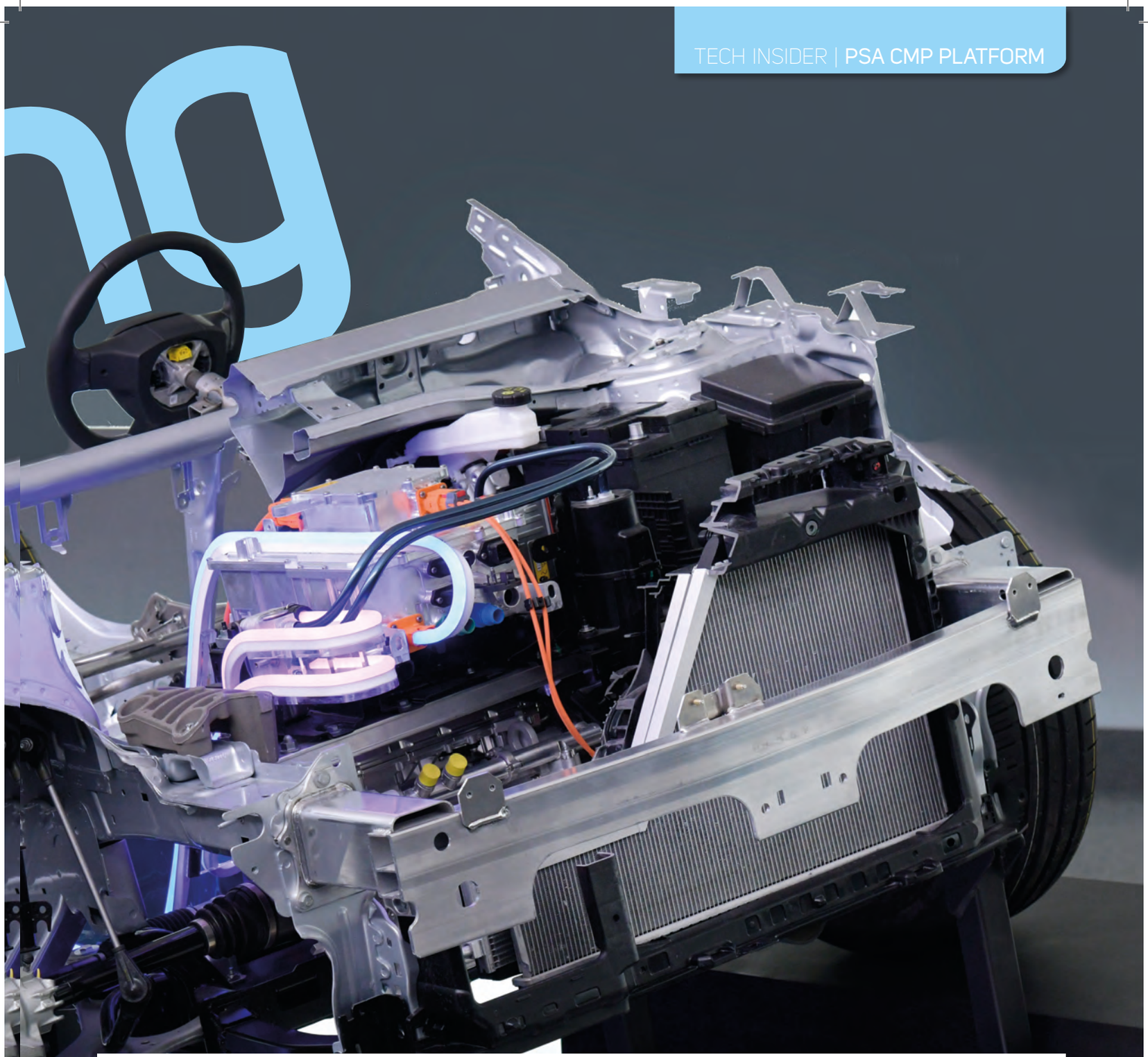
GM hasn't measured the range that the 1P pack arrangement would offer, but O'Blenes envisions offering other pack options for use in street car applications such as restomod EV conversions.

"People who take their cars to a cruise night wouldn't need this much power, so you could throttle back and do a 2P pack, or put some energy cells in it," he muses. "How cool would it be to show up in a '70 Chevelle, lift up the trunk… people would be blown away!"

Platform building

A modular platform will be central to **PSA**'s new model range, and key to the OEM's plans for electrification

WORDS: **JESSE CROSSE**



Groupe PSA has revealed further details of its new CMP platform (Common Modular Platform), which will underpin compact A-C segment cars from the DS, Peugeot, Citroën, Opel and Vauxhall brands. The first car to be built on the platform is the DS3 Crossback compact SUV, which goes on sale in 2019. CMP will replace the PF1 platform and sit alongside the EMP2 platform launched in 2013, reducing the number of Groupe PSA global platforms from six to two. The existing DS3, which is still on sale, was launched on the PF1 platform in 2009. BEVs will be produced on a variant of CMP called eCMP, with the first – the DS3 Crossback E-Tense – due in 2019. Groupe PSA plans to launch seven electric vehicles on eCMP by 2021.

"The platform was conceived from the beginning to accommodate electric powertrains with no compromise on storage and occupant legroom," says Eric Apode, senior VP, DS Automobiles. Internal space isn't compromised thanks to the modular floorpan design, enabling the battery to be sandwiched in the floor of BEVs with an electric drive on the front wheels.

Most of the development was done at the Advanced Design Network facility in Vélizy and at Poissy in parallel with the development of the DS3 itself. The platform has been developed jointly with Chinese manufacturer Dongfeng. "One of the biggest challenges was achieving a worldwide launch of the new platform in our industrial plants throughout the world," says Apode.

"We worked with all the major suppliers – Valeo, TRW, Bosch, Delphi, and so on," Apode says. "All the big names are on our cards." Aisin, for example, provided a new 8-speed transmission for the platform. The individual involvement of each supplier varied from model to model. Apode is quick

1

1. The first car to be built on the CMP architecture is the DS3 Crossback. The first BEV (built on the eCMP variant) will be the E-Tense

2. The new strategy will see PSA reduce the number of platforms it uses from six to just two

3. Eric Apode, senior vice president, DS Automobiles

to acknowledge the innovative capabilities of suppliers, but stresses that PSA works in conjunction with them to develop new features. "These are not off-the-shelf solutions," he stresses. "We have the ideas and our suppliers have the capacity to realize what we want to do.

"CMP is a step forward from the previous platform and we have been able to reduce the weight by 20-30kg [44-66 lb]." Weight savings have been made through the use of high-strength steel, aluminum front subframes, and some use of composites. "The platform is 30% stiffer than previously, giving improvements in ride and handling," Apode continues. The structure is welded and also bonded with around 22m (72ft) of adhesive per car. "The number of bolted parts has been reduced to reduce rattle and squeaks."

Electric roadmap

All new DS models following the DS7 Crossback will be electrified, as either PHEV or BEV. "The DS7 Crossback PHEV becomes available in 2019 and will have an EV-only range of 50km [31 miles]," Apode says. "From 2025, I expect that one-third or more of DS sales worldwide will be electrified." There will be no combustion-engine only DS vehicles after 2025 and PHEVs will be gasoline-electric only, so no more diesels from that time."

Autonomous driving will play a major part in PSA's future plans. "We strongly believe in autonomous driving and the DS3 Crossback will have the same Level 2 autonomous functions as the DS7," continues Apode.

CMP platform chief engineer Eric Behr explains how some of the weight savings were made. "Combustion engine cars have an aluminum subframe that weighs 6-7kg [13-15 lb] less than that of the previous platform. The use of hot-stamped high-strength steel components in the main structure saves around 20kg." The twist-beam rear axle of combustion engine cars is made from a new tubular structure design where the tube diameter reduces toward the ends, saving another 3kg.

3

The floor section module controls the wheelbase from model to model, and on BEVs contains the fully watertight battery casing. The 50kWh lithium-ion battery comprises 18 modules of 12 cells, each protected by a large shield underneath. BEVs have a different design of rear axle to maximize space for the battery between the two axles.

Behr estimates that several hundred people were involved in the development of the new platform, but numbers varied throughout the project. He agrees with Apode that global deployment across 10 different plants worldwide was a big challenge. "Highlights included the weight savings we were able to make and materials cost savings," he says.

Testing took place at PSA centers in France, Idiada in Spain, Finland and Sweden, with around 100 prototypes fitted with 'top hats' from the Peugeot 2008, mainly for validation and climate testing. Simulation played a major part in the development. "We continue to work toward more digital simulation, but we still need physical prototypes for validation," he says.

PRESENT TENSE

The DS3 Crossback E-Tense BEV is front-wheel drive with a front-mounted motor developing 100kW/136ps. Power is drawn from a 50kW lithium-ion battery sandwiched in a BEV-specific floorpan. Acceleration to 62mph (100km/h) takes 8.7 seconds and 0-30mph (48km/h) takes 3.3 seconds. A full charge using an 11kW wall box takes five hours and an 80% fast-charge at 100kW takes 30 minutes. Range is 186 miles WLTP and 280 miles NEDC (300km and 450km).

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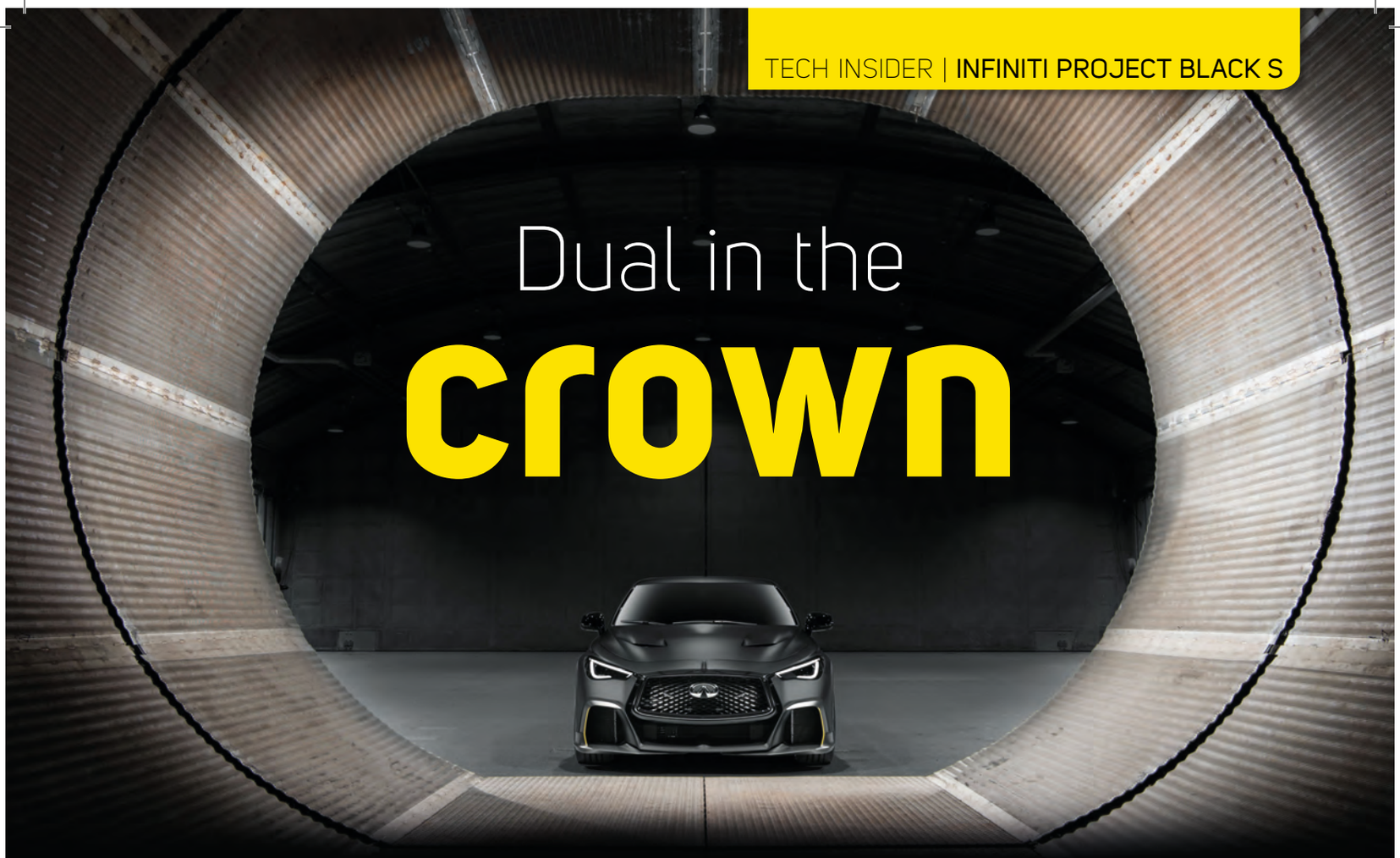

Dual in the crown

Working in partnership with the Renault Sport Formula One Team, Infiniti has developed an automotive first – a high-tech dual-hybrid powertrain

WORDS: **DEAN SLAVNICH**

Among all the shiny, stylish concepts on display at the 2018 Paris Motor Show – most of which were laying claim to some form of autonomous drive capability that the public won't actually experience on real-world roads any time soon – it was Infiniti that showcased arguably one of the most relevant cars; relevant at least in a realistic engineering sense, insomuch as the powertrain technology within the stunning Project Black S is not far off from making it to vehicle production.

Based on the Infiniti Q60 coupe, and co-developed with the Renault Sport Formula One Team, Project Black S is the first automotive example of a high-tech, dual-hybrid powertrain.

The development prototype essentially lifts the advanced powertrain tech from Renault's F1 racer and dumps it into a road-going application.

"The Project Black S engineering prototype is the first indication of how cutting-edge motorsport powertrains could be used to create thrilling hybrid cars," says Jérôme Stoll, Renault Sport Formula One Team president.

Off the back of announcing it has developed – and will launch later in 2019 – the industry's first variable compression engine, code-named VC-T, the powertrain engineering drive within Infiniti shows no signs of slowing down. The world's first dual-hybrid powertrain for automotive application represents a true F1-to-road-car technology transfer. Infiniti also says Project Black S reaffirms its commitment to developing exciting high-performance electrified powertrains, having announced in mid-2017 that the brand will 'go electric' in 2021.

Sharing the same name as the Geneva 2017 design study car, the Paris Project Black S prototype made huge engineering strides forward thanks to its rapid 18-month development program.

Infiniti's VR30 twin-turbo V6 with 405ps is used in combination with two F1-derived heat energy harvesting systems – MGU-H (motor generator unit – heat) – that develop electricity under acceleration. In what's being seen as a real technical highlight, the VR30's twin-turbos are actually fitted with the two MGU-H units, which harvest the heat energy from the exhaust gases, enabling the powertrain to generate electrical power under both braking and acceleration.

Project Black S pairs a high-performance V6 IC engine with two energy recovery systems derived from Formula One

That VR30 MGU-H setup is paired with a kinetic harvesting system – MGU-K (motor generator unit – kinetic) – that essentially generates additional electricity under braking.

The electrical energy created by the three MGUs is stored in a high-rate discharge 4.4kWh lithium-ion battery pack located at the rear of the Project Black S. Mirroring the F1 setup, the power recovered by the MGUs and stored in the battery pack is deployed in two ways. Firstly, it acts as an electrically assisted anti-lag system, spooling up the turbine blades within both e-turbos more quickly and rapidly increasing the amount of air recirculated back into the engine to boost overall power. Secondly, energy stored in the pack can be used to power the

The dual-hybrid powertrain adds 200kg to the vehicle, but engineers turned to exotic materials to save weight elsewhere, replacing the steel hood, trunk lid, fenders and roof of the standard car with lighter carbon-fiber panels

MGU-K, feeding some 120kW of additional electric power directly into the drivetrain.

For this development prototype version of the Project Black S, the extra power is applied to the rear axle through a newly designed final drive assembly on the rear, which also integrates the MGU-K. In total, the new powertrain adds a hefty 200kg to the vehicle, which now tips the scales at 1,775kg.

The V6's initial 405ps output is hugely bettered by the dual-hybrid powertrain, with Project Black S offering 420kW in total – the equivalent to 571ps. That huge jump represents a 41% power increase from the standard Q60 donor car. Project Black S produces more power and accelerates more quickly – the 0-100km/h (0-62mph) sprint time is under four seconds – than any Infiniti road car to date.

The dual-hybrid system also uses the MGU-K to provide a high-response electrically assisted launch control function, with a helical gear limited-slip diff managing power delivery to the rear wheels.

Additional technical highlights include full drive-by-wire controls and a new brake-by-wire regen braking system.

Space invader

Packaging all the different powertrain elements in a car originally designed for just a performance V6 engine caused the Project Black S team a number of considerable engineering challenges.

Placing the MGU-K and battery pack at the rear, along with all the ancillary components and subsystems, meant big technical changes needed to be made to the car's architecture. This included modifying the rear suspension crossmember to take on the MGU-K, while a new cooling system was also installed, placing the radiator core beneath the rear floor and channeling air through the center diffuser. For this, advanced CFD work enabled the team to make a number of alterations to the design of the vehicle's undercarriage, enabling the diffuser and cooling duct to work in parallel with the rear wing to aid cooling and airflow.

Matters were just as complicated at the front, where there was initially no room for the two MGU-H units or the independent hybrid cooling circuits. In the current Q60 engine bay, the VR30 3.0 motor fits its compartment with tight precision with literally no more space available.

Infiniti engineers had to move and repackage the existing engine cooling system, and install a high-efficiency radiator. A small section of the body has also been cut out in order to accommodate the MGU-H systems.

Fast movers

Infiniti teams in Hong Kong; London; and Atsugi, Japan, worked with their counterparts in Enstone, UK, and Viry-Chatillion, France (Renault Sport Formula One and Renault Sport Racing respectively), to create the tech demonstrator in a very quick timeframe.

"Working with Renault Sport Formula One meant we could operate on incredibly short development cycles," explains Infiniti's motorsport group director, Tommaso Volpe. "In just 18 months, an agile cohort of designers and engineers from Infiniti and the Renault Sport Formula One Team has turned a design study into a working demo car."

In particular, Renault's rich experience with thermal management simulations proved to be critical in validating the durability and performance of the dual-hybrid system in its journey from track to road.

"Given the compressed timescales for delivery of the Project Black S, we have used predictive computer modeling to validate how to marry the car's design, aerodynamics, powertrain and dynamics together," says Volpe. "Having a small, responsive team of experts involved in developing the prototype has meant we were able to make changes quicker than going through a traditional testing and validation process."

As for what's next for the Project Black S program: unlike many of those glitzy self-driving concepts at the Paris Motor Show, this tech demonstrator has real-world ambitions, with feasibility and performance testing to continue well into 2019, shifting from digital and dyno assessments to track and real driving conditions.

Commercial sense

Building on the development of the TX range-extended electric taxi, **LEVC** is turning its expertise to its second vehicle

WORDS: **MATT ROSS**

The LEVC van's electric powertrain is supported by a petrol range extender. Development has been aided by expertise honed on the TX taxi (below)

The second vehicle from LEVC will enter customer trials in the latter half of 2019, and will provide valuable data on driving cycles and powertrain calibration. The electric, range-extended light commercial van is based on the technology developed for the TX taxi, which means much of the testing and development knowledge can be carried over. But, as Ian Collins, CEO of Emerald Automotive (a wholly owned subsidiary of Geely), explains, there's valuable insight to be gained from real-world feedback that will enable the van's powertrain to be carefully calibrated to suit the different requirements of delivery vehicles.

"We developed a powertrain that is suited to a very particular drive cycle in the taxi. The van needs to be able to do longer runs at higher speeds, but fundamentally it's about optimizing it for stop/start conditions – many stops by the side of the road, many pick-ups. A lot of that learning will carry through from the taxi to the van, given the type of duty cycle that we have in mind. Having developed a powertrain that is proving itself in one of the most demanding applications you can think of gives us a very good starting place for the van. What we really need is the overlay of the data we get from the consumer trials to make sure that we optimize the calibration for that particular use."

The van powertrain uses much of the same hardware as the TX. The e-motor, developed by Siemens, drives the back wheels. A 31kWh LG Chem battery and GKN Driveline coaxial-design electric axle are also carried over, and the three-cylinder Volvo-designed, Geely-produced ICE continues to serve as the range extender – with no direct link to the wheels, meaning the van will be electrically driven at all times.

"What will be different is the calibration of the system, in terms of driveability – the calibration of how the controls relate to the operation of the powertrain, and the strategy of how the range extender works," Collins says. "You try to use it as little as you possibly can. But if what you're trying to do is save energy for a particular part of the drive cycle, you can control that manually (operated by the driver), but there are also ways of looking at it from an automated standpoint. That's part of the work that we are currently doing."

Alterations to the packaging of the powertrain have been confined to rearward of the B pillar. In the TX, the fuel tank fits under the rear seats, but the van called for a low, flat floor with minimal wheel arch intrusion. The fuel tank has therefore been packaged into the area just forward of the rear axle.

Carrying capacity

The specific demands on the powertrain in the van, Collins explains, should also bear some similarities to the TX – part of the rationale of carrying the hardware over. But there will be differences, and the customer trials will provide more useful data in that respect.

"Van users are often going to be carrying heavier loads for longer – high-load situations, close to gross vehicle weight, climbing hills and the like. I expect that to be the main difference. You can test for that, and look at worst cases, but it will be interesting to see what the loading conditions are when we start to get data in."

The TX has made development on the van easier, and the benefits of the extensive testing program for LEVC's first vehicle promises to do the same for future applications.

"The first mules for the van were converted taxis," says Collins. "We know the wheelbase is a little longer, and the load distribution is different, but [we had] something that is proven in a very demanding application. We could take the existing hardware, modify it relatively simply and start testing it straight away.

"All manufacturers think about platforms and how they can reuse the development they've done on one vehicle and use it in others. The range of options in front of us is wide, but we've got to – as a relatively small player in the market – grow one step at a time."

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A bold new design strategy underpins **Peugeot**'s vision of the future – the e-Legend Concept

Stuff of legends

POWERTRAIN

The e-Legend has an all-electric powertrain, producing 800Nm of torque and 340kW of power, distributed to the four-wheel drive

ACCELERATION

Peugeot intends the concept to achieve the 0-100km/h (62mph) sprint in less than four seconds, before continuing on to a top speed of 220km/h (137mph)

CHARGING

Although light on details, the e-Legend Concept will, Peugeot believes, offer induction charging

Unveiled at the 2018 Paris Motor Show, Peugeot's new e-Legend Concept showcases the French OEM's modern-meets-retro design direction for future vehicles, while suggesting an indication of the brand's all-electric intentions. The e-Legend will be autonomous and all-electric but, according to Peugeot CEO Jean-Philippe Imparato, it is not just a technological manifesto: "This is the vision of a brand actively focused on an optimistic and ultra-desirable future. For Peugeot, autonomy and electric are synonymous with even stronger sensations. Boredom will never be part of our DNA."

MANUAL MODE

Two manual modes will also be available: Legend, which boasts a cruising mode with a dashboard inspired by the famed 504 Coupe's three dials and a digital wood effect on screens; and Boost, which offers the most dynamic driving mode and 180° projection of the road on a single, large screen

BATTERIES

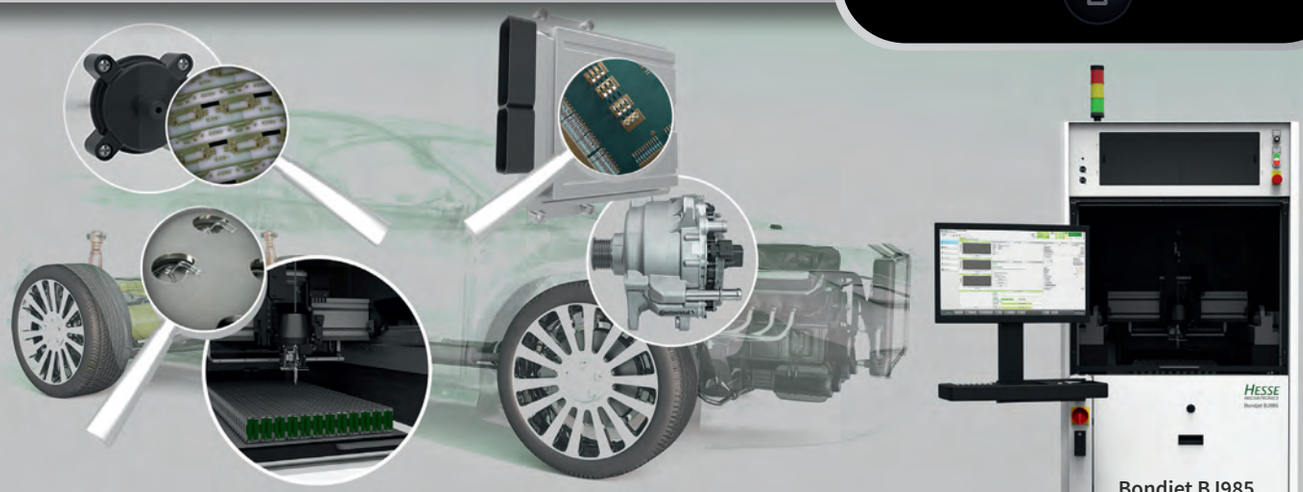
The e-Legend Concept's 100kWh batteries will offer a range of 600km (373 miles) according to WLTP, of which 500km (311 miles) will be available in 25 minutes thanks to fast charging

AUTONOMOUS OPERATION

The e-Legend Concept will offer a Soft autonomous mode, focused on the comfort of the occupants and with projection on digital material screens and information displays reduced to a minimum; and Sharp, which will feature maximum connectivity for digital activities such as social networks and "arranging electronic calendars"

HESSE MECHATRONICS

Wire Bonder for automotive applications



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Easy rider

An all-electric premium motorcycle from Indian developer Ultraviolette aims to put its ICE rivals in the shade

WORDS: **MATT ROSS**

Bangalore-based Ultraviolette Automotive will begin production of its first vehicle in 2019, with the all-electric bike set to hit the road in the second half of the year. And the two-wheeler is already garnering interest, with its developers claiming that the premium electric motorcycle will be the fastest in India, having already outperformed 200cc ICE competitors during testing, hitting a top speed of 150km/h (93mph).

But for founders Niraj Rajmohan and Narayan Subramaniam, the development of the vehicle is just the tip of the iceberg. The pair are determined to do more than just create a single product, intending instead to develop a multisegment, multivehicle portfolio that is just one part of a wider mobility solution.

"What we're building is not meant to compete with other electric vehicles," explains Subramaniam, who also serves as Ultraviolette's CEO. "We are competing with and outperforming petrol-powered vehicles – and doing so from multiple angles, including acceleration and performance, energy efficiency, user experience and the total ownership experience."

"Production will start early in 2019," adds Rajmohan, who is the company's CTO. "We have several prototypes undergoing extensive road testing. The batteries, the powertrain, the durability of the entire vehicle, and its suitability for extreme conditions are also being tested. We know that Indian roads are not the best in the world, so we are working on things such as the battery [performance] in conditions with extreme shock and vibration, and considering temperature, too – there are areas in India with a tropical climate, and areas where the temperature drops below zero. We are building for these conditions, this is where a lot of the intellectual property developed by Ultraviolette is important."

Subramaniam and Rajmohan have worked together on previous ventures, and have complementary skill sets – Subramaniam has worked for leading vehicle manufacturers in Japan and Germany, while Rajmohan comes from a computer science and electronics background. Ultraviolette, which recently received backing from TVS Motor, has a 50-strong team, with many of its engineers boasting automotive, aerospace or consumer electronics backgrounds.

Market leader

The first vehicle – there are internal designations, but Subramaniam and Rajmohan are still weighing up a number of names, with a decision expected closer to the launch – has been under development for the last three years, and is currently in its fourth iteration. The powertrain and architecture are now close to the version that will be on the roads in less than a year.

Benchmarking tests have already seen the new Ultraviolette motorcycle outperform ICE-powered equivalents in the 200cc segment

1

"There will be incremental changes, but from the technology side, it's all set to go," explains Rajmohan. "We're using a brushless permanent magnet motor, capable of delivering 25kW peak power and 10-11kW continuous power."

"We have experimented with several existing motor designs, and we have some designs in-house that have been tested as well," Subramaniam adds. "Ultraviolette is going to be a multiproduct company, so while we're talking about the first vehicle right now, there will be varying vehicles thereafter."

"We're building a platform that can include multiple vehicles," continues Rajmohan. "So there are multiple configurations of motors and batteries being tested simultaneously, and we are exploring what is commercially available from external manufacturers. In terms of this first vehicle, we have multiple options."

The scalable platform means that, though the first vehicle has been under development for several years, expanding for other variants will take the company less than a year.

Continuing the flexible approach, the bike will use Li-ion battery technology. Ultraviolette will be cell agnostic – a huge amount of work has gone into developing the pack to be structurally sound and suitable for harsh conditions, and the entire battery management system has been created by the company, but standardized cylindrical cells from a variety of manufacturers will be suitable for use.

With a range of around 150km (93 miles), the Ultraviolette bike will be a premium, desirable lifestyle product competing in the 200-250cc equivalent segment, where the targeted urban users tend to cover around 20km (12.5 miles) in a day and refuel once a week. But, in line with the company's vision of being a mobility provider, Subramaniam and Rajmohan also have plans to establish a charging infrastructure.

"We are working with the regulatory authorities, and there has been some talk about finalization of [charging] standards," Rajmohan explains. "Our vehicle will be able to use the infrastructure which the government is investing in, and capable of working with any of these infrastructure providers as well as using our own network."

> "There are multiple configurations of motors and batteries being tested simultaneously"
>
> Niraj Rajmohan, founder and CTO, Ultraviolette Automotive

The company has designs on markets outside India, too. The bike has been designed according to global standards and regulations, to make international expansion as simple as possible. Development has also focused on future technology and its availability: when selecting components and designing systems, Ultraviolette considered when such components might be discontinued and made the planning of redundancies and alternate mechanical designs part of the process.

By the time the bike launches, Subramaniam says, development will already be underway on future vehicles – though he's keeping specifics of potential markets and vehicle types close to his chest. But the design of the first vehicle will also mean that new Ultraviolette customers will be able to tailor and customize their experience after they ride away for the first time.

"We'll be offering better performance at a similar price point to ICE vehicles," Rajmohan explains. "And as users become familiar with the different performance capabilities, we'll be able to customize that on the go. This is already under development."

2

1. Narayan Subramaniam (left) and Niraj Rajmohan

2. The Ultraviolette team includes engineers with backgrounds in automotive, aerospace and consumer electronics – with experience bringing those products to market

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FEV

Twist in the tail

The fastest **McLaren** ever built has been unveiled, complete with hybrid powertrain and groundbreaking aerodynamic design

WORDS: **ALI PHILIPS**

Not only is the Speedtail the first McLaren to be developed under the OEM's new Track25 business plan, but the hybrid vehicle – the British manufacturer's first Hyper-GT model – will be the fastest car the company has ever built. A petrol-electric hybrid powertrain will deliver a combined 1,050ps, capable of pushing the Speedtail to a top speed of 403km/h (250mph). The car is so powerful that McLaren has even skipped over the usual 0-100km/h stats, instead claiming a 0-300km/h (0-186mph) time of 12.8 seconds.

Unveiled to future owners and customers at a private event in London in late 2018, the OEM is, for now, light on the powertrain specifics. It did however reveal some of the aerodynamic measures that make the Speedtail the most aero-drag efficient McLaren road car yet designed. The elongated 5.2m carbon-fiber bespoke body contains a teardrop-shaped cockpit that will seat three. Carbon-fiber, front-wheel static aero covers remain fixed in position while the wheels rotate. The covers work in conjunction with multiple ducts and air paths to reduce turbulent air within the wheel arches.

Retractable digital rearview cameras replace traditional wing mirrors, while a pair of active rear ailerons form part of the rear clamshell. Hydraulically activated, these are formed from flexible carbon fiber, enabling the body of the Speedtail to actually bend.

Air supply

A pair of intakes behind the glass canopy provide the required airflow to the powertrain, while cooling is provided by carefully designed aerodynamics that have been previously seen on the McLaren P1, the second-generation Super Series and the Senna. Intakes for the high-temperature radiators are mounted on the shoulders of the vehicle, within the doors. Raised front wings and flush glazing keep the airflow close to the vehicle, driving the air over the front fenders, into the door channels, and then into the petrol-electric powertrain.

The subtly named Velocity mode, developed for the Speedtail, optimizes the hybrid powertrain and tailors the angle of the active rear ailerons. The digital rear-view cameras can also be retracted to further reduce drag. The Velocity active chassis control lowers the car by 35mm (1.5in), thereby reducing the Speedtail's maximum height from the road surface to 1,120mm (44in).

"As our first Hyper-GT, the Speedtail is the ultimate McLaren road car," explains McLaren chief executive officer Mike Flewitt. "A groundbreaking hybrid powertrain sits within a lightweight carbon-fiber body that is reminiscent of sleek streamliners that once set world speed records."

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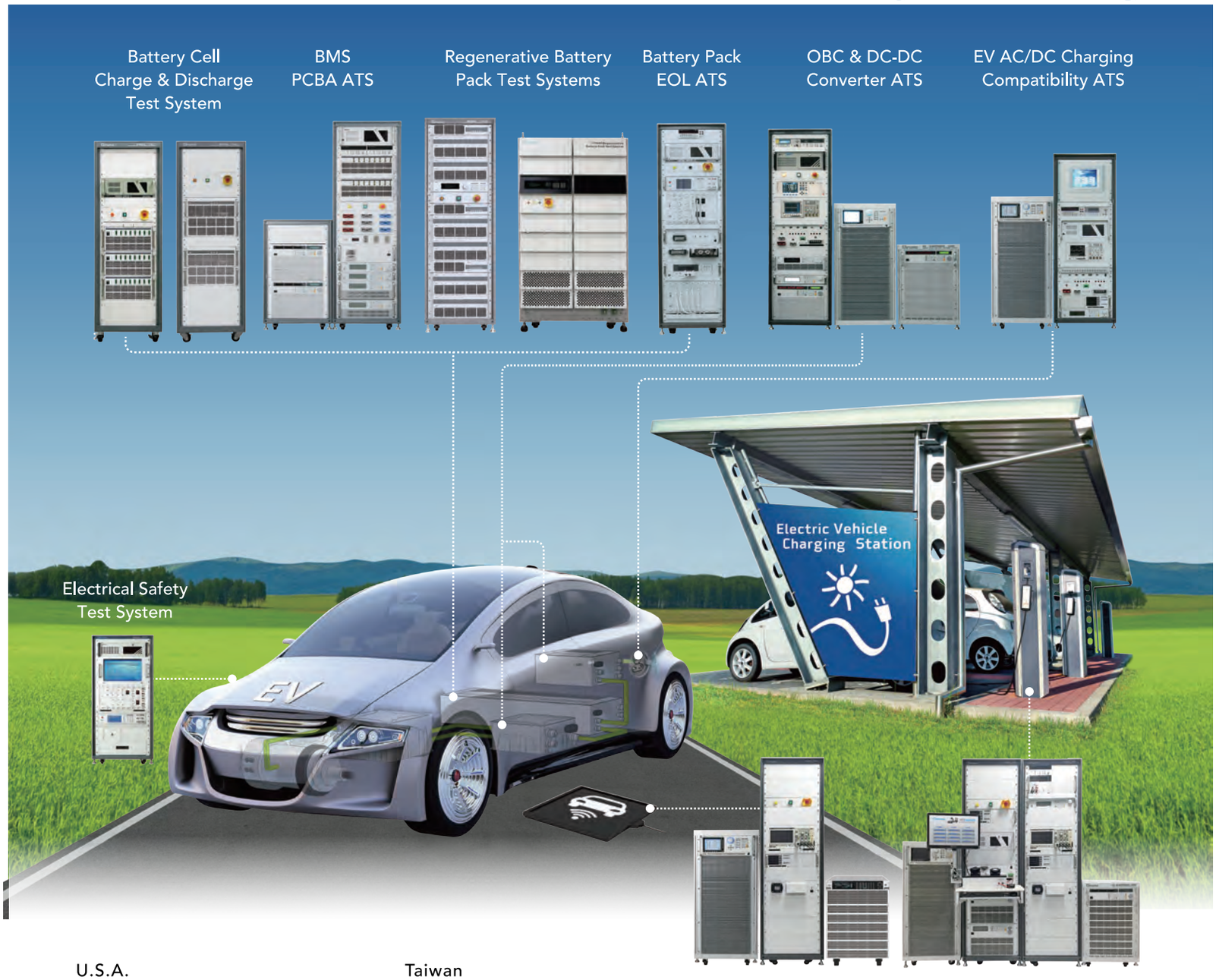

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Single minded

Jaguar's all-electric I-Pace will sport a single-gear transmission and will, the OEM believes, usher in a totally new driving experience

WORDS: **MICHAEL TAYLOR**

The purveyors of continuously variable transmissions have been trying to convince the world for decades that one speed is all a car needs. And, on the whole, they've mostly failed, with most serious car makers instead increasing the number of gears they run torque through to 8-, 9- or even 10-speed automatic transmissions.

But some electric car makers are trying to succeed where CVTs continue to falter. Tesla set the trend with the single-speed Model S, then followed that up with the Model X crossover. And the mainstream car makers sliding into the BEV space in the Californian brand's slipstream seem to agree Tesla got the one-cog part right.

Volkswagen's toe-in-the-water E-Golf ran through a single gear and now the premium BEV wave is about to break – all with one speed. The first out of the blocks will be Jaguar's I-Pace, the OEM's all-electric performance SUV, which will tote just one forward gear, albeit one gear at each end.

Audi's e-tron SUV, revealed in September 2018, will follow suit with just one gear, as will VW's entire four-model ID EV range. Mercedes-Benz also plans just one gear for the EQC. Porsche's high-performance Taycan (née Mission E) will run a single-speed transmission at each end, even though it will stretch beyond 250km/h (155mph) in top speed.

The other big engineering change is that almost any BEV with prestige pretensions will arrive with all-wheel-drive capability, with only Volkswagen's ID hatch expected to have two-wheel drive as standard. So where transmission makers are losing on cogs, they can make something up on driven axles.

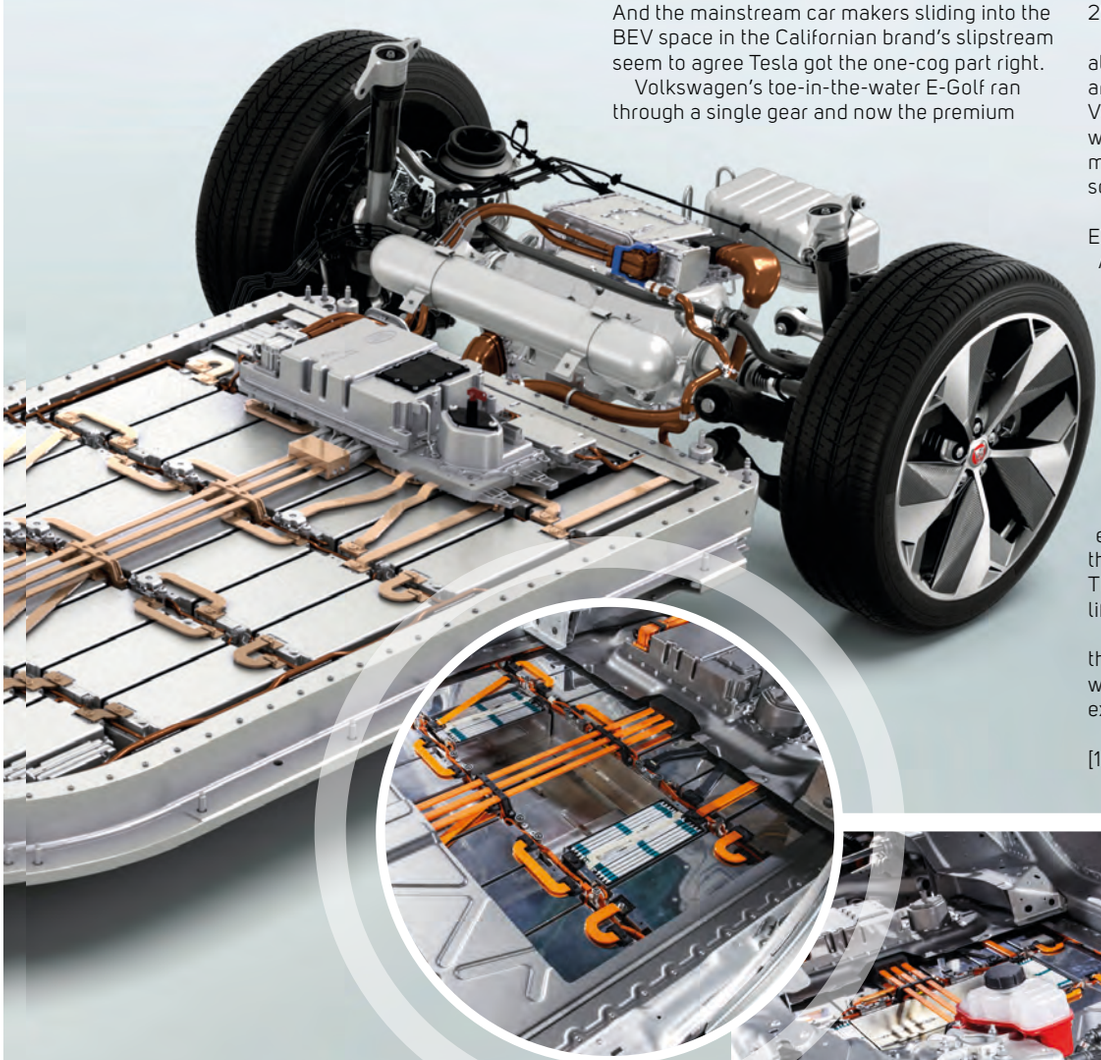
It's also indicative of the changes in attitude EVs are expected to bring, with Jaguar and Audi insistent that the move to an electric powertrain will deliver such a completely different driving experience that people won't ever want to go back to IC engines and all that gearshifting.

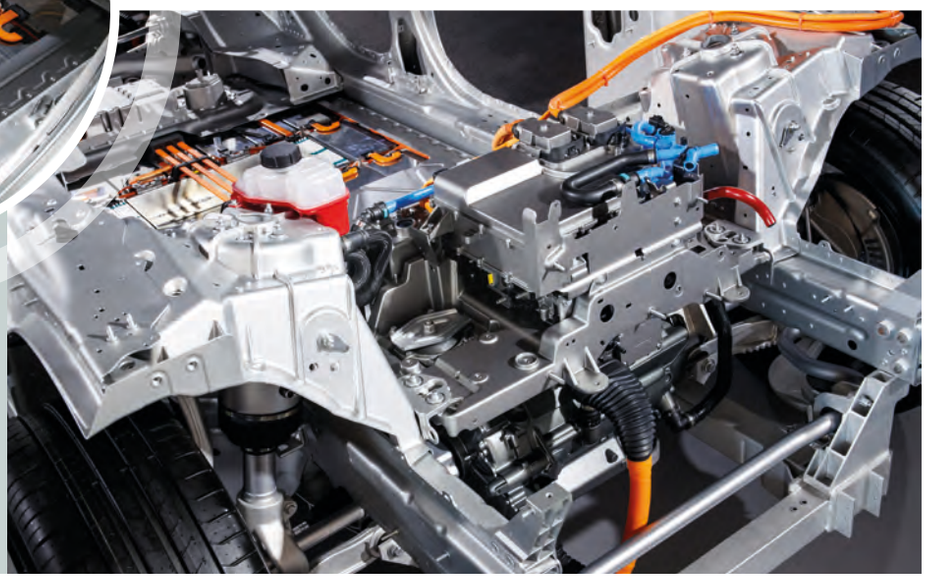
"For those people who have driven an EV for 1,600km [1,000 miles] or so, it's basically impossible for them to go back," Jaguar's technical design director, Dr Wolfgang Ziebart, insists.

As such, Jaguar has developed its own electric motors in-house, with Ziebart boasting they are the most efficient available today. They're also unusual in design, which made life difficult for anybody hoping for extra gears.

"The motors are hollow so the driveshaft goes through the motor itself. This saves space and weight and keeps the center of gravity low," he explains. And yet, there's still no gearbox. Why?

"At the end of its speed range at 220km/h [136mph], it's at 95% of the maximum engine





The Jaguar I-Pace's synchronous permanent magnet motors are light and extremely efficient. Packaging them with the single-speed transmission system makes them as compact as possible

The I-Pace's 90kWh lithium-ion battery technology delivers a 470km (292-mile) range

revs, so we don't need a gearbox," Ziebart counters. "If we have a smaller motor then it's different. But we don't.

"Also, in an EV, every kilogram counts and anything that saves you energy has to be exploited. A bigger engine with higher revs weighs less than a multispeed gearbox."

Shifting focus

Yet Jaguar – along with probably all the other mainstream premium car makers on their 2020 BEV charges – is still aware that some people might want the familiar shift patterns of automatic transmission systems.

"There will be a mode to make its delivery feel more like an auto transmission, with two levels of regeneration [high and low]," says Ziebart.

Other car makers have already insisted they'll limit their EVs' top speeds instead of being forced to apply a second gear – which they'd have to duplicate at both ends.

But that's not the only part of the car where traditional power transmission technology is being supplanted. The premium cars will almost universally be all-wheel drive, and they'll obviously render traditional center differentials obsolete. Instead, sophisticated power electronics, unique to model, will tell the electric motors at each end precisely where and when to apply power or regeneration.

Sources at Audi said the e-tron will switch between rear- and all-wheel drive, like Quattro without the mechanical linkage, and slick power electronics could become a battleground.

"If you have a variant with one motor you are already lost," JLR's Ziebart insists. "If you have all the torque on just the rear axle you have to move the rear axle forward and it already looks like an IC engine and you have already lost the advantage in interior space.

"That means the power electronics become critical, and here we can vary the torque to plus or minus 100% instantly, which gives us unprecedented handling possibilities."

Essentially, that will be like the latest high-performance center differentials in cars like the Mercedes-AMG E 63 and the BMW M5, but with greater accuracy and no mechanical connections between the axles.

The canary in the cage for the rest of the car industry in this part of the transmission development game was, again, Tesla, as Ziebart freely admits.

"We have found some interesting stuff on the Model X, mainly in power electronics. They build that up themselves from scratch, whereas we buy our inverters in a box from Continental, to our specifications.

"We found some interesting solutions in the power space they use. There are always things you can learn from others. It's not that you are always doing everything the best way.

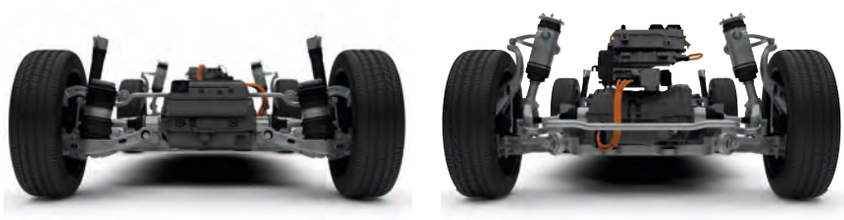
"We have integrated motor control and stability control. If it yaws, you first work it in the motors, and if the car is really out of control, you then act with the brakes. It's just an easier way to drive."

In Ziebart's future world, it will be these "center differential" power electronics that will create a premium EV's character as much as the e-motors.

"But the core is that it will be very hard for a manufacturer to differentiate by the battery," he insists. "We all have access to all the cell manufacturers of relevance. We know what they have now, and what they will have three years from now, and we know what they are working on for the next 10 years.

"It's basically impossible for somebody to gain an advantage from such a supplier, because we know what's going to come and there are no miracles.

"No car company can get a sustainable advantage in one of the components that the others can't catch up on in two or three years, except in the field of power electronics."



Both the motor and the transmission are integrated into the front and rear axles

I-Pace offers all-wheel-drive performance from twin Jaguar-designed motors, with a combined 400ps and 696Nm delivering 0-100km/h (62mph) in 4.8 seconds

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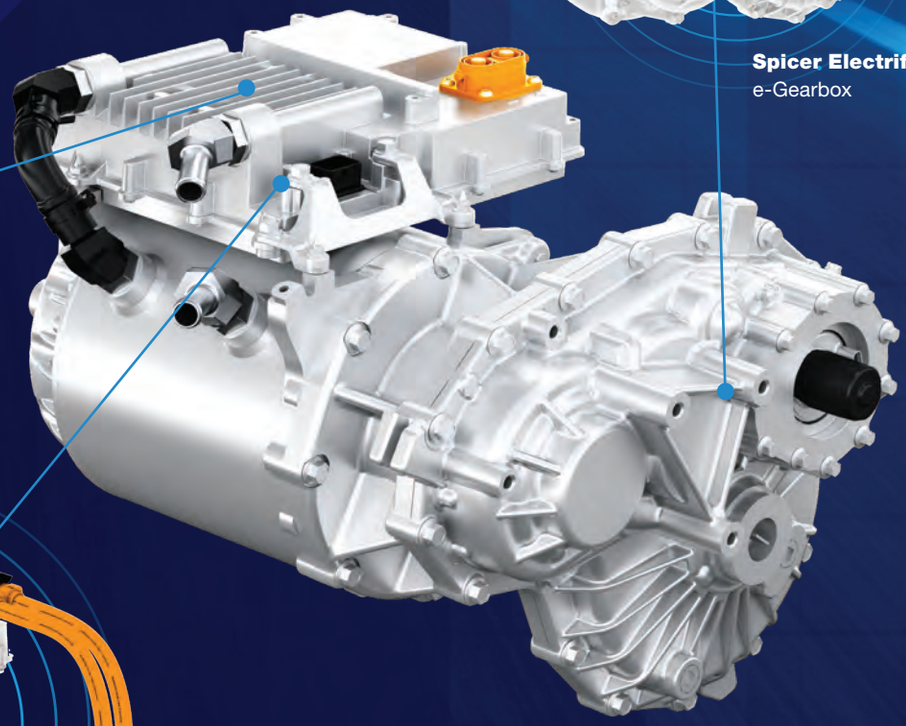

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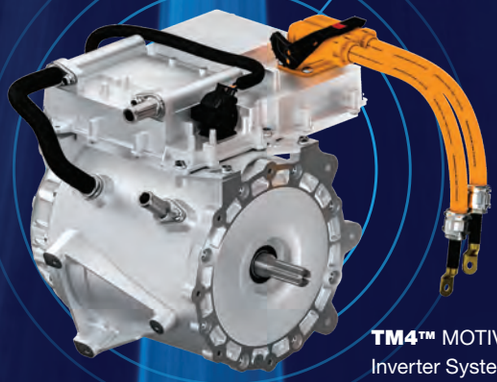

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ELECTRIC POWERTRAINS **ON TEST**

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

RENAULT **ZOE R110**

Groupe Renault has given its flagship BEV, the Zoe, another update. And while it's not the most dramatic of changes – a new, more powerful motor is the most notable revision – the OEM hopes it is enough to keep pace with similar upgrades to the Nissan Leaf and the BMW i3.

Thanks to the new R110 motor, the 2018 Zoe delivers 110ps and 225Nm. That's around 20ps and 5Nm more than its predecessor, the R90. But perhaps most importantly, the upgrade doesn't affect battery range. The Renault EV is claimed to have a real-world range of 305km, although out of Eco mode and with heavy acceleration, that figure drops quickly.

During development of the R110 Zoe, long-distance speed was the main point of focus – and that is quickly apparent. The R110 is two seconds quicker between 80km/h and 120km/h – you feel less vulnerable on the highway and switching lanes is far less daunting with the confidence that there's power if needed.

That's not to say that there hasn't been any improvement from standing. Although it's not as quick off of the line as the Leaf or the i3, the Zoe isn't sluggish. The trademark EV instant acceleration makes the Renault feel quicker than the quoted 11.4-second 0-100km/h.

The latest Zoe upgrade brings it right up to date with its rivals. Originally reserved for those with short commutes and decent access to charging, the Zoe now has impressive range and the acceleration you need for a city car – making it a great BEV option.

KIA SPORTAGE **2.0 CRDI 48V MILD HYBRID ECODYNAMICS+**

Kia's first mild hybrid diesel powertrain adds a new dimension to the OEM's engine portfolio in the Sportage, and the car maker already has plans to introduce the 48V system to other variants in the line-up – mild hybridization will be added to the 1.6-liter U3 diesel engine in 2020. For now, the system is available in the EcoDynamics+ model, which sees the electrified system combined with Kia's 2-liter, four-cylinder diesel unit in the popular SUV.

Targeting greater efficiency from the ICE in the Sportage EcoDynamics+ involves two methods of electrification. Acceleration is supplemented with power from the vehicle's compact 0.44kWh 48V lithium-ion battery, and engine off-time is extended with a new mild-hybrid starter generator (MHSG) unit, which is connected to the engine crankshaft via a belt. This unit switches between motor and generator modes, deploying battery power under acceleration and providing assistance to the engine (reducing load and, therefore, emissions), or recuperating energy under deceleration (when braking, or when coasting downhill, or to a stop) to charge the battery. The Sportage's ECU calculates the most efficient strategy – taking into account the current state of charge – and adjusts battery usage accordingly.

The 48V battery and the MHSG are also used for what Kia is calling 'Moving Stop & Start' – if sufficient charge is available, the ICE will disengage during in-gear acceleration and braking – and reignite when the throttle is pressed by the driver. The mild hybrid system has had a minimal impact on the Sportage's layout – the 48V battery is located beneath the floor of the trunk, while the MHSG's direct integration with the engine has meant only a little repackaging in the engine bay.

In truth, the mild hybrid system is not intended to fundamentally change the driving experience of the Sportage, and much of the electrification technology strives to go unnoticed. The system contributes a 13ps electrical boost – you'd have to be really looking for it during acceleration to notice the additional power, while the energy recuperation is pleasantly unobtrusive. You might raise an eyebrow the first time the ICE drops off, but the system re-engages seamlessly and, after a while, it's easy to be virtually oblivious to the hybrid system's machinations.

Strangely, the best compliment for the Sportage's hybrid system is that it's kind of unremarkable. During our test drive, *E&H Vehicle* experienced fuel consumption not too dissimilar to Kia's claimed 48.7mpg combined (4.83 l/100km), and the Sportage remains a fun SUV to drive. Maintaining that positive driving experience, while improving efficiency and reducing emissions, is not something to sniffed at – even if you don't really notice it's happening.

JAGUAR **I-PACE**

Having spent half a day with the Jaguar I-Pace, three key questions leap out: is this the best Jaguar yet? Perhaps. Is this the most important Jaguar yet? Very likely. Is this the finest example so far of battery electric vehicle engineering from the automotive industry? Absolutely! In every respect, the I-Pace is a stunning piece of work from Jaguar. The car's stylish exterior design and brilliantly beautiful interior – the inside of the I-Pace is a wonderful place to be: luxurious and calm, but also buzzing with technology and oozing modernity – is matched by its engineering reach. A state-of-the-art 90kWh lithium-ion battery using 432 pouch cells enables I-Pace to deliver a real-world driving range of 470km (292 miles) on the WLTP cycle. Just to repeat: that's 470km from a BEV! And that Range Rover diesel-style long-distance capability (well, almost!) is matched with remarkable performance prowess. How does 696Nm torque, 400ps of power and 0-60mph in 4.5 seconds sound? On the axles of the I-Pace are two in-house-developed synchronous permanent magnet motors (one on each) that are packed concentrically with a single-speed transmission, which smoothly flows through that huge torque and power output. Behind the wheel, the I-Pace is a delight to drive: responsive, blink-and-you'll-miss-it quick, and surprisingly agile for a car of this size. It really is everything a modern-day family car should be. In fact, editor-in-chief Dean Slavnich says it's probably one of the best cars he's ever driven. High praise indeed.

MERCEDES-BENZ **CLS 450**

There is a lot of pressure on the Mercedes-Benz CLS. When going up against the likes of the Audi A7 and the Porsche Panamera there always will be, but pair that with the burden of being one of the first applications to feature the German OEM's EQ Boost mild-hybrid system and you realize the weight of expectation. The CLS 450 features a newly developed 3.0-liter in-line six-cylinder twin-turbo gasoline engine, a 48V integrated starter-generator (ISG) and a lithium-ion battery. The ISG, which is placed between the engine and the 9-speed automatic transmission, acts as both a starter motor and a hybrid assist motor, while also enabling kinetic energy recuperation.

That means that while the CLS 450's ICE will deliver 372ps and 500Nm of torque, under heavy acceleration, the EQ boost system will generate an extra 22ps and 250Nm. And at low speeds you feel all of that added power behind the wheel, pushing the saloon from 0-100km/h in just 4.8 seconds.

But perhaps the most telling thing about this powertrain is that 90% of the time most wouldn't even realize that the 48V system is there. The IC motor and the ISG combine seamlessly. Even when the CLS is sailing in eco mode, there isn't an audible change in engine note. EQ Boost just silently goes about its business, giving a power nudge when needed and saving fuel when not.

LEXUS **LS 500H**

Going up against high-end competition from the likes of BMW, Audi and Mercedes, the new Lexus LS 500h certainly looks the part. It's longer, lower and wider than previous versions, and has a remarkably plush interior, but if it's going to compete with the industry big boys, its powertrain needs to match its looks. Our test LS 500h came with the OEM's now-familiar 3.5-liter V6 powertrain paired with the Multi-Stage Hybrid technology, which comprises a pair of motors and a CVT that couples the electrically controlled power-split device and a 4-speed planetary automatic final drive. The result is a combined system output of 359ps channeled through a simulated 10-speed automatic transmission, and Lexus claims this will propel the LS 500h from 0-100km/h in 5.5 seconds.

The drivetrain switches seamlessly between electric and combustion power, allowing for smooth, low-speed zero-emissions motoring without any kind of jump when the ICE kicks in at higher speeds. Much like the LC 500h, the car does feel a little weighed down by all the extra componentry, but the power delivery is (for the most part) enjoyable. There's the occasional over-rev as you click up through the simulated gears, but the LS 500h is no slouch. Lexus's hybrid system is getting a healthy workout across the model line-up and, in this case, it's certainly been put to good use.

PROFILE: **PATRICK FONTANA**

Job title: C5 Aircross SUV project manager
Company: Citroën

What career did you want when you were growing up?
I've always been interested in automotive, but when I was a kid I wanted to be an astronaut. I remember the night Neil Armstrong set foot on the moon. I was nine years old and I remember it perfectly, and I wanted to go to the stars too. After that, I always thought about technology, and about means of transportation. So it was rockets at the beginning, but later it would be cars, motorcycles, and so on. I'm a light aircraft pilot, so I'm interested in everything that moves. I'm an engineer. I have always been very technically minded.

What was your first job?
My first long-term job was at PSA. I joined the group in 1985 and I'm still here. I've been here more than 33 years, so I'm something of a dinosaur – there aren't many people like me working in the industry today! I joined the group when it was the Peugeot brand. It was an attractive place to work in terms of career, in terms of development. And I stayed with PSA because the opportunities have been there to continue to grow, and to develop within the group.

What are some of the best elements of your current job?
What is interesting in my job is that we combine the capabilities of a lot of different people, with a lot of different talents. To reach that point where you can present a finished car, it's a long process and it involves a lot of people with various ways of thinking, various competencies and knowledge, coming from various sectors – marketing, commercial divisions, style, design, architecture, electrical, mechanics. To mix all of that together is interesting. And everything has to match properly, at the right time, if you are going to make something that is not just an object made out of plastic and metal. To work with all those kinds of people is honestly incredible. To realize something practical, starting from an idea – which is not always your idea – you begin with a need. That can be something as simple as a phrase that's written on a piece of paper, and by the time you get to the end, you have a vehicle.

> "I'm almost certain that there will be no unique [powertrain] solution. We have to think about adapting the solution to the local needs and to the local possibilities"

And some of the worst?
There are constraints such as time and money. But these are also a way to be motivated to create something. That pressure is important. Sometimes I would appreciate a little less pressure, however. But I think it is necessary to make you move forward without getting too comfortable. You have to be motivated to move past what is comfortable. I can assure you that I haven't been in that 'comfortable' position once in my career. I have always been under pressure to move forward – to develop.

In your opinion, what is the best powertrain that has been designed?
That is difficult to answer. I could say the greatest engine is the engine we haven't designed yet! It is still to come. The engine that will enable us to propose something even more efficient, even more comfortable.

Can you think of any engines from the past that have inspired you?
Something that has given me a lot of pleasure is the Citroën Xantia Activa. That was a fantastic car with a 2-liter gasoline engine that was very impressive, or a Peugeot 406 coupe with a six-cylinder engine. This car was perfect, a real pleasure to drive.

What car do you currently drive?
I drive a Citroën C4 SpaceTourer.

Do you think a single propulsion type will dominate the industry in the coming years?
I think it will be all-electric. Well, maybe not exactly. In fact, I'm almost certain that there will be no unique solution. For example, in Europe, certainly the mainstream will be electric or plug-in hybrid with a big electric engine and a little gasoline engine on the side. But if you go to China, there will be a different powertrain dominating. If you go to Iran, or Argentina, for example, there will be something else again – perhaps a thermic engine with petroleum gas or natural gas. I feel we have to think about adapting the solution to the local needs and the local possibilities. You can produce electricity in various ways, and then the motive element of a vehicle can be almost the same. In some countries, the USA for example, or Latin America, the distances between the various cities are so huge that even with a lot of batteries, you can't do all your travel without putting some petrol in the tank.

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The 512 featured ICE, hybrid and electric powertrain variants

TRIPLE THREAT

Nearly 50 years ago, GM debuted a novel concept for a small city car – a single model with a trio of powertrain options

WORDS: **MATT ROSS**

In May 1969, General Motors held a show for the US media called Progress of Power. The exhibition, held at the GM Technical Center in Warren, Michigan, saw the OEM showcase 26 special vehicles – many of which were unveiled for the first time – and demonstrate a range of so-called unconventional powerplants, including turbine, steam, electric and hybrid drivetrains, as well as experimental piston engines with reduced pollutant characteristics.

Introducing the vehicles to the assembled press, GM president Edward N Cole explained, "The cars and power systems you see here today are working experimental models developed by General Motors. They are designed to illustrate current technological progress by General Motors scientists and engineers, and by our consultants in various fields."

Four experimental cars were demonstrated at the presentation. One, the 511, was a three-wheel gasoline-powered model with a rear-mounted four-cylinder Opel engine that generated 68ps at 6,000rpm for an 80mph (129km/h) top speed. The other three vehicles were part of GM's 512 series – a car line-up that included three powertrain variants long before single-model, multiple-propulsion options were common.

The tiny two-seater 512 was (arguably and with the benefit of hindsight) a precursor to the city cars so often cited as the future of modern urban mobility nowadays. It was available in gasoline, electric and hybrid versions, and, if archive images are to be believed, had a hinged roof.

The gasoline vehicle had a 19.6in^3 (321cc), two-cylinder, 12ps aluminum engine with an 11:1 compression ratio. Top speed was 45mph (72km/h) and the 512 would sprint from a standing start to 30mph (48km/h) in 18 seconds. A four-gallon fuel tank gave a range of 280 miles (450km), and the car's automatic transmission operated on the variable ratio V-belt principle with a centrifugal clutch – the first time such a system was used on an American vehicle.

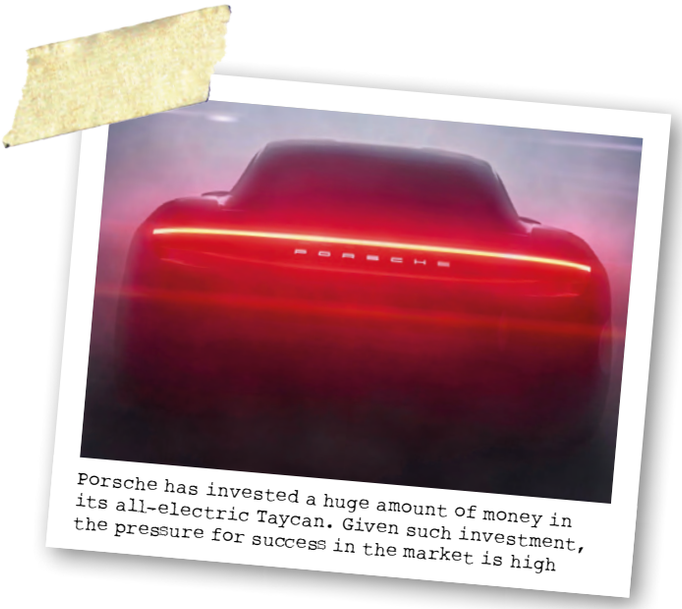
The 512 electric car had a 52in wheelbase and was 86.3in long (220cm). It had a curb weight of 1,250 lb (567kg) and featured a dual-battery power supply. An 84V pack provided power to the vehicle, while a 12V battery stored energy for accessories. The 512 electric had a built-in charger – important if drivers were to take advantage of the complete recharge time of seven hours from a 115V household outlet. The vehicle range, when driven at 25mph (40km/h) was 58 miles (93km). If driven at the top speed of 30mph (48km/h), however, the 512 electric would continue for 47 miles (76km).

The hybrid variant – heralded by GM as one of the world's first – featured a 12in^3 (196cc) gasoline engine coupled to a series DC electric motor through an electromagnetic clutch. Electrical energy came from the 72V battery pack and the hybrid carried the dual-battery theme on by including the 12V power supply for accessories. Like many of today's modern hybrids, the vehicle could operate in pure EV or hybrid mode – hybrid operation topped out at 35mph (56km/h), while all-electric mode would peak at 30mph (48km/h) – however, hitting the top of the speedometer would reduce the 512 hybrid's range to a rather paltry 5.2 miles (8.4km). Fueled up with three gallons of gasoline, however, the hybrid would keep going for 150 miles (241km).

Those visiting the Paris Motor Show toward the end of 2018 will have seen a number of all-electric concepts on some of the OEMs' stands – many of which boasted two seats, had a short wheelbase, were designed for inner-city driving, and offered shorter ranges befitting frequent, low-distance journeys. In the case of Smart's striking Forease concept, even the roof seemed to be deemed optional.

GM's route to wider electrification is well-documented – not least for its rather... circuitous path, and although it seems a little far-fetched to credit Cole and his teams with predicting the EV city car trend, the parallels with the 21st century are nothing if not striking.

Lars Thomsen



Porsche has invested a huge amount of money in its all-electric Taycan. Given such investment, the pressure for success in the market is high

We are at a moment when a number of major car manufacturers are bringing their electric vehicles to market – cars such as the e-tron, the EQC, the I-Pace and so on. It is an important time for the industry. I think, for the first time, that car makers are getting serious about electrification – and they need to. They have seen what Tesla has done – and it really is to do with what Tesla has been doing – and how it is capturing a part of the market that could hurt the incumbents.

Until now, most plug-in vehicles, and the fully electric vehicles that the car companies talked about, were kind of a token gesture. They were something that meant a car maker like Porsche, for example, could offer a Porsche with a plug, but didn't really need to sell the vehicle. It had it in its line-up so that it could say it was on board the electrification train. If you continue to look at Porsche as an example, it is releasing the Taycan, its Mission E vehicle. And this time, it is betting more than €1bn (US$1.1bn) on that car, just on development costs. It is even building a new production facility in Stuttgart for electric vehicles. For the first time, it's not a line extension, it's a totally new line, and Porsche has bet too much on it for it not to be a success.

> "Porsche has bet too much on the Taycan for it to not be a success"

The pressure that companies are putting themselves under is increasing. Some are serious, and some are at the point where they are not sure yet whether electric vehicles will become mainstream. But in just the last few months we have seen several of these mass-market, fully electric vehicles being presented from companies including Mercedes, Audi and Jaguar, and car makers such as Kia are also committing to electric. Particularly in Germany, as far as I can see, following the diesel scandal, a lot of cities are debating whether you should be allowed to drive your diesel car at all. Pressure from the consumer side is rising as well, so demand for electric vehicles is increasing. As part of my job, I talk to a lot of people, and increasingly those who have previously been skeptical about plug-in hybrids or fully electric vehicles are now thinking about whether or not they should buy one, just to be future-proof.

Sometimes it takes a brand that people know to inspire confidence. There are people who are fans of a particular brand, and they have been driving those cars for decades, because they trust them. Just a few days ago I heard that Audi has signed 10,000 pre-orders for the e-tron. That's a very good sign. It would be much worse if they didn't (or couldn't) sell them.

The thing that is really interesting for the industry, and what we are doing research on right now, is that if the demand for electric vehicles rises from 1% or 2% to, let's say, 10% or 15% within three years – with more attractive models, longer ranges, more charging infrastructure, and with people prepared to take the time to think about it and who are now ready to buy – we are going to have quite a problem with batteries. It would be easy to cater for, say, double the number of electric cars we have right now, but to do something on ten times the scale? That calls for a huge industry in a very short time.

Lars Thomsen is chief futurist and founder of Future Matters. As a researcher of future trends, he is considered one of the most influential experts in trend forecasting in energy, mobility and smart networks

Greg Offer

Where an EV has been used and how it has been charged during its lifetime have a significant impact on its suitability for second-hand use

Electric vehicles sales are finally starting to take off, and the number of models on offer seems to be increasing every month. However, for those who are more price conscious, second-hand electric vehicles – although small in number at present – are already starting to appear on the market. Any new technology improves rapidly. Think of the first cell phones and how much they have changed. Therefore, by definition, earlier-generation EVs are not as good as a new one, but should this be a worry?

Electrical machines, power electronics and the rest of the car are all pretty mature technologies, and although the integration into a product can sometimes cause issues, that is no different from conventional vehicles. The main question to ask when buying a second-hand electric vehicle is whether the battery is still good. There are some good forums out there as, thankfully, first adopters tend to be quite technologically savvy and have written a lot about the Nissan Leaf and Tesla Model S. However, it can take a long time to do the research.

Therefore, understanding a little bit about battery degradation can really help. Modern lithium-ion batteries were originally designed primarily for laptops and cell phones. A day or two on standby and four hours in use is the minimum required, and products are typically designed to last six years and be charged daily. This means the battery is designed to be discharged relatively slowly, and to last for around 2,000 cycles. Batteries were also designed to operate at temperatures humans like – around 15-30°C (59-86°F).

What batteries really don't like is being stored or used at high temperatures, as this causes bad chemical reactions inside to speed up, reducing capacity and power. A crude rule of thumb: 20°C (68°F) hotter can speed up degradation by tenfold. However, fast charging when cold can be equally bad, as this causes lithium plating, a particularly aggressive form of degradation. Lithium plating can also occur when left at a high state-of-charge, so trickle charging and holding a cell at 100% can age a battery many times faster than keeping it below 80%. This is why many hybrid vehicles only use the battery between 20% and 80%. However, for an EV this is not practical, as the customer wants to squeeze out the maximum possible range.

> "Second-hand electric vehicles are already starting to appear on the market"

How does this knowledge help? First, look at where the EV was used – if it has been used in hot climates, or left in the sun all day (where the temperature under the hood could easily reach 40-50°C [104-122°F]), then steer clear. Secondly, look at the mileage and range of the vehicle. A Tesla Model S with a 500km (310-mile) range and 100,000km (62,000 miles) on the clock, would actually only have the equivalent of 200 full charges, and hence may be almost as good as new, but watch out for how many of those were fast charging. In contrast, a first-generation Nissan Leaf with 120km (75-mile) range and 100,000km would have undergone about 800 full charges.

In general, existing battery technology is actually very well suited for electric vehicles, as the user profile is similar to the original application. However, fast charging and larger temperature extremes are the things to watch out for, and vehicles subjected to these might not be a good purchase. Moving forward, as EVs take over as the main user of batteries, cells are beginning to be redesigned for vehicles. All manufacturers are working on higher operating temperatures, and on fast charging, but it will take time for the technology to be optimized.

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

The 2015 takeover of Italian design house Pininfarina by Indian OEM Mahindra saw the company presented with an opportunity to reinvent itself. Enter Automobili Pininfarina, a newly formed luxury electric sports car maker

WORDS: **RACHEL EVANS**

This time four years ago, the fate of famed Italian designer Pininfarina was hanging in the balance. Known for some of the world's most iconic car designs of the mid-20th century, in recent times the company's work had slowly dwindled, causing it to suffer financial problems as many OEMs brought their design capabilities in-house, instead of outsourcing the work. Then, following two years of speculation, it was announced in December 2015 that Mahindra was to purchase a controlling stake in the company.

Fast-forward to the present, and the two have spawned something remarkable – a luxury electric sports car developer. Officially 'born' in April 2018, Automobili Pininfarina combines the design prowess of Pininfarina with Mahindra's EV expertise, accumulated through its involvement in the Formula E series. Headquartered in Munich, Germany, at the heart of the European auto industry, the newly formed company is in the process of building up its capabilities and team, while simultaneously developing its first model.

The Pininfarina design arm continues to exist as a separate business, providing guidance on concepts where needed, from its home in Turin, Italy.

Leading all technical development work at Automobili Pininfarina is chief technical officer, Christian Jung, ex-Porsche Mission E project leader, and former Faraday man. Asked why he made the move from sunny California back to his homeland, Germany, Jung says he had planned to stay longer, but the role of creating a new breed of electric vehicles from scratch was clearly the next logical step for his career.

The PFO's powertrain architecture, including the batteries, motors, and hardware and software, was developed in-house at Rimac

"The Pininfarina name was a big factor for me ... building sports cars is in my blood"

Christian Jung, CTO, Automobili Pininfarina

POWER LINES

The automotive industry is at a tipping point of mass-market electrification. But with no other purely electrically driven hypercars on the market, why the decision to go battery-electric with PFO? Both Jung and Tutzer are in agreement that it's the future. Jung believes that, in 10 years' time, the performance of an electrified engine will be almost comparable to an ICE.

He explains further, "Electric cars are a little bit heavy right now, which is an issue that must be overcome, and the main contributor to that is the battery. But in terms of the performance of the technology, you have much more torque and more power, and the driving characteristics of the cars are much more fun. In an ICE vehicle you have to bring the revs up to 3,000, 4,000 or 5,000rpm, dip the clutch, and then you can pull away, while with an e-motor you instantly get the full torque."

In reference to other types of powertrains, Tutzer says that while he recognizes the potential of hydrogen fuel cell technology, it's important to look at the bigger picture: "In the short term, unless the infrastructure network for hydrogen cars improves, the best solution is electric cars. Although frankly speaking, if you have an electric car and one day you want to convert to another system, you can do it.

"We are in a period of transition. If you start on the path with another technology that isn't electric, I believe you will be making a mistake," he concludes.

"While I was at Faraday, I did have other offers, mostly from startups, but I believe the Chinese startups will mainly be successful in China. Michael Perschke [CEO of Automobili Pininfarina] got to know me very well in my old role over at Faraday. He told me he was building up a brand and asked if I would be interested in working for him. I thought, 'Wow, Munich is a great place to live,' and it was such a good job offer," he says.

"Plus I had to think in the long term – what would the prospects be for me at Faraday? I believe they will succeed – but predominantly in China. My guess is that they will use California as a design center and most of the technology development will move to China.

"The Pininfarina name was also a big factor for me. I've worked at Porsche and BMW, so building sports cars is in my blood," he adds. Jung admits that he is relishing the freedom

PERFECT PARTNERSHIP

Croatian entrepreneur Mate Rimac says the collaboration with Automobili Pininfarina will enable his company to broaden its horizons.

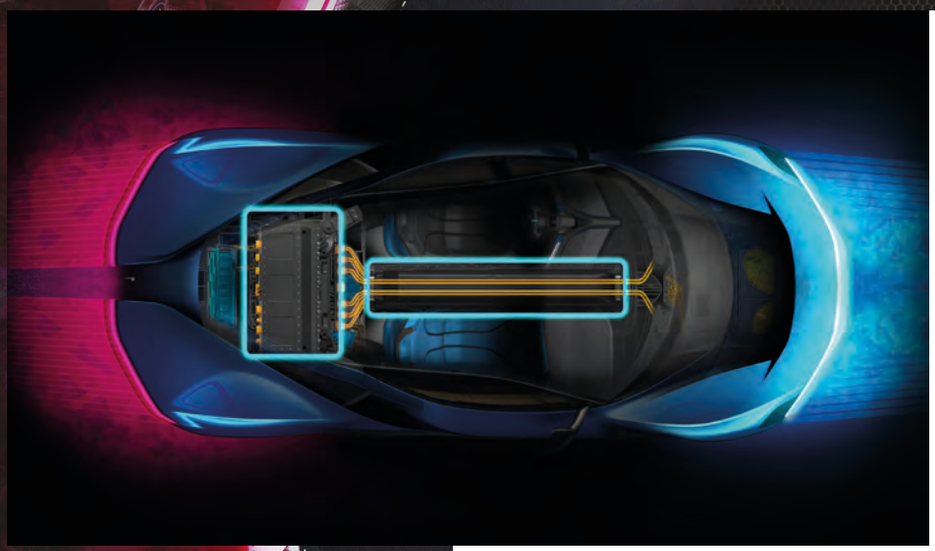
He recalls how the notion for the partnership initially surfaced: "About a year ago, the Automobili Pininfarina guys came to visit us in Croatia and this was when we started discussions. At the beginning it was just an idea, then it became more serious and a business case developed."

He quips that he doesn't "think much about the romantic story behind it", but says "it's difficult to believe that a crazy idea that came about only a year ago is now happening".

On a day-to-day basis, Tutzer and team converse regularly with their counterparts at Rimac, and often travel between sites. For example, the Automobili Pininfarina purchasing team spent two weeks in Croatia checking Rimac's procurement processes.

Asked if he thinks the fact that German OEM Porsche has a stake in Rimac will affect how it works with Automobili Pininfarina, Rimac is confident it will only have a positive impact: "It's in their best interests that they help us to become a serious company sooner rather than later," he comments.

Automobili Pininfarina's Jung adds, "I know my Porsche guys and I know that their influence will only be positive. There will be an exchange of ideas and solutions, which can only help to take things forward."



Tutzer explains that when developing any new electric vehicle, all aspects must be designed around, first of all, the battery pack, then the tires. The seats are then placed, forming the major geometric shape of the car

that comes with working at a smaller, newly established OEM, as opposed to a big company where processes are clearly defined. "These processes guide you and give you a safe way to do things. Even if you're doing something new, there is somebody who knows somebody with the knowledge," he explains. "In a startup there is more uncertainty and risk, so you have to develop the capability to judge things on an abstract level without the full set of information, as you might have at Porsche, for example. But this also means you have the freedom to try out new things."

High on his list of priorities, in addition to visiting India, is building up the team in Germany. Jung reveals that the level of applications flooding in has been of a high standard, with many from people at big OEMs. He avoids a definitive number of employees, but informs *E&H Vehicle* "it's a multicultural team, which is small but growing".

Jung also plans to explore the technologies and services on offer at parent company Mahindra, as well as from suppliers close by. "We need to look at how and where we want to do things ourselves, but how we can be lean and use the experience of these companies in places such as Germany and Italy. It's like a puzzle – we have to piece it together," he adds.

Dream team

Automobili Pininfarina aims to launch its first showpiece, a pure-electric hyper GT code-named PF0, in 2020. Designed from the ground up, work is currently underway to solidify key elements of the car, including the powertrain architecture and chassis systems. According to senior technical advisor Peter Tutzer, benchmarking for the PF0 has been tough: "There are no other electric hypercars," he notes. "Although ultimately, it's about creating an outstanding car. It has to have a soul. It has to have individuality."

Automobili Pininfarina is partnering with Croatian EV manufacturer Rimac to develop the PF0 powertrain, including the battery systems and the motors, as well as the hardware and software.

Although it has not been officially publicized, both Jung and Tutzer allude to the fact that aspects of the powertrain have been

carried over from Rimac's Concept One car, which was claimed to be the world's fastest accelerating EV when it was built in 2013.

The company aims for the PF0 to race from 0-100km/h (0-62mph) in under two seconds, hit a top speed of over 350km/h (217mph) and have a range of more than 500km (310 miles).

Tutzer notes that the progressive culture within Rimac was a central factor in his team's decision to go with them. "If you look at the market, there are the big engineering companies like Ricardo and AVL, but in my experience, they don't have the same dynamism as Rimac," says Tutzer, whose CV also includes positions at the likes of Thunder Power EV, Lotus Cars, Bugatti and Pagani.

Labor of love

The PF0's battery pack is mounted down the center and across the back of the car in a T-shape, and the four motors are coaxially arranged at the front and rear axles.

"The battery pack is not in the floor like in a Tesla. Instead, there is a bigger volume [of cells] behind the seats and a tunnel of cells down the middle of the car," Tutzer says. "If the battery pack is placed under the floor, you lose some 130mm [5in] and that's not sporty."

To shave weight off the battery pack, Rimac has used CFD and flow simulation to reduce the amount of connectors and optimize the rest of the design.

Meanwhile, the team is exploring the potential of other lightweighting technologies to further slim down the PF0 design. Tutzer comments, "I cannot tell you where we will end up, but in comparison with other battery packs of the same capacity (around 100/120kWh), ours will be lighter."

The team chose lithium-ion chemistry. Jung says that they may look at solid-state batteries in future, but the technology is not yet ready for production on a mass scale. He adds that due to the lack of electrolytes, the C-rates of the cells are currently very low, so it's not performance technology yet.

In order to reach high speeds, the hypercar will likely have two gears. "The transmission will have one ratio in the front, and in the rear we could either have one or two ratios – it's a case of optimizing the acceleration levels," says Tutzer. They're yet to decide on a supplier.

The PF0 features extensive use of carbon fiber throughout, enabling the amount of sheet metal to be kept to a minimum.

The battery pack is made of a mixture of materials including carbon fiber and plastics, the cooling system from aluminum, the motors from steel. Target weight for the full vehicle is below 2,000kg (4,400 lb). "Wherever possible we are using the lightest solution."

Throughout the project, Automobili Pininfarina has been able to call upon the Formula E knowledge available at Mahindra. "The crucial thing we have been able to learn is how to manage high power from a relatively small battery and how to be energy efficient – so looking at thermal management and power management."

The plan is to use liquid cooling and the team is assessing both direct and indirect methods. Notes Tutzer, "Direct cooling is more efficient, but it's not easy to do."

To date, no mules have been built, only a show car. In September 2018, the GT's guise was revealed exclusively to a group of prospective buyers at Pebble Beach Concours d'Elegance during Monterey Car Week. The team intends to go into on-road testing at the end of 2019.

When asked to recall the greatest technical challenge of the project so far, Tutzer doesn't hesitate in stating that it has been the battery pack. "All the other elements I have done several times before," he comments. "This is really an opportunity to raise the bar."

"If the battery pack is placed under the floor, you lose some 130mm and that's not sporty"

Peter Tutzer, senior technical advisor PF0, Automobili Pininfarina

The location of the company's HQ in Germany provides easy access to partners across the continent. Automobili Pininfarina is still in the process of selecting all the suppliers for PF0

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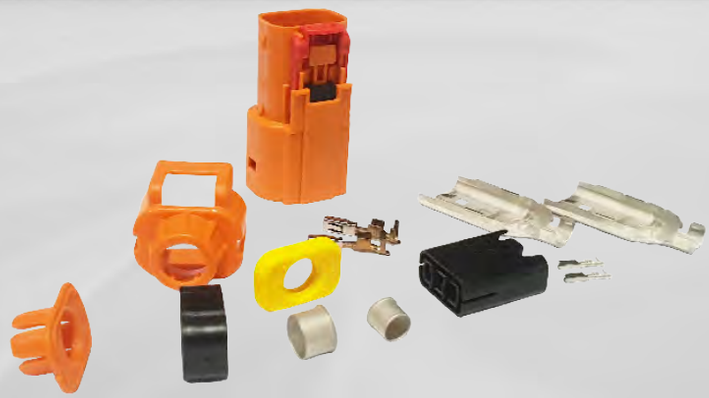

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State of play

Often heralded as the next step change for electric vehicle energy storage, could solid-state battery technology offer the range, power and safety advancements for the next generation of EVs?

WORDS: **RICHARD N WILLIAMS**

Forschungszentrum Jülich

Electric vehicles have been around for over a century, but the recent industry uptake owes a lot to lithium-ion technology. Initially developed for the consumer electronics market, lithium-ion technology combines sufficient energy density with lightweight packaging to make electric vehicles a practical alternative to ICE cars.

Solid-state batteries offer a further generational step in energy storage, and could remove many of the anxieties consumers have about owning an EV.

"The OEMs all went in the same direction with lithium-ion," explains Graeme Purdy, CEO of Ilika, an advanced materials developer that was founded in 2004 by Prof. Brian Hayden from Southampton University's Physical Chemistry department, based on the university's research into material science. "It offered a reduction in weight compared with other batteries but it has safety issues around the flammable electrolyte."

Traditional lithium-ion cells, Purdy explains, consist of a cathode, an anode, a plastic separator that allows only lithium ions to pass through, and a liquid electrolyte. Replacing this flammable electrolyte with a solid material could provide a number of benefits, but so far, nobody has found the right material.

"Over the past 12 months there has been a consensus building in the auto industry that solid-state batteries are the natural heirs to lithium-ion," Purdy says.

Ilika has been producing miniature solid-state batteries for some time. While these have the same cathode materials as conventionally used in lithium-ion batteries, the anode is silicon, and the flammable electrolyte is replaced by an inert, solid ceramic material. However, Ilika's commercially available batteries are only 250μA, designed for powering sensors in IoT applications. To be able to power an electric vehicle, Purdy and his team have to scale up the technology, something they are currently working on.

"We print a slurry of composites, and when it dries, what is left are the composite materials, so you print a cell in different layers," he explains. Ilika is now collaborating with, among others, Honda and Ricardo, to create enough cells to create a working proof of concept.

Single-minded

Other OEMs are also racing to find a working solid-state battery for EVs. BMW has formed a partnership with Colorado-based Solid Power, which has also received US$20m of investment from the likes of Samsung, A123 Systems, and Hyundai CRADLE (Center for Robotic-Augmented Design in Living Experiences).

The company's solution is a sulfide-based solid-state cell, says Dean Frankel, strategic business development at Solid Power. "We are replacing two key parts with a single solid ion conducting material," he says.

Solid Power's approach is to replace the graphite anode conventionally used in a lithium-ion battery with a lithium metal anode and a solid electrolyte made up of lithium, sulfur and phosphorus.

"So the battery is no longer lithium-ion, it is a lithium metal battery," Frankel continues. "In EVs, you should expect a big energy boost by creating improvements in energy density."

The battery cells developed by Solid Power have a density of 300Wh/kg, which is a 20% increase on current lithium-ion batteries. But energy density is not their only advantage.

"Because you have inherent safety with solid-state batteries, you don't have to worry about cooling," he continues. "And it is not just a battery with better energy density, but also a battery with packaging and efficiency improvements."

According to Frankel, up to 30% of current EV battery mass and volume is packaging and thermal control, which could be dramatically reduced with solid-state technology, allowing more cells for the same weight.

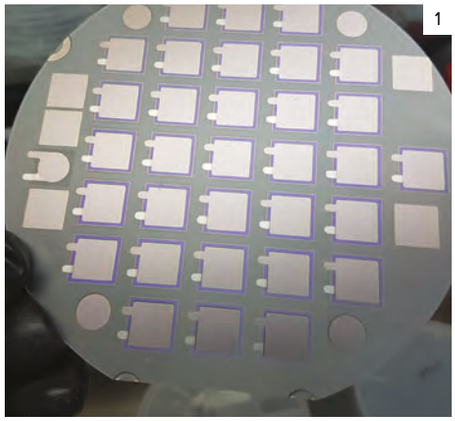
Furthermore, thermal management systems, which are power-hungry but necessary to prevent batteries from overheating, are not required in a solid-state battery.

Quiet progress

While they remain tight-lipped about their progress, most OEMs are investigating solid-state technology. Volkswagen recently invested US$100m into USA-based QuantumScape, which is yet to produce a prototype.

Even British company Dyson, a relative industry newcomer, has smoothed the way for production of batteries for its new electric vehicle by writing off US$43m of solid-state battery developer Sakti3's debt.

"This is a real strategic business decision for the OEMs," says Frankel. "They have all come to the conclusion that solid-state batteries are a key enabler for the next generation of EVs and batteries."



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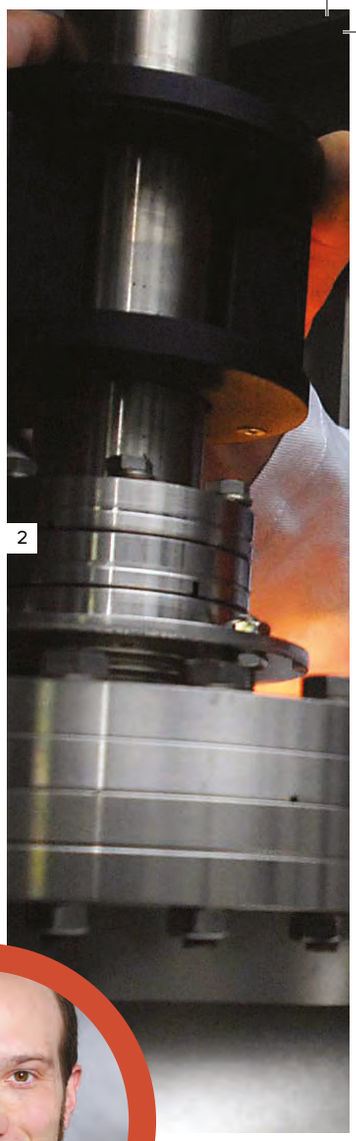

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1. Ilika's Stereax M250 solid state-batteries produced on six-inch wafer

2. An Ilika scientist checking progress of thin film deposition

Many see Toyota as leading the way in the race to find a solid-state solution for EVs. The Japanese OEM has teamed up with Panasonic, initially claiming that it wants to realize the next-generation battery technology by "the first half of the 2020s". Reluctant to comment publicly on its progress of late, the car maker's chairman, Takeshi Uchiyamada, admitted to Reuters in 2017 that: "We're scrambling to finish developing this technology, but a few issues still remain as we try to mass produce this."

"The materials are degrading," explains Hermann Tempel, group leader at the Jülich

3

4

Forschungszentrum Jülich

"[Solid-state] is not just a battery with better energy density, but also a battery with packaging and efficiency improvements"

Dean Frankel, strategic business development, Solid Power

3. Hermann Tempel of the Jülich Institute for Energy and Climate Research, which has collaborated with BMW on solid-state technology

4. A test set up by the Jülich Institute for Energy and Climate Research. The miniature battery is visible in the center

Institute for Energy and Climate Research, which has collaborated with BMW on a solid-state battery solution. "If they are using the sulfide-based system that is in their published material, then it is good for maybe 100 cycles."

But the sulfide and silicon approaches to creating the first solid-state battery for an EV are not the only methods being tried. Ionic Materials, which has partnered with Hyundai CRADLE, Renault, A123 Systems, Hitachi and Total (owners of Saft Batteries), is using a solid polymer, which conducts in a similar way to liquid electrolytes.

"What's unique is that it operates over a wide range of temperatures," explains Erik Terjesen, senior director of licensing and strategy at Ionic Materials. "Polymers have only worked at high temperatures before, but this works at room temperature."

The major advantage of using a polymer, Terjesen explains, is that the battery manufacturers and OEMs do not need to reinvest in new battery infrastructure. "The processes are very similar to today's manufacturing. We are just replacing the liquid electrolyte and the separator."

Manufacturers can simply insert the polymer instead of the separator in what he describes as a "drop-in" production process.

Finishing line

Some, however, remain skeptical that this is the way to go. "The alternative solutions are not inherently improving safety and energy density at the same time," argues Frankel. "You can increase safety, or increase energy density, but increasing both is very difficult, and I believe our way is the only way to do it."

These are not the only hurdles developers of solid-state batteries are facing. Recharge time is also a major challenge, but at Jülich, they think they have found a solution to this.

"People want to charge a car in minutes rather than hours," says Tempel. "The low current is considered one of the biggest hurdles in the development of solid-state

batteries. It is the reason why the batteries take a relatively long time to charge."

By using similar materials to produce all their components, the Jülich Institute team believes it has enabled the largest possible flow of current across the battery, allowing greater charging rates with limited degradation.

The team at Solid Power also believes it will soon crack this problem. "Our long-term goal at Solid Power is to achieve parity with lithium-ion batteries," explains Frankel. "I really don't think super-fast, five-minute charging is very realistic with solid-state batteries, but 20 to 30 minutes is achievable."

When this new technology will finally enter the market still remains to be seen. While Toyota initially said it expected the technology around 2021, the company has since backtracked, with Shizuo Abe, Toyota's powertrain general manager, reportedly saying it could now be "a decade away". At the start of 2018, Volkswagen's Herbert Diess told *E&H Vehicle* that he didn't expect to see solid-state batteries in the first generation of batteries and BEVs. "Solid state can only take effect in 2024 or 2025," he explained. "To say 2020, that's courageous."

But could solid-state battery technology be another cold fusion, an impossible dream that never materializes?

"It will definitely enter the market, but the question is where," argues Tempel. "Is it really possible for the mobility sector or would it be better suited for a notebook or cell phone? Nobody can answer that question for sure, but I do not think we will see this in mobility in two to three years."

"It is definitely not an endless Holy Grail search," adds Frankel. "The improvements we are seeing in the industry are real. There have been big improvements in materials and combinations of materials. It is not fully matured, but it is progressing."

HYBRID POWER

Solid-state batteries are not the only next-generation battery currently being developed. Metal-air batteries, sodium-ion batteries and magnesium batteries (multivalent ion batteries) are all being researched.

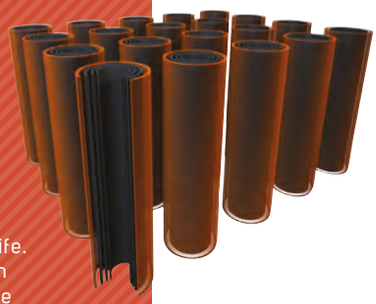
And while developers such as Ionic are using a polymer electrolyte, which is not quite a solid, some believe this type of hybrid system could be close to addressing the major issues with solid-state batteries if they can find the right polymer compound.

"If you could use a ceramic material in the polymer there would be no thermal runaway, so a hybrid solution could be possible, and you could use the same technology to produce the batteries, but no right combination has been found yet," says the Jülich Institute's Hermann Tempel.

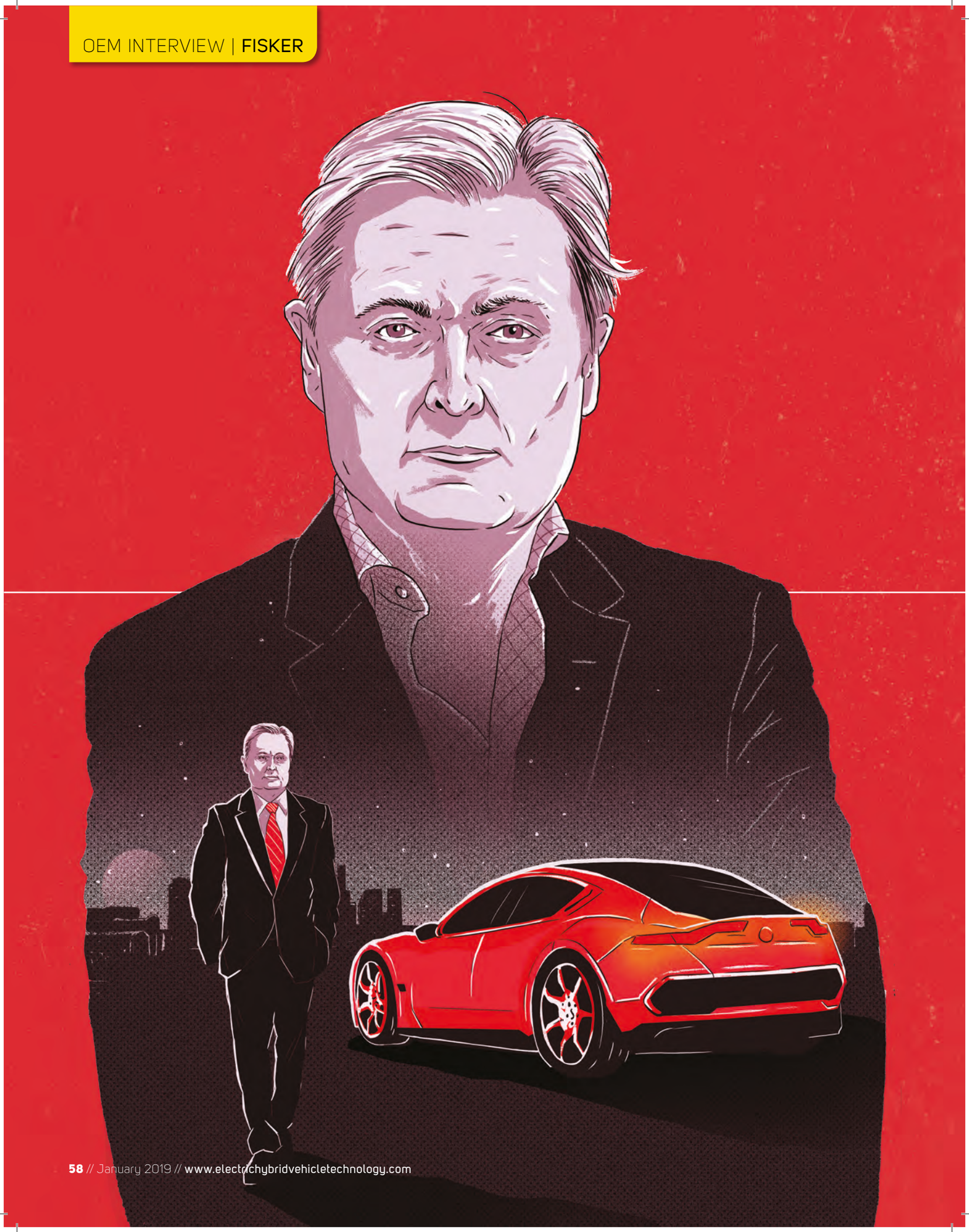
And other hybrid solutions are also being tried. France-based Nawa Technologies has developed an Ultra Fast Carbon Battery that, while it only has 10-20% of the energy density of a Li-ion cell, can be recharged in seconds with an almost endless cycle life.

By combining this technology with traditional Li-ion cells, Nawa believes it could create a battery with the same energy density as a conventional battery but with less weight, and as the Ultra Fast Carbon Battery could take the heavy loads of recharge, it could enable a long cycle life.

"We carried out some digital simulations on one of the world's most advanced automotive batteries: the motorsport battery used in Formula E, which is a highly sophisticated Li-ion system," explains CEO Ulrik Grape. "By combining our ultracapacitors with this battery, we could reduce overall weight from 300kg to 210kg, with the same overall power, by making the Li-ion battery smaller and reducing the complexity of the energy and thermal management system. That's a 30% weight reduction, but with more performance and greater range, as the overall pack weight is much lower, not to mention the longer life for the system."



Nawa Technologies has developed an Ultra Fast Carbon Battery, which could be used in conjunction with lithium-ion cells



SECOND COMING

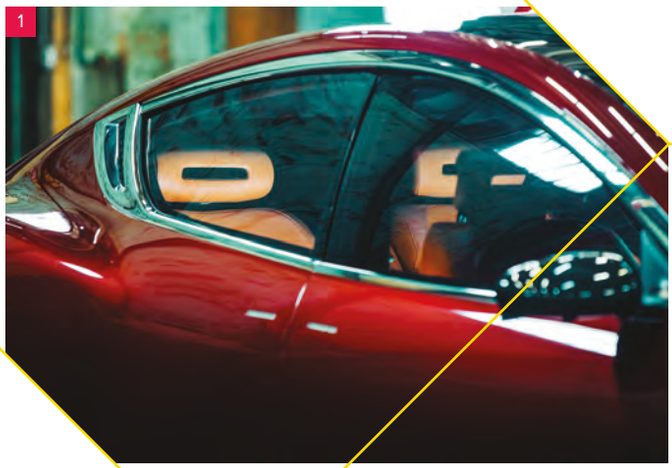
Henrik Fisker believes that a breakthrough battery technology and a new business model will secure success for his revived company, which plans to launch a range of affordable EVs

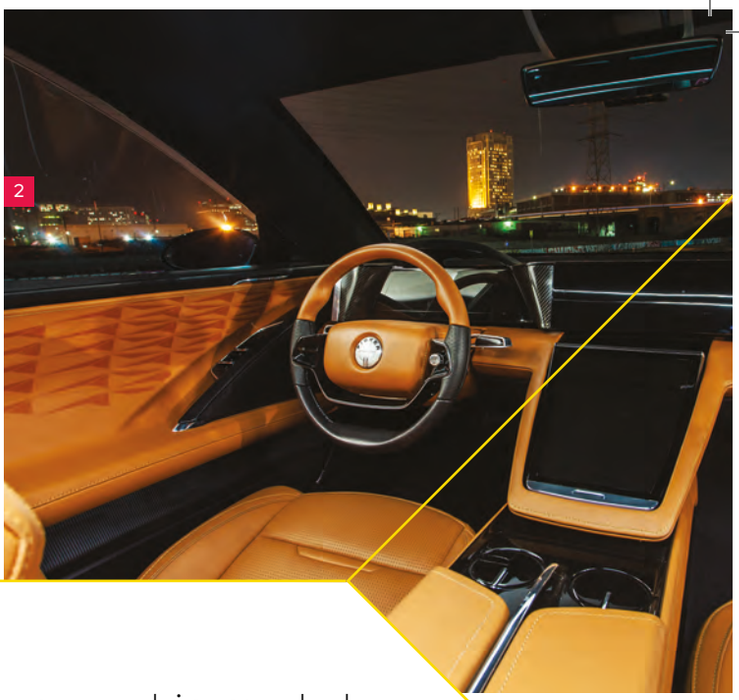
WORDS: **GRAHAM HEEPS**

ILLUSTRATION: **MITCH GEE**

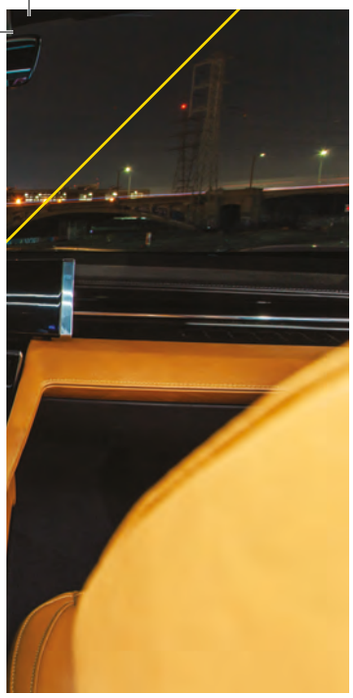
1. The EMotion features automatically tinting electrochromatic glass

2. Technology is a big focus with displays found throughout the cabin





"We see a big market opportunity to make a high-volume vehicle as an independent EV maker"



3. Fisker's butterfly doors are designed to offer greater accessibility

4. Henrik Fisker believes customer interface will be an important factor in the future for brand identity

Fisker Inc. turned heads at the Consumer Electronics Show in January 2018 when it revealed not only a luxury electric vehicle prototype, the EMotion, but also a new solid-state battery technology in an advanced state of development.

Company chairman and CEO Henrik Fisker has been here before. His former company, Fisker Automotive, brought the Karma hybrid to market in 2011 before battery issues and the bankruptcy of supplier A123 Systems derailed the fledgling auto maker's progress and led to Fisker Automotive's own failure just three years later.

Since then, Tesla's production has ramped up, traditional OEMs have stepped up their own EV efforts, and numerous other luxury EV startups are positioning to join the market. But Fisker believes that his experience leaves him uniquely placed to create a new, successful business, second time around.

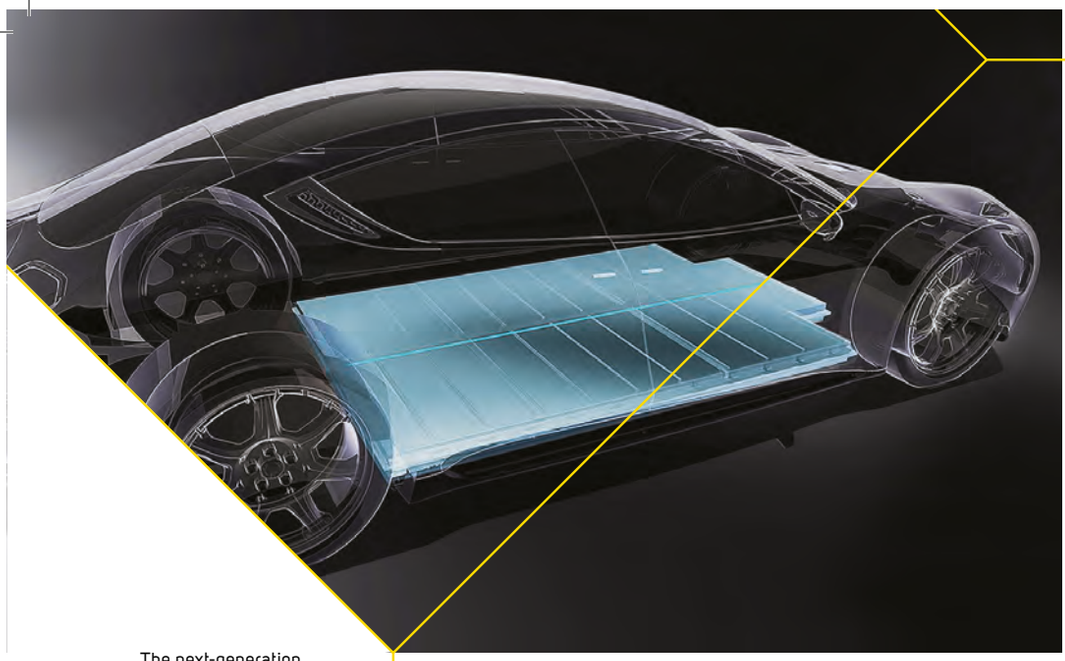
"There's a lot of competition from other startups, especially here in California," says Fisker, whose new venture is based in Torrance. "I'm one of the only ones who's started a car company before and I've taken that learning and applied it to what we're doing now.

"One of the biggest lessons I learned is that to try to start a car company and use a traditional OEM setup to become a well-oiled machine is not the right way. You have to come up with a different way of doing it so we completely changed the business model and the way we develop the cars. These are very important factors in us becoming a well-oiled machine faster and turning a profit."

As a private company, Fisker is under no obligation to give away details of its business model, and for the time being Fisker himself is being cagey on the size and scale of the operation: "It's unique, and we want to keep it under wraps," he says.

Nevertheless some aspects are clear. First, Fisker sees the new venture as an e-mobility and technology company, rather than as a car company. The progress made with the Orbit autonomous connected shuttle underlines plans to go into other mobility segments rather than just sell private cars to customers.

Nor does Fisker have plans to develop complete powertrains for its future vehicles. "I believe that a lot of components, including powertrains, will end up being produced by suppliers and shared by many OEMs," he argues. "Today, most car makers make their own gasoline engines as an important part of their brand identity. I believe that in the future, the electric motor, inverter, connectors and other items in the powertrain won't be that much of a differentiator. It will be things such as the type of customer interface or how



The next-generation solid-state battery will debut in the EMotion, which won't be released until the technology is fully developed

the powertrain feels, which is a lot to do with software. Therefore, we're not concentrating our main effort on the powertrain."

Solid-state update

Fisker's technology focus in the powertrain field is on a next-generation, solid-state battery (see sidebar, *Rock solid*).

"We are already building and testing cell phone-sized batteries," says Fisker. "We are ensuring that we have the repeatability in our data that we need to freeze the specification for the first production version of this battery by the end of 2018. In 2019 we hope to make enough cells in pilot production to create some battery packs to put into cars so that we can begin testing. If everything goes as planned, I hope we will have something ready for low-volume vehicles in 2020. Of course, there are many unknowns when you do everything for the first time as an innovator and always unforeseen bumps in the road, but that's the rough timeline we're looking at."

Fisker won't mass-produce the batteries itself. Instead, the solid-state technology will be licensed to third parties, either independently or as part of a JV with Fisker, and either separately for automotive and consumer electronics applications or to a company that could produce both. According to Fisker, all options are on the table and nothing is finalized.

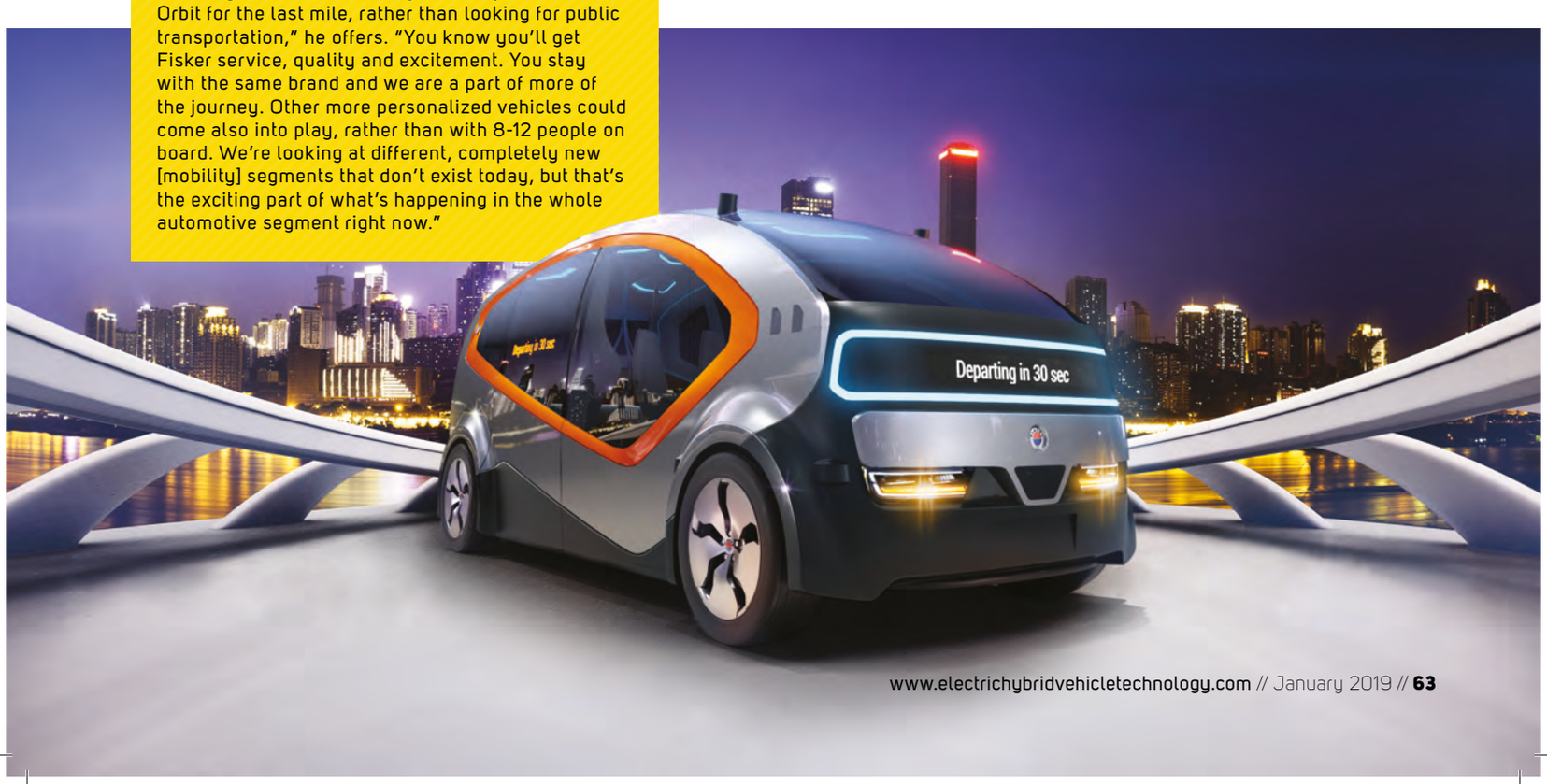
"We could partner with an existing battery manufacturer, although that's less likely as most of the them have a lot of investment in current technology," he observes. "We see more interest from automotive suppliers who are not currently doing batteries and want to get into next-generation technology."

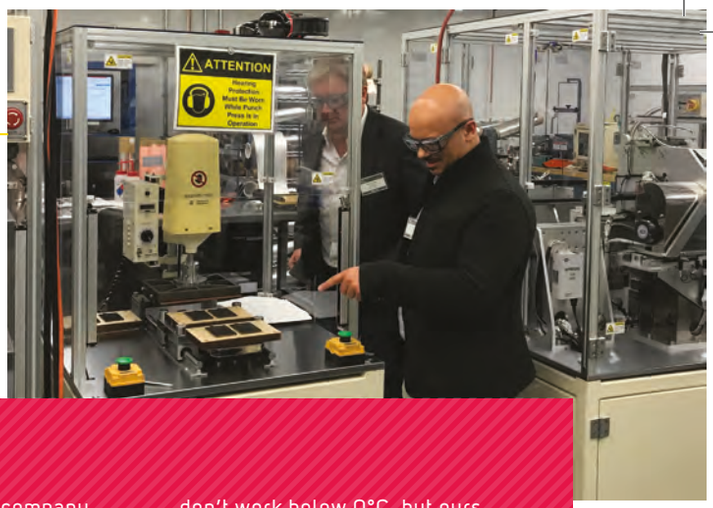
> "If everything goes as planned, I hope we will have something ready for low-volume vehicles in 2020"

PLANET FISKER

Henrik Fisker believes that his company will be ready to take advantage of new forms of mobility as consumer trends evolve. That could include using an app to link journeys in privately owned Fiskers with rideshare Fisker shuttles.

"It may be more interesting to call up a Fisker Orbit for the last mile, rather than looking for public transportation," he offers. "You know you'll get Fisker service, quality and excitement. You stay with the same brand and we are a part of more of the journey. Other more personalized vehicles could come also into play, rather than with 8-12 people on board. We're looking at different, completely new [mobility] segments that don't exist today, but that's the exciting part of what's happening in the whole automotive segment right now."





Fisker reveals that use of the technology in the automotive sector would be restricted to itself and a few automotive partners. "We would not sell it to our competitors right away, because we see it as a competitive advantage. But that's still a few years away."

He expects the solid-state battery to debut in the EMotion, and as such, the launch date for the 160mph (260km/h) four-door has been delayed to peg it to the battery launch.

"The solid-state battery technology is an important part of that vehicle and is a technology leader for Fisker, so we don't want to launch the EMotion with a normal battery."

Priority projects

Indeed Fisker insists that, despite being the company's most high-profile announcement so far, the flagship EMotion isn't one of Fisker's two priority programs. The first of those is the Orbit, which uses in-wheel electric motors from Protean Electric. A prototype is being built ahead of a first deployment on a US corporate campus in the second half of 2019, from which Fisker expects to collect a wealth useful of data.

"We want to understand not only the technical part but also the human interaction, and the monetization of this vehicle," Fisker explains. "We want to start to understand the mobility choices that people might make. We're developing a Fisker app ecosystem that will be connected to both our private cars and Orbit. We're looking at new revenue streams and how to monetize that whole system. We are a smaller car maker and can't afford this to be a loss leader; we have to make money on it from the get-go."

The other focus is the first in a new range of high-volume, affordable EVs.

"The EV market is still growing," he notes. "There's not much choice out there and we see a big market opportunity to make a high-volume vehicle as an independent EV maker. We are planning a range of vehicles and have some innovative ways in mind for how they'll be developed and sourced, and how our business plan can make a competitive vehicle in that segment. That means, however, that you have to find some non-traditional ways to get the vehicle to market. We're working on that right now and there will be more detail at the end of 2018 or in early 2019."

He describes the launch of the first vehicle as "still a few years away" but promises "a focused program with a business case that hasn't previously been seen. It will totally set us apart from all the other startups and Tesla. Tesla is the only other independent electric vehicle maker that is a global brand, but we are the polar opposite of what Tesla is doing. We are an extremely lean company with a unique business model. It will get us to profitability very quickly, with unique timelines in terms of fast development, fast to market and fast to high volume."

ROCK SOLID

Fisker isn't the only company working on solid-state batteries for automotive applications, but Henrik Fisker believes that his small team, led by VP of battery systems Dr Fabio Albano, is ahead of the game.

"There are three main elements that a solid-state battery technology has to demonstrate and I think we have a handle on all of them," says Fisker. "First, the battery needs to be powerful enough to pull a car. A lot of the thin-film solid-state batteries that have been developed simply don't work, but our three-dimensional bulk battery, as we call it, solves that issue. The next thing is that most solid-state batteries don't work below 0°C, but ours goes down to -20°C. The third part is the cost. Our battery is way below current [Li-ion] technology, somewhere between US$40-75/kWh, which is extremely low."

Crucially, Fisker claims to be developing a fast, low-cost form of cell manufacture.

"Right now we are refining that production method, which also means creating new machines to make them, which takes time. We feel we're ahead of everybody else, but there are still a couple of years of refinement, testing and pilot lines to come before we get into high-volume production," he says.

As well as producing its flagship EMotion, Fisker is looking at the potential opportunity to create high-volume, affordable vehicles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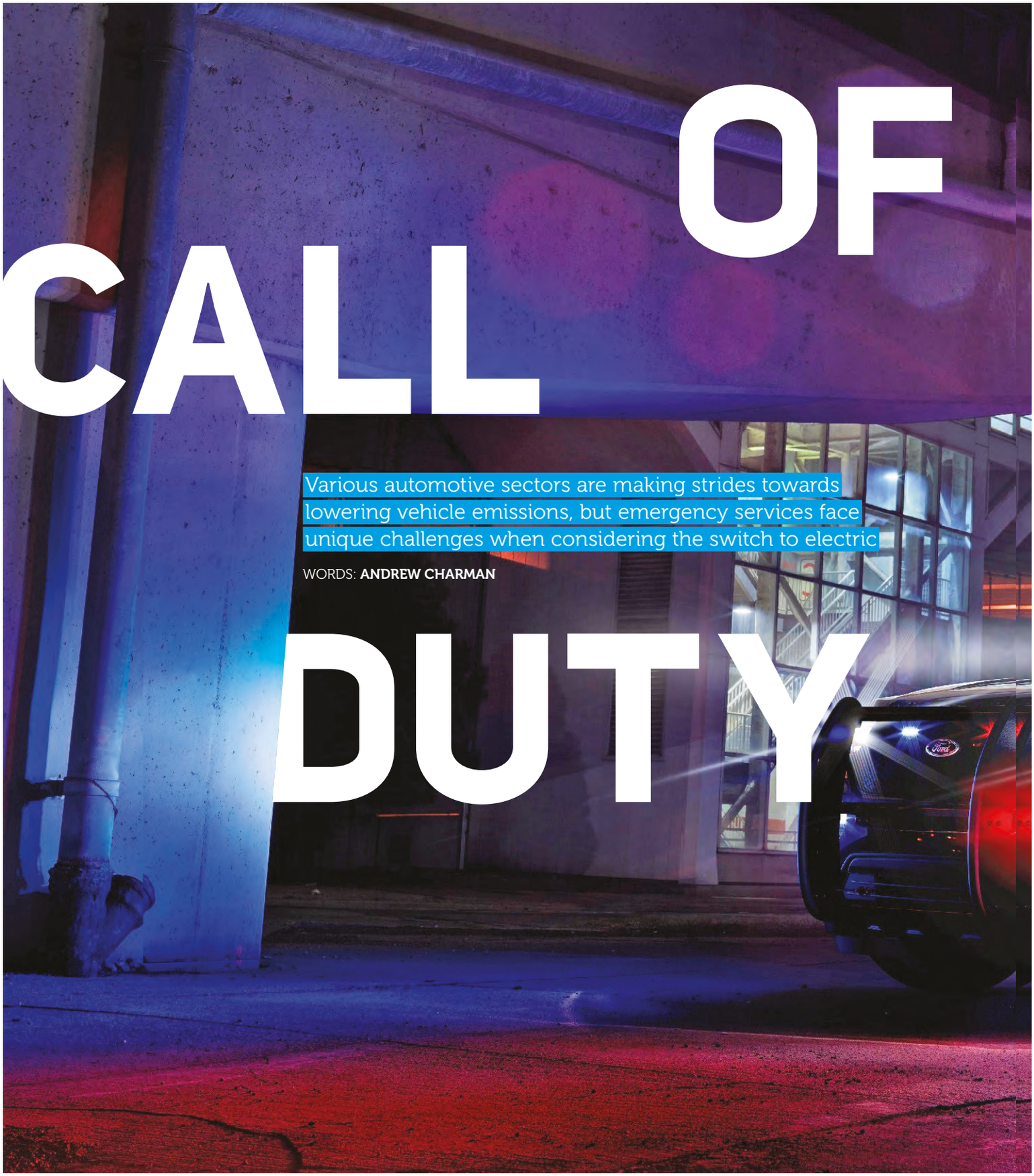
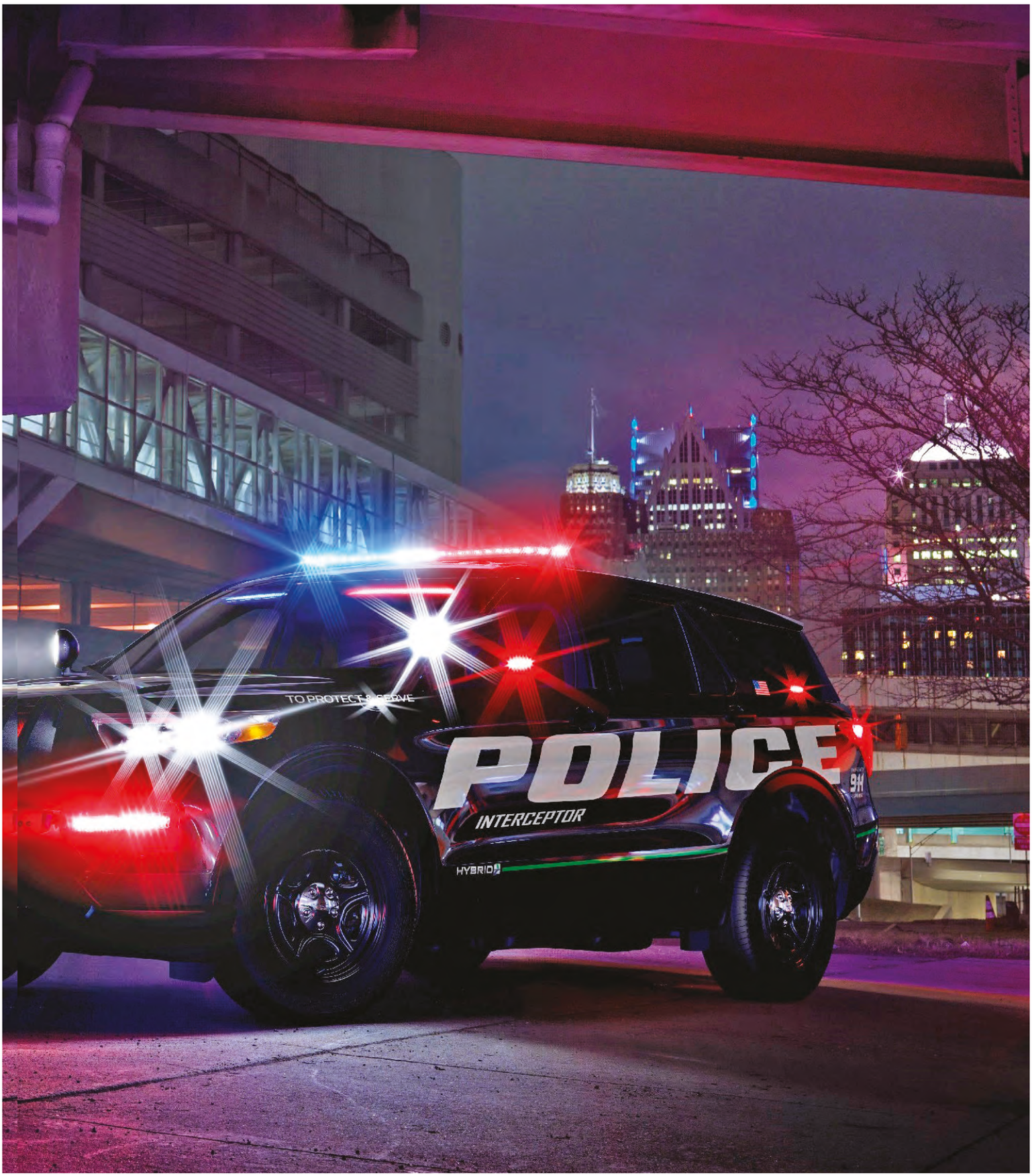


CALL OF DUTY

Various automotive sectors are making strides towards lowering vehicle emissions, but emergency services face unique challenges when considering the switch to electric

WORDS: **ANDREW CHARMAN**


TO PROTECT & SERVE
POLICE
INTERCEPTOR
HYBRID

1

1. Though emergency services have begun introducing electric and hybrid vehicles, they typically tend to be limited to support roles

2. The electric motor of the WAS E-Concept and integrated battery management system is installed in the space in the engine bay created by the removal of the traditional IC engine

3. The WAS E-Concept's normal instrument panel is replaced by a battery monitor that enables the driver to monitor battery status, the battery management system, speed, revs and range

Pressure to convert to electric power in the automotive world is increasing – the UK plans to stop selling new petrol and diesel cars by 2040, and a number of European countries, including Germany, are considering implementing a ban in 2030.

Emergency services are not immune to the demands to change to ultra-low-emissions vehicles (ULEVs), despite making the greatest demands on those vehicles – and their powertrains – on a daily basis.

In September 2018, the UK's National Institute for Health and Care Excellence (NICE) published draft guidance which recommended public sector organizations, including National Health Service Trusts, should identify ways to reduce air pollution from their vehicle fleets – emissions should be "one of the key criteria when making routine procurement decisions."

Police, fire and ambulance services have already introduced hybrid and full-electric vehicles to non-critical roles such as pool cars

2

3

and patient transport. The BMW i3, for example, has proved popular in such roles – the London Fire Service and Metropolitan Police now routinely use the i3, and in August 2018, the Surrey and Sussex police forces each took delivery of 30 of the cars in a three-year pilot scheme.

However, all of these i3s are range-extender versions, with gasoline engine backups that remove the range anxiety that still exists around full-electric vehicles.

The UK's North East Ambulance Service replaced five of its pool cars with Nissan Leafs, but has since changed to range-extender BMW i3s. "The Nissan Leafs worked well over short journeys, but our organization covers more than 3,200 square miles [8,300km^2] and most staff did not have confidence in driving them over long distances," fleet manager David Parkin says.

In 2016, BMW won a bid to supply the Los Angeles Police Department with 100 all-electric i3 models, with the then-president and CEO of BMW North America, Ludwig

4. Los Angeles Police Department's fleet of 100 fully electric BMW i3 vehicles was unveiled in June, 2016. Photo: Danny Moloshok/Newscast US

4

CELL DIVISION

Challenges over EV charging times and range could open the door to hydrogen fuel cell technology.

In addition to emitting only water, the fuel cell vehicle does not require charging, but rather an infrastructure of hydrogen filling stations where it can have its tank replenished in minutes, in similar fashion to refueling a gasoline or diesel car.

In March 2018, a program aided by a European Union grant saw the Metropolitan Police in London equipped with a fleet of 11 Toyota Mirai FCEVs, as part of the force's stated aim to have 550 ULEVs or EVs in its fleet by 2020.

The Mirai FCEVs serve as unmarked and fully marked-up front-line police vehicles, in overt and covert response roles as well as general duties. Five hydrogen refueling points are available in London, with more to come. When fully fueled, the cars have a 480km (300 mile) range.

A newly announced five-star Euro NCAP crash test rating for the Hyundai Nexo is helping to dispel public concerns over hydrogen vehicle safety, but there remain doubts as to how quickly the technology can be applied to heavier, more demanding roles, such as fire appliances or ambulances. "We are not aware of any [fuel cell] vehicles that currently fulfill our needs due to the amount of equipment we need to carry," says David Parkin of North East Ambulance Service.

Willisch, championing the i3's attributes, which "position it to excel as the ideal vehicle for municipal organizations". But once again, the all-electric i3 variant was only put into service in a non-emergency, support capacity.

A far greater challenge is to electrify front-line vehicles such as ambulances, police pursuit vehicles and fire appliances, due to the demands placed on such vehicles during high-intensity and (potentially) critical applications, as well as the often prohibitive cost of buying EVs.

First responders

Development of such vehicles is proceeding. In Germany the WAS E-Concept, a conversion of a five-ton emergency ambulance with an 87kW electric motor, has quickly developed from a pilot project to a working vehicle. It offers a range of between 120km and 200km (75 to 120 miles) between charges and a maximum speed of 120km/h (75mph).

> "Once you add telematics, mapping systems, communications equipment and, of course, blue lights and a siren, the extra weight of a vehicle reduces its range"
>
> David Parkin, fleet manager, North East Ambulance Service

In Austria, Kreisel Electric has produced a small electric fire appliance based on the Mercedes Sprinter van. Its 120kW motor enables a range of 160km (100 miles) between charges. Charging can be done overnight or using a fast charger and Kreisel CEO Markus Kreisel says such appliances are ideal for electric propulsion. "They only have to cover short distances and charging can be done between use – I am particularly thinking of stations in the districts of large inner cities, in town centers and small communities in the countryside or at airports," he says.

However, such performance and range capabilities make these vehicles non-starters with UK emergency services, where ambulances routinely cover 240-320km (150 to 200 miles) per day, and can exceed 160km/h (100mph) on an emergency call.

Moreover, these vehicles are in continuous demand with no

Ford's Police Responder Hybrid sedan is based on the Fusion. The OEM will introduce a hybrid version of its Interceptor Explorer SUV in late 2019

downtime for recharging – unavailability due to an ambulance being plugged in at a charging station would be unthinkable, particularly given that emergency response times are under constant scrutiny.

Fire appliances tend to have much lower mileages, but are typically heavier, often weighing 12 tons or more, which eats into EV range. What's more, certain situations can require emergency vehicles to remain at an incident, in operational mode, for several hours – sometimes even days.

Power struggle

According to Parkin, the three main criteria followed when selecting a new front-line vehicle are its size, range and 4x4 ability. "Emergency vehicles need to be fast, safe, capable of carrying the amount of equipment we need and come within our revenue or capital budget," he says.

Ambulances have been steadily gaining weight as they gain more equipment – in 2017 the UK's South East NHS Trust initiated a vehicle weight program after discovering that several of its ambulances were perilously close to their gross vehicle weight limit.

"Once you add telematics, mapping systems, communications equipment and, of course, blue lights and a siren, the extra weight of a vehicle reduces its range," Parkin says.

The other major issue is electrical demand and recharging times. Most conventional ambulances, for example, employ two batteries for the engine and three large batteries for medical and ancillary equipment and lights, while paramedic cars have two, again adding to the weight.

> "Emergency vehicles need to be fast, safe, capable of carrying the amount of equipment we need and come within our budget"
>
> David Parkin, fleet manager, North East Ambulance Service

A vast range of equipment, from stretcher batteries to defibrillators, is charged while on the vehicles, and the vehicles also carry 12V/240V inverters to power equipment such as incubators. Plug-in charging for this equipment is available at ambulance stations, but not typically at hospitals. Recharging the EV itself would therefore be highly challenging due to constant use.

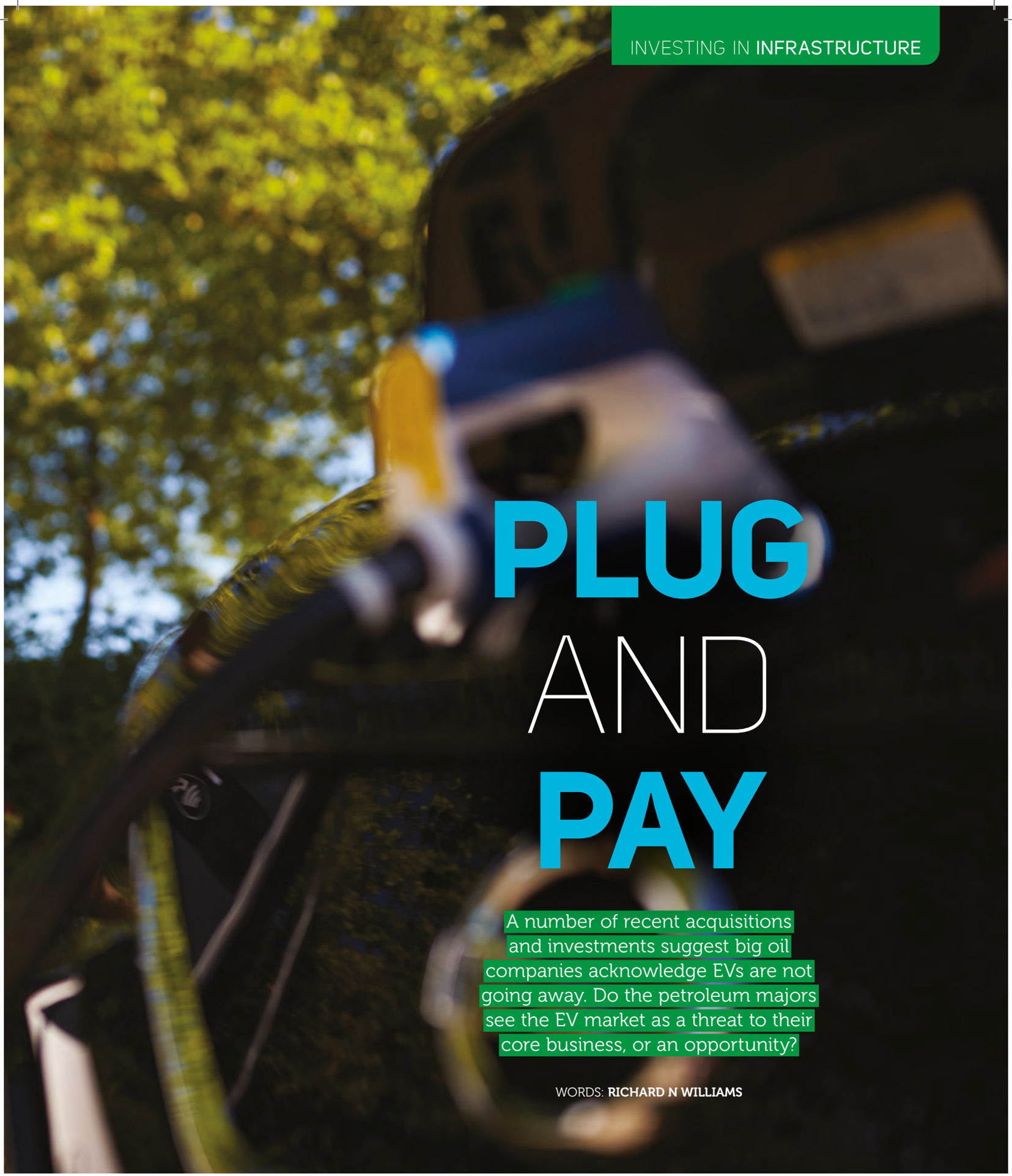
"Often there is no downtime between incidents," Parkin says. "Although our fleet of cars do fewer miles overall, the majority are operational 24 hours a day, and only the specialist roles would have a chance to charge overnight."

Alongside range-extender vehicles, hybrids are being pursued as a means for organizations to reduce their carbon footprint. In the USA, Ford offers a Police Responder Hybrid sedan, based on its Fusion saloon, which combines a 2-liter petrol engine with an 88kW electric motor. Recently unveiled is a hybrid version of the best-selling Ford Police Interceptor Explorer SUV, set to enter service in late 2019. While full details of its powertrain are yet to be revealed, the hybrid claims a combined fuel economy of 9.8 l/100km (24mpg) compared with the petrol Interceptor's 13.8 l/100km (17mpg).

Parkin is less convinced by the value of hybrids. "The MPG is no better than a diesel when the vehicle is in constant use and, because we have our own fuel bunkers, we can maximize a reduction in spend. We have tested a number of vehicles and will continue to look at alternative options as more vehicles become available."

In a view that will no doubt be echoed across other services, Parkin does not foresee early major uptake of EVs on the emergency frontline. "Ambulance trusts are struggling to design a suitable vehicle that is fast, safe, capable of carrying the amount of equipment we need to, and comes within our capital or revenue budget for the year. We would also need the correct infrastructure in place."


Ultracharge electric
vehicle charging station
Ultracharge
bp
chargemaster



PLUG AND PAY

A number of recent acquisitions and investments suggest big oil companies acknowledge EVs are not going away. Do the petroleum majors see the EV market as a threat to their core business, or an opportunity?

WORDS: **RICHARD N WILLIAMS**

Ten years ago, nobody in the oil business was taking electric vehicles seriously. Things have changed, however, and some of the big oil companies are now making moves in the EV space.

While many oil majors remain bullish about the health of the gasoline market, some are no longer underestimating the threat EVs pose to their core market – and want in on the action.

"We expect there will be around 300 million EVs globally by 2040, and the transition from primary ownership to shared models will only continue," says Roy Williamson, vice president for advanced mobility for BP. The multinational has established an Advanced Mobility Team, Williamson explains, to investigate solutions that will enable BP to "play in this new world".

Among its moves into the charging sphere, BP recently bought Chargemaster, the UK's largest electric charging network, for £130m (US$168m). It has also invested in a number of startups, including US$5m in Freewire, a company that produces a rapid charging system, and a US$20m investment in battery developer StoreDot.

BP is not alone in moving into the charging business. In 2017, Royal Dutch Shell signed an agreement to acquire NewMotion, a Dutch EV charging network. The oil giant has also introduced a Future Fuels program, and (also in 2017) started a partnership with Allego to introduce 150kW chargers into Shell gas station forecourts. In 2016, oil and gas company Total acquired French battery manufacturer Saft for US$1.1bn.

Threat or opportunity?

But what exactly is the motivation behind these recent acquisitions?

"The oil majors have big operations, and effectively they are watching these operations disappear," explains Mark Gottfredson, leader of energy and oil and gas practices at global consultancy Bain & Company's Dallas, Texas, office. "Most people now agree that EVs are going to be part of the landscape."

Gas station forecourts are a valuable asset for the oil companies. They are found in prime

1. Major petroleum companies are investing in the vehicle charging industry. Shell acquired NewMotion in 2017 and has also established a Future Fuels program

2. Shell has also entered a partnership with Allego, which will see charging points introduced to Shell gas station forecourts

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"Oil and gas companies will need to embrace new business models and new approaches, but with the right investments and strategic approach, they can create new business and new revenue streams"

Michael Schweikl, automotive expert, PA Consulting

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locations, not just in cities, but along highways, and they provide more opportunities for revenue than just selling fuel.

"EVs remain a threat to the oil companies because most charging takes place at home or work," adds Gottfredson. "When you visit a gas station, you don't just buy gas, you might buy a coffee or a soda."

"Oil and gas companies will need to embrace new business models and new approaches, but with the right investments and strategic approach, they can create new business and new revenue streams," adds Michael Schweikl, automotive expert at PA Consulting. "Charging stations at petrol stations give companies a way into providing broader services."

Forecourt charging

If gas stations are to lure people to fill up, not just with gasoline and diesel, but also electricity, charging times will need to come down first.

"The current 20- to 30-minute charging times are a bit of a barrier for them," suggests Gottfredson. "But 15 minutes? A lot of people

3

3. In 2018, BP acquired Chargemaster, and will commit resources to the development of new charging technologies and higher charging rates

may spend 15 minutes at a gas station, taking a break or having a coffee."

Getting the charging time down is certainly on BP's agenda. The company not only has plans to roll out Chargemaster's 150kW rapid chargers across its forecourts in the UK over the next 12 months, but has made it clear that it wants even faster charging options available.

"In the UK, 50% of drivers do not currently have access to the off-street parking that enables at-home charging," says BP's Roy Williamson. "We firmly believe that in order to support the adoption of EVs, we will need to provide a network of convenient and safe ultra-fast charging that allows drivers to charge quickly – ideally in 10 minutes or so – and get back on the road."

Achieving charging times of 10 minutes means charging rates that are upward of 300kW – not something Chargemaster was considering until the BP acquisition, admits strategy director Tom Callow.

"I guess we were happy with 150kW and were not sure about going faster than that, but BP obviously sees possibilities with 300kW," Callow says. "BP has deeper pockets than Chargemaster, and that gives us more resources for R&D, so currently there is a lot more appetite to look at what we can do in the ultra-fast space."

BP is not alone in its desire to see improvements in EV charging speed.

Allego, the Dutch-based charging company that has partnered with Shell to install chargers in the latter's gas stations, is also planning an 'ultra-fast corridor' from the Dutch coast to the Austrian border, with 25 ultra-fast charging points at various locations.

"These will enable those drivers in Europe to recharge in between five and eight minutes, then have enough recharge to drive more than 100km [62 miles]," claims Harold Langenberg, head of strategy at Allego.

Shell has also unveiled a 350kW charger at a gas station just outside Paris – one of 80 European locations the Anglo-Dutch firm has earmarked for installation of ultra-fast chargers by 2020.

These chargers will form part of the Ionity network, a pan-European ultra-fast charging plan backed by companies including BMW, Mercedes, Ford and Volkswagen.

Other OEMs believe ultra-fast charging is the way forward too. Volvo Cars has also acquired a stake in Freewire Technologies via its Volvo Cars Tech Fund.

"Society needs to make charging an electric car as simple as filling up your tank," says Zaki Fasihuddin, CEO of Volvo Cars Tech Fund, although he says they are skeptical that forecourt charging will be part of EV infrastructure in the future.

Ultra-fast challenge

But there are still barriers to the adoption of fast charging. One problem in particular remains: "Cars today can't take more than 150kW, and the battery technology definitely has questions to answer about degradation,"

1

1. For forecourt-based vehicle charging to be feasible, technology must increase charging rates, but also consider battery degradation. Doing so could open up lucrative new revenue streams

2. The Volvo Cars Tech Fund acquired a stake in Freewire Technologies. BP has also invested in the charging startup

"Society needs to make charging an electric car as simple as filling up your tank"

Zaki Fasihuddin, CEO, Volvo Cars Tech Fund

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CHARGING AT THE PUMPS

The big gas companies are not the only ones getting involved in the EV space. Gilbarco Veeder-Root, a leading supplier of fuel dispensers and other gas station infrastructure, recently made a minority investment in charging manufacturer Tritium.

The company said it was the right time to enter the space, and sees the potential of the EV market if charging times do come down.

"This investment provides early and judicious entry into a market with a growing need for rapid charging, which is one of the top barriers to EV purchase," says Martin Gafinowitz, senior vice president of Fortive, the parent company of Gilbarco Veeder-Root.

Tritium already has an ultra-fast high-power charging (HPC) system, the Veefil-PK, a 350kW system capable of a fully charging an electric vehicle in 5 to 10 minutes.

"Mass-market adoption needs the gas station experience because it doesn't require any behavior change," says CEO of Tritium, David Finn. "If you can go to your gas station and get a 100-mile [160km] charge in 5 to 10 minutes, you might not need to install a charger at home."

The Veefil-PK is scalable, so is able to rapid charge existing cars on the market, while being able to ultra-fast charge the next generation of EVs.

"One of the biggest challenges to EV infrastructure is finding the right real estate," Finn adds. "And the gas stations can answer that."

Investment from BP will enable Chargemaster to develop charging rates that can cut waiting times, and match the power requirements of the next generation of vehicles

"BP has deeper pockets than Chargemaster, and that gives us more resources for R&D, so currently there is a lot more appetite to look at what we can do in the ultra-fast space"

Tom Callow, strategy director, Chargemaster

admits Callow. "But there are solutions being worked on."

Indeed, Porsche's Taycan is expected to be the first model capable of charging at 350kW, but technology isn't the only challenge. Up to now, rapid charging and ultra-fast infrastructure has been a risky investment.

"Fast-charging investments do not pay – ROI can be 20 to 30 years!" argues Schweikl. "While the oil majors are investing in them, they are doing it to repurpose existing assets rather than to make money."

Gottfredson disagrees: "Do you know, 50% of Coca-Cola revenue comes from a store with a gas pump out the front," he says. "There's a lot of revenue to be made."

Not all the oil majors are embracing EVs as a potential opportunity. Exxon is being more skeptical. The company's forecasts for EV adoption by 2040 are nearly half those of BP, and the company states it is "continuing to evaluate the potential for electric vehicle charging points" at its stations.

There's no sign that the oil majors will abandon gasoline any time soon, but if they do have a role to play in removing one of the biggest barriers to adoption, and if drivers can recharge a car as quickly as filling a gas tank, it could increase EV ownership and reduce the number of gasoline cars on the road, which could hit the oil majors hard.

BP, however, remains buoyant. "We are committed to remaining a major energy provider in a low-carbon future, irrespective of powertrain," says Williamson. "And while we continue to support advances in EVs, we also continue to work with OEMs on advances in ICE technology."

Keeping track

The old adage of 'win on Sunday, sell on Monday' may no longer apply to most motorsport series, but Porsche's hybrid and electric road car programs are genuinely benefiting from innovations developed on the track

WORDS: **CHRIS PICKERING**

The winding down of the record-breaking Porsche 919 Hybrid Evo's tribute tour could be described as the end of an era. Having won just about everything that matters in the World Endurance Championship's LMP1 class for three years in a row, the Porsche team withdrew at the end of 2017. The tribute tour that followed saw a heavily revised version of the car break a string of outright lap records, besting Formula 1 machinery in the process. But in truth the whole program was not so much the end of one chapter as the beginning of another.

Porsche doesn't do things by halves, so when the decision was taken to develop a car for the 2011 LMP1 hybrid regulations, the company set about recruiting 260 personnel. At the same time, a suite of new facilities covering an area large enough to accommodate a small F1 team was added to the Weissach development center. It's no coincidence that this long-term investment came at a time when electrification was becoming a hot topic in other areas, both on and off the track.


PORSCHE
919 tribute
CHOPARD
24 LE MANS
PORSCHE

1

"A lot of things have transferred over to the Formula E car"

Jens Maurer, head of systems, Porsche Motorsport

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Spin forward seven years and Porsche is in the latter stages of developing the all-electric Taycan road car, a hybrid version of the iconic 911 and a full works entry into the FIA Formula E Series. The all-electric race series entry in particular relies heavily on engineers who worked on the 919 project, and *E&H Vehicle* is assured there is already genuine technology transfer between the two.

"A lot of things have transferred over to the Formula E car," explains Jens Maurer, head of systems at Porsche Motorsport. "The motor is very similar in design, although the philosophy is a little different. In Formula E, where it's a pure EV, you're focused very much on efficiency, whereas in the WEC it's about power density. There's an interesting parallel there to road cars, which is why we expect the Formula E program to generate more technology transfer to the production models."

One aspect of the Formula E car that won't benefit directly from the 919 is its energy storage system. For the Gen 2 cars that will debut toward the end of 2018 (ahead of Porsche's arrival in 2019) the battery will be a spec item supplied by McLaren Applied Technologies. However, this is a key area of interest for Porsche's road car engineers.

"At the beginning of the 919 project the work we were doing on the motorsport side was kept quite quiet," comments Maurer. "This even applied in-house, because some of the road car engineers also worked with Audi, who we were competing with on the track. We only really shared things like dyno procedures and safety concepts. Now we are

1. Lessons learned from the 919 project have found their way into Porsche's road car and motorsport programs

2. The Porsche 919's complete hybrid system displayed on a bench

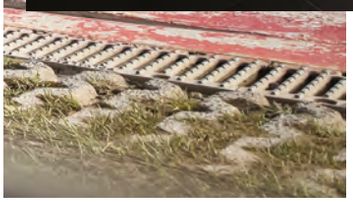
3. The 919 uses an 800V architecture – a feature which has reappeared in the Taycan vehicle project

GOING ALL IN

Porsche joins the Formula E ranks for season six of the series, which kicks off at the end of 2019. By that point there are expected to be more major road car manufacturers involved in Formula E than in any other international series, with fellow heavyweights Audi, BMW, PSA, Jaguar Land Rover, Nissan and Mercedes all confirmed.

While the possibility of rebranding a privateer team was never in doubt, Porsche was adamant it would only join the series if it could field a full works effort. "For us it was never an option to enter Formula E without substantial technical input," explains team principle Andreas Seidl. "The deeper our engineers get into the topic, the more fascinating the solutions become. We can't wait to receive our first vehicle in early 2019 and test our own powertrain in it."

The Gen 2 technical regulations come into force at the end of 2018. The battery remains a standard component (albeit nearly twice the capacity of the outgoing unit at 54kWh) but the teams are free to develop key items such as the motors, inverters, cooling system and ECU. With the emphasis firmly on efficiency, the series offers a uniquely relevant testbed for potential road car technologies.



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4. While Porsche's Formula E program has enjoyed plenty of crossover with the 919's technology, the Mission E – later christened the Taycan – production car has also been heavily influenced by the 919

working closely together on cooling for the batteries and e-motor."

Keeping cool

Cooling is a particularly road-relevant area, Maurer explains. Motorsport is a notoriously punishing environment for thermal management, but the solutions to these particular challenges tend to be relatively low-cost. That means they are generally more applicable to production applications than, say, the exotic materials used in the motors.

In the case of the 919, a direct cooling system is used, with each of the cells enclosed in its own cylindrical metal capsule, surrounded by an oil-based dielectric fluid. The design was carefully evaluated using computational fluid dynamics (CFD) to ensure it would dissipate heat as effectively as possible. In particular, great care was taken to balance the cooling effect across the battery compartment to balance the thermal and electrical loads.

Perhaps surprisingly, Maurer says the potential crash loads in motorsport never posed a particularly daunting challenge. A composite construction was used for the battery case, with a glass-based material included in the lay-up to provide electrical isolation. So robust was the hybrid system that it was still said to be fully functional after Mark Webber's massive crash at Interlagos in 2014. In fact the biggest structural issue for the battery was vibration, which led to a special mounting system being devised. The whole unit was then tested for hours on end using a hydraulic shaker rig before it was signed off.

Projecting power

One of the most important milestones at the beginning of the 919 project was the decision to use an 800V architecture. Just as in road cars, this would enable the system to charge

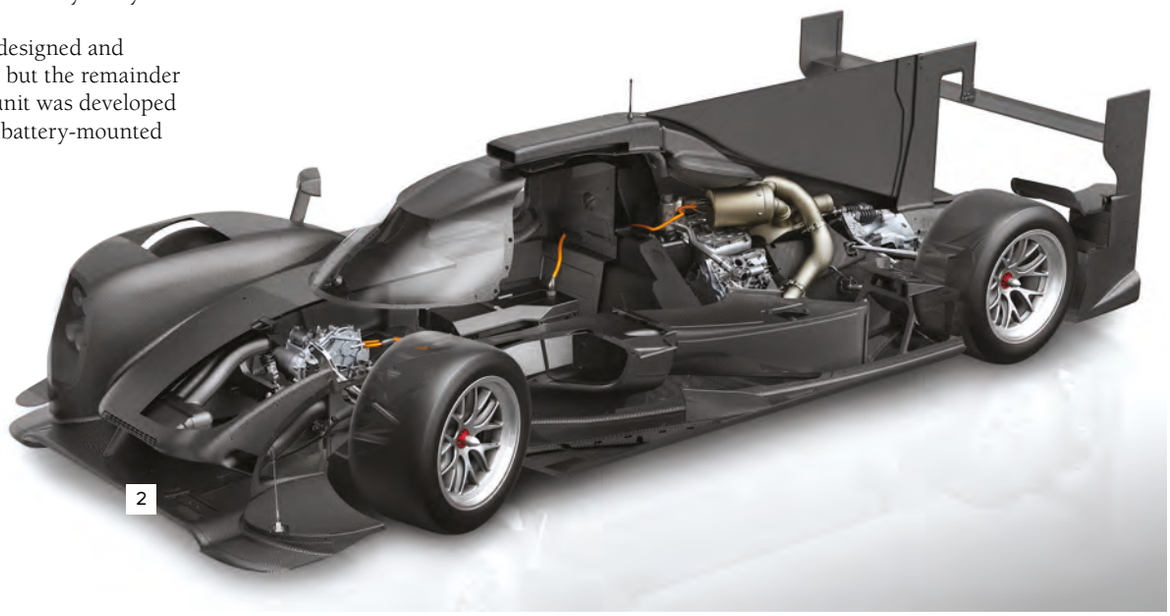
1. The 919 Hybrid Evo was dominant in the World Endurance Championship LMP1 class, and its legacy is still visible throughout Porsche's motorsport and on-road car development

and discharge at very high power levels while running at a comparatively low current, which would reduce the size and weight of the wiring required. The downside was that there were virtually no motorsport-grade components on the market at the time that would cope with such high voltages, which meant that most of the hardware needed to be designed from scratch.

"It's generally the energy capacity that is the main factor in other applications, but for the 919 we required a very high power capability," explains Maurer. "It's the sort of requirement that you are only likely to find in motorsport."

An external supplier designed and produced the windings, but the remainder of the motor generator unit was developed in-house. Likewise, the battery-mounted inverter was initially supplied as what Maurer describes as a 'black box', but by the end of the program around 50% of its design was being handled by Porsche. It meant that by the time the project began to wind down at the end of last year, the department had accrued nearly half a decade of hands-on experience of working with electrified powertrains.

E&H Vehicle's visit to Weissach came on the day the Porsche 919 Hybrid Evo departed for Laguna Seca, the last race circuit on its tribute tour. All that remained after that were a couple of demonstration drives before the car was put into retirement. Porsche's electric adventure, however, has only just begun.



2. The 919 has given Porsche almost half a decade of experience with powertrain electrification

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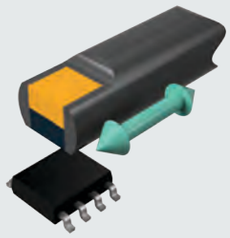

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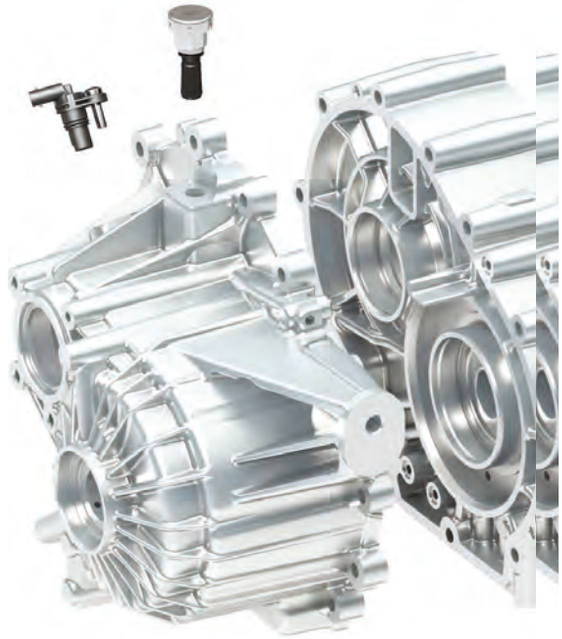


Joined-up thinking

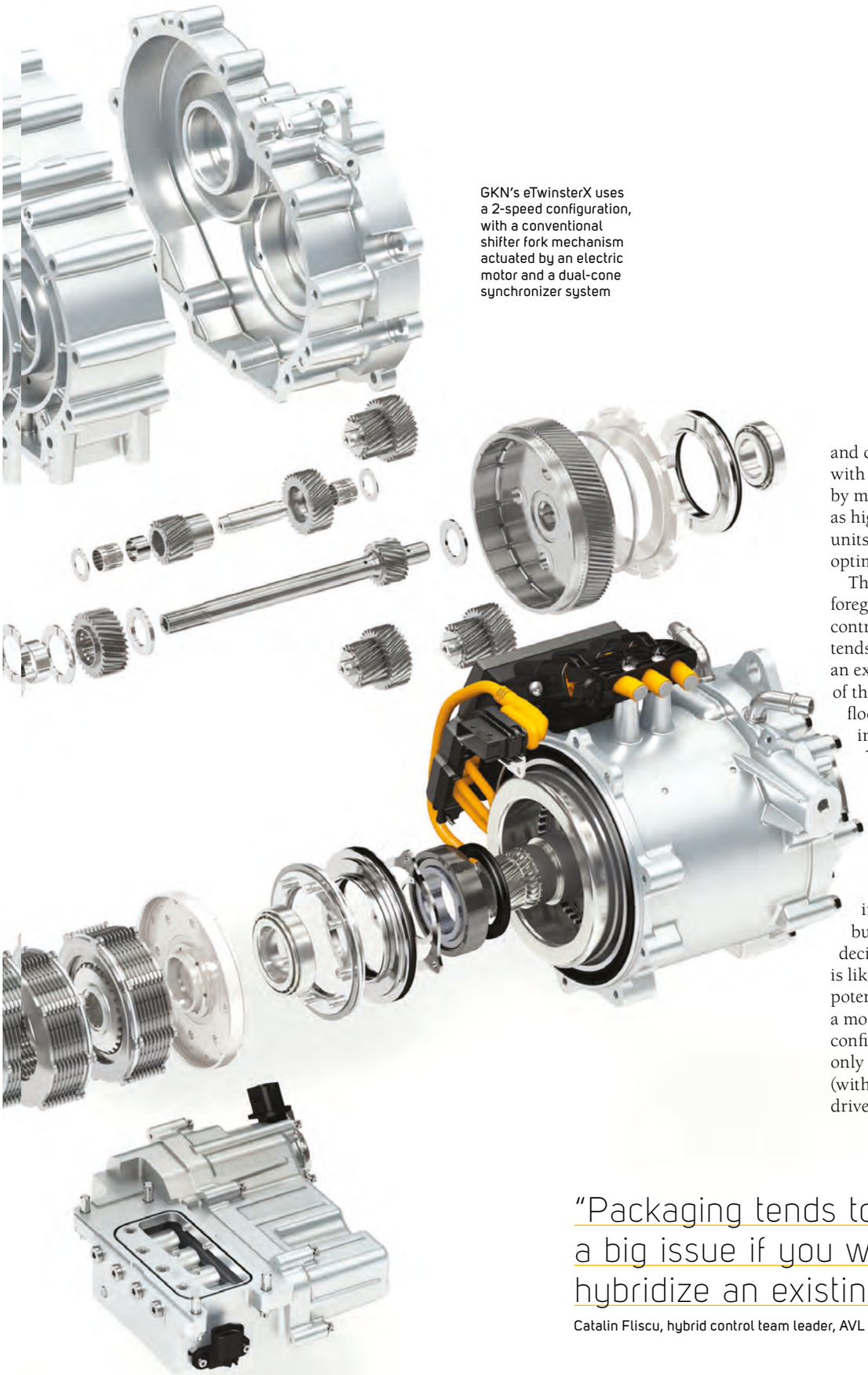
E&H Vehicle takes a look at why e-axles are forecast to be the fastest-growing driveline technology in electric and hybrid vehicles

WORDS: **CHRIS PICKERING**

The automotive industry appears to have struck gold with the e-axle concept. To some, this means in excess of 300kW of permanent assistance on the front of a million-dollar hypercar; to others it may mean a 'hang-off' system providing four-wheel-drive traction for a family crossover; or perhaps an affordable route into electrification for a low-cost city car. There's an e-axle, it would appear, for every occasion.

Research carried out by IHS Markit last year predicted a compound annual growth rate of 46% for rear e-axles and 35% for front e-axles until 2023. That would see the annual production of front e-axles grow from around 750,000 units to more than 4.5 million per year over the same time period.

The arguments for adopting an e-axle architecture are compelling. Integrating as much as possible of the electric drive hardware into one unit – potentially including the power electronics and associated ancillaries – can reduce the total packaging volume of the drivetrain, as well as cutting down on weight



GKN's eTwinsterX uses a 2-speed configuration, with a conventional shifter fork mechanism actuated by an electric motor and a dual-cone synchronizer system

and cost. There are also performance benefits, with the potential to reduce electrical losses by minimizing the use of components such as high-voltage cables, connectors and cooling units. Plus, each individual part can be optimized specifically for use in that package.

That's not to say the use of an e-axle is a foregone conclusion, as Catalin Fliscu, hybrid control team leader at AVL, explains: "Packaging tends to be a big issue if you want to hybridize an existing platform. If you can reduce the size of the fuel tank or perhaps raise the boot [trunk] floor slightly you can maybe drop an e-axle into the back of a front-wheel-drive platform. That also gives the benefit of four-wheel drive or electric-only rear-wheel drive, which is seen as a sporty attribute. You can't always do that, though. Sometimes it's easier to find the packaging space for a P2 installation in the engine bay."

Several OEMs have successfully integrated e-axles into legacy platforms, but for the next generation of vehicles the decision to equip them with this technology is likely to be taken at the start. This will potentially enables manufacturers to pursue a modular architecture, covering a range of configurations that could include combustion-only two-wheel drive, hybrid all-wheel drive (with the addition of an e-axle) and electric-only drive on either axle (or indeed both).

"Packaging tends to be a big issue if you want to hybridize an existing platform"

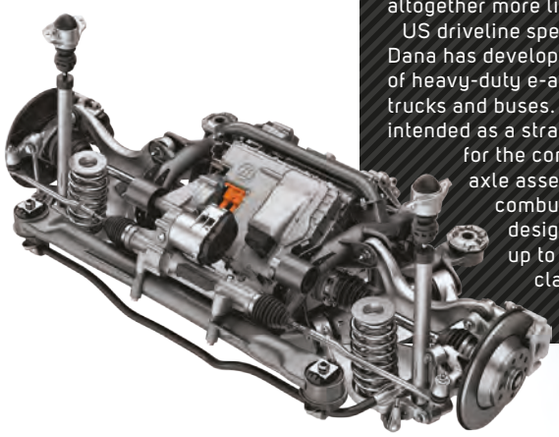
Catalin Fliscu, hybrid control team leader, AVL

JUST ADD WHEELS

The term 'e-axle' is perhaps a little misleading, as it's generally used to describe an integrated drive unit rather than a true axle assembly. In some cases, however, it takes on an altogether more literal meaning.

US driveline specialist Dana has developed a range of heavy-duty e-axles for trucks and buses. These are intended as a straight swap for the complete solid axle assembly on a combustion-engined design, providing up to 237kW and claiming to yield considerable weight savings over a separate electric drive system.

At the opposite end of the spectrum, ZF has arguably gone a step further with its mSTARS system, intended for passenger cars. This is a complete axle carrier assembly for a semi-trailing arm suspension system, right down to an optional rear-wheel steering system, all designed to accommodate the company's fully integrated 150kW electric drive unit. This not only houses the electric motor, but also the two-stage single-speed spur gear drive, differential, power electronics and the control system.



ZF's mSTARS (modular semi-trailing arm rear suspension) is a rear axle system

This multitude of options raises some interesting control challenges, Fliscu points out: "If you have two separate drive systems, you need to look at how you manage the torque split to maximize safety, performance and efficiency. You don't want one end dragging the other. Regenerative braking also becomes quite interesting, because recovering energy on the rear axle sometimes poses stability issues. One approach we adopt at AVL is to develop the supervisory controller to the point where it is largely agnostic to the layout of the hybrid system."

Bolt on

The simplicity that comes from a single, integrated unit is particularly useful when it comes to vehicle assembly, as Alan Cherrington, chief operating officer at Integral Powertrain, explains: "The OEMs' supply chain requirements often dictate that they would like a complete integrated unit that's ready to fit into a vehicle.

> "The OEMs' supply chain requirements often dictate that they would like a complete integrated unit that's ready to fit into a vehicle"
>
> Alan Cherrington, chief operating officer, Integral Powertrain

McLaren Applied Technologies' combined traction unit is an e-axle system that takes energy from a hybrid or electric vehicle battery pack

That makes the build process on the production line a lot neater than trying to bring together disparate elements from different companies."

Integral Powertrain supplies the motors for a joint project with McLaren Applied Technologies and Hewland Engineering. The end result is a single unit ready to lift into the chassis with just four mounting bolts, two wires for the DC supply, and a couple of cooling connections.

There are potential challenges when it comes to servicing a heavily integrated unit, but Dr Stephen Lambert, hybrid and EV product manager at McLaren Applied Technologies, doesn't believe that these will pose an issue for e-axles.

"Historically in the automotive industry, integrated designs have tended to make things more difficult with regard to serviceability," he says. "If you had a failure in one component, it could potentially be harder to rectify, particularly if you had to service the entire integrated system. But with the reliability and comparative simplicity of electric vehicle drivetrains there are no real servicing requirements, apart from basic checks and transmission fluid changes. This opens the door to higher levels of integration and innovative new products."

The eTwinsterX is currently installed in a Mercedes AMG GLA 45 working demonstrator vehicle

THE 48V OPTION

When 48V electrification is mentioned, it's generally in the context of a mild hybrid setup, aimed principally at coping with the demands of power-hungry auxiliaries. However, some see a great deal more potential for these low-voltage concepts.

At last year's North American International Auto Show, Schaeffler presented its High Performance 48V concept vehicle, which combined a belt-driven starter generator with a rear-mounted e-axle. This was capable of delivering 20kW and as much as 2,000Nm at the wheels, providing electric-only running at speeds of up to 35km/h (21mph) and a 'sailing' function at speeds of up to 70km/h (43mph) via a 2-speed transmission. The company notes that the majority of braking energy released on the WLTC cycle could be captured and stored in the battery using this system.

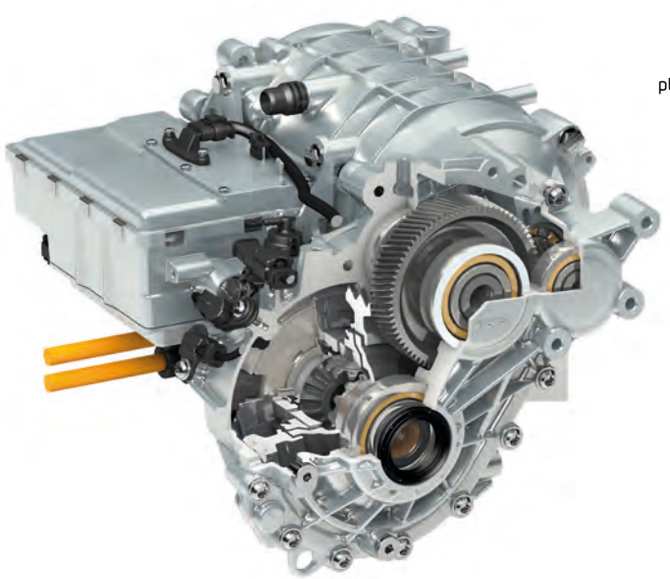
Elsewhere, Magna's eRAD Traction Assist is a 48V e-axle designed to provide a limited amount of pure electric driving functionality, as well as all-wheel-drive support in low-friction conditions.

In particular, he explains, the biggest advance seen in recent years has been the addition of power electronics.

"Taking a motor and putting a transmission on it isn't too difficult. But one of the biggest challenges and innovations was in tightly integrating the power electronics into the same package. That's where we see the industry going."

There are still some question marks beyond integration, however. With a finite speed range covered by the electric motor, e-axle developers essentially have three options: disengage the motor at high speeds; find a fixed-ratio transmission and a motor capable of covering the entire speed range; or use a multispeed transmission.

> "Taking a motor and putting a transmission on it isn't too difficult. But one of the biggest challenges and innovations was in tightly integrating the power electronics in the same package"
>
> Stephen Lambert, hybrid and EV product manager, McLaren Applied Technologies



GKN Driveline's eDrive system for plug-in hybrids features an integrated inverter

GKN's eTwinsterX concept – currently a working demonstrator in the advanced prototype stage – uses a 2-speed configuration, with a conventional shifter fork mechanism actuated by an electric motor and a dual-cone synchronizer system. However, the eTwinsterX's twin clutch packs still have the ability to disengage the driveshafts when required. Elsewhere, Japanese motor specialist Nidec has showcased an integrated e-axle design with an optional clutch mechanism.

These innovations continue to push the functionality of e-axle units, making them an increasingly attractive solution, both for hybrids and full EVs. There will always be some applications where factors such as the packaging constraints or the hybridization strategy require the use of alternative layouts. But for everything else, the e-axle appears to be here to stay.

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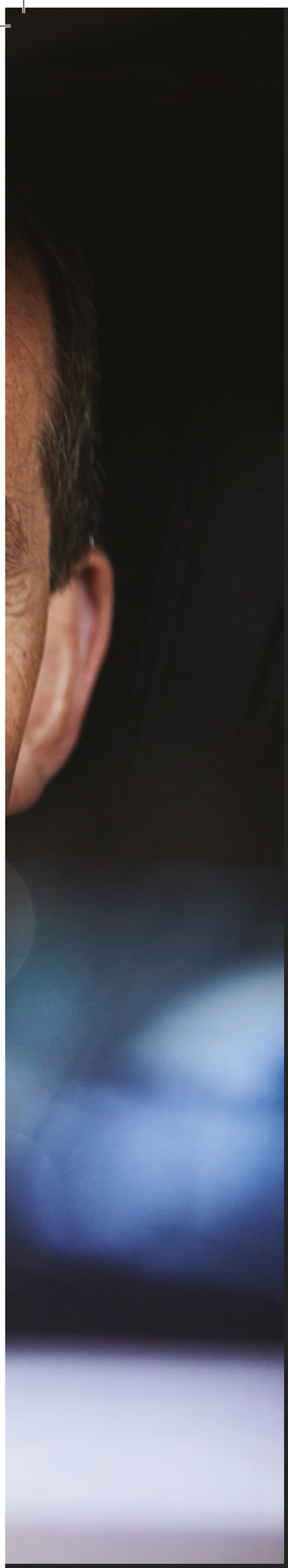


Back and forward

Robert Irlinger, head of BMWi, looks back on 10 years of the OEM's groundbreaking electromobility program, and talks about what lies ahead

WORDS: **MATT ROSS**

THE BMWi PROGRAM IS NOW 10 YEARS OLD. LOOKING BACK ON IT NOW, HOW DO YOU FEEL THE PROGRAM HAS CHANGED AND EVOLVED DURING ITS LIFETIME?

When we set up at the beginning, we wanted to be ahead of new trends in mobility – not only in e-mobility, but mobility in general – and we wanted to be something like a think-tank for new technologies coming into the automotive industry. Maybe at the beginning it was a little hard, and it seems sometimes that we were too early. But if you look back now over the 10-year history, or if you look at the cars coming onto the market, so maybe five years, we did everything right at the right time. Now we have already had five years of real experience in bringing these cars to the market. Most of the things we tried out have found their way into the BMW group – e-mobility is now everywhere; carbon fiber is in other cars as well; the whole [focus on] sustainability is now in all our normal processes.

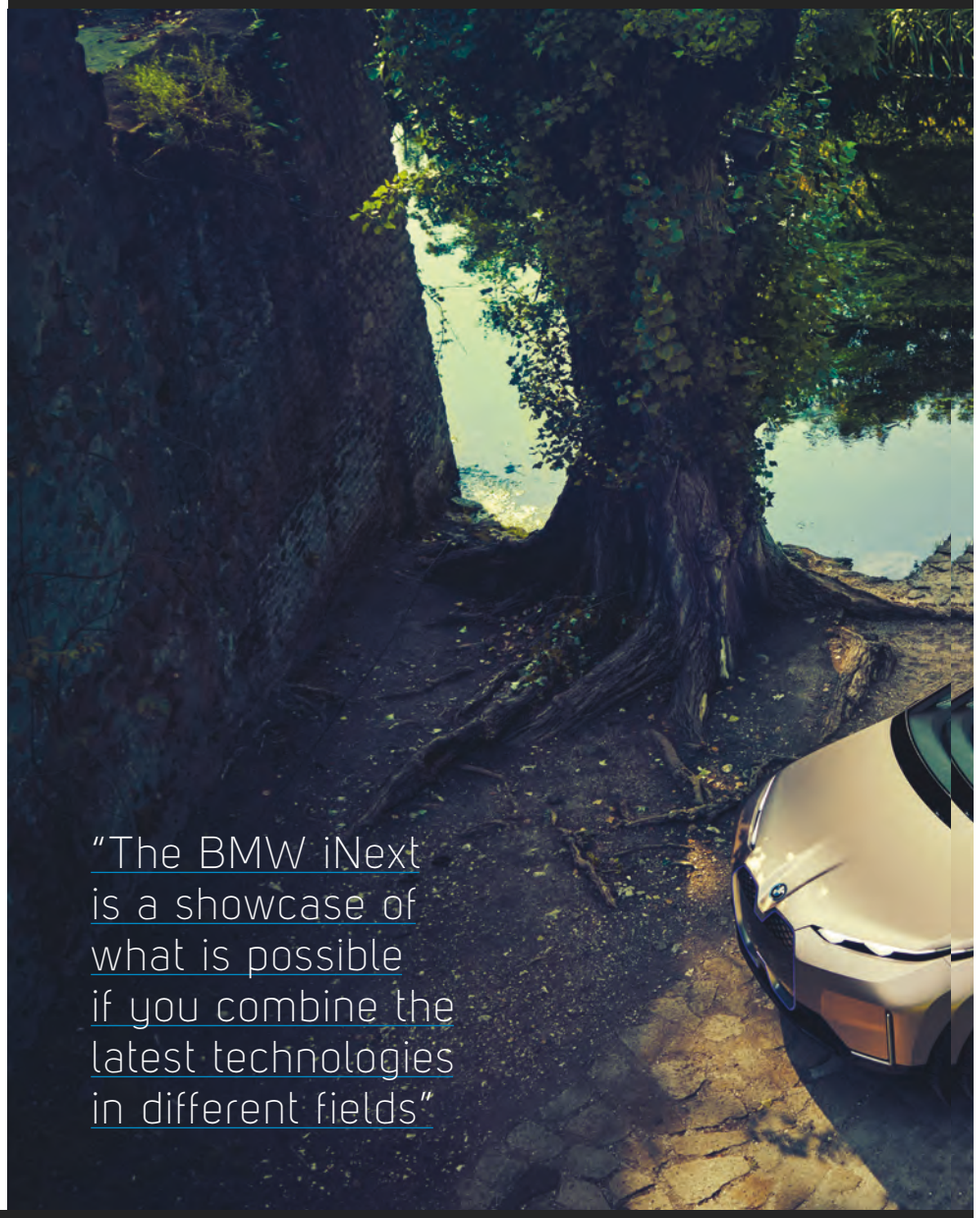
We said at the beginning that we would use BMWi to foresee trends, to bring things to the customer first, but then spread them out to the group. We have really done a good job in that respect.

For example, if you look at the i8, it demonstrated how sporty and emotional a PHEV could be – because at the beginning all these plug-in hybrids could only achieve low mileages. This car showed five years ago what is possible with plug-in hybrid vehicles.

So overall, it's a very positive evaluation. What is good now is that we can set up on a very broad fundament to go to the next step – something that has been prepared for some years already. We sell a lot of BMWi cars, so dealers are ready and they know how to handle the customers. We have very good relationships with our suppliers when it comes to batteries and engines and things like that. In the end, the program has prepared the company for the next big step. To be honest, I feel very proud to be the head of BMWi.

DOES THE iNEXT REPRESENT EVERYTHING YOU'RE TALKING ABOUT IN TERMS OF WHAT THE PROGRAM WAS SET UP TO ACHIEVE?

When we talk about iNext, we are obviously talking about two things. When we talk about iNext in terms of the program, it is a way to prepare the whole company for the next level of technology. When we talk about cars, we are talking about the BMW iNext, which is a showcase of what is possible if you combine the latest technologies in different fields, but not just 'add them up'. It's about how you combine and integrate these things in the right way. This is about showing what you can do when you combine electromobility, autonomous driving and the highest levels of connectivity of services. There's a lot of technology in there. From an internal point of view, it's our think-tank for new technology. But from the customers' point of view, they won't see that much technology. We try to support our customers and put them at the center of our thinking, but we try to hide this technology – to make them feel cozy and comfortable.



"The BMW iNext is a showcase of what is possible if you combine the latest technologies in different fields"

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We have seen already that customers can sometimes be afraid of too much technology. That's the next step for us. For BMW, however, it's the same role again that the first generation of BMWi [technologies] played – pioneering new technologies, bringing them to the customer. It's not just about building show cars; it's about bringing these technologies to customers in big numbers, and then spreading that technology out to the rest of the brand.

IS THE POWERTRAIN FOR THE iNEXT PRODUCTION VEHICLE STILL EVOLVING, OR ARE YOU FAIRLY CLOSE TO KNOWING WHAT WILL BE POWERING THE CAR?

It's a little of both. Obviously we know what we're doing, but e-mobility is in a very

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1. BMW has upgraded the battery performance of the i3 at regular intervals, and expects to achieve similar improvements with upcoming i vehicles

2. The iNext represents a culmination of many of the disciplines that have developed during the BMWi program

3. The battery capacity of the i3 has doubled within five years of development

dynamic situation. When it comes to [the development of the powertrain], it's still a very steep improvement in battery technology. Just look at the progression of the i3 – it was 21.6kWh in 2013, then we had 33.2kWh in 2015/2016, and now its 43.2kWh.

So we have doubled the energy within five years. And it's the same thing with the increases in ranges. If you look at the iX3, you will already see 400km [248 miles] on WLTP. For the i4, we're talking 600km [373 miles] or even up to 700km [435 miles].

It's still a very fast-developing field of technology, but we know what to do. We decided to keep most of it in-house, even when it comes to engineering and big parts of production, because it's still a key component and defines the car [to a large extent].

IF THE i PROGRAM WAS SET UP TO SPREAD THE TECHNOLOGY THROUGHOUT THE BRAND, WILL WE EVER COME TO A POINT WHERE ALL OF BMW IS ESSENTIALLY BMWi?

Theoretically, if you say that everything electrified will be called BMWi, then this could be the case, because we see a very strong increase in the number of electrified vehicles in some markets. But BMWi is not only about e-mobility – we always combine it with different technologies. So there might be a time when we say that, perhaps, electromobility is no longer called i.

Therefore I don't think that the time will come when all BMWs are BMWi, because i is just part of the brand. The brand is BMW, and there are two additional brands that support it – BMWi, which is about pioneering new technologies and visionary mobility approaches; and BMW M for dynamics, racing, power and so on. They support BMW in moving forward. So no, there won't be a time when all BMW is BMWi. There will be a different BMWi.

GIVEN THE POTENTIAL PERFORMANCE GAINS THAT ELECTRIFICATION OFFERS, COULD WE EVER SEE BMWi AND BMW M CROSS OVER?

Not on a brand level, but on a technology level. So, for example, there will be electrification in M cars in the future. It's true for both of them – you will see parts of M developments in i cars. Just look at the i8, the precise steering, and so on, was something we learned from M cars. And elements of e-mobility will make their way into the M brand. But the two brands will be clearly distinguished by their roles.

"Elements of e-mobility will [make their way] into the M brand. But the two brands will be clearly distinguished"

1. The iX3 is the first all-electric X model that BMW has developed

2. The iX3 will feature the fifth generation of BMW's eDrive technology, which features a new modular packaging design

3. The iX3 was initially announced for Chinese customers, but will now also be exported to international markets

THE NEW iX3 WILL SHOWCASE THE FIFTH GENERATION OF BMW'S eDRIVE TECHNOLOGY, WHICH WILL SEE THE MOTOR, TRANSMISSION AND POWER ELECTRONICS PACKAGED TOGETHER IN A SEPARATE COMPONENT. HOW BIG A STEP IS THE DEVELOPMENT OF THIS TECHNOLOGY?

What we see is that e-mobility will increase, and people will not only demand bookmark cars such as the i3 and the i8, but will also want electrification in cars they normally drive, and in cars they are used to driving. That's why we decided we need to bring e-mobility into all our cars. It was challenging to define a modular system that fits into all our architectures and all our production sites, and which can fit into different kinds of cars – in 'flatter' cars like the i4 and bigger vehicles such as the iX3.

The combination of new cars and the modular system means that complexity rises and you have to integrate it into existing production lines. This made the task complex, but we were able to fulfill it in the last two-and-a-half or three years – to improve our architectures and our modular systems, to combine our existing architectures and production sites – to combine [all these capabilities] with modular systems and bring total flexibility.

Now we have engines and power electronics that fit into all our cars, and which we can scale. And now all our production sites can build electrified cars – from plug-in hybrids to fully electric cars, all on the same line. We are extremely robust when market developments may be different from what we expect today. Even if [the uptake of electrification] goes faster, we can just switch the ratio between electrified vehicles and normal combustion engines.

Or, if it goes the other way – and you never know – we could just switch back. We think there will be something between 15% and 25% electrified vehicles in 2025, but maybe the take-up will be a little faster or a little slower, and we will be able to produce them worldwide. We are ready, we are in the middle of development, and the iX3 will be on the road in 2020. Concepts are set, development has started – cars will be on the road in the not-too-distant future.

THAT FLEXIBILITY IS SOMETHING THAT BMW HAS, BUT PERHAPS SOME MORE RECENTLY EMERGING CAR MAKERS DO NOT. ARE WE SEEING THE ESTABLISHED AUTO MANUFACTURERS DOING THINGS THE 'RIGHT' WAY, RATHER THAN DAZZLING CUSTOMERS WITH PRESS CONFERENCES AND SHOW CARS, BUT LITTLE END PRODUCT?

[Doing things the right way is] something we have always done, throughout our history. When we show a concept car, it's on the road. Look at the i3, look at the i8, look at the i Vision Dynamics concept. They are

"There might be markets, or regions of the world, where hydrogen will be a good solution. In our opinion, it's still not ready for series production"

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things that we will definitely bring to the road. Yes, there are a lot of new competitors that tried to get into the field of e-mobility, but I think [they have discovered that] it is quite difficult. There are a lot of brands, and there are some [like Tesla] that are strong in terms of brand and volumes but are struggling with production and finance. Maybe there's a time when it will get better, you never know.

There are others – Faraday Future, Byton, Nio and so on – so it is a very interesting game. There will be competition. Maybe these new companies have the advantage of not having old technology in their company, but the good thing for us is that with this 'old technology' we earn the money to invest in our own businesses in these new fields. That's something we wanted to do, to stay profitable, even with going into e-mobility quite fast. It's not only about bringing cars to the road; it's about earning money with them.

Putting a car on the road is easy if you have someone to finance you. But you have to know if there will be customers, and if they will buy your cars. Are they going to pay a premium price? How do you service them? Is the production okay? Is the quality okay? What happens if there is a problem?

It is a huge challenge to set up a new car company. We think, with our history, and especially with the BMWi brand, that we are in a very good position – it's more than just a starting position, because we started 10 years ago. Last year we sold 100,000 electrified vehicles and this year it will be 140,000. If you look at our conventional competitors, we are far ahead.

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IS BMW STILL INTERESTED IN CONTINUING TO DEVELOP HYDROGEN FUEL CELLS AS A PROPULSION SOURCE?

We are still in cooperation with Toyota because we still think there might be a market for fuel cell, especially when it comes to bigger cars. But there is competition between fuel cells and batteries. As batteries get better and better, maybe there will be a point in time where it's not really wise to set up a third infrastructure [after ICE and electric], because you *will* need a third one. But there might be markets, or regions of the world, where hydrogen will be a good solution.

In our opinion, it's still not ready for series production. We could showcase some cars, but is it really customer-ready for series production? We don't think so. But we are still working on it because that's the thing we discovered with BMWi – you have to always be prepared for new technologies. And if we decided to move ahead with it, we could do that.

1. BMW has continued to develop hydrogen-powered technologies

2. R&D is ongoing, but the OEM does not currently see hydrogen technology as suitable for series production

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STREET fighter

Paul Fickers, performance program engineering director at Nio, reveals what the company has learned from joining Formula E, and the crossover with its road car development program

WORDS: **DEAN SLAVNICH**


NIO
NIO
ABB
MICHELIN

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1. Formula E has provided a platform for Nio to showcase its engineering capabilities as an electric car maker

2. Paul Fickers, Nio's performance program engineering director

How's is Nio's Formula E experience panning out so far?
We started from scratch, which was a real challenge. We had a conference call on January 12, 2016 with Martin Leach [who, sadly, passed away that year], and basically we were tasked to build a team from scratch with the aim of going racing on October 8 in Hong Kong. It's been quite an experience. The effort we put into the team – and its growth – has been spectacular.

Are you now on a par with the more experienced Formula E teams?
We're still playing catch-up with them – it's hard work, but that's competition. And we're making huge progress.

Was that short development time – January 2016 to August 2016 – the most stressful period?
It was one of the biggest efforts, for sure. To get the whole structure in place – suppliers finalized, people onboard (including engineers and mechanics), establish the supply chain, understand Formula E and understand the competition, too – was the biggest challenge of all.

How easy is to recruit engineers?
In general, when you're a new team it's even more difficult. Being a new team, I feel people are initially a little skeptical, but as we have proved to be a reliable team and a growing company, it's becoming easier for us. In fact we've now had cases where people approach us! Another factor to this is that, not only were we new as a team, but the Formula E series was new as well. Formula E has stepped up massively with the announcement of the new-gen car and more OEMs entering the series, so it has become a far more attractive series for engineers.

How many people work on the Formula E side of things at Nio?
We have 20 operational people at the track and 20 more back at our base, so it's a compact organization.

Will that number grow?
It grows by definition, because we not only have Formula E activities but also performance automotive work – future supercars and a follow-up for the EP9. So we're more than just a Formula E team in that regard. It's a fluid setup with an interesting mix of people, and this covers future concepts too.

What have you learned from competing in Formula E so far?
From a mechanical engineering point of view, it's been quite interesting for me, because I've had to learn everything over again, to cover electrical engineering. I think that was the most interesting engineering area. You don't find many mechanical engineers who have a profound understanding of electrical engineering and *vice versa*. So we need to bring those qualities together and optimize them. Personally, I found that an amazing process.

Is there engineering crossover in Nio between the Formula E work and performance automotive development?
There is, yes. Compared with the old-fashioned Formula 1 to road cars crossover, I'd say on the electrical side there's even more potential. Electrical machines, up to now, have been used statically or quasi-statically. A Formula E car is very dynamic and there's quite a lot of vibration, so making those components reliable in such a hostile environment is challenging and very interesting. That [expertise] will go into any future performance road car. The same is true for thermal management, efficiently using and regenerating energy, and controlling the temperature of the batteries. That know-how is fundamental for any performance car, be it a motorsport or automotive application. Here the crossover is much closer to the real-world, as these practices apply to road cars, too.

With the shift toward e-powertrain product development, should you worry if you're just a pure IC engineer?
Not really. I do think there will be a phase-out of the IC engine, but I always compare it with the horse. When automotive came along,

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the horse, in that sense, became obsolete – but we still have racehorses. I can imagine that the IC engine, at the end of the day, will become a toy for the very rich. Like any technology, I wouldn't write off IC because they keep working on it and improving it, and there are still options for it moving forward.

What's next for Formula E?

First, I would like to see what Season 5 is all about – it's a game-changer in terms of the car. Basically, we have double the amount of energy, so we can run the entire race with one car, and that by itself will be interesting in terms of what that will do. So [at the time of writing] we're learning all about that factor. Running a car for 20 or 22 minutes is quite different from running it for 45 minutes! Season 6, I feel, will be mostly a growing together again of the field, and then Season 7 will, like Season 4, hopefully be extremely competitive.

From an automotive perspective, both in terms of engineering and brand, how important is the EP9?

The EP9 was basically a project to show the automotive world what we can do. And I feel it's really paid off. We wanted to show that Nio is a very serious company and we're not like some other startups from China that are not so serious. We showed that we are a dedicated company, we're growing and we're pushing on all fronts. It's important to put things into context here. The company started with four people in November 2014, I joined in February 2016 on the OEM side, and if you consider that we finished the car and started production in under three years, that represents some serious effort.

How important are accolades like 'fastest EV yet' and 'record-breaking Nürburgring lap time'?

When you dive into the technical capability of the car you always find potential to be even faster! Actually, at the Nürburgring we broke the record in only three laps. If we could have stayed longer – perhaps several days – to optimize the car further, we would have found something more. But the objective wasn't to have the EV record [fastest EV around the Nürburgring] but rather to be the first electric car to take the overall record. That's something we'll always be remembered for. Our record has already been broken [Porsche's lap time with the 919 Hybrid Evo in June 2018] but we'll always be the first EV that did it.

So that blistering 6:45.900 EP9 lap time didn't surprise you?

It didn't surprise me that the EP9 was capable of doing that. We were pretty convinced we could do that time and pace.

What are your future plans for EP9 – will there be further derivatives and iterations of the car?

We would like to do some further development on it but that depends on resources. I'd love to do a road car version of the EP9 – that would be so interesting. But that's a question of resources. It's something I can't say we'll do, but you never know.

How has the feedback on the ES8 been?

From what I've seen and heard, things have gone well for us.

Any teething problems?

You always have teething problems [with a new car] at the factory. You have to get the supply chain to work, and production lines

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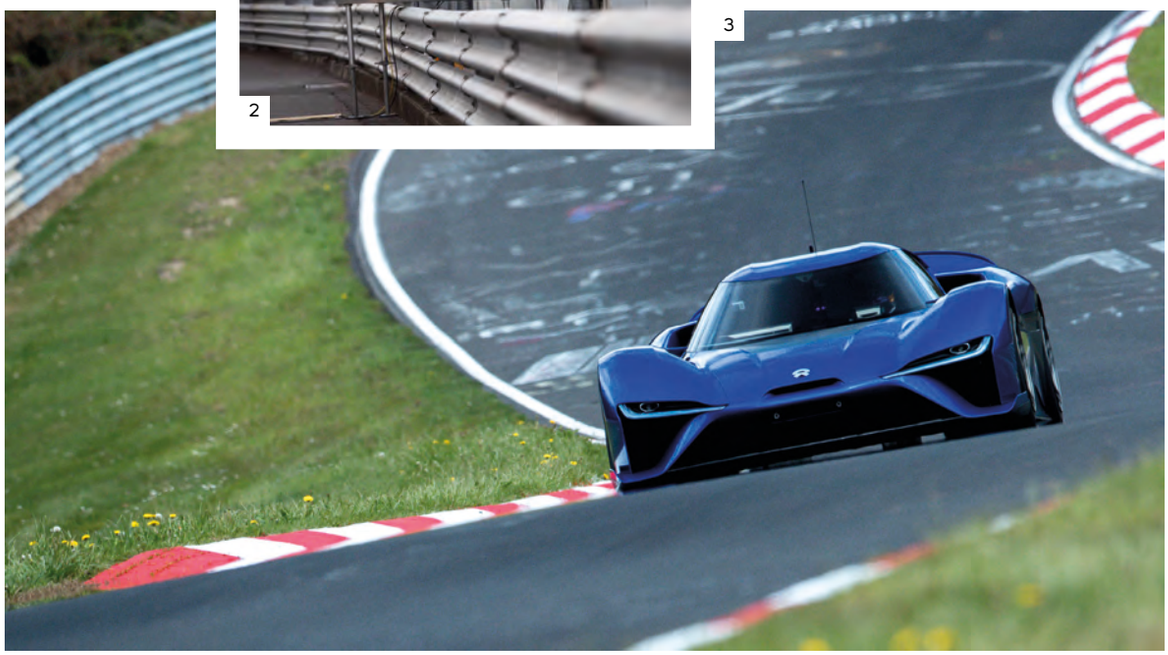

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1. EP9 was developed by Nio's UK arm, which is also responsible for the NextEV Nio Formula E team. The Chinese-backed company has four global bases in China, Germany, the USA and the UK

2&3. In 2017 Nio rewrote the Nürburgring record books for electric cars with its EP9 hypercar

Fickers notes that the learnings from Formula E are applied to the firm's road car development

need to run smoothly, but overall – and going from a white sheet of paper three years ago to launching a new car – it's gone well. We've gone far in a very short time.

To launch an all-new car in just three years, did you end up buying in a vehicle architecture?

No, it was all developed in-house. If you put good people together – people who have been in the industry for many years and understand what they want and what needs to be done – things like this can happen. We presented the concept in Shanghai and we had many CEOs of various German companies come and check out the platform. They were impressed – it is a properly engineered platform. It's fully developed by us – we have our suppliers that we work with, but it's totally under our guidance.

Is your vehicle architecture like a Tesla setup insomuch that a 'skateboard' structure underpins many future models?

It's common practice when you do a new architecture that you allow one or two variants to be built upon. You're not going to do a new architecture now and then do another for the next car. So for Tesla you have the Model S, scale that down to a Model 3, and scale up to a Model X.

Is your architecture just as flexible?

It depends on what direction we go in, but there is, of course, variability in it.

In terms of actual battery and e-motor development, is that bought in from suppliers or also developed in-house at Nio?

That too is in-house. We developed both [technologies] from prototype in-house.

To have that battery expertise in-house must be a huge advantage?

Well, we have some 4,000 people [working on automotive engineering development as part of the wider group] so we have a lot of access in that respect.

What do you make of the argument that EV startups, such as Nio, should focus more on real-world range over huge power outputs?

At the end of the day, the customer will need to make up his/her mind on what they want. I think starting up in the automotive world is very difficult – you need to have quite a bit of cash to do so – and obviously once you start developing and producing, your cash flow will decide what you're going to do for the future. It is very harsh once you're in the production stages, and customers decide what they want.

Does Tesla help or hinder the electric vehicle movement?

It's difficult to say. New technologies will always have issues and it also falls to the media as to how that is presented. It could be a headline that one car is burning with an electric battery, but there are many other cars that catch fire that don't have these batteries.

Is Tesla your biggest rival?

No, not really. First of all, as a company we focus on Nio in China – that's our main market and it's a place where we produce cars, so we have a certain advantage over Tesla there. So [China] is our first aim. Secondly, I feel we have a different mindset to other companies. We're engineering and car driven, and it's about realizing the vision of the founder.

You've been with McLaren, FCA, Ferrari, Maserati and Ford, but what's it like working for a new car maker?

It's completely different. You really have to focus on certain issues, engineering for example, because you're starting from scratch. But also with a startup you don't have the good or bad heritage from an existing company. If you're starting from scratch, you create your own architecture, your own production lines, and you don't have an old factory or old lines that give you boundaries. So in that respect, you're far freer, but you have to do everything – *everything* – from scratch. It's completely different. It's really interesting but it's a lot of hard, hard work.

Flexibility must be another key advantage when working for a startup?

That's right, we can be very flexible. We can decide very quickly if we want to go in a new product line direction or create a new car because we have extremely short and efficient chains, which is something that's good about a small company and a startup. But like every other large company, as it grows, you'll see inertia coming in.

As part of future product plans, Nio will launch an autonomous car in the USA in 2020. Is this an overly ambitious plan?

It is ambitious – but if you're not pushing for the technology then you might fall behind.

Will the production car be based and look like the EVE Concept?

Well, we always create a concept to bring some aspects of that out in the future. But that's all I can say on this subject.

What level of autonomy will the car have?

That's still an unknown. When it comes to autonomy, I'm not looking at things from the technical side but rather the legal side – that's where I see challenges. So, for example, what happens if there are accidents? I think that's still a very open point. The technical issues will be resolved sooner or later, but I really can't see the legal side, including insurance, being pushed hard and completed soon.

What are Nio's product plans following on from ES8?

We have plans but I can't give you details. What I can say is that there will be more cars, for sure.

SHIFTING PERCEPTIONS

According to experts at ZF, changes brought about by electrified and autonomous vehicles look set to place a development emphasis on transmission NVH

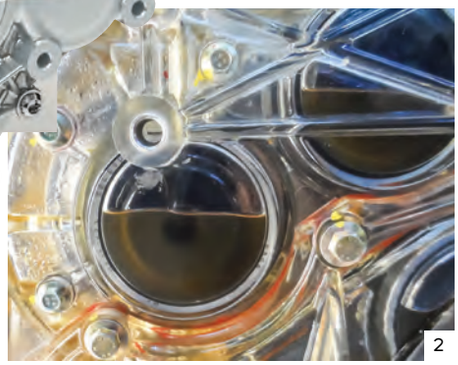
The wave of electrification in new vehicle designs means transmissions systems developers face a host of new challenges – and are developing an array of tests and simulations to aid them in their work

WORDS: **CHRIS PICKERING**

To paraphrase General Motors CEO Mary Barra, the auto industry is poised for more change in the next 5 to 10 years than it has seen in the last half a century. Indeed, autonomous driving, connectivity and electromobility look set to irrevocably disrupt the status quo. And while transmission systems might not make it onto this increasingly familiar list of buzzwords, they actually have a major role to play in each and every one of those areas.

Electrification is perhaps the most obvious influence on transmission design. While opinions are somewhat divided on the exact solutions, everyone seems to agree that a widespread switch toward hybrid and electric propulsion is on the cards.

"It's likely that hybrid electric vehicles will be an intermediate solution on the way to full electric vehicles taking over, but it's hard to say when we will reach peak hybridization. I expect both forms of propulsion to be significant in the coming years," says Barry James, chief technology officer and head of R&D at Romax Technology. "And I suspect OEMs will offer multiple options and then see how the market reacts. For example, the range might consist of a DCT [dual clutch transmission] for conventionally IC-engined



1. GKN Driveline's eDrive system for PHEVs will start production in 2019

2. A clear casing for lubrication analysis offers limited insight

3. DSD's smoothed particle hydrodynamics (SPH) simulation

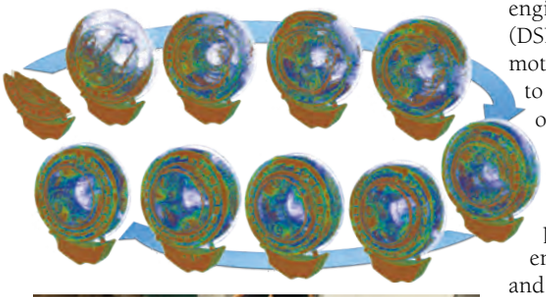
vehicles, a DHT [dedicated hybrid transmission] and a much simpler EV gearbox with perhaps only one ratio."

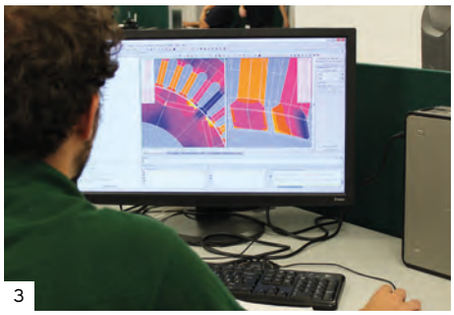
Most seem to agree that the pace of transmission development for pure IC-engined vehicles and mild hybrids will plateau somewhat as OEMs look to concentrate their R&D efforts elsewhere. That's not to say that overall production volumes will decrease for conventional transmissions – in fact, the opposite is predicted – but rather that the bulk of development challenges will come from new technologies. Chief among these is the rise of the DHT.

"DHTs simply don't work without electric machines, so in many cases you have no option but to carry out a full system test," explains Theo Gassman, vice president of advanced engineering at GKN Driveline. "That requires a more complex rig setup than a conventional gearbox test. You're not going to develop specific software just for bench testing, so the transmission system on the rig requires all the inputs and communications channels that it would find in a real car."

"Simulation is key to managing risks in this highly dynamic sector"

Theo Gassman, vice president advanced engineering, GKN Driveline





Ahead of the curves

Aside from the added complexity of the transmission systems themselves, the radically different power and torque curves of an electric motor also pose challenges. With input speeds potentially exceeding 20,000rpm, it can be hard to find suitable motors to test the drivetrain in isolation.

"We're currently looking into some alternative solutions," says John Morton, engineering director at Drive System Design (DSD). "At the moment, if we have a prototype motor and a prototype transmission we have to test both at the same time. There are no off-the-shelf motors that we can use to drive the rig across the full range of speed and torque conditions."

The prospect of near-silent electric propulsion is also placing increased emphasis on transmission refinement and some have suggested that autonomous driving could make vehicle occupants even more sensitive to noise and vibration. In addition, autonomy could bring new control requirements, as Gunther Wehr, manager for validation strategy at ZF, explains.

"Autonomous driving will create a lot of new functions. I can imagine there might be a requirement for more interaction and communication between subsystems, such as the transmission and the autonomous driving control unit. It's also likely that an autonomous driving functionality will result in different load profiles from a human driver."

He also notes that connectivity is enabling the use of condition monitoring. At present this is primarily seen as a means of implemented predictive maintenance in long-distance commercial vehicles, but there may also be opportunities elsewhere.

"You could argue that most drivetrains are actually over-engineered at present," says DSD's Morton. "If we could use connected vehicles to record usage data from real customers then we could be much more confident in the input data for the test cycles. We think we could push for transmissions that are maybe 20% lighter, which would put them somewhere around 20% cheaper. For most applications that would balance pretty well any increase in warranty costs."

Weight reduction and mechanical efficiency are particularly critical in EVs, where DSD predicts that careful optimization of a fully integrated electric drive unit could reduce battery demand by as much as 5kW – enough to have a meaningful impact on EV range.

Integrated approach

There is also a growing trend toward heavily integrated designs in the DHT market, packaging not only electric machines, but potentially power electronics, control systems and cooling hardware within the

1. DSD updated its UK facility in 2015, adding new testing equipment to meet future demand

transmission. All this now has to be evaluated, introducing test requirements for things such as electrical interference that previously simply didn't figure on a transmission company's radar. Meanwhile some existing aspects have suddenly become far more critical, such as monitoring the temperature of transmission oil, which may now double as the motor coolant in some cases.

This degree of integration will mean that the conventional approach of designing and testing the separate subassemblies before they are tested as a complete powertrain may no longer be sustainable.

"Testing will need to be carried out on the system as an integrated powertrain much earlier on in the process," says Romax's James. "In some areas, we see a convergence of real and virtual testing in the form of a digital twin. In this case it is possible for the simulation model to remain associated with a physical asset throughout its operational life, providing valuable information on its performance and remaining value."

Additional time pressure also plays a part here. In the past it could take five to seven years to develop a transmission system, but that sort of approach is no longer compatible with the pace of e-drive development. What's more, the same product line can now contain a greater range of variants.

"Simulation is key to managing risks in this highly dynamic sector," says GKN's Gassman. "You need a sufficiently advanced model to minimize the chance of errors once you go into the next design phase. Everyone has had to invest a lot in virtual testing capabilities. It's no longer just about finite element analysis and gear calculations, but thermal management, fluid simulation and electromagnetic effects. There are a lot of additional tools involved."

Detailed work

The auto industry is therefore turning to a concurrent approach as it enables engineering teams to extend the use of simulation much further along the development cycle to minimize physical prototyping requirements. However, this approach is not without its challenges.

"Physical testing is particularly useful when you need to understand what's happening in a complete system," explains ZF's Wehr. "If you have an automatic transmission, with mechanical components, hydraulics, control electronics and software – all becoming increasingly complex – then it's difficult to simulate all those domains at a systems level."

The rapidly evolving landscape of electric and hybrid drive systems is also changing the dynamic that exists between OEMs and suppliers. These days it's not uncommon for two or more suppliers to remain in contention for a contract beyond the concept phase and right up to physical prototyping.

Similarly, OEMs now want far more detailed predictions for a product's performance – providing not just increased accuracy on conventional metrics, but also additional data that once wasn't required at the concept phase. This becomes particularly important when, for example, a 0.5% difference in mechanical efficiency could potentially save an OEM from incurring a financial penalty for its fleet average CO_2 emissions.

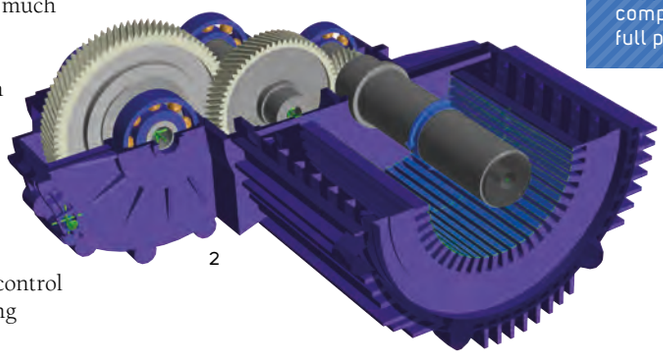
In many respects, the stakes have risen, imposing time pressures and development targets that would have been thought impossible with conventional test processes. But at the same time there are new opportunities, with a rare chance to put forward some genuinely innovative clean sheet designs.

WET WORK

With an increased emphasis on reducing parasitic losses and the advent of so-called wet-running e-machines – those that share their coolant with the transmission – there is now a growing requirement to simulate fluid flow in transmission systems. Historically this has been a lengthy process, with CFD simulations potentially taking weeks of runtime to generate a few seconds of data. However, there may be an alternative in the form of smoothed-particle hydrodynamics (SPH).

The technique approximates fluids (or indeed solids) to a collection of particles. These can be scaled down to the point where they provide an accurate representation of fluid flow without the computational demands of meshing and solving a CFD model. "With SPH we can get much more simulated time into much less real time than we can with CFD – it's probably 10 times quicker," says DSD's John Morton. "Conventional methods take even longer to stabilize when you add thermal analysis into the equation, so we're looking at combining that with SPH."

In one example, he explains, the company modeled the heat transfer in a wet-running motor. Here the fluid sprayed out of the rotor and stuck momentarily to the windings before dripping off. "You can imagine how complex [it] would be to model that full process in CFD," says Morton.



2. Virtual development of transmission systems requires a suite of tools

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From its beginnings as a niche vehicle developer, to becoming part of Daimler, Smart is now leading the EQ brand. But where does it go from here?

WORDS: **SAM PETTERS**

Smart has a habit of flying under the radar. Though Tesla gets a lot of the credit for its role in starting the electrification movement with the first-generation Roadster in 2008, the Daimler-owned brand was pushing electric drive technology a year earlier.

Initially released in a batch of 100 as part of a trial, the 2007 Smart Fortwo Electric Drive was equipped with Zytek-designed and manufactured powertrain technologies. A then-state-of-the-art 55kW brushless DC motor and a sodium nickel chloride battery gave the city car a top speed of 120km/h and 110km of range.

And while those numbers aren't particularly impressive, 10 years makes a big difference. In 2018 Smart unveiled the first cars to sit under the Mercedes EQ electric car brand – the EQ ForTwo, the EQ ForFour and the EQ ForTwo Cabrio.

The Smart EQ range didn't arrive with quite the same fanfare as the first Mercedes-Benz BEV, the EQC, but it brought the EQ brand to the fore. The move also ensured that Smart was the first company to have its entire vehicle portfolio in both ICE and BEV variants.

1

But that is just phase one of the plan. Under the stewardship of recently appointed head of Smart, Katrin Adt, the company hopes to be all-electric in Europe by 2020. However, this follows a troubled transition to become an all-electric brand in North America earlier in 2018.

Power struggle

As a result of the decision, it is estimated that 58 of Smart's 85 North American dealers have decided to move to being service-only operations. The remaining dealers are mainly located in California and New York, where there are zero-emission vehicle mandates.

Smart's head of brand and product management, Daniel Lescow, is unfazed by the scale of the challenge ahead. "Certain markets are far more developed than others in terms of electric mobility. Norway, for example, is the front runner in electrification," he explains. "And in North America, we have always had a certain focused interest in electric mobility, mainly in California, where people specifically opt for EVs. So it's about following customer demand. We will be all-electric in Europe by 2020, and then other markets will follow soon after."

But perhaps the bigger threat to Smart lies a little closer to home. It has been suggested that, if Renault decides to call time on its role as a development partner, the Smart brand could be swallowed up by EQ as soon as 2026.

However, Lescow believes that the two brands will continue to collaborate. "Smart and EQ are the perfect combination. Smart launched EQ as a brand, and we were able to do that because of the features that make it a true EQ representative. That includes fast-charging capabilities and Smart EQ Control, which allows you to precondition the car.

"But EQ is more than just a technology brand, it really represents the essence of intelligence, emotions and technology. Smart was the perfect frontrunner for that, and now the Mercedes EQC will further develop the brand."

2

1. The Smart Fortwo electric drive was first introduced to the market in 2007

2. Smart is now all-electric in North America, with the European market to follow by 2020

"It's about following customer demand. We will be all-electric in Europe by 2020, and then other markets will follow soon after"

Close knit

Soon, the combination of EQ and Smart will be even more tightly interwoven. In May 2018 Mercedes-Benz announced a €500m (US$589m) investment in its Hambach plant in France to produce a new EQ-badged compact EV – the same site that produces the Smart car.

At the time, then-head of Smart Annette Winkler said, "The Hambach site has many years of experience in building fully electric cars. We want to take advantage of the enormous expertise and prepare the plant for the production of an electric Mercedes-Benz."

But while the sharing of components seems likely, Lescow is keen to keep Smart EQ and Mercedes EQ as separate as possible. "We're sharing a lot of knowledge in the development of these vehicles, but this is a completely different segment that we're talking about.

"There are components that might be shared, but that's not really the focus. We don't want to look internally and say, 'What can we share?' We want to look at the customer and say, 'What do they need in that specific segment?'"

1

The result is that though Mercedes-Benz plans to integrate its newly developed EQC powertrain into all future EQ models, Smart vehicles are unlikely to get a spec upgrade. In fact the city car brand has taken the unusual stance of wanting to stick with the 160km (99 mile) range that its current lithium-ion battery permits.

"For what people use the car for, it is an ideal combination of technology and an attractive price," notes Lescow. "As technology improves, so will battery [power] density. But an increase in range is really not the focus – with that battery it is far more important to be able to charge quickly at your home. With 22kW charging you are able to charge the ForTwo in under an hour. That is what is important to the EV city car segment."

Networking opportunity

By Lescow's admission, even with an all-electric line-up in 2022, electrification skeptics will need to see improvements in infrastructure to be convinced about EVs.

1. Smart's move to all-electric will have an impact on the OEM's relationship with Brabus

2. Smart's current charging specs are suited to the EV city car segment

3. Daimler has invested in the Smart Hambach plant in France ahead of an EQC compact EV

STYLE OR SUBSTANCE?

Smart's electrification strategy is also likely to see the OEM's relationship with Brabus change. Aftermarket tuning company Brabus has long been synonymous with Smart. Reworked suspension and exhaust systems, as well as an increase in boost pressure, brought added performance to the city car. But now a 0-100km/h time of 11.5 seconds and 160Nm of torque is seen as more than enough.

Instead, any Brabus additions will focus squarely on styling. "Brabus is not only about additional power," says Lescow. "That is how it started, but now it is specifically about vehicle individualization." That means an increased emphasis on the Brabus tailor-made program that was introduced in 2010.

With each Smart Brabus individually customized by hand using high-quality materials, the idea is to turn every car into a one-off.

2

"With 22kW charging you are able to charge the ForTwo in under an hour. That is what is important to the EV city car segment"

3

"Although infrastructure won't hinder us in our decisions, it will determine the speed in which EV acceptance will accelerate," Lescow admits. "But we do not want to wait for infrastructure to improve. What we have to do is offer our customers a solution to find electricity along the way."

Around 20 years ago, Lescow recalls, the founders of the Smart brand had an idea for a Smart car with an electric powertrain. And it's that kind of forward thinking that will see the car maker hit its target of a full BEV portfolio in the next couple of years.

"It is a huge challenge for the organization," he admits. "But we have started early, we are well prepared and we are clear about where we are going. There is no doubt that by 2020 Smart will be fully electric."

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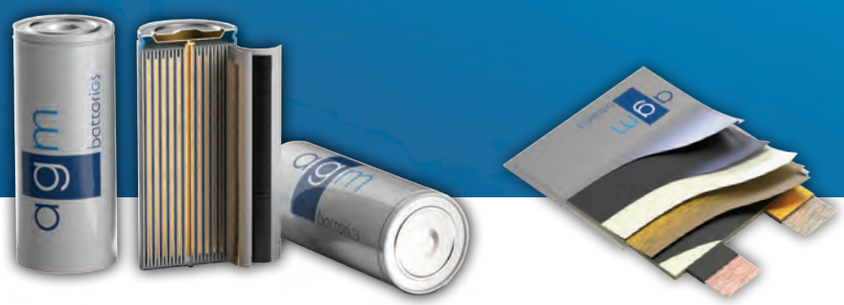

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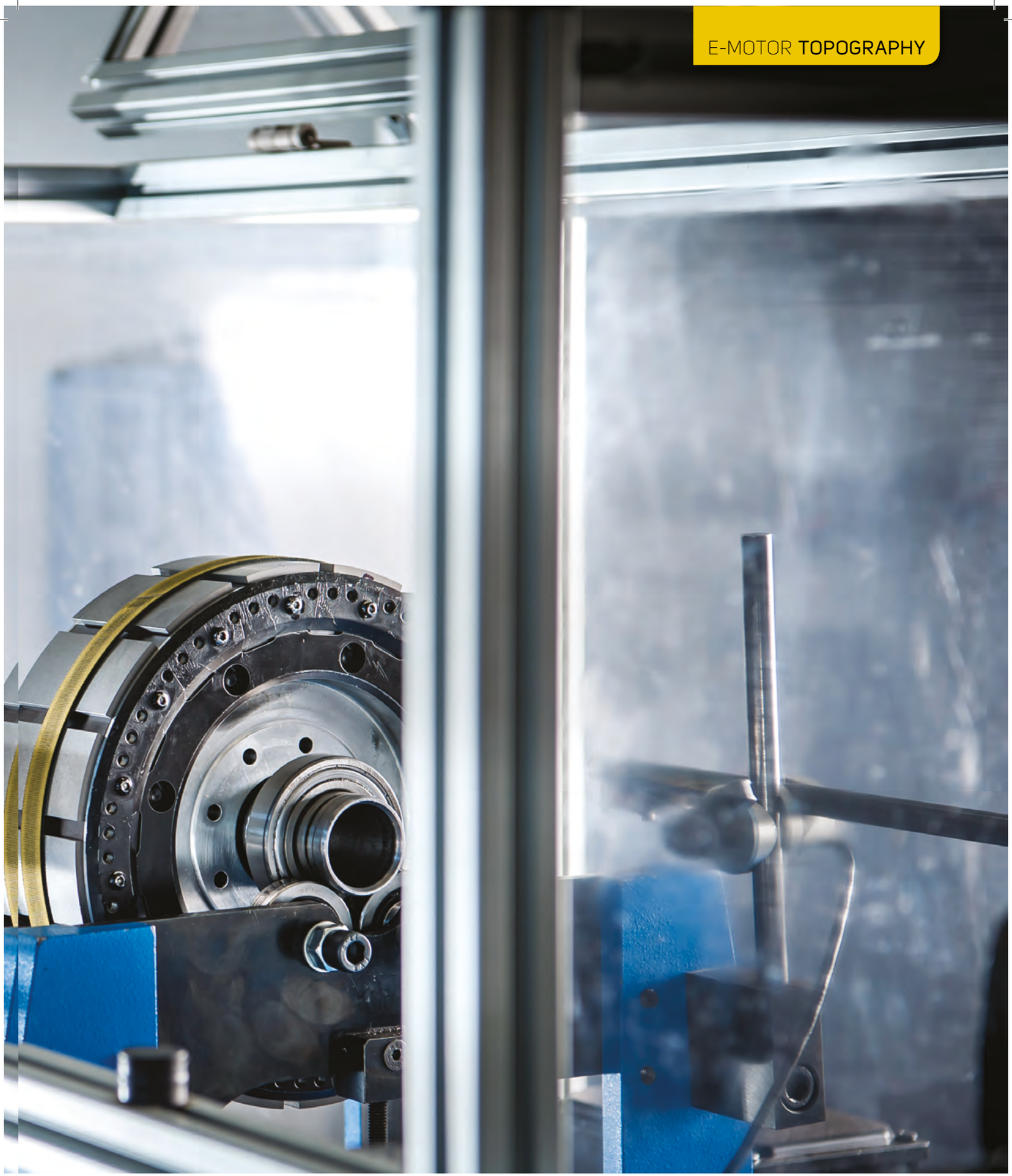
Power trip

When designing an electric powertrain, vehicle OEMs are faced with a plethora of choices with regard to the type, number and location of electric motors. Leading developers have their say on the debate

WORDS: **JOHN EVANS**



For a component that is, in concept, relatively simple, the electric motor is the cause of a healthy level of debate within the electrification industry.

"The trouble is, you start with theoretical benefits, and a few years later you must deal with reality!" Ian Foley, managing director of Equipmake, developer and manufacturer of electric motors, reflects on the arguments raging in the EV industry about matters such as motor location and type, transmissions, cooling, power densities, packaging, and a host of other factors that he and his colleagues must grapple with as they chart a course through the electrification landscape over the next 10 years.

However, one thing is for sure – cost will usually wield the biggest stick.

"With mass-market, the big issue is cost," explains Foley. "The magnetic material in the motors is expensive, so we're using less of it by spinning motors faster – up to 20,000rpm.

"But then you have to get the motor speed down to wheel speed, so you need a gearbox. Fortunately, gearboxes are cheap, giving you a cheap EV motor for a certain performance."

As is often the case, the math influences the development – in this case the trend toward motor and gearbox being mounted in-board with driveshafts going to the wheels. With other approaches, designs tend to simply get too complicated – or compromised – and, therefore, expensive.

And then there are other issues to deal with, not least weight and how to reduce it. Equipmake's answer is to reduce the size of the motor, but without sacrificing power and torque, or pushing up the unit price.

Cooling such a motor is next – a challenge Equipmake is addressing with what it says are "novel additive manufacturing cooling designs for integrating liquid cooling".

Once a powerful, compact motor is nicely cooled, the next step is to integrate it with the inverter and the gearbox, thereby reducing cabling, improving efficiencies, improving packaging and – crucially – saving money.

"If we succeed, you'll have a unit you can hold in your hand," says Foley. "A 30,000rpm motor, inverter and gearbox with cooling – weighing just 20kg [44 lb]."

Location, location, location

But where to put something like Equipmake's small motor? And how many? A two-motor setup is an option, as is four (one at each corner of the vehicle), but with each of these approaches, vehicle designers must consider how the car will behave under acceleration and regenerative braking. What's more, some EVs lend themselves to certain layouts better than others.

> "If it's a sporty vehicle with a lot of regen, you want motors at the front and the rear to balance the car's behavior"
>
> Ryan Maughan, managing director, Avid

1. Equipmake specializes in small, lightweight and powerful electric motors with integrated inverters, gearboxes and cooling

2. Avid's next-generation Evo PM axial flux motors are based on proprietary and patented technology, which can be used in conjunction with custom-built or standard inverters

KEEPING PACE

Simon Patel, senior BEV electrification delivery manager for Jaguar Land Rover, details the development process for the all-electric Jaguar I-Pace, and explores some of the challenges of in-wheel motors

"For the I-Pace, integrating an electric motor into each axle delivered the ideal balance of attributes. They are synchronous, PM machines, and deliver efficiency greater than 95% over a very wide speed range. They are also extremely compact and light, weighing around 40kg [88 lb] each.

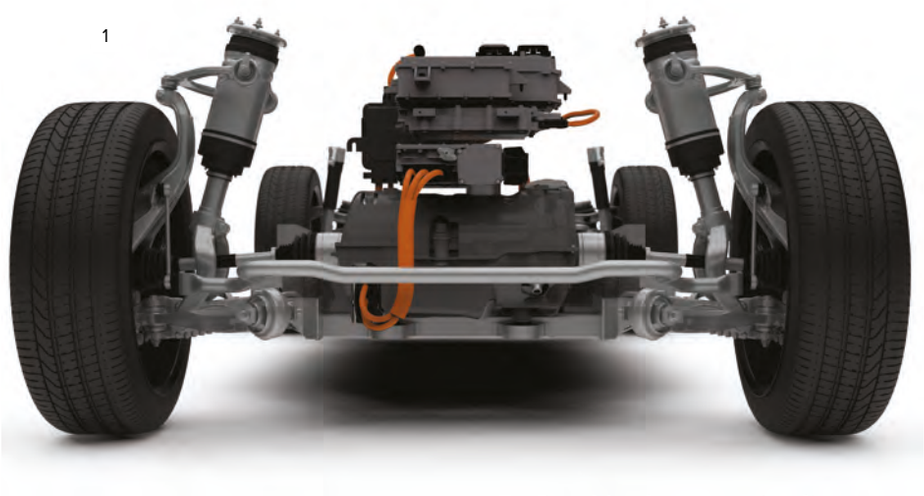
"The motors are hollow and have concentric rather than conventional offset transmissions, with driveshafts passing though the center. This saves up to 30mm in height, providing great ground clearance, a spacious cabin and a 656-liter luggage compartment.

"Having independent front and rear motors means we have control over the torque distribution. This layout also provides high levels of regen on the front axle without impacting stability.

"In-wheel hub motors are interesting and offer benefits of independent torque control across an axle, and, if fitted to all four corners, front to rear as well. They also offer cabin packaging benefits.

"However, packaging the motor and transmission within the wheel envelope restricts the maximum motor diameter – and therefore the maximum torque rating. It also makes packaging the friction brakes more difficult. Unsprung mass is also increased, which is detrimental to vehicle dynamics.

"Durability and robustness are also challenging. Finally, you must consider how to manage HV cables and cooling hoses connected to a moving mass."



1 & 2. The Jaguar I-Pace features an electric motor integrated into each axle. In-wheel motors were not selected due to possible restrictions on torque

For Ryan Maughan, managing director of Avid, a designer and manufacturer of electrified powertrains, it all starts with the vehicle platform.

"Is it a new design or is the OEM using an existing base vehicle platform?" he says. "Most OEMs have a lot of sunk cost in their existing ICE platforms. They don't want to reinvent the chassis for EVs, although VW has done just that with its MEB platform, which it'll just 'top hat' to create different models."

But whether it's a repurposed ICE or all-new EV platform, the type of vehicle that is to be powered must be established.

"If it's a sporty vehicle with a lot of regen, you'll want motors at the front and the rear to balance the car's behavior," says Maughan. "Otherwise, if you're doing all your braking through the rear wheels, you'll unsettle the handling, so you'll have to limit the amount of regen, which you don't want to do because you want to capture as much energy as you can. These are fundamental considerations in terms of the front versus rear argument."

On the question of radial or axial flux motors, Maughan says the jury's still out, but that the industry is leaning toward the former.

"The most popular machine for the high-volume passenger car is a radial flux motor. Axial flux motors are not the most efficient at any one point in the operating cycle, but they will give you a good efficiency over a range of operating points. It's a good compromise and it's relatively low cost."

Ian Foley is less equivocal: "The fact is that the industry is geared to produce and work with radial flux motors. For someone to come along and challenge that, there has to be a significant benefit associated with axial, which I don't see."

Getting on board

In terms of inboard versus in-wheel-mounted motors, Foley is likewise unconvinced, as is Maughan. "They bring gains in terms of packaging and perceived reductions in

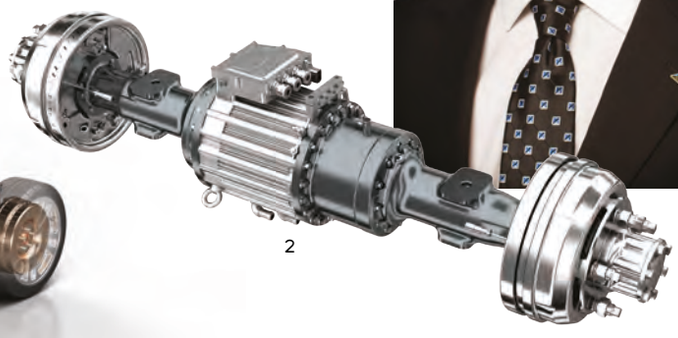
1. Protean believes that in-wheel motor technology offers an array of benefits

2. Dana's experts see future vehicle designs dominated by inboard designs and highly integrated systems

"In 10 years' time, we'll see motors are established as internally mounted and not wheel-mounted"

Seth Metzger, vice president, light vehicle engineering and global driveline engineering, Dana

1



2

"Increased efficiencies, greater design and packaging freedoms, improved handling and performance: these are the benefits of in-wheel"

Andrew Whitehead, chief commercial officer, Protean

drivetrain complexity," Maughan says, "but they're hard to get right from a reliability point of view. Inboard is the focus."

However, he does forecast in-wheel gaining a foothold in autonomous, low-speed, shuttle-type applications.

"Its drawbacks are less significant here, and the benefits – notably improved packaging – are worth more. So it has niche value."

But Andrew Whitehead, chief commercial officer at in-wheel motor developer Protean, doesn't subscribe to the niche value argument.

"Increased efficiencies, greater vehicle design and packaging freedoms, improved vehicle handling and performance: these are the benefits of in-wheel," he says. "Plus, there's a cost benefit, because while two-wheel motors are more expensive than one centralized axle, when you take into account the powertrain components you can delete, the in-wheel vehicle costs about the same to produce – but will demand a higher price in the market given its improved vehicle attributes."

The arguments against in-wheel motors include the belief that the motors' unsprung mass destroys the vehicle's ride, that reliability suffers in the wheel environment, that vehicle controls are difficult to integrate, and that cooling is hard to achieve. But Whitehead is not convinced.

"We've the data to defeat these arguments and already we're seeing near-term demand from China for passenger cars, from the light delivery vehicle sector and for autonomous people movers."

However, Seth Metzger, vice president of light vehicle engineering and global driveline engineering at Dana, is not persuaded.

"Basically, if you stay with inboard, your risks are fewer," he says. Metzger is aware of the challenges associated with the technology, thanks to Dana's acquisition of a controlling interest in TM4, an e-motor developer and manufacturer. The company started out with in-wheel motors, but having failed to get it adopted, turned its attention to trucks and buses, replacing its diesel motors with its centralized EV motor technology.

"In 10 years' time, we'll see motors are established as internally mounted and not wheel-mounted," he says. "There'll be wider adoption of silicone carbide for high-speed switching, and to enable higher speed motors and higher power densities. Highly integrated, high-speed systems will help us address the challenges of cost, packaging and weight."

Still, as Ian Foley might say, that's the theory. Reality might be something else entirely.

Taking

What started out as a low-emissions vehicle project at the UK's Coventry University has developed into a fledgling car manufacturer with plans to build a niche, low-volume, all-electric sports car

WORDS: **MATT ROSS**

When Mike Dickison, associate dean of the Faculty of Engineering, Environment & Computing at Coventry University in the UK, launched a new engineering project for his students, it was unlikely he could have predicted that, less than five years later, he'd be working on a prototype vehicle that could kick-start a new, low-volume, all-electric car company. As part of Dickison's role at the university, he provides industry-based projects for engineering and design students. In 2014, faced with a situation where some industrial partners weren't available to provide quite as much devoted time and support to students on certain projects as Dickison might have hoped for, he struck upon the idea of something on a slightly larger scale – something he hoped would give his students invaluable experience in terms of timescales, deadlines, technical objectives, teamwork and project pressure.

"I've been running projects for students since 2009, when I joined the university, which were based on industrial concepts," Dickison explains. "A good example is a project for a lightweight chassis, or perhaps a low-carbon vehicle concept, or working on aerodynamics to see how you could reduce drag and use less fuel. Ever since I've been at the university, the focus has been on the reduction of energy and then, on that basis, lower pollution."

As he observed consumer and governmental attitudes toward emissions and electromobility shift, Dickison thought about combining some of these disciplines into a single project.

"All of these projects I've been running, they're very relevant to zero-emissions vehicles," he says. "So I thought I'd focus all these individual projects, and some of our group projects, into one single product – a university product – not something for a large manufacturer. That way, we would have complete ownership of it, and we wouldn't

flight

The Spectre is the all-electric result of Coventry University's Sparrowhawk project

be constrained in terms of technologies, or in terms of approvals from partners, and so on. Effectively, we'd have a program whereby one set of students would do a series of projects on the vehicle – lightweight structure, lightweight suspension, powertrain solutions – and then the next round of students would take the output of those projects and refine it.

"The original brief was to do a low-carbon vehicle, and there would be the possibility, maybe, when it was completed, to turn that into a series production, low-volume vehicle which would be a showcase for the university. And it would also form the basis for an organization that could provide really good quality projects for future students as well."

The students, as it turned out, exceeded Dickison's already high expectations, but the first vehicle in the Sparrowhawk project was still a little way from the all-electric car under development today.

Power transfer

"The very first concept we had was to optimize aerodynamics, optimize the mass, and we actually had a gasoline engine – a Ford 2-liter EcoBoost," Dickison says. "We were fully aware of the issues associated with diesel, so we selected an efficient, high-output gasoline engine. Plus it was available as a package from Ford, it arrives on a crate with the ECU, and you can drop it in and have a powertrain solution."

However, two years into the project, and still observing the shifting public and legislative attitude toward electrification, Dickison made an important choice regarding the Sparrowhawk's powertrain.

"It became apparent that we were working on what would effectively be a dinosaur with a petrol engine in it. We looked at hybrid solutions, but if you're aiming for future-proofing, you don't really want hybridization unless you have to. Or if you have to, it needs to be something like a hydrogen fuel cell […] I thought that we wanted to go for a vehicle that wouldn't be an everyday, commuter car for family holidays. This is going to be a fun car that doesn't need 300-400 miles [480-640km] of range. So let's go for something that's pure electric, with more than 100 miles [160km] of range, with good performance – something that's a joy to own."

Initially, Dickison imagined that the switch from ICE to EV wouldn't cause too much design upheaval. However, the team ended up completely re-engineering the car to accommodate the new powertrain.

"I have the luxury of access to a lot of students, all of whom are very enthusiastic and well qualified. So I was able to do a whole range of powertrain scenarios in terms of motor selection, transmission selection, battery design, the packing layout, and so on. And we found that every solution we did using the existing chassis was essentially a compromise."


1

"It's a massive project in terms of ambition, which is why I'm keeping my targets quite close"


2

The Sparrowhawk team evolved the design. The suspension and brakes remained similar, but the whole package has been significantly altered. And the redesign has led to the development of the car's current concept.

"A concept we've come up with is what I'm calling a semi-integrated battery," Dickison explains. "I don't know that anyone has done this before. EVs tend to have a platform-type battery, with an array of cells set out in a large box of some sort that is typically under the seats. They then build a robust frame around it and bolt that into the framework, and often the front and rear suspension assemblies are attached via frameworks from that main battery. Of course, with a sports car, you can't do that because you jack up the occupants by about 150mm [6in] at least. We needed something different."

1. Dickison and some of the project's students

2. The car will most likely be clad in carbon fiber

3. Earlier iterations of the car featured an IC engine

4. Successive rounds of students will work on the project, gaining valuable industry experience

"If you're aiming for future-proofing, you don't want hybridization unless you have to"

The solution – which also needed to retain the car's mid-engine layout to keep a lower polar moment of inertia to keep the car agile, and which opted not to put the motors at the front due to the cab-forward design and a reluctance to have the torque steer of driven front wheels – features a rear electric motor with a reduction drive and a central battery. The semi-integrated battery design sees three of the four sides of the battery casing form part of the chassis structure.

"Then you build up the battery on a robust lower plate, and insert that into the structure and have it held on with multiple fixings," Dickison explains. "We've created a very stiff and well-protected spine going up the center of the vehicle, which gives the majority of the structural stiffness." An added advantage is that the battery remains serviceable as it's not built into the structural chassis.

Funding the vision

Dickison has managed to secure £300,000 (US$394,500) of funding from the Niche Vehicle Network, and is aiming for a driven prototype vehicle – which will sell under the name Spectre – by the end of March 2019. He's also formed a collaboration with UK company Indra, which has a deal with Nissan to provide the OEM's components to new vehicle projects. Although developing an in-house battery system is well within the Sparrowhawk's wheelhouse (given its links to the R&D projects at Coventry University), taking a bespoke design to a specialist supplier was unlikely to prove cost-effective.

"We looked for existing, entirely proven modules to build into our own batteries – we do our own mechanical engineering in the connection of the cells, but we're using a proven part," Dickison says of the decision to use Nissan cells. "Effectively we've had to design the car around the cells. I'd love to say that we could have a slightly shallower tunnel thanks to smaller modules, but the reality is that this is what we have – it's proven, it's at a sensible price. Buying parts through Nissan and Indra, although they're expensive, they're considerably less expensive than if we go to a specialist supplier. Plus, the additional safety testing and so on would add huge amounts of development cost."

The first prototype will also use Nissan's electric powertrain, and the chassis has been engineered so that it can drop straight in.

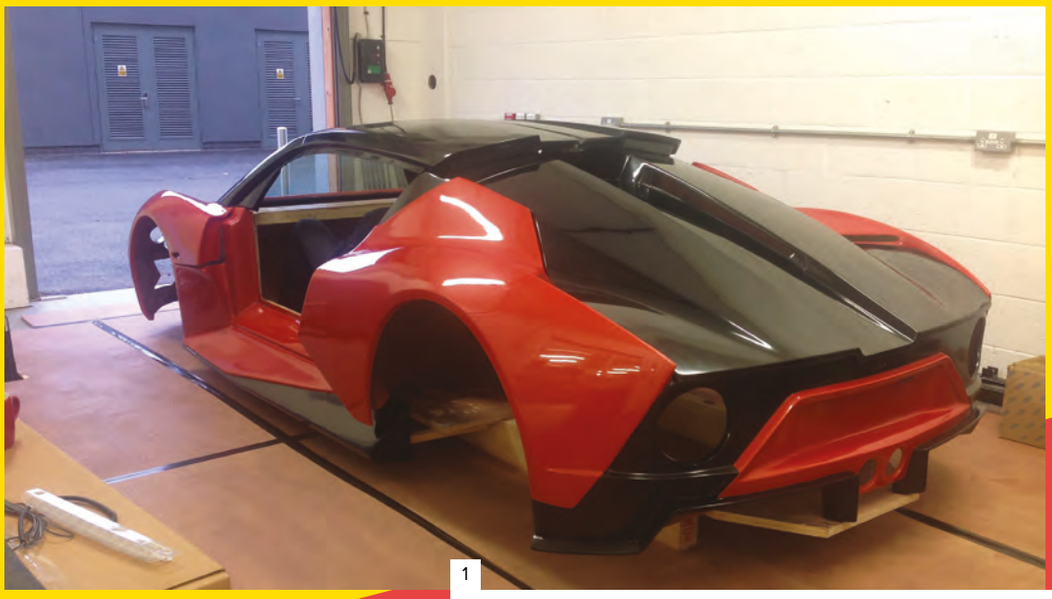
"That might not sound very sporty," Dickison admits, "but if you drive a Leaf, it's impressive in terms of its performance. Not supercar performance, perhaps, but I'm not convinced that everyone wants a car that can do 0-60mph in less than two seconds. What you want is for your mid-range performance to be good. I don't think 200mph [320km/h] is something the majority of people want to explore. They want something that feels brisk, safe, and has an acceptable top speed."

And there's already a further powertrain iteration under consideration.

"I've been working with Yasa Motors – we had a PhD student that's just finished with them," Dickison says. "They're very prepared

1. UK politician Jeremy Corbyn at Coventry University's National Transport Design Centre

2. The Spectre will initially be fitted with a Nissan powertrain, though other solutions (including a two-motor setup) are possibilities



1. Development of the car has combined a number of vehicle design projects

2. The next goal for the project is completion of the driving prototype

3. The Spectre is a niche vehicle with an emphasis on driving experience

to assist in terms of providing electric motors, and the Yasa motor is one of the most efficient you can buy in terms of power density. It's a very advanced design, and we know it quite well because we've had a PhD student working on it for four years."

Dickison is also considering the possibility of a two-motor solution, which he believes would offer supercar performance. "But let's develop something that works with the Nissan powertrain, and then we do have a supercar version that we could incorporate without too much difficulty," he says. "Then you could easily go up to 150mph [240km/h] top speed. But I think we have to be careful not to be too ambitious, too soon."

Setting waypoints

The driving prototype is the next milestone for the Spectre, something key to the Niche Vehicle Network funding.

"We'll then carry on and put that through an individual vehicle approval, then really it's just further refinement. There is some further funding available now – I have an investor who's keen to take it further," Dickison says. "It would have been tempting to go with an organization that says we should be selling 100 cars a year, 10 months from now, but I just can't achieve that. And we've been clear about that. The Sparrowhawk organization is part owned by the university, part owned by me, and part owned by a couple of other parties. So the conversation has been, 'If you come in now, we might have a good time, but never actually produce any vehicles – but that's not our aim.' Our aim is to create niche products that people want to own."

And Dickison is already giving thought to how limited production might work.

"Major components would be brought in, such as the motors, the drivetrain, and so on. In terms of the chassis, it's a fully rigid driving chassis, so it's all aluminum. I think we can subcontract the chassis – there are numerous suppliers out there. The vision I have is that we have a unit, probably quite close to the university, in the Coventry area, with a relatively small team of staff. Maybe around 10, a combination of professional engineers and assembly guys. At the start, I'd like to keep it small, have the vast majority of parts built locally – Coventry is the Motor City of the UK – and as such we can give employment to local organizations, [and maintain strong links with the university]."

Those links will also ensure the project serves as a demonstration of Coventry University's commitment to being at the forefront of the industry.

"If you come here to do automotive, you're not going to be taught from notes from the 1980s," says Dickison. "Students will have access to the company, and of course that's great for the company, because you effectively get a lot of technology and development work, and a lot of fresh ideas."

But right now, Dickison remains keenly focused on the prototype.

"It's a massive project in terms of ambition," he admits, "which is why I'm keeping my targets quite close. My main target is to build a working and driving car and demonstrate good value to the funders. One of the major considerations when it comes to funding is whether it's a realistic project, and if there's a route to market. Fortunately, I was able to prove that in my application. I'm not saying I want to sell 10,000 cars next year. But equally, I'm not just playing."

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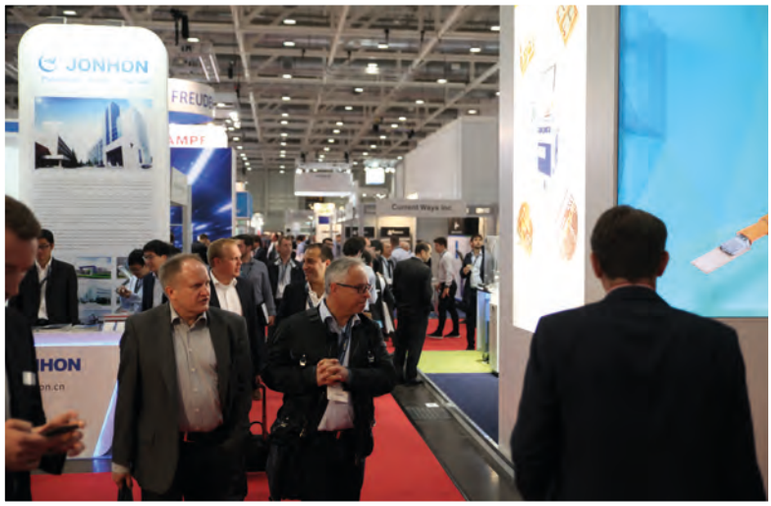
Electric & Hybrid Vehicle Technology Expo Europe and **The Battery Show Europe**, May 7-9, 2019, Stuttgart, Germany

Fueling H/EV growth

When Electric & Hybrid Vehicle Technology Expo Europe returns for a third edition in May 2019, it will park up in the region's most important automotive cluster



Stuttgart, Germany, is the new home of Electric & Hybrid Vehicle Technology Expo Europe. The capital of Germany's Baden-Württemberg state, Stuttgart is a renowned vehicle manufacturing hub, home to the likes of Mercedes-Benz and Porsche. It brings outstanding innovations to market every year, and it continues to represent huge opportunity for industry players across e-mobility and battery development. Baden-Württemberg is known around the world as the birthplace of the car, and today remains a prominent force in the automotive industry.

The event itself is Europe's largest and fastest-growing fair and conference for plug-in hybrid, electric vehicle and advanced battery technology. It is the place where ideas, innovations and technologies converge, providing a unique opportunity for international manufacturers and service providers to source next-generation solutions for passenger, commercial and industrial vehicles under one roof.

Attendees are also presented with pioneering battery solutions at co-located event The Battery Show Europe. Here, visitors can discover the latest design, production and manufacturing innovations from across the battery supply chain and stay informed on the numerous and varied factors contributing to falling battery costs.

Fueling the growth of Electric & Hybrid Vehicle Technology Expo Europe is a globally expanding hybrid and electric vehicle industry. By 2026, the global vehicles battery market is forecast to reach US$93.94bn as demand for electric cars continues on an upward trajectory. Big market players – Ford and Toyota among them – are positioning themselves at the fore of developments, increasing investments in vehicle electrification and expanding their portfolios to feature hybrid and electric models.

A confluence of factors is driving this trend, from perceptible growing global appetite for green transportation options to cheaper fuel and maintenance costs. Tumbling battery

ACCESS EUROPE'S LARGEST TRADE FAIR FOR HEV/EV AND ADVANCED BATTERY TECHNOLOGY FOR FREE! REGISTER FOR YOUR FREE TRADE FAIR PASS ONLINE AT EVTECHEXPO.EU

More than 400 companies will exhibit in 2019, bringing the latest technologies, innovations and demonstrations to Stuttgart in Germany

costs coupled with improved performance is a key element, too.

For the industry as a whole, this means piqued interest from new actors, which for Electric & Hybrid Vehicle Technology Expo Europe means a broader attendee base than ever before.

Each year sees high footfall from manufacturers, suppliers, vehicle OEMs and stakeholders from a diverse range of global markets. Commenting on last year's event, Raymond McWilliams, senior engineer at Bentley Motor Cars, said, "There was an overwhelming sense that the people and companies represented there are at the cutting edge, shaping the future of the automotive industry."

More than 8,000 international visitors – from 70+ countries – are expected in 2019, all arriving to discover brand-new technology from more than 400 exhibiting companies. Many perform live interactive demonstrations of their products.

Innovative featured solutions include electrical powertrains and components, battery management systems, materials and equipment, all designed to reduce manufacturing costs and achieve optimum performance of hybrid and electric vehicle applications.

The trade fair is free to attend. Register online at evtechexpo.eu to be part of the H/EV and battery industries' most important event of the year.

2019 TECH PREVIEW

TE Connectivity

Handling the high voltages that come with the introduction of electrified powertrains not only requires advanced battery technologies that support the power demands of tomorrow's vehicles, but also the supporting infrastructure. At The Battery Show Europe 2019, TE Connectivity will highlight its products and technologies that enable these developments.
A broad portfolio for hybrid and electric vehicles, including power distribution, electric vehicle charging, interconnection systems and e-motor sensors, will be on display. TE is ready to complete the connections its customers need to help safely, efficiently and reliably make hybrid and electric mobility a sustainable reality.

"THERE WAS AN OVERWHELMING SENSE THAT THE PEOPLE AND COMPANIES REPRESENTED THERE ARE AT THE CUTTING EDGE, SHAPING THE FUTURE OF THE AUTOMOTIVE INDUSTRY"

Raymond McWilliams, senior engineer, Bentley Motor Cars

Leading suppliers and developers will be at the expo, giving visitors the chance to learn about the latest industry advances

Elaphe Propulsion Technologies

Elaphe, the leading high-tech in-wheel electric powertrain producer, will highlight creative torque-vectoring solutions and a modular, plug-and-play platform for the next generation of electric vehicles. Building on its portfolio of record-breaking in-wheel performance electric motors, Elaphe will showcase the heart of its propulsion systems: Elaphe PCU 2.0 is a vehicle propulsion control unit that can interface with an autonomous driving controller unit or receive input from a human driver, depending on vehicle design. The controller is designed specifically for multiple-motor control and built up as an ASIL-D-concept automotive grade hardware platform. However, the true value lies in the software and the advanced algorithms that are able to support groundbreaking performance and responsiveness that the distributed powertrain offers.

Electric & Hybrid Vehicle Technology Expo is Europe's largest and fastest-growing fair and conference for the electric, hybrid and energy storage industry

Not only will visitors be able to visit stands from leading exhibitors, but the Expo runs parallel to an industry-focused conference with speakers from leading companies

Valeo

Hybridization is a cornerstone technology to help meet the increasingly drastic CO_2 emission standards. The 12V solutions are not able to cover the whole range of the automotive market, thus usually requiring heavier vehicles to use high-voltage technologies with stricter safety requirements. To provide higher electric power at lower cost, Valeo introduced the 48V air-cooled iBSG. Now, the company is positioned on the second generation of 48V systems as a full propulsion system provider with the reducer, the 48V e-motor and its inverter range, plus the 48V DC/DC converter. Electrification revolution concerns passenger cars, but also affects whole emerging mobility solutions. Valeo will capitalize on its automotive expertise and industrial footprint to address the light electric mobility market, reusing its serial products such as a belt electric drive concept or a more powerful e-drive and a 48V onboard charger.

VOICES OF THE INDUSTRY

Running alongside Electric & Hybrid Vehicle Technology Expo Europe is an industry-focused conference covering three distinct tracks.

As in previous years – when speakers from Toyota, Porsche and Volkswagen took to the stage – high-level speakers are lined up to share their unique insights on some of the industry's hottest topics.

Areas to be covered include market trends and growth opportunities, improving power management across a vehicle, scaling and commercializing new technologies, recycling and second life, OEM lessons learned from low-voltage architectures, and much more.

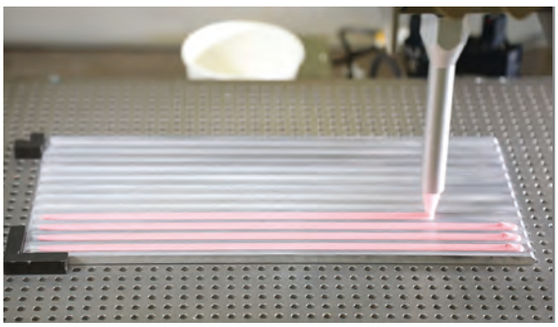
Commenting on the 2018 conference, Williams Advanced Engineering's Wasim Sarwar said, "I've attended and participated in many conferences over the past seven years, and this was certainly the best run." Others agreed, with Benteler Automotive's Peter Steinbrueck saying, "I've never experienced such dense e-mobility know-how and networking opportunities in one place."

Visit evtechexpo.eu/conference to discover the agenda and take advantage of the super early-bird rate, available until Friday, January 18, 2019.

400+ COMPANIES WILL EXHIBIT IN 2019 INCLUDING VALEO, CONTINENTAL, SIEMENS, HUBER+SUHNER, MAHLE, RICARDO, EATON, MAGELEC, AKASOL, BOSCH REXROTH, 3M, LECLANCHÉ, HENKEL, LORD, DUPONT, TRUMPF, LEONI AND ROCKWELL AUTOMATION

LORD

LORD Corporation brings its CoolTherm brand to this year's show – the latest advancement in thermal management, featuring high-performance thermal interface materials. CoolTherm combines highly responsive technical expertise with industry-leading thermal management technologies, resulting in tailored products for managing heat issues and increasing power density. LORD's CoolTherm portfolio delivers reliable custom solutions for use in electric vehicles, energy storage systems, motors and other power electronics. Additional products include potting and encapsulation solutions, gap fillers, structural adhesives, gels and greases. These are available in a range of customizable thermally conductive chemistries, including silicones, epoxies, urethanes and acrylics to meet specific performance, cost and schedule targets.



Smart electrification

As electromobility continues to proliferate, combining ICE and electrification expertise into a single portfolio provides vehicle OEMs with a full suite of powertrain solutions

WORDS: **MATT ROSS**

The automotive industry's trend toward electrification is no longer breaking news – the increasing prominence of hybrid and electric powertrains is rapidly becoming commonplace across model portfolios from virtually all major OEMs. Federal-Mogul Powertrain has established itself as a leading provider of highly engineered, advanced engine components and technology solutions that enable improved powertrain efficiency, and the company has been quick to target the same level of proficiency in electrified systems.

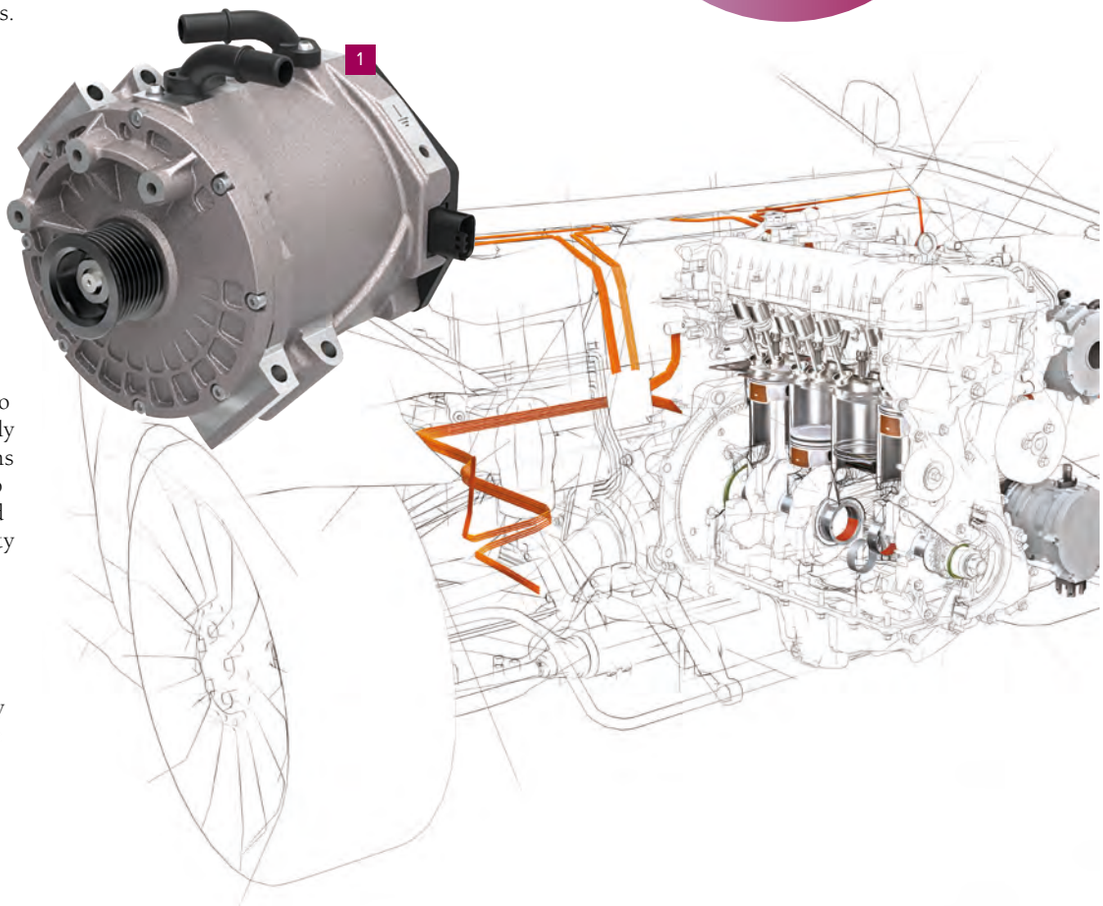
"While IC engines will continue to play a vital role for many years to come, we see hybridization and the electrification of powertrains as a key enabler for vehicle manufacturers to meet future emissions targets," says Gian Maria Olivetti, CTO of Federal-Mogul Powertrain. As part of Federal-Mogul's commitment to hybrid and electric mobility, the company acquired Controlled Power Technologies (CPT), adding a suite of driveline electrification solutions to its portfolio.

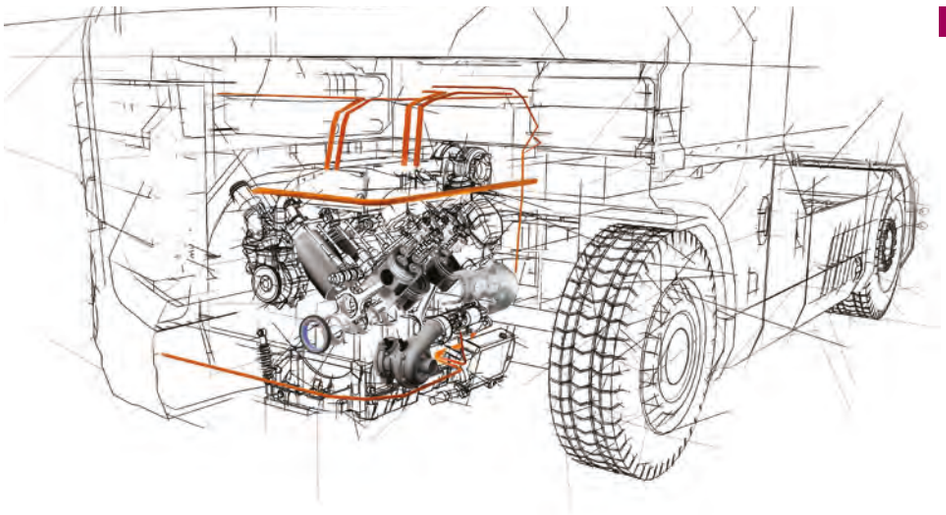
"The acquisition of CPT extends Federal-Mogul Powertrain's range of technologies into this area with a new portfolio that is extremely synergistic," adds Olivetti. "All hybrid systems still require the most efficient ICE in order to deliver their full performance advantage, and CPT hybridization technologies add the ability to use intelligent electrification to increase engine efficiency even further."

Federal-Mogul Powertrain's new CPT product group is headed up by managing director Nick Pascoe.

"For us, electrification does not necessarily mean driving the wheels electrically," Pascoe says. "It's about clever energy management – how we can improve fuel economy and CO_2 emissions by harvesting waste energy, including both vehicle kinetic energy that is lost during braking and exhaust gas energy, then store it efficiently and return it to do useful work. Even modest hybridization leads to significant improvements in real-world emissions and fuel economy."

The synergies between the two companies, both executives believe, made the acquisition a natural fit, and the CPT product group will aim to continue its parent company's level of expertise across a wide range of powertrain applications.





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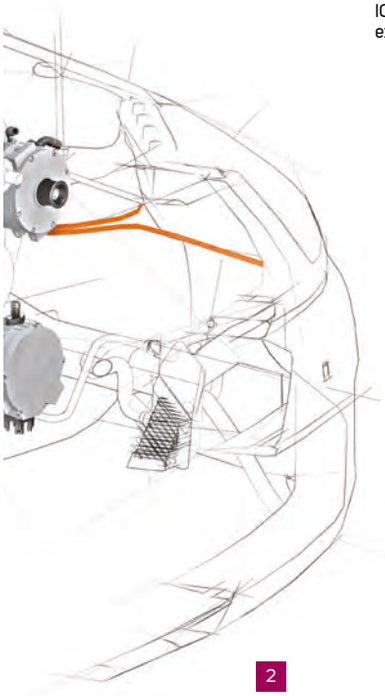
"For us, electrification does not necessarily mean driving the wheels electrically. It's about clever energy management"

Nick Pascoe, managing director, Federal-Mogul Powertrain's CPT product group

1. CPT SpeedStart is just one of a number of products which offer powertrain designers new solutions for electrification

2. CPT's modular portfolio is designed to cater for an extremely wide range of electrification applications

3. Federal-Mogul also provides solutions that enable OEMs to optimize IC-engine powertrains, extending their usefulness



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"We intend to become a leading supplier of powertrain electrification technologies across all sectors, from small passenger cars up to the largest commercial vehicles," Pascoe adds. "The portfolio includes systems for mild hybridization, electric superchargers, exhaust energy recovery turbines and a high-efficiency water-cooled e-compressor for fuel cells."

Covering all bases

CPT is pursuing a modular approach based on scalable hardware, software and electronics, with CPT expertise benefiting from Federal-Mogul's global reach, volume capabilities, delivery and support network.

"Engine designers will be able to take some interesting new approaches to increasing efficiency and reducing emissions," says Olivetti. "In addition to the existing mild hybridization options, they will be able to recover exhaust energy in new ways and get more out of investments in existing systems such as advanced fuel injection and engine management, as CPT e-boosting technologies provide faster, more precise control of induction air, enabling air-intake flow to keep up with the high responsiveness of these systems."

CPT specializes in the development of 12V, 24V and 48V electric motor generators for stop/start applications, mild hybridization, exhaust-driven electrification technologies, e-boosting for ICEs, e-compressors for fuel cells, and a host of other products. The technology is primarily developed around switched reluctance motor (SRM) technology – which is well suited to hybrid applications because, when combined with effective thermal management, it enables high-efficiency harvesting of kinetic energy over a wide range of speeds, with impressive dynamic response. SRM technology also offers the ability to provide peak power and torque consistently for around 30 seconds, unlike permanent magnet e-machine technology.

Part of the product portfolio, CPT SpeedStart and CPT SpeedTorq are highly controllable, water-cooled motor generators for stop/start, mild hybridization and engine torque-assist.

In addition, the COBRA (controlled boosting for rapid response application) range features liquid-cooled electric superchargers that offer CO_2 and fuel economy improvement up to 10%. The SRM technology has low rotor inertia and excellent control characteristics, providing on-demand air that supports a range of air loop improvements, as well as providing control of air to fuel ratios, especially in transient conditions that can lead to spikes in emissions and fuel consumption.

Building on the technology, the COBRA FC has been developed for the control of fuel cell airflow, increasing efficiency of the fuel cell by providing consistent, high-precision control of air for the stack.

TIGERS (turbo-generator integrated gas energy recovery system) is a liquid-cooled generator coupled to an exhaust-driven turbine, recovering energy that would otherwise be lost and reducing demand on the alternator system. This concept includes software control and backpressure monitoring to maximize efficiency of energy harvesting, ensuring the system operates only when there is a net benefit.

"It's clear a wide range of implementation strategies are needed so that the best solution can be applied to each pattern of vehicle use," says Pascoe. "Our modular approach provides the flexibility to do so – stop-and-go traffic requires a different approach than long-distance driving at constant speeds."

As the industry moves to RDE and WLTP, compliance relies on strong emissions performance during aggressive transients. "That means any supporting electric motor technology must be more dynamic," Pascoe adds, "which is exactly what our systems offer."

For Olivetti, the acquisition enables Federal-Mogul to offer its customers an even greater array of powertrain expertise.

"Our customers already choose Federal-Mogul technologies to help increase the efficiency of their ICE powertrains," he explains. "The acquisition of CPT adds even more to this capability with validated electrification technologies that are ready for integration with development programs."

Made to measure

Data acquisition and engineering expertise are key tools when innovating for the electrified vehicle industry

WORDS: **ALI PHILIPS**

Ipetronik's technology has adapted to suit the changing requirements of the automotive industry

Vital for the validation of prototype vehicles, datalogging has become a fundamental part of development for the automotive industry. Ipetronik (and its IpeMeasure business unit) has established itself as an expert in automotive datalogging, and will celebrate its 30th anniversary in 2019. Excelling in the market has relied on a constant cycle of innovation, as well as an ability to adapt to the changing requirements of an evolving industry. The industry trend toward electrification has proved no different.

"The emergence of electric powertrain architecture – including BEVs, HEVs and PHEVs – has affected the datalogging requirements of our customers," explains Jörg Strothmann, CTO of Ipetronik. "The interplay between driving modes of combustion and electric engines, and combined driving modes, brake recuperation and battery management systems takes overall ECU software programming to a higher level of complexity."

Such complexity increases the number of test scenarios typically required during vehicle validation, and calls for more on-road fleet testing prior to production – making datalogging all the more vital.

"In the past, the power source [the ICE] had a clear status – ignition on or off," adds Strothmann. "The situation has now changed fundamentally with the introduction of battery systems. In-vehicle bus network communication is always active, which demands more complex datalogging configurations and network logging functions to spot errors in internal ECU communication."

Moving with the times

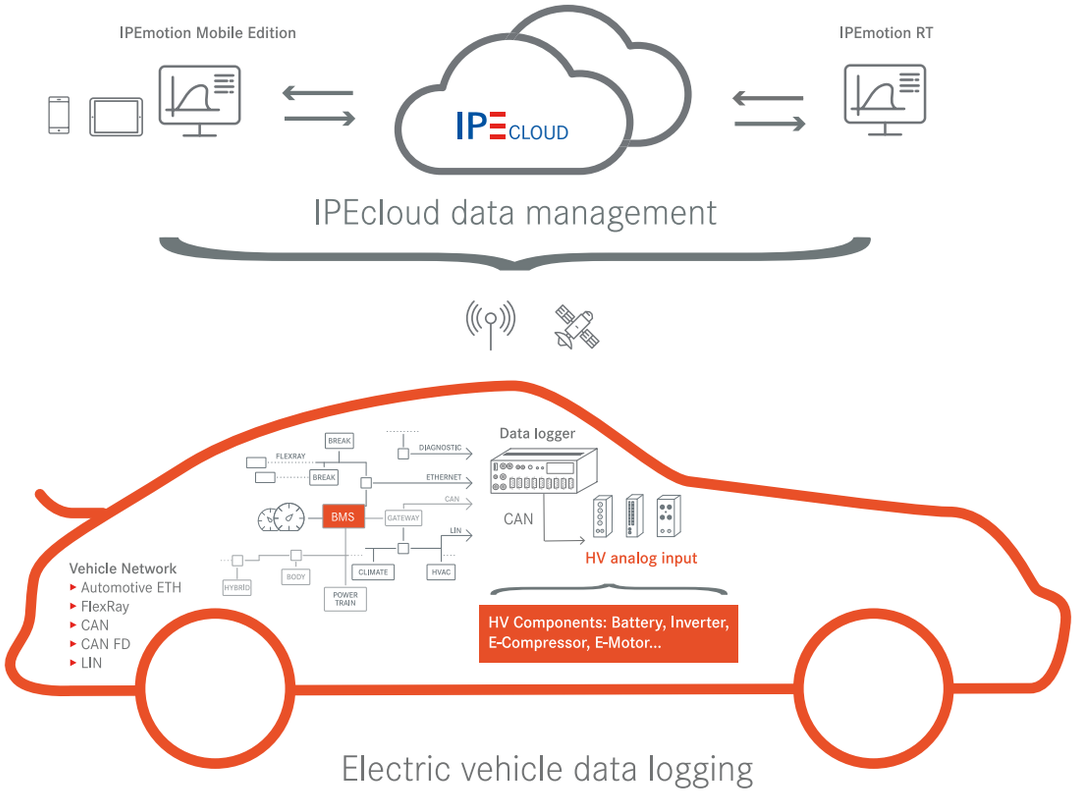
To address these increasingly complex requirements, Ipetronik is continuously expanding the functionality of its loggers. Specific software functions have been added to operating systems, with trigger functions to capture data according to complex logical conditions. This makes it unnecessary to log all data – and avoids the associated time-consuming task of analyzing it – instead recording only that which is relevant.

IoT connectivity has also been added, enabling customers to access the logging system remotely, and making it possible to gather system health and status information about the vehicle. Remote commands can also be issued, triggering diagnostic jobs or obtaining detailed status information.

Ipetronik also ensures that its equipment is tough and reliable.

"The reliability of measurement operation, and the ruggedized hardware makes the equipment suitable for harsh environments," says Strothmann. "Extensive testing in winter and summer can be handled extremely well."

In addition to large-scale vehicle fleet and on-road testing, Ipetronik also continually



Electric vehicle data logging

innovates in terms of its engineering and test bench expertise, including development work for electrically driven high-voltage HVAC compressors for vehicle climate systems.

"As this system contributes significantly to range extension in EVs, our work in this area can be key to successful development," explains Strothmann. "The e-compressor can also operate as a heat pump to save up to 20% energy within the battery system. Our design for an integrated HVAC and water-cooling system for electric vehicles, and building the associated test benches, contributes to overall development."

Recently, Ipetronik introduced a dedicated high-voltage shunt system – HV CCS Shunt. Developed by the company's engineering department, this unit monitors the current flow between the charging post and the vehicle. Combined with the datalogging system, network communication within the vehicle and the charging infrastructure can be recorded. The system is based on the CCS standard connector, and covers standard 230V AC charging, as well as high-current DC charging, enabling customers to easily benchmark and analyze the charging behavior of plug-in and electric vehicles.

Ipetronik's datalogging systems can be used for test bench applications and on-road testing at the same time. The ability to share the same data acquisition software between road and rig adds value for customers, as data generated from two different test applications can be easily compared and fed back into simulation models.

The road ahead

Key to the company's continuing success is the ability to look at potential trends.

"In the past, innovation was mainly hardware-based," explains Strothmann. "This would include adding more storage capacity to the logger, more measurement inputs, higher sample rates or wireless data transfer functionality.

"In the past five years, we have seen an increasing shift toward more software-centered innovations. These relate to a wide range of functions, which integrate our products deep into the workflow of our customers. One major innovation is that we can deliver customer-specific solutions, based on our core IPEmotion data acquisition software, on a large scale."

The IPEmotion software includes a Windows version for all PC-based measurement tasks, but Ipetronik has also modularized the software over the past three years so that it can be used on Linux-based datalogging operations.

"Based on a common source platform, we provide customer-specific OEM setups, which include dedicated functions to optimize workflow," Strothmann explains.

Strothmann believes three major trends will emerge in the coming years.

"The electric drivetrain is the enabling technology for fully autonomous vehicles," he says. "Once the software is able to operate these powertrain systems, it will be possible to have self-driving vehicles. We are preparing new datalogging systems to support validation of autonomous vehicles."

Vehicles will also be fully connected, Strothmann continues. "However, the datalogging systems will need IoT connectivity too. We implemented this in our loggers for remote access and health status diagnostics. The functionality will be expanded to provide remote service operations, such as vehicle software updates and diagnostic functions."

Big data will also play a role, and Strothmann believes it will be important to have software tools to convert this data into usable information.

"With our new IPEcloud MDM software platform [due in 2019], we will introduce a new product that can manage data in a systematic and structured way, and can apply MATLAB-based data analytic functions."

Keeping up with the rapid pace of electrification is a constantly evolving challenge. Ipetronik's development means its products – and the customers who use them – will be ready to deal with whatever the industry throws at them.

High-power charging

Advances in charging infrastructure technology have enabled development of a fast-charging system that is already operating in major projects being rolled out all around the globe

High-power systems are required to reduce the time spent charging electric vehicles

When consumers think about purchasing an electric vehicle, one of the biggest concerns is how long they will have in-between charging, and how long charging will take. In areas where charging stations are few and far between, it becomes a 'postcode lottery' as to where to park up to charge – nobody wants to be stood by the roadside for hours waiting for the vehicle to power up.

With more service and petrol stations offering charging systems, car buyers are slowly becoming less anxious and more open to the idea of opting for an electric vehicle. During the past four years alone, there has been a remarkable surge in worldwide demand for electric vehicles, with more than 3.2 million EVs sold. A rise of more than 33% confirms that EVs could soon replace combustion engine cars. The popularity of electric vehicles, which produce fewer climate-warming carbon emissions, is being driven by growing concerns over air pollution. In the EU, where toxic air is at illegal levels in most urban areas, sales of diesel vehicles have plummeted by 17% in the past year – while sales of electric cars have soared by one third.

Now, as the public's perception of them warms up, electric vehicles are no longer the new kid on the block. With consumers constantly looking for the easiest way to charge the vehicle in the shortest time, fast-charging solutions have never been more vital. Currently, charging times are lengthy and disruptive to everyday life, as many charging spots offer average outputs of 7-50kW, with full charging taking up to three hours. Although one hour is short compared with the previously typical eight-hour wait, if a driver must stop at highway services to charge their vehicle, an hour can soon drag and become tiresome.

Huber+Suhner, a Swiss manufacturer of components and systems for electrical and optical connectivity, has developed an innovative power cable solution to enhance electrical charging stations. This has gone from strength to strength in the past year and was recently implemented in a high-profile project in the USA. Thanks to an integrated cooling system, it cuts the time for the charging of electric cars to less than 15 minutes (80% state of charge), while still ensuring safe and easy operation.

The HPC is designed to handle higher power ratings for future vehicles

The Huber+Suhner Radox HPC (high-power charging system) guarantees safe performance for power delivery up to 500A and 1,000V. The Radox HPC system has been developed to be flexible, easy to handle and lightweight, and enables higher ratings, ensuring it is future-proofed. The upward-compatible and customizable system helps the utility provider to be prepared for future needs and, as a result, secure vital investment.

Safe performance is guaranteed for power delivery levels up to 500A and 1,000V

The Radox HPC system is flexible, lightweight and easy to handle

To bring more advanced and adaptable electric cars successfully into the market, a solid network of charging stations is also required. Along with the existing standard charging points for electric cars at home, work and in car lots, a new generation of high-power charging points are being implemented along main travel routes to ensure drivers are not restricted, with experts suggesting that the worldwide number of public charging points will increase from 550,000 in 2017 to approximately 33 million in 2030.

With the ability to charge an electric vehicle in less than 15 minutes from a convenient station and enough battery to last for hundreds of kilometers, Huber+Suhner believes it makes sense for motorists to switch to electric cars as their favored method of transportation. The state-of-the-art infrastructure will not only make lives easier and safer, but with the addition of more charging points with the Radox HPC system implemented around the world, charging an electric car away from home will no longer be uncertain – drivers will be able to park up, plug in and drive off in record time.

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Multilayer materials

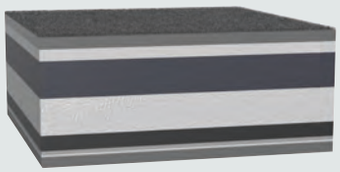
A combination of lightweight composite material and microperforated aluminum layers achieves the same rigidity and stiffness as body sheet steel, with major weight reductions

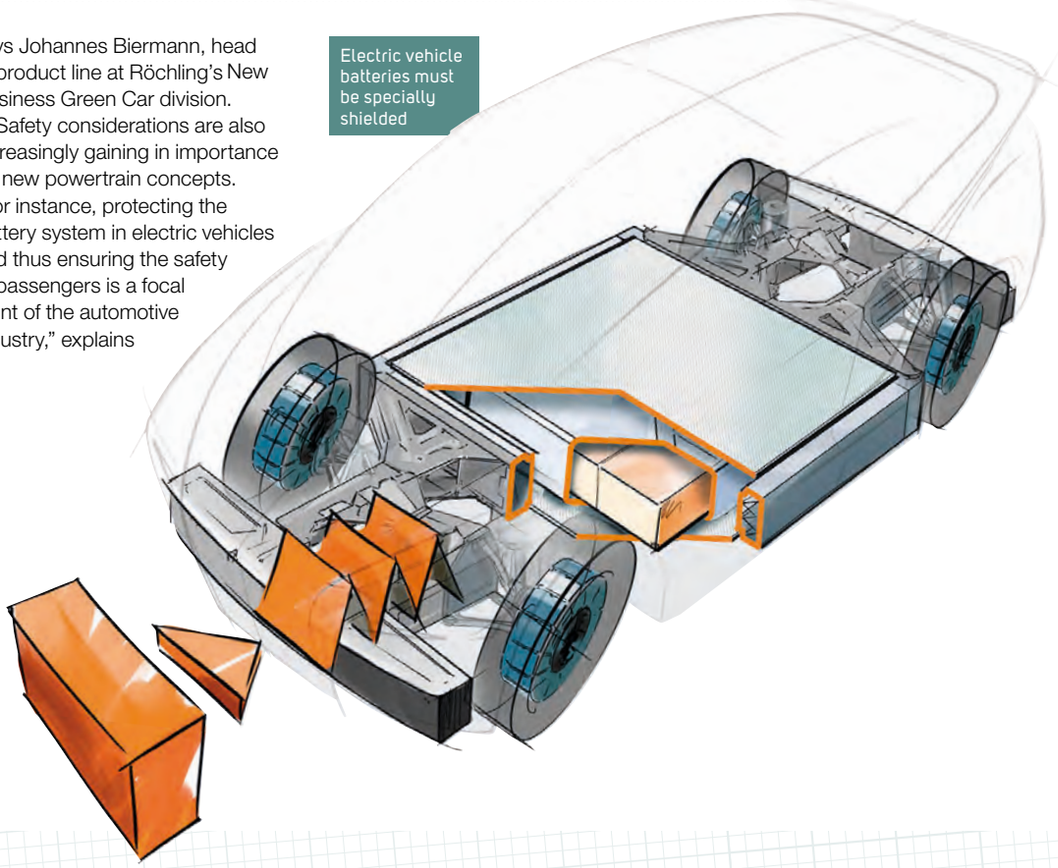
When selecting the most suitable material for an application, developers are often spoiled for choice. Many materials offer positive properties in one way or another. But what can be done when a combination of properties is required? How easy would it be if the material in question were not only lightweight but, for example, also had acoustic, crash safety and bending stiffness properties? Röchling has the answer: Stratura Hybrid – a combination of the lightweight composite material LWRT (low-weight reinforced thermoplastic) and microperforated aluminum layers. This is an innovative materials approach with the potential to achieve the same qualities as body sheet steel in terms of rigidity and stiffness.

One application area of Stratura Hybrid is the Integrated Sandwich Floor (ISF), a multilayer, integrated floor that replaces the conventional car body floor. Consisting of a carpet layer, the multilayered functional structure of Stratura Hybrid and a layer resistant to stone chips, weight and thickness are reduced by more than 50% compared with a conventional car body design. To meet increasing crash requirements, it is even possible to include aluminum profiles to increase the structural properties. As part of the Light-eBody research project funded by the German Federal Ministry of Education and Research, together with the other partners in the consortium, Röchling has created material cards used for mechanical and crash simulations.

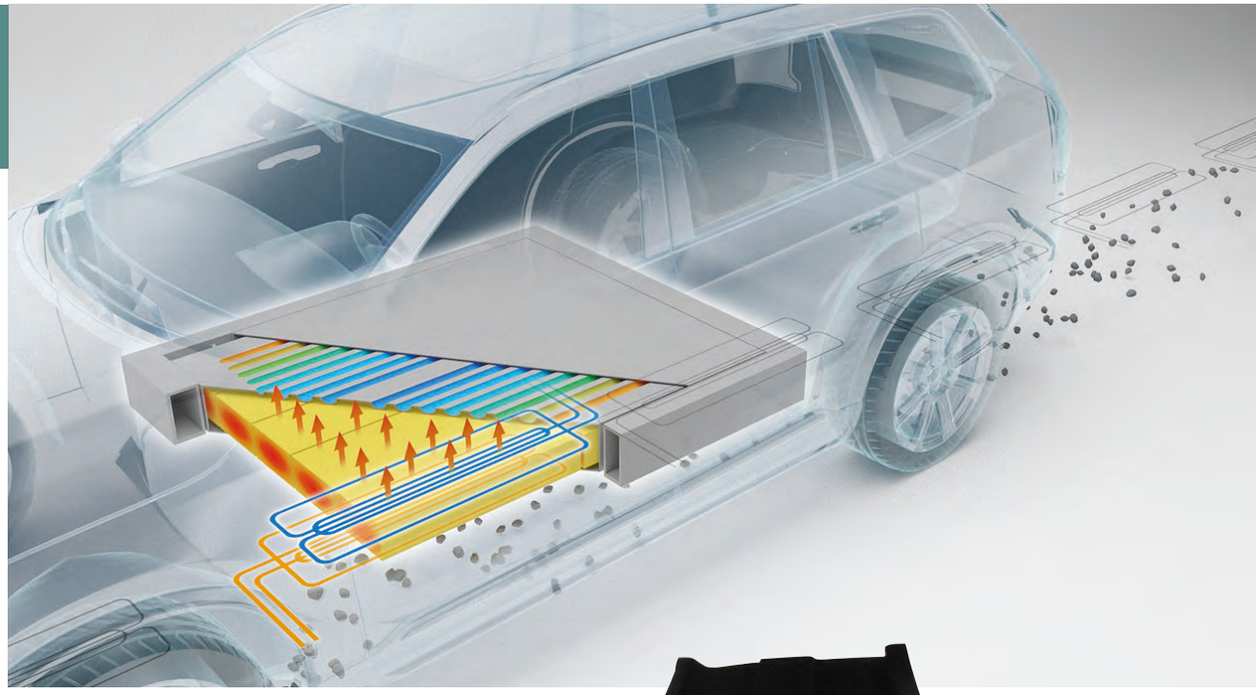
"Our materials approach allows us to create extremely rigid and very light components. With regard to electromobility, however, the excellent acoustic absorption behavior is the greatest advantage," says Johannes Biermann, head of product line at Röchling's New Business Green Car division.

Safety considerations are also increasingly gaining in importance for new powertrain concepts. "For instance, protecting the battery system in electric vehicles and thus ensuring the safety of passengers is a focal point of the automotive industry," explains

Standard floor	Integrated Sandwich Floor
	
• Carpet • Impact protection • Damping • Foam • Anti-drumming foil • Sheet metal • Anti-rust coating • Underbody cover	• Carpet • Microperforated aluminum foil • LWRT • Microperforated aluminum foil • Stone-chipping resistant layer • **More than 50% weight reduction** • **More than 50% lower part thickness** • **Higher absorption of crash energy**



Electric vehicle batteries must be specially shielded



Tests have demonstrated that Stratura Hybrid is ideally suited for vehicle crash situations

Biermann. Currently metal housings are still used to protect the batteries in EVs, even though plastic-based housing materials can meet all the requirements and reduce both cost and weight.

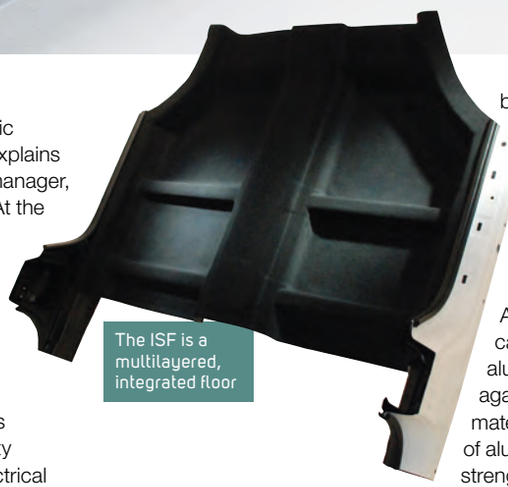
Materials that are effective in the event of a crash must essentially meet two requirements: a high degree of elasticity and a large elongation at break to absorb the considerable amount of energy generated during a crash.

However, all these positive material properties are useless if an unfavorable component design does not enable the application of the material properties. Suitable components must be able to support themselves in the event of a crash. Therefore undesired notch effects, changes in wall thicknesses, additional reinforcing elements, soft areas and accordion effects must be avoided.

Stratura Hybrid does not have any of these unsuitable geometric properties. On the contrary, tests have shown that the material is ideally suited to crash applications. "The test samples consistently absorbed the kinetic energy of the trial crash with very uniform deceleration curves until the movements had come to a complete stop and the kinetic energy was fully used up," explains Richard Koehnsen, senior manager, New Business Green Car. "At the same time, the samples remained in one piece without fracturing or splintering. This behavior can be adapted to specific requirements by selecting appropriate aluminum foils."

Stratura Hybrid also offers electromagnetic compatibility (EMC) protection for the electrical components in electric vehicles. Why is EMC so important? Every time an electrical circuit is opened or closed, magnetic fields – known as induction fields – are generated around the conductors. These fields can pose a particular danger in electrically powered vehicles.

This could happen when sudden load changes occur, for instance when an emergency stop is performed at full speed. If an 85kW electric vehicle has to perform emergency braking at full acceleration, a driving voltage of 400V in the circuits means that over 200A are suddenly released, which creates an induction field around these circuits. In turn, electric currents, which correspond to the drive power in terms of both voltage and amperage, are induced in adjacent electrical components into which this induction field protrudes. If countermeasures are not taken, the components will be damaged by the induced currents.



The ISF is a multilayered, integrated floor

The induction caused by load changes cannot be prevented, but the effects can be reduced by shielding. If a closed electrical conductor is placed around the induction fields, countercurrents will be induced in this conductor and absorb and short-circuit the electromagnetic pulse. Electromagnetic shielding works best with a highly conductive material. Silver, copper and gold are the best shielding materials. Nevertheless aluminum is the material of choice here because it is more cost-effective and offers greater weight advantages. A shielding effect of over 110dB can be achieved with a sheet of aluminum just 0.1mm thick. Once again, Stratura Hybrid is the ideal material partner. Thanks to its use of aluminum foils as a mechanical strengthening layer, the material offers excellent shielding.

"We see enormous potential for Röchling in the field of electromobility thanks to the extensive materials expertise we have built up over the years," explains Koehnsen.

"In the course of several development projects we have integrated aluminum layers to create a stable, hybrid solution. In the future many components in a vehicle could be replaced by Stratura Hybrid."

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WHICH SIDE ARE YOU ON?

Electrical transport plays an important part in building a sustainable future – but BEV batteries can also make a substantial carbon footprint. The level of CO_2 in the upstream value chain makes a huge difference.

Battery production

SWEDEN

Time to CO_2 neutral*

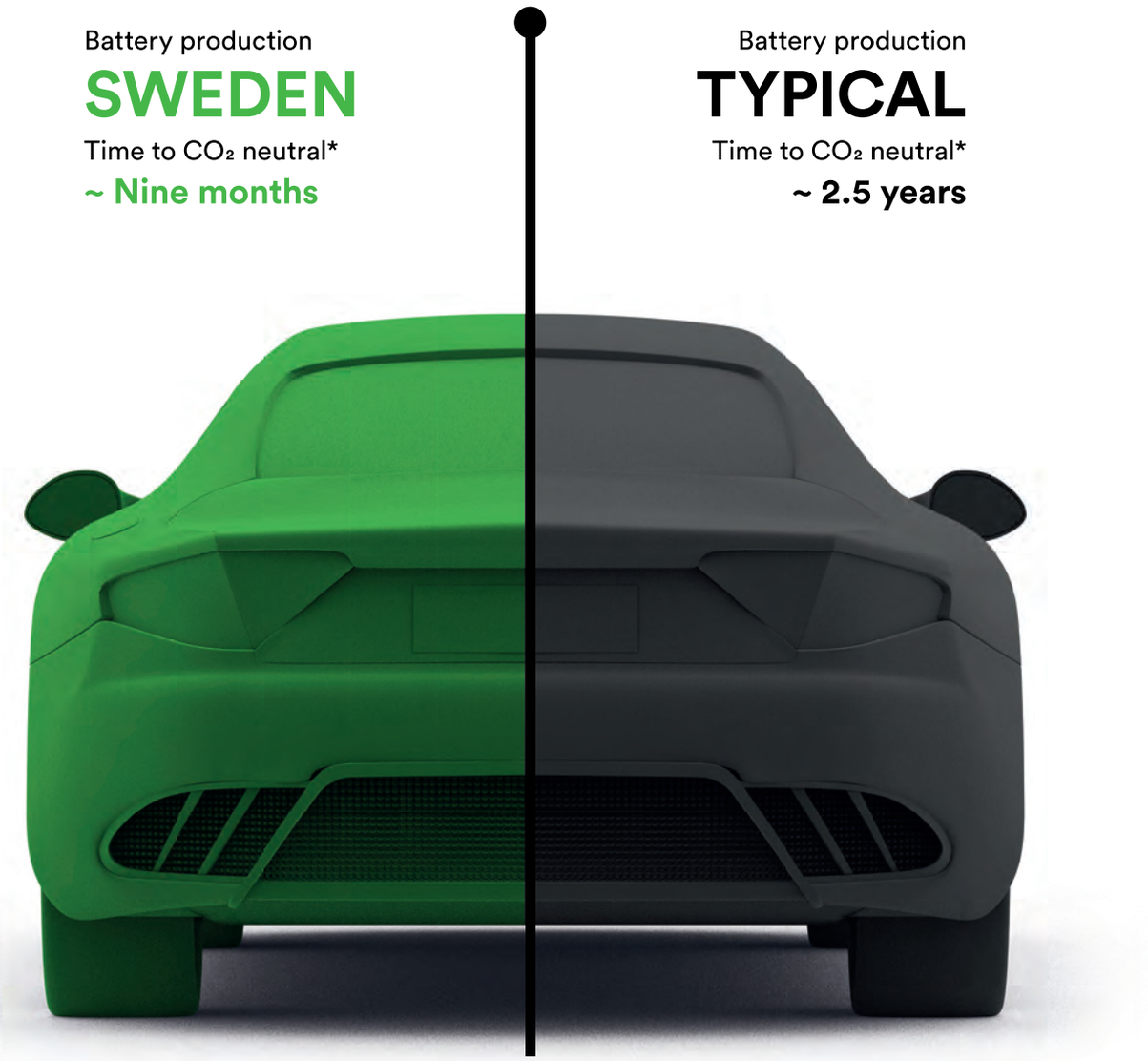
~ Nine months

Battery production

TYPICAL

Time to CO_2 neutral*

~ 2.5 years



Calculated for mid-class BEV with Swedish electricity mix for charging (0.04 g CO_2/kWh) compared to mid-class ICE-Vehicle with an emission of ca. 150 g CO_2/km.
*Compared to 150 g CO_2/km ICE-Vehicle (12.000 km/yr)

www.nodepole.com

NODE POLE

EV drag race technology

Powerful electric drag racing vehicles, designed from scratch by a pair of Danish cousins, rely on the latest battery technologies, controllers and management systems

In 2007 two cousins, Hans-Henrik Thomsen and Glenn E Nielsen, began building an electric motorcycle in their backyard in Denmark, with few resources but big dreams. Today their Danish drag racing team, True Cousins, holds seven world records under the National Electric Drag Racing Association (NEDRA) with two bikes (Silver Giant and Silver Bullitt driven by Thomsen) and two cars (TC-9 Hornet and TC-X driven by Nielsen) built by the pair from scratch. The team runs only battery-powered vehicles. NEDRA promotes electric vehicle drag racing to increase public awareness of EV performance and to encourage advances in technology.

Thomsen and Nielsen's world record run in higher voltage classes started in 2012, when the Silver Bullitt achieved a record time of 6.75 seconds in the 96V class. In 2013 the bike took a second record in the 144V class with 5.58 seconds. After alterations and rear reinforcements, the Silver Bullitt achieved a hat trick with the quickest time ever for the eighth-mile (200m) track, at 4.82 seconds.

Equally impressive, the team's first electric car (the TC-9, based on the old British kit car the Eagle SS) set two world records in the 240V and 300V classes (7.07 seconds in the eighth-mile). Since the chassis construction was limited, the cousins constructed the TC-X, a full-blown doorslammer drag racer, cast with much lighter glass-fiber bodywork. In 2017 the TC-X successfully posted a world record time of 4.89 seconds on the eighth-mile track at Malmö Raceway in Sweden.

Key to the team's success was the effort put into perfecting the battery. "In drag racing you need enormous power for acceleration for just a few seconds," says Thomsen. The team now uses 5,000mAh lithium cobalt pouch cells in 48V modules, a battery management system (BMS), controllers and a charging system – all produced in-house. The BMS helps to protect the battery cells, carefully surveying the voltage and the temperature.

Above: The Silver Bullitt can cover an eighth-mile in 4.82 seconds, and achieves the 0-100km/h sprint in just 1.1 seconds (Photo: Nico)

Each cell is measured and inspected visually for imperfections, and is delivered specifically without wires, which create resistance and can burn. The team uses cells with a C-rating of 60-70 and keeps the battery within a range of 3.0-4.15V. If the cells run outside that range, they could destroy the battery or cause a fire.

Thomsen and Nielsen have gained considerable expertise, working closely with their battery cell supplier and building the battery packs with their precision soft-welding tools. They use a permanently installed BMS that constantly checks voltage. To date, the team has not had a fire, and has even started building packs for other racers.

Thomsen, Nielsen and their sponsors are proud of their accomplishments. A 0-100km/h in 1.1 seconds is "far quicker than the Tesla Roadster at 1.9 seconds", says Thomsen. The team's aim for 2018 is to break the Guinness record for electric motorcycles over the eighth-mile, and to compete on a quarter-mile track – most likely the Hockenheim NitrOlympX or Mantorp Park.

Above and left: The TC-X can do an eighth-mile in 4.89 seconds, 0-100km/h in 1.1 seconds (Photos: Photophobia (above), Smile B (left))

The True Cousins team credits its sponsors for providing access to the very best battery technology. The main sponsor is Munters Corporation, where Thomsen works as an area sales manager in Denmark. Munters and the True Cousins team share a passion for innovative solutions. Inventor Carl Munters founded the company 60 years ago with a focus on dehumidification and evaporative cooling. Today Munters supplies highly energy-efficient dehumidification, which is installed in lithium battery research and production dry rooms around the world. These systems maintain ultra-dry conditions for new battery chemistries under development for EVs, including the record-breaking vehicles used by True Cousins.

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3D surface heating for EVs

Electrified and autonomous vehicles rely on technologies that must be fully functional in any weather conditions, as well as being lightweight and extremely energy efficient

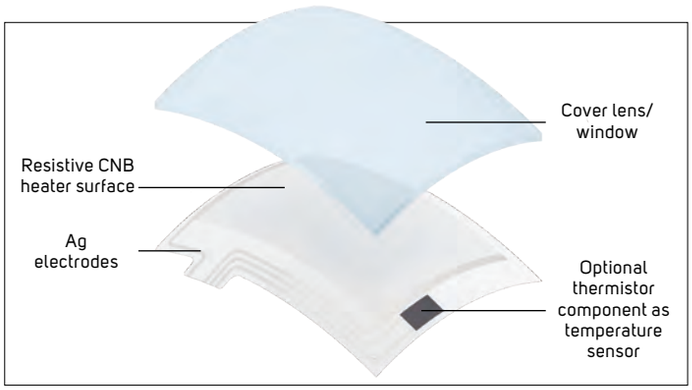
The rise of electric vehicles and autonomous driving is changing the driving experience, as well as automotive manufacturing. Autonomous cars and driving/parking assistants require fully functional sensors to be reliable and usable in any weather conditions. People have to trust their vehicles to use them.

Canatu's unique, transparent CNB films enable 3D heaters, similar to the company's 3D touch surfaces. The CNB film can be integrated with sensors supporting autonomous driving and enabling driver assistants, as well as with LED lights and mirrors. It has possible applications in numerous features likely to be found in future cars. The heater can be integrated with complex 3D surfaces by forming, molding and laminating. This increases usability and design freedom, as the heaters are embedded unobtrusively. These surfaces remain clear in humid or freezing conditions with efficient, electric de-fogging and de-icing.

The optical properties and formability of Canatu CNB films enable sensors to be fully functional in transparent surfaces with 360° or fish-eye view. The material also has very low haze, meaning it does not fuzz the transmission light, which is important when sensing through the CNB heated surface. The CNB film offers fast and even heating, meaning the full area remains clear and there are no local hot spots.

EVs are very energy conscious and require lightweight and low-energy solutions. Canatu CNB film is extremely lightweight. Compared with the conventional way of heating the air first – which results in waste heating – and then heating the required surface, the direct CNB heater surface integration offers considerable energy savings.

Electrified, autonomous vehicles must use sensors that function in any weather conditions



"Autonomous driving is a mega trend. It has to be safe so that people can trust in it. Canatu is enabling autonomous driving in any weather. Additionally, we are combining energy savings with seamless body design," says Juha Kokkonen, Canatu CEO.

Denso Corporation wants to be at the forefront of future mobility and is investigating how new technologies can help to realize its visions. Denso has therefore invested in Canatu during a recent investment round in 2017, and is now pursuing joint development for several applications. "We have done calculations with the material and we trust the unique technology can be used in several product areas of future driving," says Hirotsugu Takeuchi, executive director, Denso Corporation.

Canatu's CNB technology warms sensors to prevent the build-up of ice, which could impair functionality

Canatu CNB is a conductive and transparent thin film, with 200% stretchability and 1mm radius. It offers good optical clarity, is transparent with no haze, and heats up fast and evenly. The heaters are very light and thin, with a simple stack structure integrated within the cover lens. A typical heater stack consists of a thermoformed/injection-molded lens, polycarbonate resin, 0.25mm polycarbonate film and HTR N layer for thermoforming.

An A5-sized heater with a 2.25mm-thick PC cover can increase the surface temperature by 10°C (50°F) in 5.7 seconds and keep the surface warm during vehicle driving.

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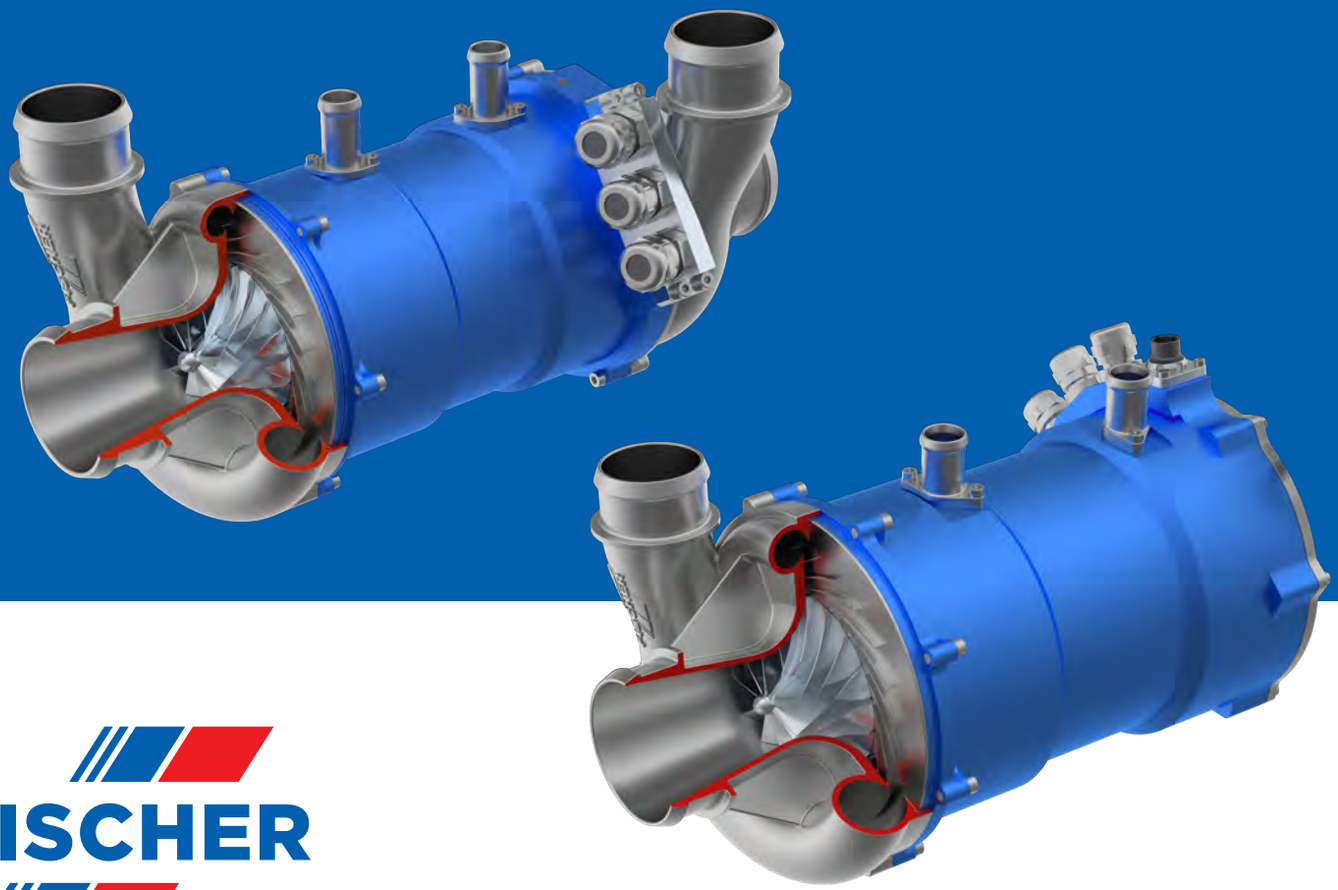
The **Power** of **pure Air**



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FISCHER AG Präzisionsspindeln
Ernst Fischer-Weg 5
3360 Herzogenbuchsee
Switzerland

Reliable measurements

Testing vehicle components and prototypes requires external measurement technology that can provide data under difficult conditions, including in high-voltage environments

CSM's all-round solutions measure analog voltages and temperature

Sooner or later, the moment of truth will come for every vehicle component. Then the newly developed components have to prove in extensive tests whether they, in practice, meet the standards for which they were designed. Internal sensors can only be used to a certain extent as environmental influences – heat, shock, vibration – pose specific demands on the measurement technology used.

Contrary to laboratory devices, CSM's compact measurement modules are resistant to moisture and dirt (protection class IP65 or IP67) and provide an operating temperature range from -40°C to +125°C (-40°F to +257°F). This enables these modules to be mounted close to the points of measurement – for example, on the underbody or in the wheel housing. Thanks to the distributed mounting, sensor cable harnesses (which can be as thick as arms when used with centrally mounted modules) can be reduced to pencil-thin connection cables.

Anyone familiar with the automotive sector knows that temperature measurements on a wide variety of components in and on the vehicle (such as engine, exhaust tract, transmissions and brakes) are among the most common areas of application. With the introduction of e-mobility, high-voltage resistance and the operational reliability of measurement technology became a new challenge. Since the best-possible user safety is of the utmost priority, CSM's high-voltage safe modules are developed and tested according to safety standard EN 61010.

Temperature management in the energy storage unit (high-voltage battery) is of vital importance when developing electric drives. Heat and cold have an immediate impact on the battery efficiency, and thus the range of an electric vehicle.

And as charging and discharging processes of an HV battery have a decisive influence on the operating temperature and, accordingly, on the service life of individual battery cells, measurements at the charging station and its surroundings are just as important as the battery measurements themselves.

High-speed and safe power measurement with CSM's HV Breakout Modules

Precise temperature measurements on the HV battery help to localize sources of heat loss, which cause power losses. Temperature measurement modules in combination with thermocouples or high-precision resistance sensors (PT100/PT1000) offer a safe and reliable solution.

Many sensors convert their measured quantities into analog voltages. Examples can be found in the measurement of pressures in brake systems, oil circuits, charge air coolers, compressors or exhaust tracts, as well as in the monitoring of oscillations and vibrations (NVH). CSM offers a range of innovative AD measurement modules for flexible voltage and current measurement to meet the challenges of a growing spectrum of measurement tasks.

How efficient are vehicle electronics and the onboard electrical system? For an optimum adjustment of sensors and actuators to each other, later operating conditions have to be taken into account during the development phase. Even here, AD measurement modules provide important information.

The dimensioning of electric components requires precise knowledge of voltage and current curves. The measurement technology must detect even very short voltage and current peaks, as these components may otherwise suffer considerable damage. Oscillation measurements also require very high sampling rates. With measurement data rates up to 1MHz and exact synchronization (≤1µs) regardless of the measurement setup's dimension, CSM's EtherCAT-based AD modules offer a solution for the analysis of fast signal curves. CSM HV Breakout Modules even provide the means for HV-safe power measurements. CSM also offers modules for specific measurement tasks in addition to the all-round solutions for analog voltages and temperature. As different as measurement tasks and fields of application may be, CSM can provide its customers with the solutions to suit.

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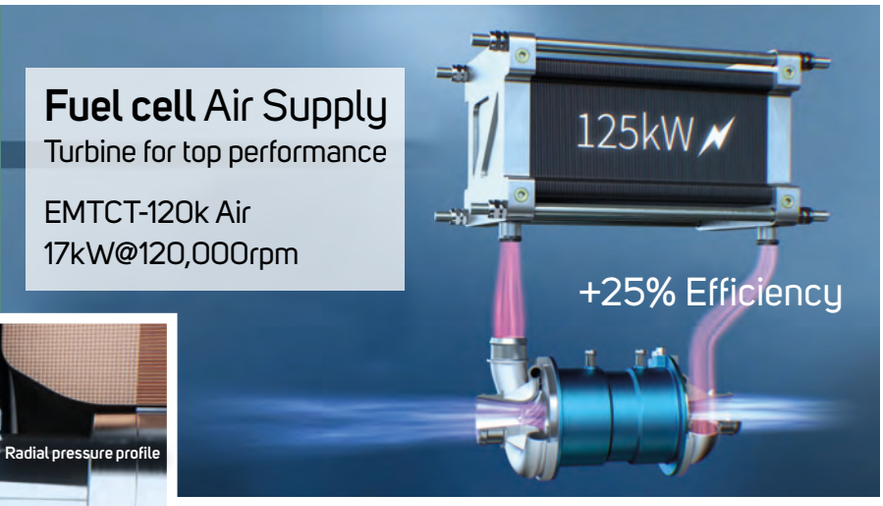
INQUIRY NO. 505

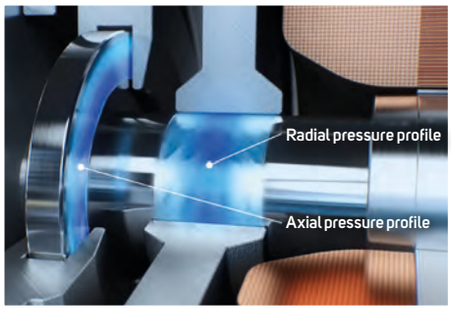
Fuel cell air supplies

With mobile fuel cell technology growing in popularity, electric micro-turbocompressors with unique gas bearings can provide high-specification air supply to the FC stack

Right: A 125kW fuel cell with EMTCT-120k air supply with compressor and turbine for energy recovery

Below: Aerodynamic precision high-speed profile gas bearings





Batteries aren't the only thing driving the upswing in electric transportation: another smart power supply solution is also ready to roll. Electric vehicles only make environmental sense if they're powered by electricity from renewable resources. In many cases, efforts to achieve a positive carbon footprint involve wind and solar power. But irregular generation patterns mean that energy from these sources always has to be stored before use. Long-distance travel stretches battery-only electric vehicles to their limits, and lengthy charging times, even with rapid systems, make them unattractive for users. The most efficient energy storage solution for this purpose is hydrogen. Used in fuel cells, it enables a vehicle to run efficiently and emissions-free, and to refuel in less than three minutes.

An effective fuel cell system depends on having the most efficient peripheral (balance of plant, or BOP) components possible. The stack is supplied with oxygen by an air compressor. This compressor acts very much like the human heart in the circulatory system to ensure the effective and efficient operation of the entire drivetrain. The supply of air to fuel cells has to meet the highest standards of performance, efficiency, robustness, price and durability, as well as keeping dimensions to a minimum to enable optimal packaging. Radial compressors are perfect when it comes to handling variable volume flows and high pressure in a broad vehicle map.

As a specialist in high-precision, rapidly rotating mechatronic systems, Fischer was quick to recognize this trend, and over the past 12 years has developed electric micro-turbocompressors with unique, contact-free high-speed gas bearings.

The modular portfolio of turbocompressors for supplying air to 30-120kW fuel cells is built on the basis of PSP (precision speed profile) gas bearings coupled with sophisticated synchronous drive technology. This specific gas-bearing system does not require any additional peripheral equipment, and guarantees unsurpassed stack longevity as it is free of oil, particles and hydrocarbons. The turboshaft floats contact-free on a dynamic cushion of air with excellent shock-absorbing properties for virtually vibration-free and wear-free operation. The bearing produces only minimal friction and low noise emissions, even at high rates of rotation, enabling excellent system efficiency and quiet operation. It is robust, compact and lightweight, giving the integrator plenty of space and freedom when it comes to vehicle packaging.

Fischer gas bearings require extremely precise engineering in the micron range; the bearing geometry is defined exactly, and the quality of the monoblock precision components is systematically documented. Competing technologies such as foil bearings, by contrast, comprise a number of delicate spring-loaded components that in most cases, as described in the relevant patents, rely on air drawn in to cool the hot axial bearings. This inevitably leads to overall efficiency losses of up to 15%. Given their flexible construction consisting of multiple components, foil bearings are also much more sensitive to vibration and shock, and are up to five times less resilient by comparison.

EVs have recuperation systems enabling them to recover energy while braking. Analogous to this, EMTCT compressors are fitted with an additional turbine that generates useful energy from the air discharged from the stack. The highly efficient turbine for smart energy recovery improves efficiency by up to 25%.

Fischer's electric micro-turbocompressors are mainly used in mobile applications such as ships, buses, trucks and cars, and have successfully proven their reliability in intensive field trials and on the test bench.

The EMTCT-120k Air easily passed shaker tests with axial and radial acceleration of up to 15*g*, and acceleration curves below one second. To meet demand for a wide range of applications from customers all over the world, the product ramp-up is in full swing, with continuous increases in production capacity and systematic cost optimization for serial production.

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Rapid electrification

Understanding and controlling power use and distribution in electric vehicle systems is fundamental to moving with the fast-changing electric and hybrid development landscape

The automotive industry is facing interesting challenges with electrification, as multiple forces move the development along quickly. Rising to the top of these are the increasing regulatory restrictions on emissions and a shift in consumer preferences.

On one side, there's a proliferation of legislation from countries around the world. The general dictate is to reduce greenhouse gas emissions in the average fleet over time. This can only be achieved by adding electric propulsion to the powertrain.

Added to that, there is a clear lifestyle factor that weighs in on the argument, as more car makers are offering desirable electric vehicles that trade on the value of their brand image. This very image can entice customers to switch from traditional ICE vehicles to alternative fuel, low-emission vehicles.

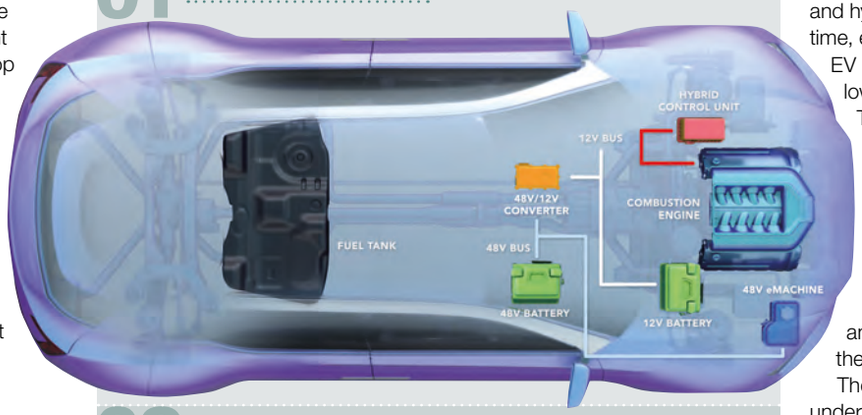
With this development comes challenges. The combustion engine is a predominantly mechanical machine, with electronic components that help make it more efficient. In contrast, an electric powertrain is straightforward – much like the motor in simple household appliances – with a battery to provide power. The hybrid powertrain is more complex as it combines a mechanical motor with electric motor requirements.

This is a new challenge for automotive OEMs and one which requires new design approaches. There is also a huge market growth potential for electronic components associated with the increasing sales of electric and hybrid vehicles. At the same time, entry barriers to the pure EV market are lower due to their lower architectural complexity. This explains the advent of startups around the world focusing uniquely on pure EVs. In contrast, legacy car OEMs are challenged to bridge the gap between the ICE era and the future of electrified powertrains, and the change of fleet portfolio they need to handle this flexibly.

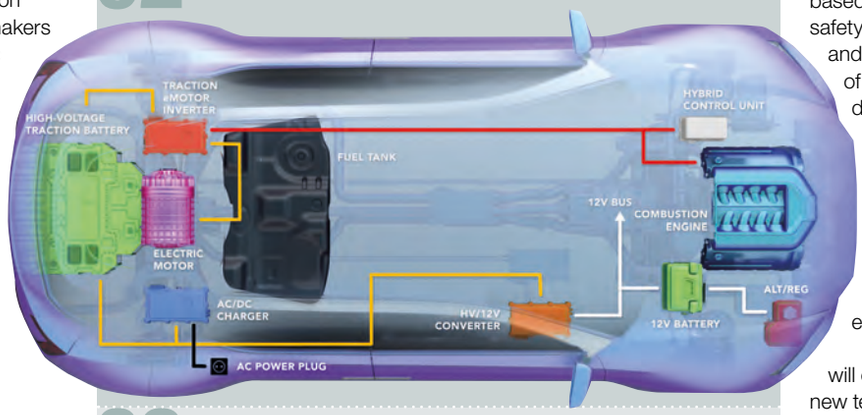
Therefore, it is crucial to understand the forces driving the EV electronic components market, based on the principles of functional safety and security, zero defects and high-volume production of robust automotive-quality devices. Key ingredients are new generations of high-performance microcontrollers coupled with dedicated precision peripherals to safely and robustly control batteries and traction motors in both pure-electric and hybrid powertrains.

The electric vehicle market will continue its evolution with new technologies and challenges introduced by autonomous operation. Understanding how these challenges will shape vehicle architectures and the market in the years to come is critical. Auto makers need to be flexible to quickly respond to market dynamics with the right electrification strategies to maximize their share in this growth domain.

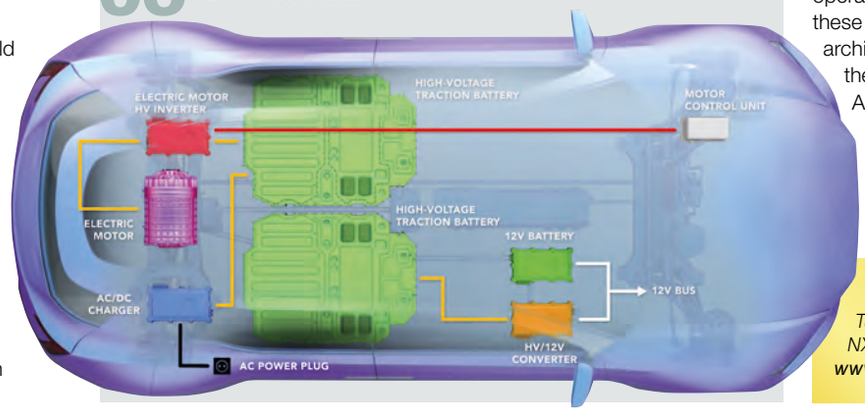
01 48V Mild Hybrid Powertrain



02 Plug-in Hybrid Powertrain

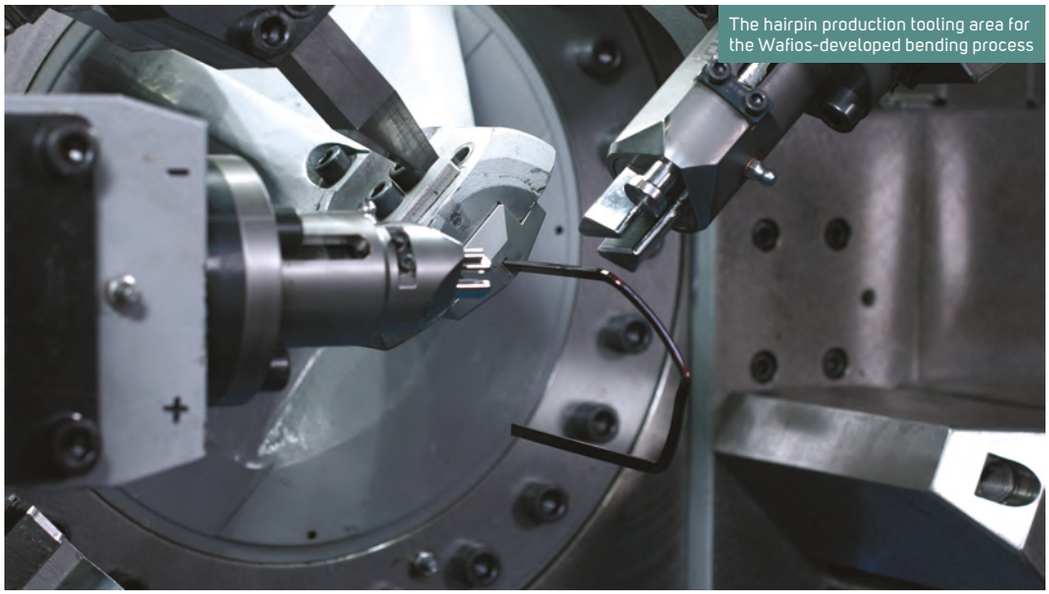


03 Electric Powertrain



Hairpin bending process

A flexible technique for hairpin bending enables the process to be accurate and free from physical damage, with geometric programming to speed up geometry definition

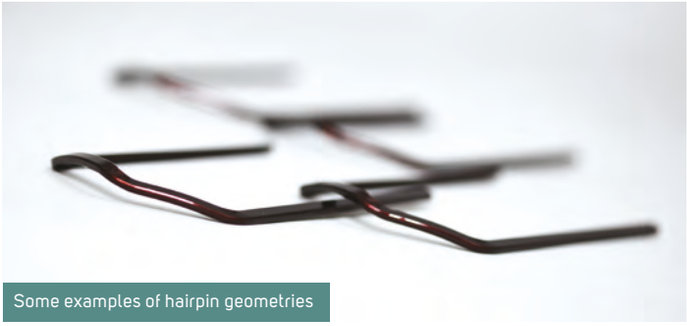


The hairpin production tooling area for the Wafios-developed bending process

A stator with hairpins that have been produced using the new technique

Hairpins are challenging bent wire components with copper wire as the core element, clad in a layer of insulation. These electrically conductive parts are used in a new generation of hairpin motors and are subject to extremely demanding requirements in terms of their geometry and surface properties. Existing manufacturing processes, such as those involving the use of automatic multislide units or transfer systems, usually entail a high level of overheads (in terms of system tool setup and programming work) as well as substantial tool costs.

With the wealth of experience that comes from 125 years spent forming wires and tube components of all kinds, Wafios elected to address the challenge of hairpin production. The result is one of the most flexible machines currently available on the market. The process means that the majority of hairpin geometries for a stator, including the connection assemblies required, can be manufactured in any sequence without the need to change tools.



Some examples of hairpin geometries

A patent for this new bending process has been applied for, and the technique enables bending work to be accurate and free of physical damage. This is a field in which Wafios has many years of experience. The measurement and feedback control algorithms this process employs ensure that the machine is able to monitor and control itself during production operations. Even in situations where the paint gets stripped inadvertently from the contact points, Wafios is able to offer various solutions to suit customers' wishes.

Geometric programming dispenses with the need for the user to program individual CNC axes. This speeds up the definition of hairpin geometry.

Flexibility depends on the geometric programming of bending parts and/or hairpins. The Wafios WPS 3.2 EasyWay controller also enables system users to import 3D geometries automatically using Step/IGES files. After the coordinates have been imported, the requisite bending program can then be produced automatically.

There is also the option of integrating and using the simulation tool to run throughout the complete production sequence of the bending component. The entire process is simulated using a digital twin – including machines, tools and workpieces – to create a dependable collision check in advance. The entire production planning process, including the programming of parts, simulation, definition of cycle time and the collision check, can be performed in parallel at an external programming station. In addition, simulation is used to establish the optimum tool arrangement for the specific bending part.

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INQUIRY NO. 508

Simplifying EV charging

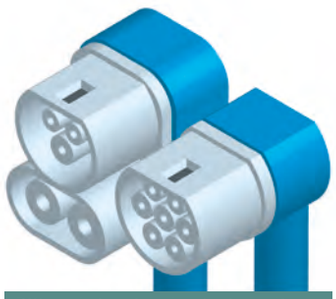
A greater focus on charging methodologies, as well as interoperability to counter international variations in charging technologies, will be vital to increased EV uptake

Although few actually realize it, electric vehicles have their origins back in the 19th century. Current environmental pressures, along with the acute scarcity of fossil fuel reserves, have now provided a particularly strong motivation for technological progression in this area. While battery technology has formed the predominant focus for development of the vehicles themselves, charging methodologies have also been placed in the spotlight.

The UK government's Road to Zero strategy sets out its ambitions for between 50% and 70% of new car sales, and up to 40% of new van sales, to be ultra-low emission by 2030. There is also a plan for all new homes to provide charging points, and newly installed streetlamp infrastructure to incorporate charging points too (with retrofitting into existing infrastructure also being an option).

While considerable sums of money have been granted to companies to develop charging infrastructure, there have been few constraints as to how this was to be spent. As a result, 72 different operators now exist in the UK. The Office for Low Emission Vehicles provides charging infrastructure installation incentives for companies and domestic customers. However, there is very little information available to help users decide which company to go with, or which charging infrastructure model would best suit their needs.

Governmental commitment to the development of EV charging networks will be key to the uptake of electrified vehicles



Different charging standards continue to battle for industry dominance

Zap-Map aims to help provide UK EV drivers with information about the different charging strategies available – fast, rapid and slow – as well as the different connector types. There is also information about the different charging options on offer to work users and domestic users, plus a continuously updated map of the public charging facilities available throughout the country.

Different parts of the world have adopted their own distinct tactics when it comes to the creation of public charging networks. This is due to how early on individual governments embraced the concept of the EV wholeheartedly and considered the need to create a unified approach to public charging.

Steve Large, the CEO of Hangar-19, a company that works to encourage the uptake of EVs, says that wide variation in the UK contrasts with the picture being seen in France – where one single payment card can be used over seven EV charging networks. The German state is directly funding up to 60% of installation costs for smart interoperable chargers.

At the slower (AC) end of the charging spectrum (where 4- to 12-hour charging times are expected) there are two main types of connector. Type 1 is present in North America and Japan, while Type 2 tends to be found in the rest of the world. Interestingly, the Nissan Leaf (the world's leading EV in terms of unit sales) incorporated Type 1 connectivity until 2017, but has now switched to Type 2, posing something of a challenge in terms of charging legacy EV models.

At the rapid charging (DC) end of the scale, two standards are still battling for dominance – CHAdeMO (used primarily in Japan) and CCS (found mostly within Europe). Each has a different connector shape and 'talks' to the cars in different ways. Tesla offers yet another approach, which is closer to the CCS standard. It is now recognized that every rapid charging infrastructure should be able to support both standards.

There are still barriers to overcome in convincing the public about the merits of going electric – and ensuring that there is adequate infrastructure to support their choice. While critics of EVs complain about the dangers to other road users posed by silent cars, governments also need to make more noise – the clock is ticking.

Laser welding for EVs

Application of laser welding during electric vehicle component production can save time and materials, and create new opportunities for flexible product development

The appeal of a production method that provides greater design flexibility and increases cost-efficiency is obvious, so Hollmén & Co has conducted extensive research on various manufacturing technologies. As a result of intensive R&D, the company has developed a laser welding technique for aluminum and copper cooling elements that provides a strong competitive advantage to its customers.

"We provide a solution that is more easily automated, shortens the production lead time and makes process management more efficient than with conventional manufacturing methods," says Juha Haaslahti, CEO of Hollmén & Co.

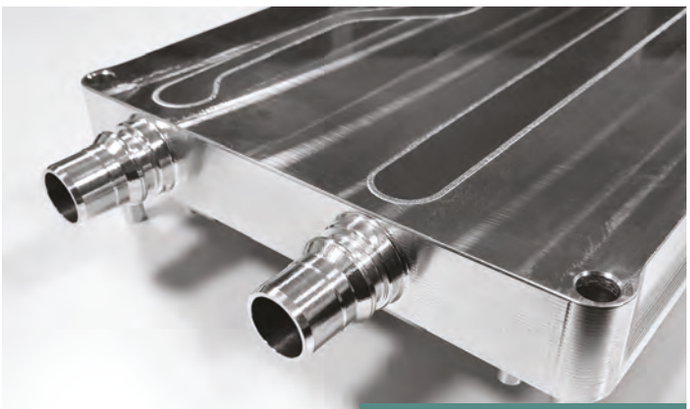
The development work at Hollmén & Co focuses on efficient heat transfer. As technology continues to progress, components become smaller but also more powerful. This trend imposes new requirements on thermal management. Hollmén & Co's technique, where the heat transfer mechanism is integrated directly inside the components, is designed to respond to these requirements.

"Laser welding gives us greater freedom to design an optimal cooling channel structure," adds sales manager Tomi Prihti. "This enables more efficient heat transfer."

The laser welding technique incorporates design flexibility into the product development process from the very beginning. For example, an extrusion processing technique enables the production of semi-finished products before the laser welding, which considerably speeds up production.

"A number of solutions can be achieved with laser welding – the solution may be simple, developed according to the profile, or could even be something more complex," explains Haaslahti.

Laser welding offers greater freedom when designing components such as Danfoss's Editron electric machine



A laser-welded housing featuring directly integrated liquid cooling

When production is flexible, the product can be better designed and developed according to the customer's specific requirements. In addition, laser welding offers a more diverse and faster technique for joining metal parts than conventional soldering. Where competing techniques require large furnaces and long heating and cooling times, Hollmén & Co's laser welding technology enables the manufacturing process to be completed quickly and conveniently.

"Welding greatly reduces the lead time," says Prihti.

This cost-effective method is also flexible. Potential drawbacks and further possible development requirements are quickly detected by simulating prototypes in authentic environments.

"We are able to respond to different development needs faster than is typically possible in our field," says Haaslahti.

Due to its relatively low melting point, aluminum is not an easy material to weld. Various aluminum alloys are used for different applications, which makes the processing of the material even more challenging. Hollmén & Co's expertise with aluminum alloys and their applications has constantly evolved through the company's long-term development work.

"We are in our element regarding the needs of our customers for both innovative ideas and problem solving. We want to be actively involved in the end-to-end production development process of our customers, who are looking for efficient solutions," says Haaslahti.

In the automotive sector, Hollmén & Co specializes in the development of thermal management solutions. Among other things, the company designs and manufactures liquid coolers for electric car components. In the future, the demand for thermal management systems for batteries and engines will grow in many industries. In addition to prototype development, the company also processes high-volume orders for customers in the rail transport, forestry and wind power industries.

"Currently we are also involved in the E-ferry project funded by the European Commission involving the building of a fully electric car ferry in Denmark. We will supply the liquid cooler components for the battery," Haaslahti reveals.

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SECURE CONNECTIONS FOR A SMARTER WORLD

Manufacturing traceability

A series of steps to ensure accurate traceability in production environments can deal with potential challenges, streamlining operations and increasing productivity

To track works in progress in real time, manufacturers in all industries have embraced a strategy called traceability – the practice of marking parts with codes, scanning the codes regularly, and uploading key data into a database. This practice can seem complex, but it becomes clearer when it's broken down into specific phases tied to concrete tasks and technologies.

Omron delivers traceability using a concept called MVRC (Mark, Verify, Read and Communicate). The four components of MVRC provide a better way to understand traceability on the production line.

The Mark component reflects that the basis for traceability is the barcode. To ensure that barcodes stay with their associated objects, manufacturers use what are known as direct part marks (DPM). These are etched, printed or otherwise marked directly on a part. Printed labels are also used, but DPMs are more permanent.

Some industries – particularly aerospace manufacturing – need markings to last for several decades. These DPMs need to be applied using a highly durable marking method. Laser marking is a method that combines high resolution with a high level of permanence. It can create a mark that is durable enough to resist damage and delicate enough to produce legible 1-point font.

The Verify component is vital because, as detailed in the paragraph above, durability is critical. Many manufacturing environments feature high heat, corrosive chemicals and other aspects that can impact code readability. To ensure that markings will hold up under the pressures of the factory floor, manufacturers need to use a barcode verification system that grades marked symbols to key industry standards.

Today's laser marking technology can mark codes with resolutions of just a couple of micrometers on a variety of materials. This gives more options for code placement, but it also poses a challenge for verification. Fortunately, verification technology keeps improving, and some of the most advanced verifiers – including Omron's LVS-9585 – can grade codes with a cell size of just two thousandths of an inch.

Once parts are marked with verified codes, the system must read these codes at key points throughout the production line – the Read component of the concept. More code reading means more comprehensive traceability and more data for process optimization.

The MX-Z2000H applies traceable marks to the manufacturer's parts

The Omron LVS-9585 can grade part codes with a cell size of as little as two thousandths of an inch

Even when codes start out with a good grade, the harshness of some manufacturing environments can wreak havoc on their readability. Since no-reads can delay or even shut down the production line, it's essential to minimize their occurrence in any way possible. Some of the highest-performing barcode readers are exceptionally good at extracting data from hard-to-read codes. Omron's MicroHAWK barcode readers, and its HS-360X handheld, are equipped with advanced decoding algorithms that can read damaged, low-contrast and otherwise troublesome codes.

The Communicate component ensures that controllers on the production floor send traceability data to the manufacturing execution system to make it available for storage and analysis.

To meet high-level quality standards, traceability is essential. The more data, the better. However, the time required to process all this data can dramatically lengthen the production cycle. This creates a difficult trade-off between gathering and utilizing valuable data,and trying to keep an optimal cycle time. Intelligently designed controllers like those in Omron's NX/NJ series can directly transfer traceability information to a SQL database without hampering machine control performance, as a result of embedded SQL clients.

The MVRC concept helps manufacturers visualize traceability as a set of four main requirements with concrete challenges and solutions, enabling them to zero in on specific issues that occur within each phase and determine the appropriate technological remedy.

Supervisory control ECU

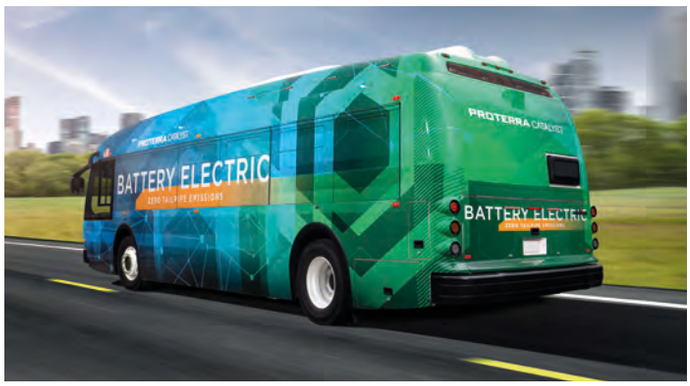
A new EV supervisory control ECU is now available for 24V systems, offering customizable I/O, advanced microprocessors, safety-oriented architecture and a user-friendly interface

Pi Innovo's M580 OpenECU controller is being applied in vehicle projects in North America, Europe, Turkey and Vietnam

Based on market demand, Pi Innovo has developed the M580 OpenECU controller for 24V applications, aimed at the truck, bus and utility vehicle sectors. Similar to the M560, which was targeted at 12V passenger car applications, the M580 was developed using ISO 26262 ASIL-D level processes to meet the critical functional safety requirements needed for supervisory control in electric vehicle systems.

As the M580 is designed for use in almost any 24V EV system, Pi Innovo provides documentation describing how the M580 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 are encountered by overall vehicle control units.

The M580 controller provides robust communication options. The 112 pins of flexible I/O are well suited to pure-electric and plug-in hybrid-electric vehicle 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 even in the most complex of system architectures, and the production-proven OpenECU model-based control development platform supports communication protocols such as UDS and J1939. Vehicle manufacturers can interface with the M580'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 electric vehicle systems use.



Much of the I/O that the M580 offers is customizable, making it ideal for development programs where the overall system architecture is evolving.

Customization is possible and costs can be reduced thanks to its 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. Through a partnership with electronics manufacturer TTM Technologies, higher volume and custom variants of the M580 controller can be delivered to OEMs with the quality and professionalism expected of a world-class Tier 1 supplier.

Pi Innovo can supply Simulink model-based vehicle supervisory control strategies. These are suitable for basic vehicle operations, or as a starting point for full production functionality to help accelerate system development. The OpenECU technology roadmap plans to include support for Ethernet connectivity, and for features that facilitate integration with ADAS and full autonomous driving solutions.

Due to its numerous customizable I/O, advanced microprocessor, safety-oriented architecture and user-friendly OpenECU Simulink application interface, the M580 is a versatile supervisory controls ECU designed for rapid controls prototyping development to volume production applications.

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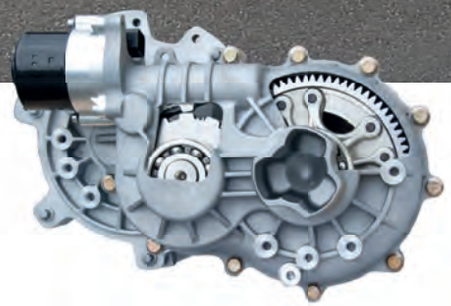
GKN ePOWERTRAIN



Drivelines that deliver

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Ideas in Motion

Contamination control

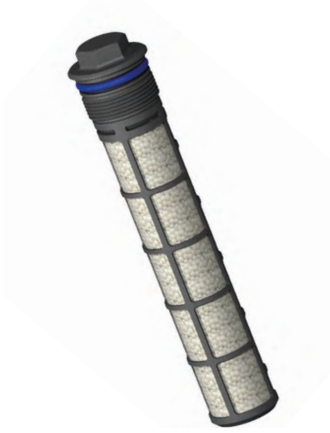
Filtration technology for a broad range of thermal management systems enables efficient heating and cooling for electrified mobility powertrains

Keeping Li-ion batteries and fuel cell stacks in the required temperature range is essential to reduce performance losses and avoid severe system failures. Depending on the system's performance requirements, air- or liquid-cooling is applied.

In open or closed air-cooled systems, particles can either enter the system from the environment or are released from the vehicle's interior itself – a few examples include the dirt adhering to baggage and containers, or animal hair. These particles can lead to wear inside the blower, reducing cooling efficiency. They can even be found sticking to the battery cells and terminals, and can lead to cell damage. Highly energy-efficient air filter media with a low pressure drop are used to protect the system from airborne contamination.

In fuel cell stacks and larger battery packs – especially if fast charging is required – liquid cooling is the technology of choice. In most applications, water/glycol mixtures are used, which flow through cooling channels integrated into cooling plates. The coolant flows are often high to dissipate the waste energy efficiently. Any damage to the pump caused by particle-induced wear will reduce cooling efficiency and lead to faster battery cell degradation, and thus to reduced electric driving range. Additionally, particles can agglomerate inside the cooling channels, blocking them. To prevent this, low Delta P filter media were developed based on filtration simulations. Special emphasis was given to the chemical stability against the coolant. To minimize energy consumption for coolant cleaning, the filter design is optimized for low pressure drop through CFD simulation.

Coolant oil particle filter featuring pressure drop-optimized filter media

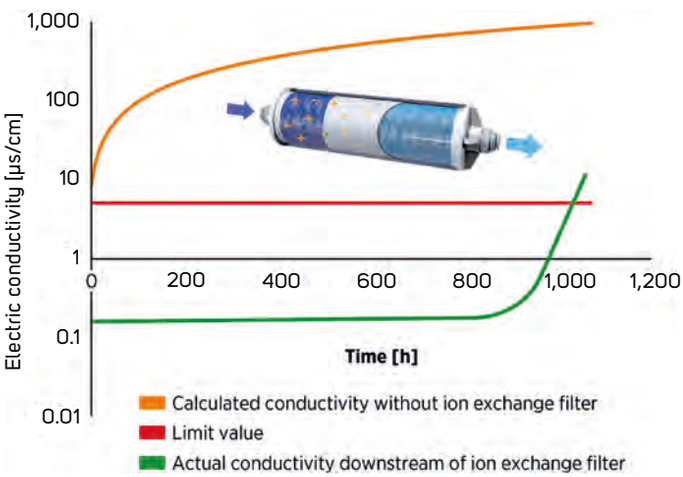


Desiccant filters ensure a constant, consistently high level of oil quality

An alternative solution for the indirect liquid cooling is the immersion of the battery cells in an electrically non-conductive liquid, such as an ester oil. In this case, particles must be separated as in the water/glycol mixtures. However, dissolved water must also be removed from the cooling oil. These liquids typically have a high water-uptake capacity, which leads to several system risks and could have a harmful effect on the battery pack itself. The dissolved water can lead to a loss of insulation properties and could form ice crystals at low temperatures, blocking the entire cooling circuit. Additionally the environment can become corrosive and biological contamination by microbial growth can appear. Highly efficient absorber materials lead to a controlled, water-free system and a constantly high oil quality.

Fuel cell coolants require an additional separation step. To avoid electric shorts in the fuel cell stack, the coolant must remain non-conductive. With continuous operation, ions can leach into the coolant – for example, from system component surfaces, additives from plastics and degradation/corrosion products. The more ions that enter the coolant, the higher the resulting electric conductivity. To separate these ions, ion exchange technology is applied, using a blend of cation and anion exchange resins. The temperature stability of these resins is essential, as are cartridge designs that enable a homogeneous coolant flow for optimum use of the resin. This is achieved through internal structures that also keep the resins from de-mixing (which would reduce cartridge performance). In addition the housing materials must be carefully selected to avoid any potential leaching of additives into the coolant.

The reliability and efficiency of modern electric mobility heating and cooling systems requires innovative filtration and separation solutions. Mann+Hummel filter products enable contamination control in a broad range of thermal management systems.



Clean coolant for low-temperature PEM fuel cells – ion exchange filter solutions

European battery production

A holistic approach to battery production for electromobility applications can point the way to sustainable production, and presents opportunities to develop commercial advantages

Batteries are the key technology of the energy transition. However, Europe has so far relied on imports from Asia. Around 90% of the batteries used in Europe for electric cars come from Asia. With the growing market for electric cars and the resulting increase in demand for innovative, efficient energy storage, the demand for a European alliance to ensure market competitiveness in the future is growing.

The battery's geographical origin, rather than its composition, plays a decisive role in its climate impact. To balance the tons of CO_2 from battery production, electric cars would have to provide about 150,000km (93,000 miles) of driving, which corresponds to a period of up to 12 years. There is no question, therefore, that the manufacture and use of batteries must become more efficient.

Patrik Ohlund, CEO of Node Pole, a Swedish investment and development hub for emerging energy industries

Lithium-ion batteries, more than any other chemistries, are facing the greatest growth and are vital for electromobility. Due to their high energy density, they are one of the most widely used electrochemical storage systems for mobile use in vehicles. What will be the largest and most modern Li-ion battery factory in Europe is already in the planning stage. Northvolt sees the establishment of such a factory in Sweden as an important strategic decision to power the transition to e-mobility. In cooperation with the ABB Group, Northvolt intends to produce the world's most environmentally friendly batteries.

Northern Sweden is particularly suitable for large battery production plants, which can enable process optimization for more efficient manufacture. Only 50 miles from the Arctic Circle and benefiting from among Europe's cheapest, 100% renewable, hydroelectric electricity, the region offers ideal conditions, especially for energy-intensive companies. Electricity prices are low and tax incentives can create even better economic conditions for companies.

In the Swedish town of Skellefteå, Northvolt's gigantic battery cell factory will follow the example of the Tesla Gigafactory in the USA and, in addition to material preparation, cell assembly and creation of the necessary tools, will include battery recycling capabilities.

With this unique large-scale project, Europe has the opportunity to develop the next generation of batteries and ensure global competitiveness through better technology. Northvolt is committed to sustainable and responsible raw material supply, clean production processes and recyclability.

The production of an EV battery, according to the standard global value chain, generates about 5,000kg (11,000 lb) of CO_2. The reason the emissions are so high is that much of the electricity for production comes from unsustainable sources of energy. By comparison, a conventional ICE vehicle emits 150g of CO_2 per kilometer and about 1,800kg (3,970 lb) of CO_2 per year. A middle-segment battery electric vehicle therefore needs about 2.5 years of operation until it is carbon neutral – rather than being carbon neutral on leaving the assembly line.

Swedish-made batteries, assuming that the separator and electrolyte are imported, would, for the most part, be produced using renewable power such as hydroelectric, wind and solar. These batteries would be carbon neutral after just nine months, enabling Europe to create an actual competitive advantage from the opportunity to develop a new generation of batteries.

A holistic approach to electromobility reveals elements of a system change with effects that will impact all stages in the value chains of car manufacturers and their suppliers. In the future, the automotive industry will drive system change out of its own global competitive dynamics. European battery production will therefore only be the next step for the future of electric mobility.

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Driveline design

The performance characteristics of electric vehicles have led to innovative design refinements for a mainstay of automotive componentry – the constant-velocity joint

The constant-velocity joint (CVJ) celebrated its 90th birthday in 2018, and though its role is unchanged, its design continues to evolve. CVJs revolutionized the production of front-wheel drive cars and are now used in almost every vehicle on the road. One of the world's leading suppliers of CVJs, GKN Driveline, has an output of more than 50 million units per year.

While EVs have marked an industry paradigm shift in terms of their powertrains, the driveline still has to transfer power from the motor to the wheels, like any other vehicle – which means that conventional CVJ systems are still required. However, given the typical differences in duty cycles and refinement between EVs and ICE powertrains, GKN is working on developments that will target higher levels of driveline refinement and efficiency for electrified vehicles.

The characteristics of EVs highlight numerous improvements required for the future design of CVJs. Of these, efficiency and NVH are the primary areas of focus. In an EV, for every 1% increase in efficiency, a manufacturer can expect an improvement of more than 1% in range. Range is typically a crucial consideration for EV buyers, so improvements in this area are arguably of greater importance to vehicle manufacturers than some other performance indicators.

Another serious consideration for EV drivelines is refinement. EVs require similar levels of mechanical driveline componentry to ICE vehicles for transferring torque to the wheels, but the noise level produced by an electric powertrain is much lower. EVs therefore demand quieter CVJs than have typically been required by their combustion-engine counterparts.

Driveline weight reduction is a useful contributor to helping car makers increase the range of their EVs. GKN Driveline's Countertrack technology made great weight savings when introduced in 2009, and the concept has been continually refined since. The counter-running ball tracks – hence the name – made it possible to reduce internal friction and heat, and to reduce the overall weight of the joint by up to 15% compared with a conventional unit.

GKN's VL3 CVJ and contoured diaphragm boot seal

The latest evolution of GKN Driveline's Countertrack technology is the VL3 sideshaft system, designed for rear-wheel drive cars. Substantial weight saving comes from a new shallow and contoured diaphragm boot seal design, which replaces the conventional conical CVJ boot design. This reduces the volume of grease required to lubricate the joint, saving weight, cost and packaging – and further boosting the joint's suitability for electric vehicle applications.

Alongside its development of technologies for CVJs, the GKN ePowertrain division is developing new electrified powertrain concepts that can maximize their benefits. The company's integrated electric axle concept – the eTwinsterX – is approximately 15% smaller and 10% lighter than electric vehicle systems that use separate components, and provides industry-leading efficiency thanks to its coaxial format, enabling a more direct torque flow. Its two-speed e-transmission and smart shifting strategy are designed to further maximize both EV efficiency and range.

"Our development of driveline innovations reinforces what we have always said about CVJs, which is that they are far from being a commodity product," says Dr Wolfgang Hildebrandt, director of advanced engineering at GKN Driveline. "If you think about CVJs in this way, then you will probably not be maximizing their performance in your vehicles. The technology is constantly being developed, and the latest systems can deliver major benefits for OEMs."

GKN Driveline produces more than 50 million units per year

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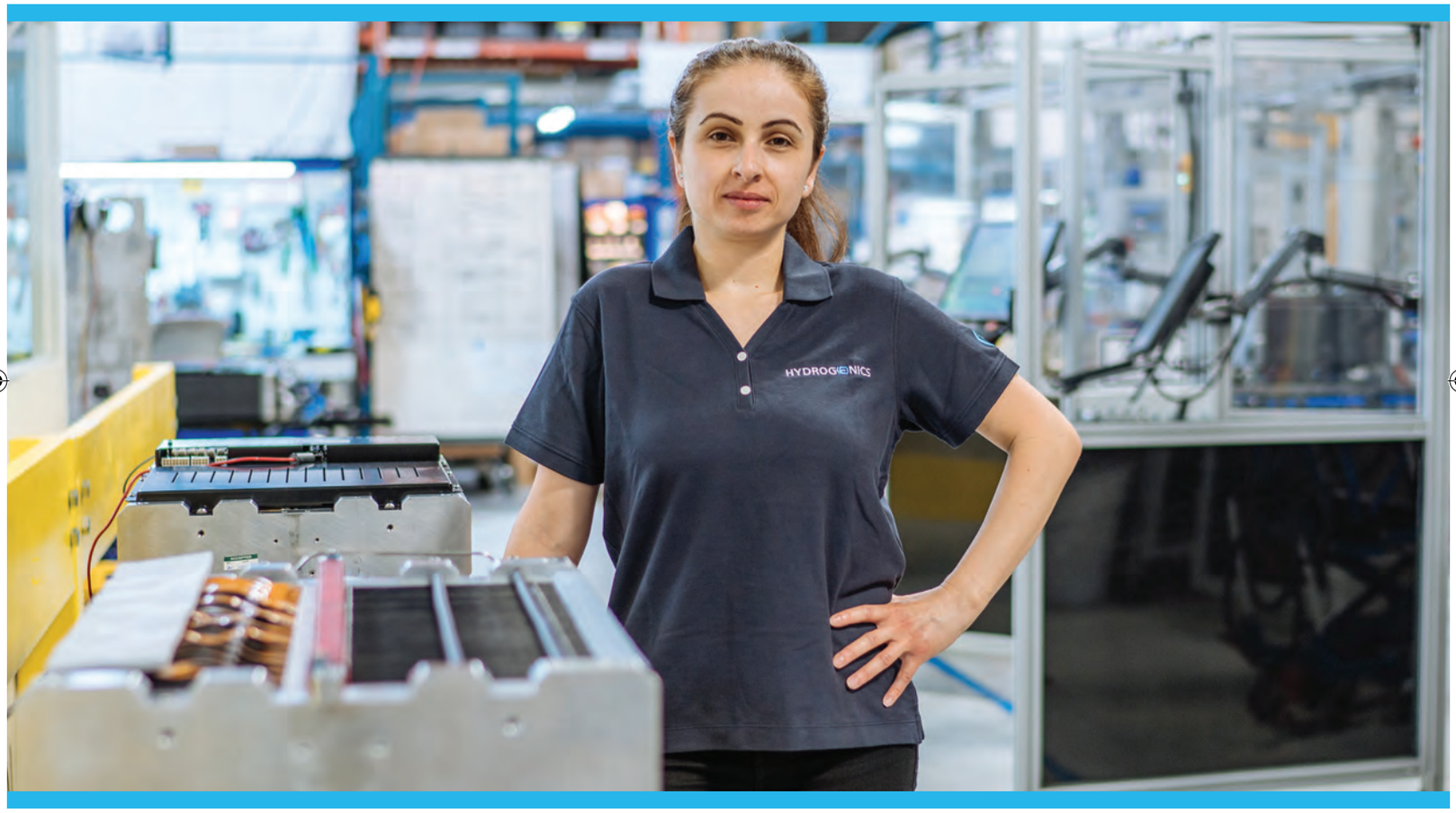
THIS IS SONIA SORBERA, MANAGER, FUEL CELL R&D.

AND SHE'D LIKE TO INTRODUCE YOU TO OUR HYDROGEN POWER MODULE.



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Embedding MOSFETs

A new technology that uses chip embedding of power MOSFETs in PCBs can meet increasing requirements for electrical power management systems

From 2021, an EU-wide average CO_2 emissions limit of 95g/km will apply to all newly registered passenger cars. This will increase demand for hybridization and electrification. Consequently product requirements for electrical power management systems with respect to power density, energy efficiency, reliability and system cost reduction are increasing.

Infineon Technologies and Schweizer Electronic are working together to roll out chip embedding of power MOSFETs in PCBs. This is a reliable way to meet such requirements. In this process, the power semiconductors are embedded into a system PCB (power and logic). It starts with copper lead frames (Step 1), which serve as carrier elements for the power MOSFETs. The MOSFETs are adapted for chip embedding and also go through copper metallization to make them compatible with the subsequent steps. Once placed in the copper lead frames, they are tested (Step 2). The scope of testing matches that of conventional discrete power MOSFETs (Figure 1).

The MOSFETs on copper lead frames are combined to form a three-layered laminate structure, then laminated to form a homogeneous bond (Step 3). Conventional bond wires are replaced by a wiring level above the chip. Gate control is implemented via tracks, and the source pads have a flat design to achieve a low-ohmic electrical connection and favorable thermal spreading of the dissipation loss. Contacting the upper side of the chip is done galvanically by way of copper-filled vias. After structuring of the outer layers, the power PCB is complete (Step 4).

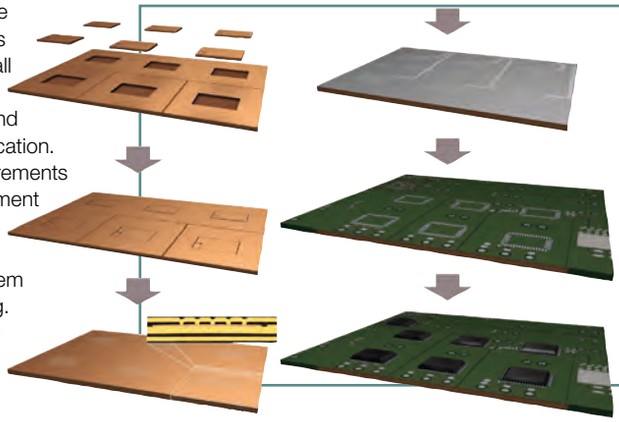

Figure 1: The process steps required for chip embedding power MOSFETs in power PCBs (printed circuit boards)

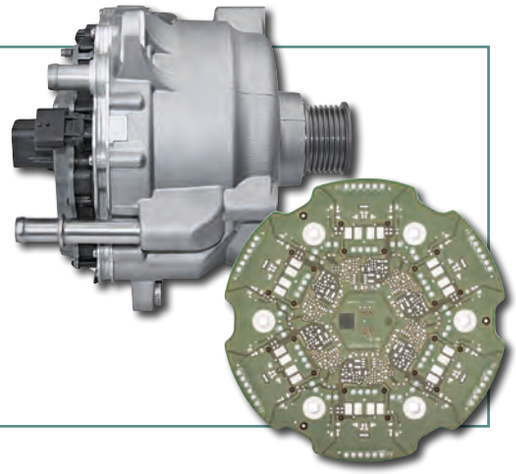

Figure 2: An example of a 48V starter generator featuring a system PCB and integrated power MOSFETs

The flat and homogeneous design of the power PCB makes it suitable for embedding in a system PCB without additional connecting elements (Step 5). This system PCB is then equipped with microcontrollers, driver components and so on (Step 6). It is then installed directly in the automotive application, including heat sinks.

Important advantages can be shown using a 48V starter generator for mild hybrid automobiles as an example. The system PCB is compactly, reliably and cost-efficiently fitted onto the housing of the 48V starter generator (Figure 2). The large surface area and direct connection of the system PCB maximizes the cooling capacity against the housing. This approach leads to optimized values for power density, energy efficiency, reliability and system cost reduction.

In chip embedding, conventional bond wires are replaced by copper-filled vias, and almost the whole surface of the chip's upper side is contacted. The part of the package resistance associated with the bond wires is virtually eliminated.

Excellent heat spreading in chip embedding greatly improves the system's overall R_{th}. Demonstrators even show advantages over DCB ceramic substrates. Moreover, Z_{th} – thermal impedance – is around 40% lower than with conventional technologies owing to the solid copper substrate under the chip. This is beneficial as a stabilizing element when intense heating occurs during brief current spikes.

The low power losses of the system as a whole, combined with better heat dissipation, result in lower heat development in the electronics compared with conventional design solutions. As a result, the 48V starter generator's activation times for power generation or acceleration can be extended.

Low switching inductance results from the almost flat connection between the top of the chip and the vias, and short distances between the intermediate circuit capacitors and power semiconductors. This enables quicker switching and thus smaller passive components.

Systems with chip embedding show very low voltage overshoots during switch-on and switch-off. 48V systems can therefore use 80V MOSFETs so no longer require a 100V junction voltage. 80V MOSFETs have a 20% lower R_{DSon}. The lower conduction losses, plus lower switching losses, result in a high power efficiency. This reduces the maximum chip temperature for any given mode of operation and reduces costs/cooling efforts.

Furthermore, replacing bond wires or DCB ceramics increases reliability. In thermal cycle tests with a temperature differential of 120K, designs were able to withstand more than 700,000 active cycles.

The technology provides savings on plug connectors and cables, optimized cooling, reductions in required chip surface areas for power components, smaller passive components, fewer EMC issues, and has insulation already in place – meaning that system cost savings are significant.

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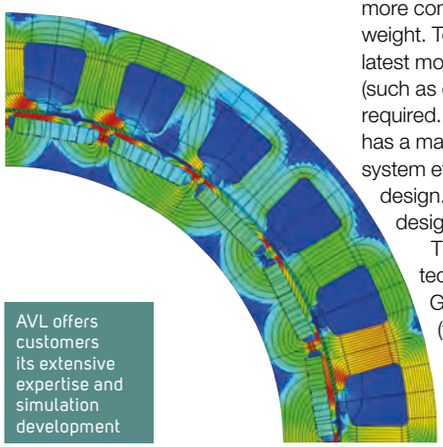
Electrification components

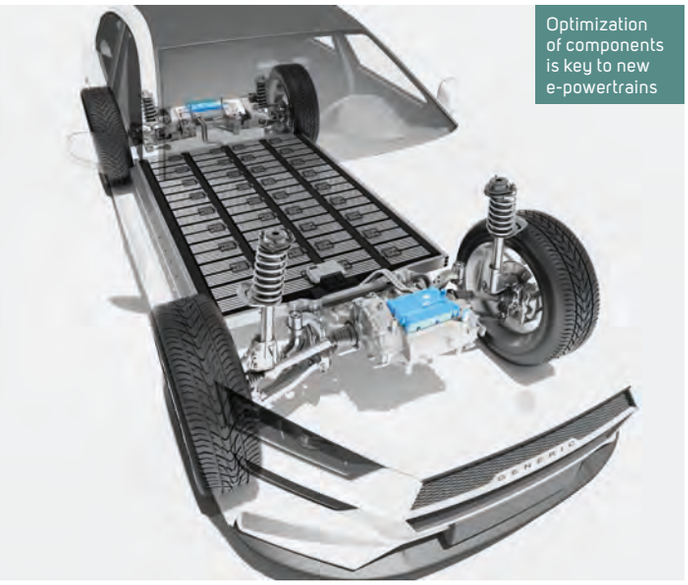
Development and engineering expertise can be applied to components for electrified powertrains, increasing efficiencies, reducing weight and enabling compact designs

Zero-emission mobility is becoming increasingly important. The automotive industry is focused on the fast-growing market of electrified powertrains for every kind of vehicle application. However, electrified vehicles seeking to fulfill customer needs face challenges such as high vehicle range and fast charging times. OEMs must also consider which technologies will enable higher powertrain efficiencies and vehicle range while also considering manufacturing challenges and costs, and work to reduce charging times to make EVs more attractive.

AVL is committed to addressing these challenges. The company's daily business is to provide a large range of development and engineering services for e-drive components, with a focus on developing and optimizing electronic components to make them lightweight, compact and highly efficient for every vehicle application. Efficiency is the most important parameter for all powertrain components, to minimize losses and enable more effective recuperation to extend range. A further important approach is R&D of improved e-motor technologies.



AVL offers customers its extensive expertise and simulation development



Optimization of components is key to new e-powertrains

Current trends include high-speed machines in excess of 20,000rpm, and multiphase applications for higher power and currents.

New motor winding technologies (for example, hairpin) or the use of fewer rare earth materials can help meet required cost targets. The aim is to reduce manufacturing costs and increase the power density, enabling production of smaller, more compact machines with lower weight. To reach these goals, the latest motor-cooling approaches (such as direct oil cooling) are also required. The cooling technology has a major impact on e-drive system efficiency and component design. Due to improved thermal design, losses are reduced.

The latest semiconductor technologies (such as SiC or GaN) in power electronics (for example, the inverter), enable efficiencies up to 99% and high-frequency operation. Of course, this leads to higher EM noise disturbances, which can affect the functionality of the system and therefore need to be addressed with adequate EMC measures. AVL's unique EMC simulation approach and 10 years of EMC experience avoid unnecessary effort and development time. This approach is a model-based simulation that starts with the early stages of concept development and operates through every progression.

The key drivers for charging are convenience (such as inductive charging) and quick recharge for long trips (such as fast charging). An increasing trend is wireless charging. AVL's solutions and holistic development approaches (for example, EMC simulations) enable the company to offer unique new solutions, resulting in added value for customers. Vehicle-to-grid connections such as onboard chargers entail security gaps. AVL development processes ensure secure charging as well as protection of the V2G connection against unauthorized trespass. AVL is working on concepts for reduction of charging time. This is achieved by high-power chargers and smart charging communication software. The latest concepts enable battery charging via new inverter technology with the benefit of reduced weight and fewer additional components compared with existing systems.

Finally, the importance of a well-designed drivetrain needs to be emphasized. Its overall efficiency is the sum of the performance of individual subcomponents, but is also related to its integration into the powertrain unit. In particular, highly integrated e-axles and good connections between components support highly efficient powertrain systems. The benefits are fewer sources of EMC radiation, and fewer connectors, cables and interfaces. AVL offers the integration of inverter, e-motor and gearbox into a highly integrated e-axle. By doing so, size, weight and cost reduction can be achieved, in addition to increased system efficiency. This guarantees the best performance at maximum efficiency. The company also offers integration of e-drive components into the vehicle.

AVL provides development and engineering services for electrified powertrain components from light-duty to heavy-duty vehicles: auxiliaries, power inverters, DC-DC converters, charging devices, e-motors and e-axles.

AVL's expertise in the powertrain sector is based on numerous completed customer projects, achieved with technical know-how and supported by in-house development and simulation tools.

EV Advanced Charging Solutions

IES, a pioneer in battery charging since 25 years, has been helping leading manufacturers and operators around the world to develop their electric mobility solutions.

Beyond Charging

This unique expertise has enabled IES to develop a fast charging solution adapted to all situations: charging stations for private vehicles whether in public places, commercial areas or dealerships… Complete charging systems for electric buses… Mobile chargers for R&D labs and service centers at car makers… Compact on-board chargers for Industrial or Light Electric vehicles…

IES has the ultimate charging solution.

Automotive testing

Decades of industry experience has led to the development of testing and assembly expertise that is invaluable to leading manufacturers of electric and hybrid vehicles

Leading test and assembly company JW Froehlich UK, is reaping the rewards of more than 40 years' experience perfecting worldwide solutions for the high-volume manufacture of internal combustion engines, with its products and processes now merging seamlessly with next-generation technology.

The company specializes in in-process and end-of-line testing and assembly for the global automotive industry, and lists the majority of the world's leading marques as customers.

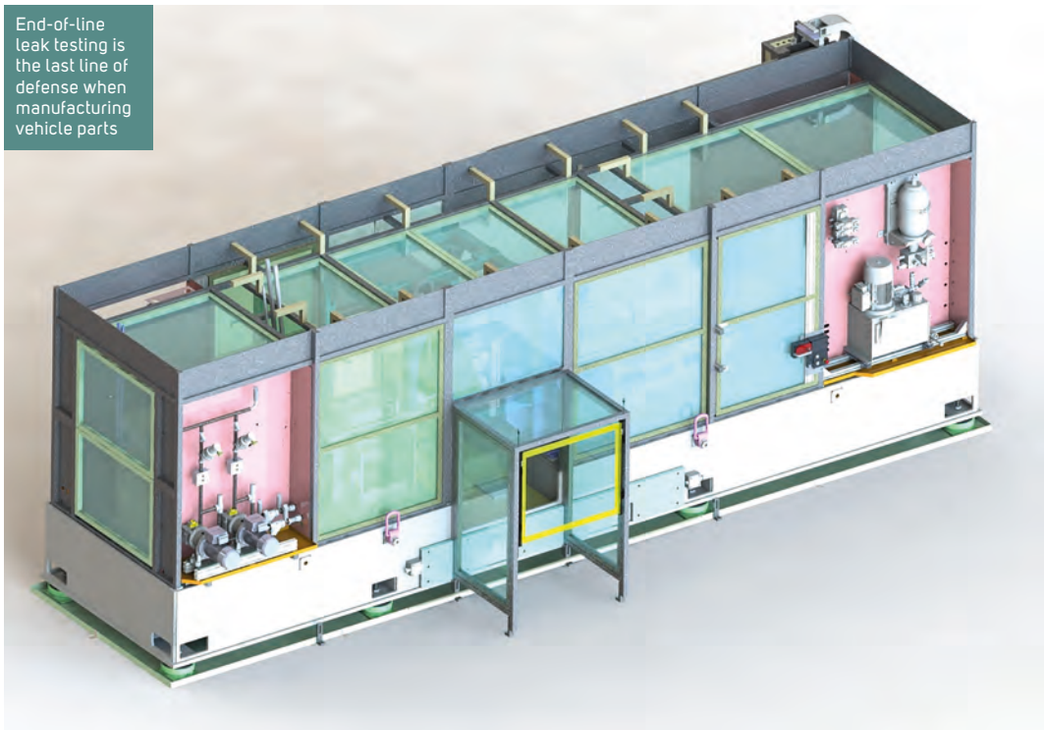
Together with Ford Motor Company, Siemens, National Instruments and HSSMI (High Speed Sustainable Manufacturing Institute), JW Froehlich UK is a partner in E-PriME (Electrified powertrain: Pilot-line for Manufacturing Engineering).

This UK government-backed consortium has been given the brief of showcasing an assembly line capable of manufacturing electric powertrains at ultra-high volumes with test times lower than 180 seconds – at the same time reducing CO_2 emissions and creating jobs and apprenticeships.

JW Froehlich is no stranger to innovation and environmentally friendly initiatives. Founder Josef Froehlich was instrumental in the invention of engine cold testing – removing emissions and improving motor plant safety and air quality.

The company was also a pioneer of leak testing, a field in which it remains a major world player. The development of new materials and chemistry in battery manufacture has renewed and re-emphasized the need for repeatable and robust leak testing.

JW Froehlich has long understood that leak testing is not just a Go/No-Go decision. It must act as a tool for evaluating and improving the production process itself and each of the components and manufacturing techniques involved within it.



End-of-line leak testing is the last line of defense when manufacturing vehicle parts

The constantly changing structural integrity of a modern EV battery creates challenges with which JW Froehlich is familiar, and the company already has solutions available to cope with volumetric change in material and protect product integrity.

The company's Zero Resistance Mass Flow Leak Test sets a global benchmark – enabling fast and repeatable testing of large volumes, which often results in fewer workstations for manufacturers. Mass flow technology thus reduces capital expenditure as production volumes increase.

Coupled with JW Froehlich's inert gas detection techniques, the technology can identify internal and external leaks; and map the leak profile of coolant circuits, battery cases, modules and packs.

In reality, discussions start with battery designers and process engineers to protect against future changes to specifications and legislation so meaningful budgets can be achieved.

It is an area in which JW Froehlich excels, with the company providing training, consultation and simultaneous engineering expertise to deliver machines that ensure customers always get flexibility and value for money.

HEVs, BEVs, PHEVs, fuel cells and turbos: the next development for the company is battery module and pack assembly and test machinery for a leading European motor manufacturer.

Gary Brinkley, engineering director at JW Froehlich, is delighted with the company's progression. "To put it bluntly, our offering is tried, tested and works," he explains. "Not only do we have the expertise and experience in-house to provide tailor-made solutions that meet the stringent manufacturing requirements of today's automotive industry – we also have the ability to build in a level of future-proofing to our offering too. Our customers like that."

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Simulating in-wheel motors

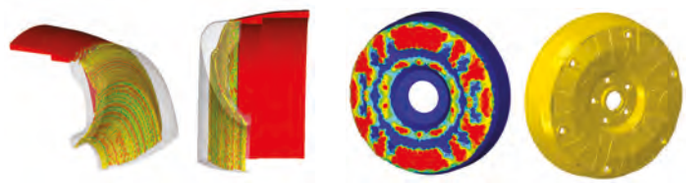
Coupled electromagnetic and acoustic simulation of an in-wheel electric motor is key to an increasingly automated and user-friendly noise, vibration and harshness workflow

Noise, vibration and harshness (NVH) is becoming one of the key aspects of electric mobility, and in-wheel motors are no exception. With high torque and high performance, in-wheel motors can cover a wide range of vehicle applications. At the same time, these high-power electric machines need to be designed in the right way to ensure they meet increasingly strict NVH regulations. To predict the NVH performance of the in-wheel motor, Elaphe has developed its own simulation methodology. Using Altair NVH products and NVH optimization algorithms developed in-house, Elaphe has managed to greatly improve the overall NVH performance of its motors.

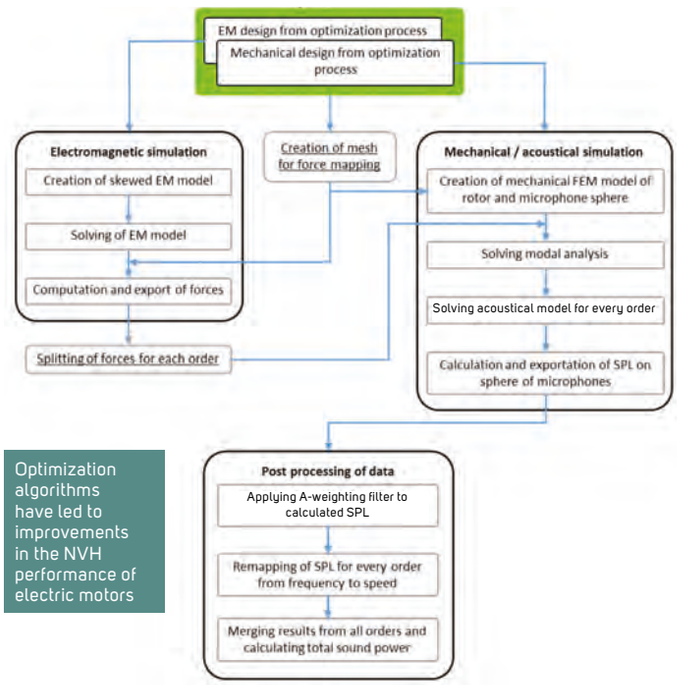
The topology of e-motors, which enables use of the otherwise empty space inside the wheel, can result in new, unexplored NVH challenges. Elaphe has found NVH to be a bottleneck in the design cycle of its motors, making it the main motivation for a more automated and user-friendly simulation workflow. Within NVH, noise radiation was the area in which the company was most interested.

The first part of the workflow included parameterization of the electromagnetic design, followed by the creation of the EM FEM model and optimization in terms of NVH. The parameterized EM model was developed in Altair Flux and connected to Elaphe's in-house optimization algorithm. Within the EM design optimization, the main constraint was to keep the proprietary Elaphe stator winding design, which is patented under US9601957B2.

Elaphe focused on the optimization of rotor topology and parametric optimization of the stator by developing and implementing process tools. A multi-objective evolutionary optimization algorithm was chosen because of the large number of degrees of freedom and very complex design space involved. Another crucial step in the process was fast and simple evaluation of radiated noise, as this typically represents one of the main challenges for the FEM model evaluation. The key benefit of the in-house optimizer is a fast estimation of the NVH performance, directly from the EM force distribution, without developing the entire structural FEM model.



Topology (left) and topography (right) optimization of Elaphe's e-motors was undertaken during early design stages



Optimization algorithms have led to improvements in the NVH performance of electric motors

Altair HyperWorks tools were used for the structural/acoustic optimization. Algorithms are embedded directly into Altair's structural solvers, which helps Elaphe during the setup and execution of the optimization. Further on, the Altair OptiStruct structural solver has a strong connection to the Altair Flux EM solver, which makes the mapping of the EM forces quick and easy.

It is advisable to use more conceptual tools of optimization in the early stages of the design. Topology and topography optimizations are mainly used in the structure stage. In Elaphe's case, the topology optimization was used first, followed by the topography optimization.

The objective for the topology optimization was to increase the stiffness in the axial and radial direction while keeping the weight as low as possible. Topology optimization gave an initial shape of the rotor housing. This design was further optimized using a topography optimization algorithm. More precisely, bead optimization was performed on the predefined shell geometry. Since the topography optimization doesn't greatly influence the overall weight of the component, only the objective function is needed. The objective function was set to minimize the equivalent radiated power (ERP).

A decrease in ERP was achieved using topography optimization. Both topography and topology methods have proved to be useful and robust. Incorporation into the design process was easy and is to be used in all future Elaphe projects.

Using the NVH workflow, Elaphe has been able to decrease the noise of the most critical range of frequencies by as much as 20dB. This is achieved through adjusting the electromagnetic part of the motor as well as optimizing the structure. Furthermore, the NVH workflow enables the company to reduce the design loop, shortening the process from days to hours.

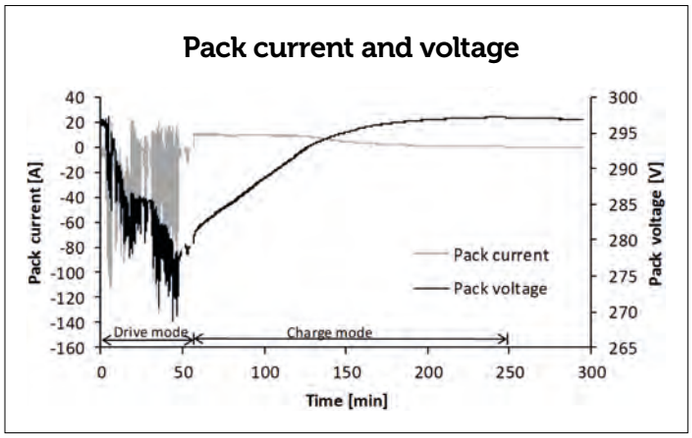
Accurate state-of-charge

High-performance battery management systems can accurately determine state-of-charge if permitted to perform either end-of-charge or SoC-OCV calibration at regular intervals

State-of-charge (SoC) estimation is a central element of battery management systems and is used to estimate the amount of charge currently stored in the battery. Lithium Balance recently demonstrated the importance of an accurate SoC estimation by the BMS (*E&H Vehicle*, July 2018, page 205).

The simplest, yet extremely precise and applicable, way of calculating the SoC is with coulomb counting, where the transferred charge is estimated as the time integral of the external electric current starting from a known SoC. Determining the SoC by coulomb counting can be assumed to be accurate provided there are no losses in the system, and assuming precise measurements of the voltage and current with rapid measurement update rates. Due to its high precision and simplicity, coulomb counting is widely used and is currently implemented in the BMSs from Lithium Balance.

Calibration of the current SoC can be made at certain operation-specific points to correct for any offset in the SoC. In Lithium Balance's BMS, two SoC calibrations are incorporated – the end-of-charge and SoC-OCV (open-circuit voltage) calibration. The end-of-charge calibration is automatically performed when the batteries are fully charged by correcting SoC to 100%. As the SoC is related to the OCV of the battery, recalibration of the SoC can be performed by comparing the OCV of the battery with a known SoC-OCV reference (SoC-OCV calibration). For lithium batteries, the OCV can only be directly measured when no charge or discharge is performed on the battery, and when the battery is in a relaxed state. The SoC-OCV calibration is therefore only performed after a period of inactivity. In this case, the cell voltage is equal to the OCV, and SoC is corrected to the value determined by SoC-OCV relation.



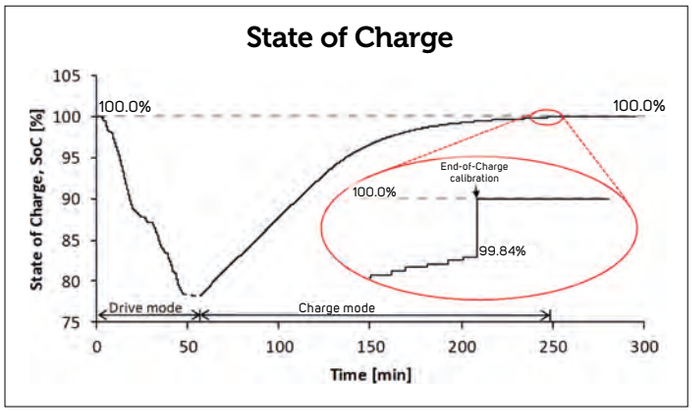
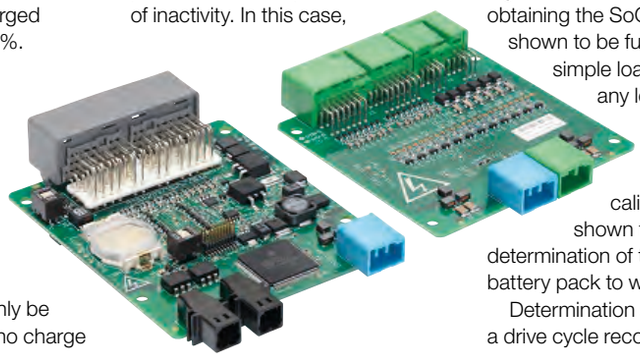


Figure 1 (left) shows pack current and voltage measured during the drive cycle. Figure 2 (below left) shows SoC calculated by coulomb counting



The Lithium Balance BMS algorithm and the process of obtaining the SoC have been shown to be fully accurate for simple load cycles without any losses. When losses are present, the end-of-charge and SoC-OCV calibration was shown to ensure correct determination of the SoC of the battery pack to within 1%.

Determination of the SoC during a drive cycle recorded on a vehicle is shown in Figures 1 and 2. The current to/from the battery pack is shown in Figure 1 with the battery pack voltage. Calculated SoC is shown in Figure 2. The vehicle was initially charged to an SoC of 100%. A drive cycle of 60 minutes was performed, decreasing the SoC to 78.36%. After the drive cycle, the vehicle was charged, and when a fully charged state was achieved, end-of-charge calibration was automatically performed by the BMS. When charging the vehicle after the cycle, SoC reached 99.84% (Figure 2) before the end-of-charge calibration (identical charge criteria as initial conditions), giving an error in SoC estimation of only 0.16%. The error in the SoC estimation for a full discharge cycle will be less than 1%.

The SoC estimation currently incorporated in the software calculation is accurate to within 1% provided the battery pack is periodically allowed to reach a fully charged state, or to reach a relaxed state, thereby enabling SoC calibration. For typical driving conditions, the precision of the SoC estimation is to within 1% for a full discharge/charge cycle. This, combined with the high accuracy when performing SoC calibration shows the high-performance BMSs produced by Lithium Balance are capable of accurate determination of battery SoC for vehicles if allowed to perform either end-of-charge or regular SoC-OCV calibration.

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Durable traction inverters

Power electronics with sintered semiconductors have been developed for the duty cycles typical of electrification applications in medium- and heavy-duty commercial vehicles

The electromobility market has taken off. International electric vehicle stock – comprising on-road battery electric and plug-in hybrid vehicles – was in excess of three million units during 2017 and, in the same year, the one million sales per year milestone was passed for the first time.

According to management consultant McKinsey, Norway has already reached critical mass on the way to all-out electric vehicle adoption, with China and Sweden also showing a clear disruptive trend toward electromobility. These countries also joined the 30@30 campaign, which has as its target a minimum of 30% sales share for new electrified vehicles by 2030.

As on-road electrification continues to increase, the commercial vehicle market has also started to electrify. The city bus segment has taken the lead. In China, this has been particularly pushed by strategic public incentive programs: the OECD/IEA has reported a global stock figure of 385,000 electrified buses; of these, an estimated 382,500 units (comprising 99%) are in China.

Besides city bus electrification, there is a growing push (especially from goods-handling companies) to move forward with electric delivery vehicles in urban environments. Fueled by the threat of increasing restrictions on the use of ICE vehicles within city limits, the established CV manufacturers started programs to roll out electrified products. At the Internationale Automobil Ausstellung für Nutzfahrzeuge (IAA) in Hannover, Germany, in September 2018, almost every well-known commercial vehicle manufacturer presented products for medium-duty or heavy-duty vehicle application. Many of those vehicles are at start of series production, or will be soon.

Figure 1: The SKA12HV converter is suited for application in commercial vehicle electric powertrains, and is designed to withstand medium- and heavy-duty vehicle cycles

Compared with passenger cars, delivery trucks and city buses experience much higher frequencies of acceleration and deceleration during their daily usage. This increases requirements for power cycling capabilities of the electric powertrain significantly. The traction inverter with its incorporated power semiconductors, for example, needs to be designed to sustain in excess of 60,000 operating hours during its lifetime.

Semikron, a leading supplier of power electronics equipment, has been providing products for vehicle electrification for more than 25 years. Starting with material handling applications (such as forklifts) in the 1990s, Semikron has since equipped more than 1.5 million vehicles for material handling, more than 53,000 city buses, and in excess of 200,000 passenger cars with power electronic products.

The company's experience has been crucial to development of the SKAI2HV converter design (Figure 1), which is suited for applications in the electric powertrains of commercial vehicles. SKAI2HV incorporates sintered power semiconductor dice, which enable the inverter to withstand all performance profiles typical of medium- or heavy-duty vehicles. SKAI2HV converters are available with either a cable-gland interface or high-power connectors. Continuous motor current is available up to 350A_{rms} depending on conditions. The maximum battery voltage can be selected up to 800V DC.

Since production began in 2013, tens of thousands of commercial vehicles, especially city buses, have been electrified using an SKAI2HV converter variant. These units have accumulated more than 800 million field operating hours. Assuming a typical city bus driving profile of 10km/h (6mph), electrified CVs with implemented SKAI2HV technology have covered approximately 8 billion kilometers.

At the recent IAA show in Hannover, multiple well-known manufacturers have presented electrified commercial vehicles using the SKAI2HV as traction converter and brake chopper device. The power ranges of these vehicles vary between 80kW and 300kW.

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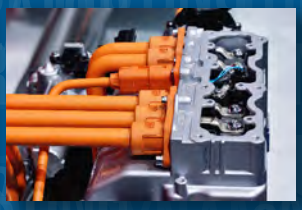

GLOBAL HEADQUARTERS – Unico, LLC | 3725 Nicholson Road | Franksville | Wisconsin | 53126 | +1.262.886.5678 | www.UnicoUS.com

UNITED KINGDOM – Unico (UK) Ltd | Garamonde Drive | Wymbush | Milton Keynes | Mk8 8LF | +44.1908.260000 | www.unico.co.uk

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EV charging solutions

A well-organized charging infrastructure will be an important factor in increasing consumer adoption of electric vehicles, and relies on innovative charging technology

With the evolving disruption in the automotive industry to include electric vehicles, the market is changing quickly. However, the backbone of the EV industry's future is the charging infrastructure. France-based IES-Synergy is positioned to address the growing demand for EV charging solutions.

Consumer adoption of EVs will depend on the availability of a well-organized and defined charging infrastructure network. This is particularly true in urban and city environments, where access will be more restricted (and limited to EVs) and where parking is limited, if available at all. New forms of transportation will also need to be considered to continue the fight against pollution issues and reduce the congestion of city centers – such as car sharing, last mile, and zero-emission public mass transportation.

To this end, IES continues to develop new products to enhance its product line, and boasts 25 years of experience in battery charging and onboard charging technologies.

To enable easy deployment of fast-charging points in crowded urban environments, IES has developed a DC universal wallbox, compatible with every EV on the market. Featuring a compact design and delivering 22/24kW charge for any EV, this multistandard wallbox provides a universal and economic solution for charging EVs, typically within one hour. Installed in less than two hours (either on a wall or an optional pedestal) and requiring lower input power, the technology provides network subscription options (including single-phase input), and offers an ideal public fast-charging service in locations such as restaurants, department stores or public parking spaces.

IES has developed a wallbox to provide urban fast charging

To address the emerging market of zero-emission public transportation, IES has also developed a charging station for e-buses. The charger features a compact footprint and the company's unique hermetic design. The new IES 50kW e-bus station is suited for use in depot environments, where implementation must account for space constraints. Maintenance is greatly reduced and service continuity is optimized. Three stations can be also coupled together to charge up to 150kW. They can be operated via smart charging platforms, providing enhanced flexibility and efficient smart energy management for charging a large fleet of e-buses during the night at the depot.

"Always at the edge of the technology, IES has capitalized on the many steps the automotive market has taken so far," says CEO Jean-Michel Cornille. "Combining expertise in HF power electronics and a true innovative spirit, IES was at the core of moments which have shaped the industry. Present during the earlier stages of the electrification trend in industrial vehicles, engaged during the first development of the CCS protocol, and chosen by the FIA for charging their race cars, all these experiences have resulted in the birth of the KeyWatt technology, used and recognized by many leading e-mobility actors throughout the world. Using this technology, we have developed the most advanced solutions to address the growing challenges of charging EVs in our cities.

"At IES, we believe developing fast-charging, economical and compact chargers will enable rapid expansion in public and commercial environments, and will provide the key essential solutions to future expansion of EV charging infrastructure.

"Another barrier seen by the users is linked to the autonomy and the cost of electric vehicles," Cornille continues. "But relentless progress in battery technology has pushed the density up and the cost down, making vehicles more affordable with higher ranges. As of today, the new generations of electric vehicles are being announced with ranges of 500-600km [310-370 miles]."

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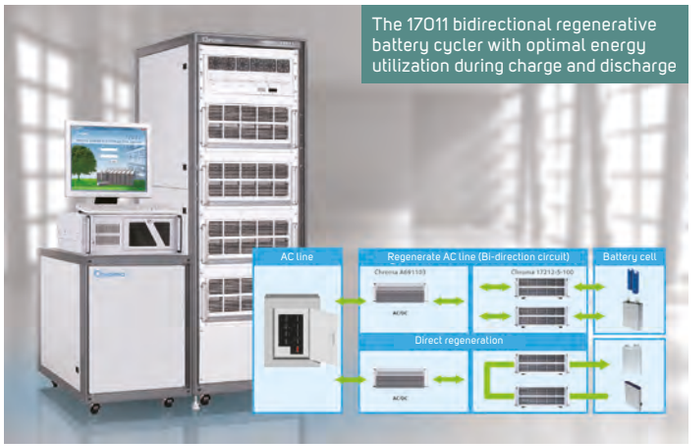
High-power battery cyclers

Development of high-power and high-voltage technology is hampered by test equipment that taps out at 1,200V. A line of high-power solutions can aid in battery R&D

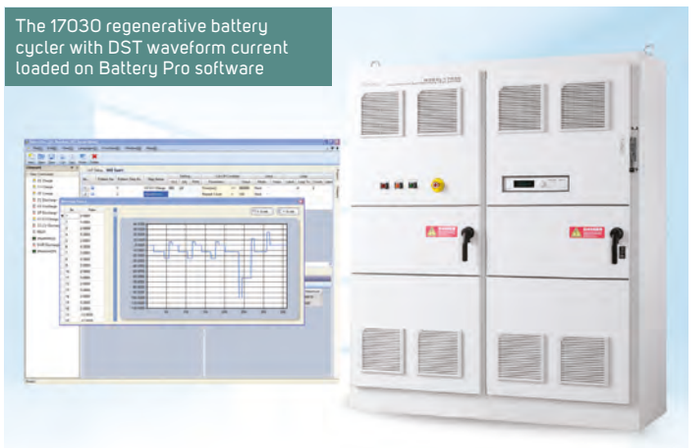
Developing the next generation of high-energy batteries is becoming pivotal to meeting the growing demands of the electronics, automobile and other energy storage industries. High-voltage batteries are of particular interest due to their potential applications, which increasingly call for high energy density, low costs and extended lifetime of cells contained in high-voltage battery packs. Those in the business of researching, evaluating and delivering high power and high voltage know how difficult it is to expand the boundaries of power and energy with test equipment that taps out at 1,000V or 1,200V. To ensure the safety and reliability of energy storage system operations, every single component – such as the battery modules, cooling system, housing and battery management – has to meet very stringent requirements. Chroma's battery systems can provide a tremendous amount of power (up to 1,500V), satisfying the most rigorous demands while meeting R&D standards and requirements.

The greatest challenge in the modern-day market is having a battery pack design that reduces the costs of individual electrical components and increases the energy density of the system without affecting safety and lifetime.

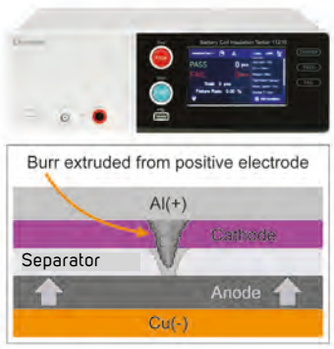
Chroma's high-precision battery cyclers and battery simulators satisfy energy requirements up to 1,500V. These modular multichannel charge/discharge systems are high-efficiency regenerative solutions that reduce operating costs, and provide driving cycle simulation and a V/I sampling rate of 50kS/s. They can also be used as regenerative programmable DC sources and DC loads. For example, the 17030 Regenerative Battery Test System is a single- or dual-output, high-precision, integrated solution designed for high-power battery pack testing. These battery testers are highly accurate power sources and measurement systems that are suitable for battery pack incoming or outgoing inspections, as well as capacity, performance, production and qualification testing.



The 17011 bidirectional regenerative battery cycler with optimal energy utilization during charge and discharge



The 17030 regenerative battery cycler with DST waveform current loaded on Battery Pro software



The partial discharge function of the 11210 Battery Cell Insulation Tester

However, there is also a growing market for high-precision, integrated battery test and energy storage test solutions for low-energy batteries as well. To accommodate this, Chroma provides systems that test down to very low voltage. For example, Chroma's 17011 series Charge/Discharge Test Systems are designed for testing Li-ion secondary batteries, electrical double-layer capacitors (EDLC) and Li-ion capacitors (LIC). This enables cycle life tests, incoming and outgoing inspection, formation, production, and reliability tests with a voltage range as low as 5V. Test channels support parallel operation for maximum flexibility between high channel count and large currents, and also charge and discharge tests in CC-CV, CV and CP modes as well as battery capacity and DCIR tests, capacitance, and DCIR tests for EDLC.

Most of Chroma's solutions are regenerative – energy sourced by the battery pack is recycled back to the channels in the system or to the grid. The systems are configurable and flexible, with multiple channel capabilities that can be upgraded as testing requirements change. In addition, Chroma satisfies charge rate, discharge rate, SoC, SoH and depth of discharge with accuracy in measuring voltage, current, temperature and power, both statically and dynamically.

Chroma provides flexible, high-feature regenerative test solutions, and also manufactures a full line of battery safety test instruments. This includes the new 11210 Battery Cell Insulation Tester, which features partial discharge (PD), which can identify defects and potential hazards in the battery before the next production phase. Chroma's global footprint enables the company to supply, service and provide support all over the world.

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EVSE infrastructure

Electric vehicles are here to stay, but the success of the electrification movement will be heavily reliant on development of innovative electric vehicle supply equipment solutions

The combination of more competitively priced electric car models and improvements in battery technology have provided peace of mind for those vehicle consumers looking to travel 200 miles on a single charge. Likewise, the commercial transportation segment is embracing the switch to greener vehicles. Public and private transportation entities are overhauling their commercial fleets from combustion to alternative fuel engines. In the USA alone, it is estimated that the engines of some 34 million commercial vehicles will be converted to or replaced by alternative fuel engines before 2025.

Despite significant strides in the right direction, most auto makers seem to agree that the industry faces two major obstacles to the adoption of electric vehicles: the need for more government incentives and the installation of a network of electric vehicle supply equipment (EVSE).

Transportation entities are facing additional challenges in construction of EVSE network infrastructure. In highly populated cities, for instance, commercial fleet entities lack adequate space to install EVSE pedestal ports. Most pedestal chargers have a limited number of plugs that can be used simultaneously. Furthermore, being stationary makes them inflexible for future changes or reconfigurations.

Overhead distribution systems counter the inflexibility of pedestals

To address some of these constraints, users are considering alternative overhead systems to distribute power. Starline Track Busway has been a leader in flexible power distribution since electric vehicles were first introduced in the market. Starline offers an overhead busway system with a continuous open channel that allows instant access to power at any point along the busway. This solution provides commercial fleets with unmatched flexibility for power reconfiguration, allowing a fast and reliable point of use power source, multiple electric charging cords and maximum space savings.

Starline offers an overhead charging system with instant access to power at the point of use

Overhead busways ease the uncertainty of elevated EVSE installation costs. The industry recognizes that EVSE installation costs are highly variable, and there is no clear consensus as to which direction installation costs are heading. Starline Track Busway offers an innovative, yet simple, maintenance-free design that allows reconfiguration, repositioning and expansion. Busway systems also eliminate the costly and time-consuming installation of subterranean concrete pads, anchor bolts and conduit from the circuit panel to the charging station. Real-time power monitoring, from load balancing to data management, is an integral aspect of the electric vehicle charging infrastructure. Starline's Critical Power Monitor is uniquely configured to capture data granularity levels ranging from an entire feed down to each individual EVSE charger.

As EVSE networks continue to transform, costly and outdated technology will be increasingly phased out by more innovative solutions. Commercial and consumer demand calls for scalable, reconfigurable charging systems. This is required to maintain a competitive advantage in such a swiftly emerging market. More than ever, the global automotive sector appears to be led by forward-thinking companies and institutions. Equally innovative EVSE infrastructure will be needed for electric vehicles to reach their full potential.

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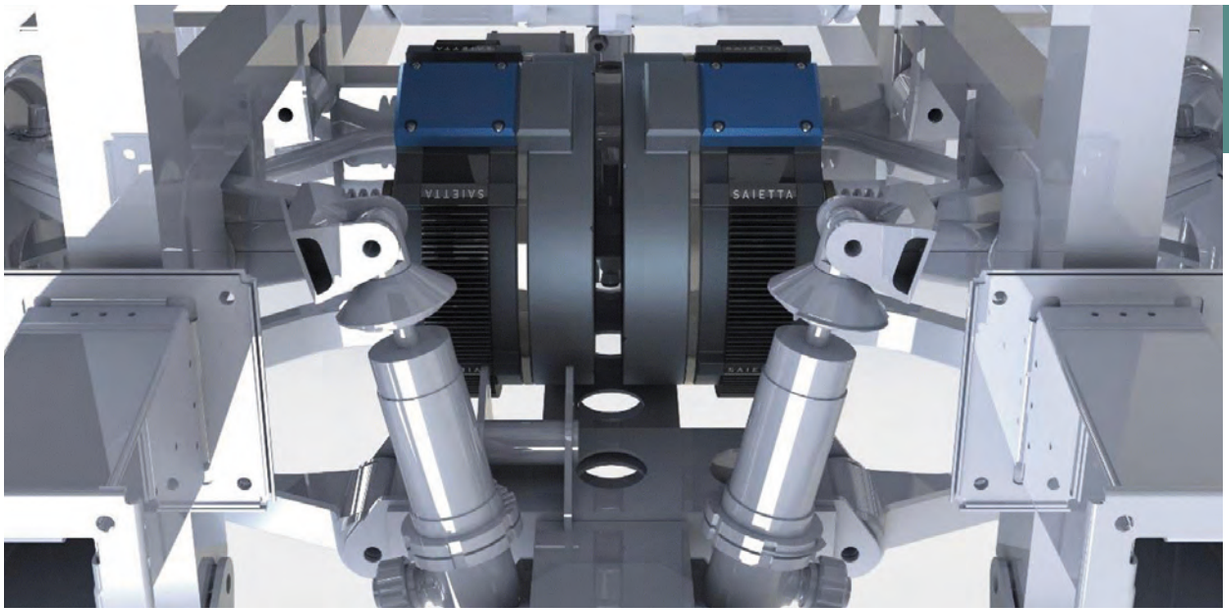
INQUIRY NO. 524

High-efficiency e-motors

A new axial-flux AC motor delivers ultra-high efficiency and torque at low rpm and voltage, and is optimized specifically for lightweight electric vehicle propulsion



The S-AC motor is optimized for mass production and can be configured to suit the application requirements

UK-based research and development company Saietta Group designs electric motors for lightweight electric vehicle propulsion. The company's latest innovation is the S-AC – an ultra-efficient electric brushless axial-flux AC motor. It boasts extreme efficiency levels at high torques from low speed.

S-AC is optimized for mass production and can be tailored to the precise requirements of individual lightweight EVs. The completely new motor architecture was designed by the Saietta engineering team and is based on the company's DC axial-flux motor – which was originally developed by Cedric Lynch, Saietta's chief scientist, who is internationally recognized as a pioneer in electric motor design. Saietta motors have been used to achieve multiple world firsts on land, sea and air, including winning the first Isle of Man TT Zero all-electric motorcycle race.

The S-AC motor is suitable for a wide variety of EV applications. It delivers continuous power and torque at relatively low voltage (48-72V) and low RPM (2,050rpm at 48V), which makes it perfect for lightweight EV propulsion. Motors can be configured to deliver continuous power from 8kW to 50kW at consistently high efficiency across a broad RPM range.

Optimized motor design can reduce battery costs or increase EV range

Depending on the application, Saietta motor efficiency is proven to deliver 10-30% improved vehicle range for a given battery capacity over competitor motors. Alternatively, battery capacity can be reduced for a given range, meaning lower battery cost and weight. The new S-AC motor is also a 'sealed for life' unit, designed to deliver a high level of ingress protection (IP67) and to be maintenance free. The motor is available in both air-cooled and liquid-cooled forms. Saietta is taking orders from vehicle manufacturers to integrate S-AC technology into EV platforms.

With the latest battery technology typically accounting for around 40% of an entire electric vehicle's cost, and vehicle range and performance both being critical factors to end consumers, high motor efficiency over the whole drive cycle is the key to making EVs commercially viable. Generally, vehicle range versus performance is a trade-off that needs to be carefully balanced depending upon the specific application. It is therefore essential to develop a motor that uses available battery power in the most efficient way. Saietta has invested heavily in ensuring that the efficiency of the S-AC motor is optimized, and S-AC technology can be configured in multiple ways depending on the precise application.

Saietta works with vehicle OEMs to understand in great detail the specific motor requirements for individual EV applications, and then engineers S-AC technology to deliver tailored solutions. The company also provides engineering and integration consultancy for entire electric drivetrains.

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INQUIRY NO. 525

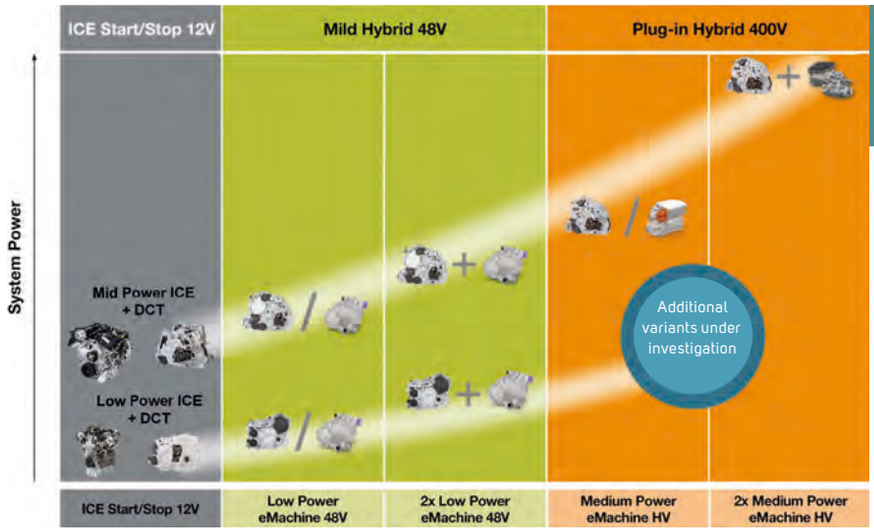
Scalable hybridization

A modular approach to hybrid vehicle architectures, featuring scalable key components and software, can optimize performance, increase brand differentiation and reduce costs

Given the global demand for various 48V mild hybrids, plug-in hybrids with full-electric driveability, electrified all-wheel applications and so on, it has become increasingly difficult for OEMs to define business cases based on standard powertrains – customer requirements are just too diverse. However, a changing distribution role between engine and e-motor can help to solve this. By shifting dynamic tasks from the engine to the e-motor, powertrain components – including engine and transmission – can be standardized and even made simpler. This shift moves scalability requirements (and opportunities) toward the e-motor and the control strategy.

Currently, some architectures seem to dominate. In Europe in particular, front-transverse 48V hybrid powertrains are expected to prevail. Moreover, in many metropolises worldwide, plug-in hybrid drives will be necessary to meet zero-emissions requirements. All-electric drives seem suited to inner-city applications, while ICE vehicles are likely to survive for quite a while to enable efficient longer-distance driving. This makes it vital to develop linking solutions that affordably combine modularity and scalability.

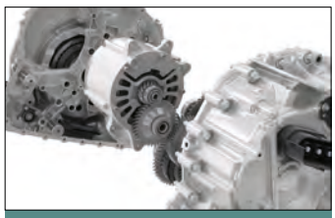
In FWD transverse architectures, scalable electric power can ensure the entire range – from mild to plug-in hybrids – uses essentially the same hardware, and even the same engine. For example, Magna's P2.5 arrangement for DCTs enables the scaling of electric power from approximately 15kW to 85kW without enlarging package and installation length. In practical terms, this means that performance can be scaled from the requirements of an efficient everyday car to sports cars and performance plug-in hybrids.



Scalable hybridization is key to the development of powertrains with increasing levels of system power

The flexibility of scalable electrification is even greater when adding an e-axle to the system, making for a P2.5/P4 electrified all-wheel drive. Besides AWD, the axle-individual propulsion sources add the basis for electronically controlled torque vectoring through longitudinal distribution. Furthermore, the P2.5 e-motor ensures permanent AWD availability. For example, 100kW in the front can fully feed a rear motor with the same power. While electric power can be scaled in a wide range, all mechanical components remain basically unchanged.

Another advantage of scalable electrification is that by upscaling electric power, engine operation can be increasingly shifted toward stationary operation. This enables a reduction in the number of gears, and in some cases even the simplification of components such as clutches. Generally, this enables significant powertrain simplification in terms of weight, complexity and cost. Such a dedicated powertrain could, for example, rely on a 4-speed transmission. While a mainstream engine typically needs seven speeds to adequately cover the engine map, a dominant e-motor relieves the engine in this respect, enabling simplification of both transmission and ICE.



The e-motor within the transmission case can be scaled up to 85kW without impacting installation length

Besides feasible business cases for the OEM, scalable electrification offers new ways to shift brand-specific powertrain differentiation from the engine to driving dynamics through electric power. Based on standard hardware, and within a standard car platform, the end customer can be offered, for example, an affordable FWD hybridization, AWD with increased traction, and additional benefits such as longitudinal torque distribution for enhanced lateral dynamics. Here, the operations strategy or software becomes key to scale characteristics. The control strategy mirrors the hardware modularity and scalability; mastering its complexity is another key element.

There is a general consensus that hybridization is needed to reduce CO_2 emissions on a large scale. However, OEMs need solutions to design these hybrid drives within cost levels that end customers are able and willing to pay. At first glance, hybrid technology may substantially increase complexity by adding another propulsion source, however, scalable electrification and an integrated systems approach over both axles can make hybrids affordable and potentially more fun to drive.

High-current testing

As the energy density of electric vehicle battery cells increases, testing solutions must develop to meet high-current industrial application requirements

Cell cyclers and high-precision test equipment from Arbin Instruments are well known within the industry, and are available for high-current industrial applications, not just for those in the lab.

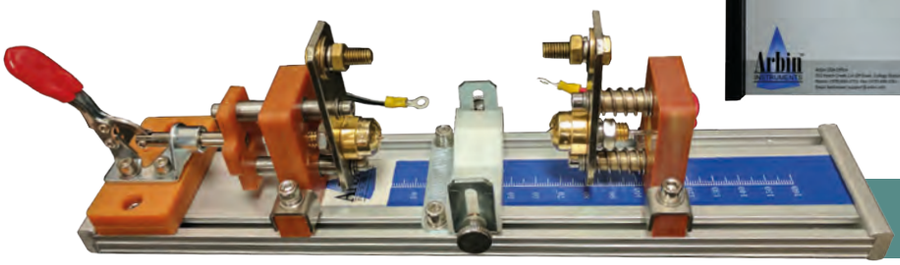
Leading companies and researchers rely on Arbin's high-current testers – combined with cell holders, battery racks and test chambers – for a complete EV battery test solution.

Several standard test equipment models are offered up to 500A, and customized equipment is available beyond. Arbin's high-current cell test equipment applies the same state-of-the-art technology with 24bit resolution and high-precision measurement circuitry that its smaller, lab-scale testers utilize. The digital voltage control technique represents the safest method of charge/discharge for high-energy density batteries used for EV applications. Coupled with fully redundant microcontrollers used to monitor communication and limit checking, the Arbin LBT series is key to a safe testing environment.

Temperature monitoring and control is another critical component of a safe testing environment, since thermal runaway of cells can lead to catastrophic results. Temperature measurement is available with all testers through thermocouple or thermistor sensors, and temperature chambers can be interfaced with Arbin software for control during testing. Chambers from many manufacturers can be controlled using an interface module and a multizone temperature chamber is available directly from Arbin.

High-current cell tester with chamber

Flat/pouch cell holder rated up to 300A



Cylindrical cell holder rated up to 200A

The eight-zone temperature chamber enables individual or small groups of cells to be separated, providing greater temperature uniformity and stability than larger single-zone chambers provide. Isolating cells in this way also minimizes the effect a failed cell can have on others under test, since they are thermally and physically separated. Each of the eight chamber zones have a pressure relief valve and battery tester connections are built in for ease of use.

The last pieces of a cell test setup are the battery holders and racks to connect cells with the charge/discharge tester. Many of these solutions exist for low-capacity cells, but Arbin offers battery holder solutions for cells up to 300A.

Individual holders are available for both cylindrical and flat/pouch cells. Trays with racks are available to hold large quantities of cells and provide an organized solution.

Pack testers are also available, once cells are integrated into an EV battery pack. The RBT models range from 60V up to 1,000V and power up to 1MW. All use regenerative circuitry to discharge back to the grid. The cell testers and pack tester can parallel their channels to achieve higher currents and greater testing flexibility.

Offering safe operation, charge/discharge circuitry, temperature chambers and cell holders, Arbin's equipment is designed to meet the increasing energy density requirements of EV applications.

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INQUIRY NO. 527

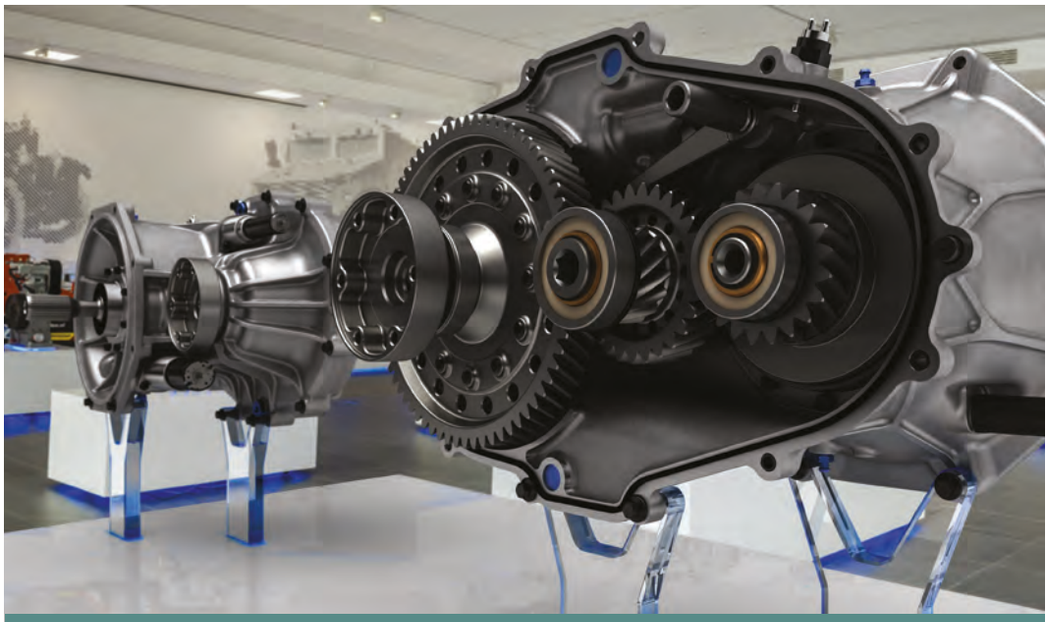
Electrified transmissions

Experience gained in conventional drivetrain solutions has led to a flexible design approach to suit electrified vehicle projects from niche concepts through to high-volume production

The level of activity around vehicle electrification continues to increase at a remarkable pace – barely a day passes without a new hybrid or EV concept being presented to the public. From prestigious high-performance sports car makers to new startup OEMs in the passenger car market, the demand for effective electric drive solutions across a very broad range of requirements is unprecedented.

For over a decade, Ricardo has been actively working in the e-axle sector, developing transmission designs for projects ranging from hypercars and commercial vehicles through to Formula E race cars. Best known for its work in more conventional powertrain design, validation and production programs, Ricardo's extensive engineering capabilities have delivered everything from single-speed, single-motor light-duty transmissions to fully integrated dual-motor torque vectoring EDUs for the next generation of hypercars.

The key to Ricardo's success is its flexibility in its approach. With cross-function teams able to develop concept designs in a matter of weeks, through to complete development programs delivering fully validated e-axles into series production over a number of years, Ricardo's design approach is always governed by production volumes and, ultimately, the overall business case for each vehicle. The company's Level 1 approach for extremely low volume (typically <100 units per annum) is based on limited modifications to existing modules for inverter, electric motor, reduction transmission and differential. Level 3 represents a 'clean sheet everything' design to meet high-volume targets at the lowest unit price and highest performance levels. Currently, there is high demand for Level 2-type development work, featuring innovative integration of some existing modules to achieve a cost- and performance-competitive solution in volumes up to 10,000 units per annum.



Ricardo has developed transmission designs for a wide range of projects, from commercial vehicles to motorsport applications

Investment in testing capabilities means the company is able to offer development and validation testing

Clearly in such a rapidly evolving area, the ability to move quickly from design into hardware accelerates the development process. Ricardo benefits from its own in-house transmission manufacturing facility, typically producing over 50,000 components per annum and occupying over 3,000m^2 (32,300ft^2), based alongside its transmission engineering center in the UK.

Ricardo's role doesn't stop there. Continued investment in transmission test capabilities enables full development and validation testing on the company's e-axles, through to motor/inverter control and calibration, integrated cooling performance and system efficiency determination, and ultimately durability tests with in-vehicle simulation using the OEM's production intent battery packs in a rig environment. In 2016, Ricardo undertook exactly this kind of project on a major OEM's e-axles for the vehicle manufacturer's first high-volume production BEV, which is now in series production.

More recently, Ricardo released the first in a family of in-house single and multispeed e-axles, designed to enable rapid integration of electrical drives into concept and niche-volume vehicles. The novel architecture of these units enables a modular approach to ratio sets, e-machine selection, differential functionality, and even park lock integration, and ultimately provides a fast-tracked route to vehicle driveline electrification.

The broad array of capabilities and products offered by Ricardo ensures the engineering challenges in this rapidly developing market continue to be addressed.

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INQUIRY NO. 528

Magnetic position sensors

Position processors with in-built linearity compensation enable improvements in sensing system performance, vital to levels of precision required by modern automotive applications

As all types of vehicles move to electrical/electronic technology to reduce size, weight and cost – as well as improving efficiency, accurate sensing becomes evermore critical to the sophisticated control functions that manage the safety and operation of modern vehicles.

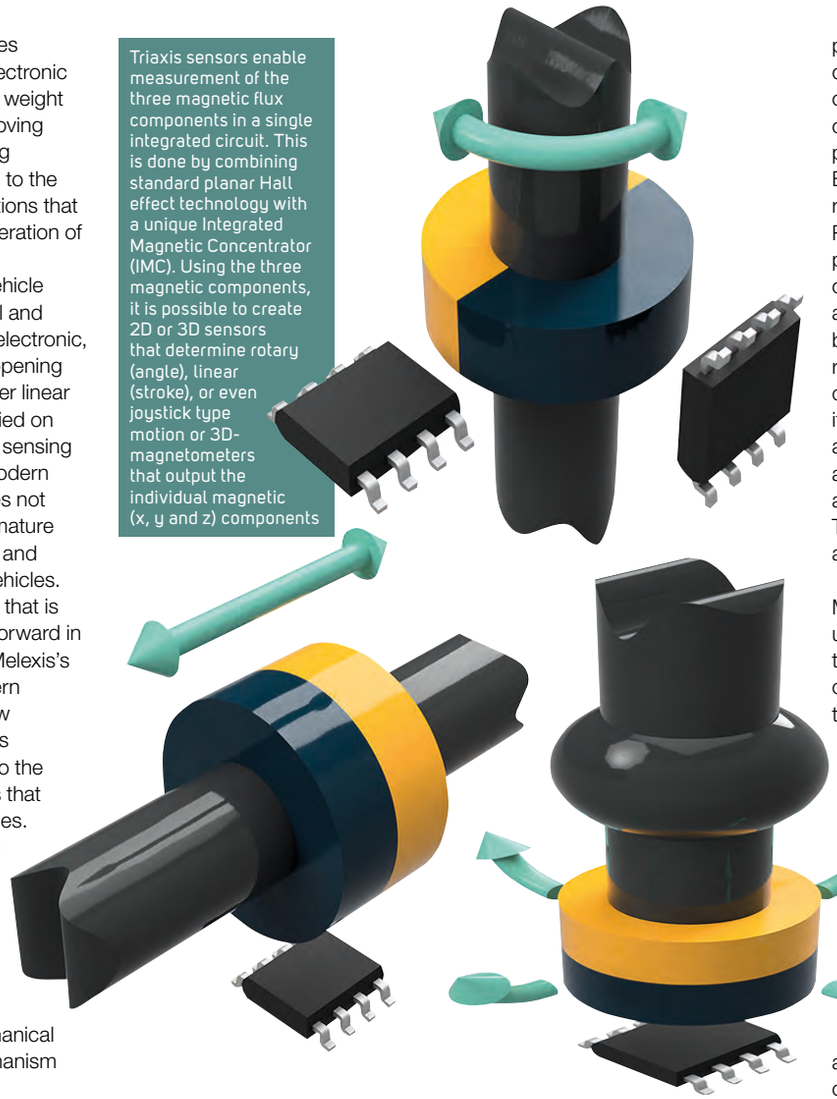
While the heart of the vehicle is moving from mechanical and hydraulic to electrical and electronic, a significant change is happening within sensing as well. Older linear and rotary sensors that relied on potentiometric and optical sensing are being replaced with modern magnetic sensing that does not suffer inaccuracies or premature failure due to the dirt, dust and grease that is present in vehicles.

One of the technologies that is driving magnetic sensing forward in the automotive sphere is Melexis's Triaxis sensors. This modern approach to sensing is now in its third generation and is fundamentally insensitive to the many stray magnetic fields that are found in modern vehicles.

However, one challenge remains. Every magnetic sensing arrangement has an element of non-linearity caused by factors including the sensing mechanism itself and also stack-up of mechanical tolerances within the mechanism being sensed.

To address this, devices from the Melexis MLX9037x series of Triaxis position processors include in-built linearity compensation, which enables the sensing system performance to be improved – critical to meeting the precision needed in today's demanding automotive applications.

The latest MLX90371 and MLX90372 devices offer between 2 and 32 calibration points, which may be selected to suit the non-linearity of the application and also the desired accuracy of the output. A lower number of calibration points may be suitable for applications with a low starting non-linearity, while higher numbers of points are suitable for long-stroke linear motion or where significant initial non-linearity is present.



Triaxis sensors enable measurement of the three magnetic flux components in a single integrated circuit. This is done by combining standard planar Hall effect technology with a unique Integrated Magnetic Concentrator (IMC). Using the three magnetic components, it is possible to create 2D or 3D sensors that determine rotary (angle), linear (stroke), or even joystick type motion or 3D-magnetometers that output the individual magnetic (x, y and z) components

Moving to increasing the number of calibration points introduces improvements in non-linearity. While non-linearity errors (NLE) as high as 28° can be expected with two-point calibration, these reduce to maxima of 1.25° and 0.8° for 16- and 32-point calibration, respectively.

To carry out the calibration, engineers use the PTC-04 programmer that is specifically designed for efficient and precise calibration of the Melexis families of programmable ICs. The programmer is very similar to an EEPROM programmer and simply requires an available PC with an RS-232 or USB communications port. The PTC-04 contains its own programmable power supply and has the ability to measure both voltage and current to 16bit resolution. It also includes multiple configuration options that make it suitable for use in prototyping as well as full-scale production, and can be used to program all the programmable Melexis Triaxis, Linear Hall, and Latch and Switch products.

To calibrate one of the MLX90371/MLX90372 sensors, users simply have to assemble the system to be calibrated and connect the PTC-04 programmer to the device through the power, ground and output pins. By moving the magnet to multiple (up to 32) positions and calibrating the sensor output, initial NLE can be compensated for and thereby reduced during operation.

The calibration process also enables tailoring the output to the application requirements. As an example, as well as the NLE calibration, the output can be programmed to reach the full span at any angle for rotary sensing, or length for linear sensing, thereby ensuring that the sensor delivers maximum resolution and accuracy in all applications.

Battery heat shields

Preventing a single damaged cell from causing damage to the rest of an electric vehicle's battery can be achieved with a silicone-based elastomer heat shield

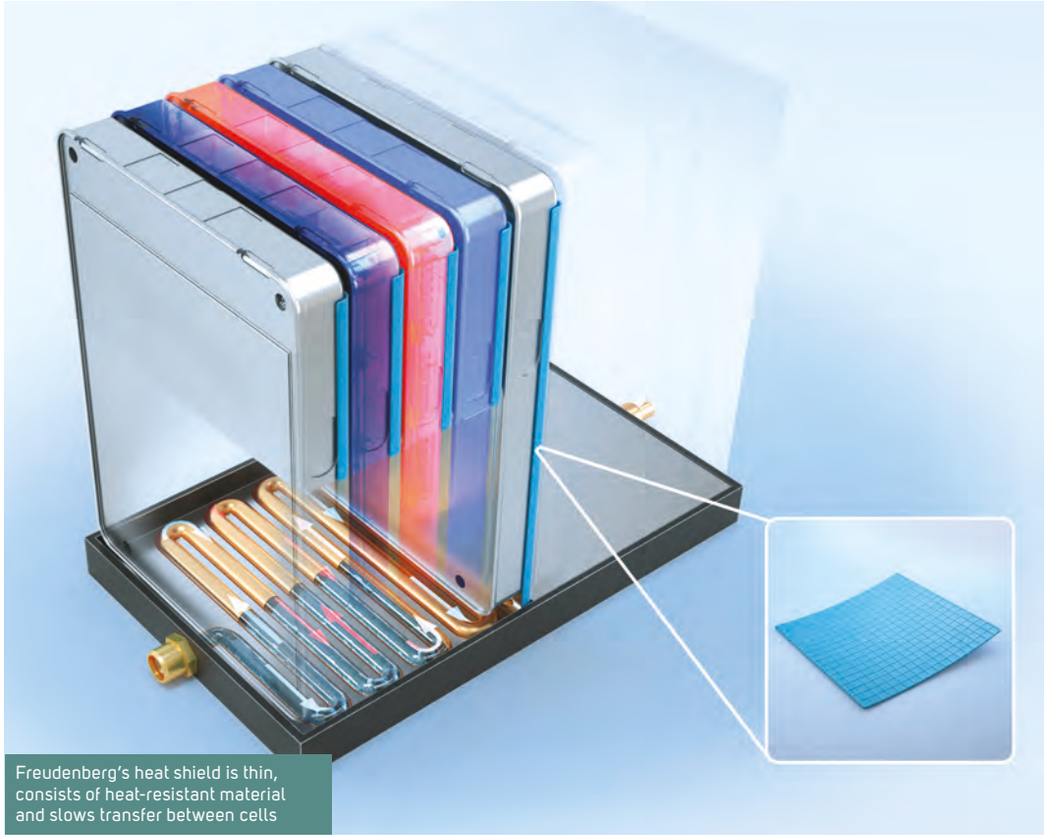
Due to the growing energy density of battery systems, the developers of lithium-ion batteries must satisfy ever higher safety requirements. It is especially crucial to keep a single damaged cell from overheating the entire battery module. Freudenberg Sealing Technologies has developed an innovative heat shield for use in prismatic and pouch cells with almost no impact on the required installation space. It combines the high heat resistance of a silicone-based elastomer with the high insulating properties of air.

The goal is greater range without the battery increasing in size and weight. Such high energy density, which has been battery developers' top priority, creates a basis for the broad acceptance of electric vehicles. But the more energy is stored in a confined space, the greater the safety requirements. Precautions are essential in case a damaged cell overheats.

Experts call the phenomenon thermal runaway, and it can cause the temperatures in a cell to rise as high as 600°C (1,100°F). The risk is that the battery's cooling system would not be able to drain the heat away quickly enough under these conditions. If the heat build-up causes neighboring healthy cells to heat up, a chain reaction can ensue that, in the worst case, could cause the entire battery system to explode.

Freudenberg Sealing Technologies is countering this risk with a new development. Heat shields between individual cells are designed so the heat from a damaged cell remains isolated until it can be drained away.

The heat shield has three key characteristics. First, the shield itself consists of a heat resistant material, a silicone-based elastomer. Second, it slows the heat transfer between the cells with a waffle-like structure, with tiny pockets of air providing outstanding heat insulation. Third, the shield is very thin, with a maximum thickness of just 1mm. The loss of energy density due to the shield's use is hardly noticeable.



Freudenberg's heat shield is thin, consists of heat-resistant material and slows transfer between cells

Freudenberg created a new test procedure for the development of the heat shield. This involves mounting samples of the heat shield on a surface heated to 600°C and recording the temperature on its rear side with thermocouples. Series of tests have shown that temperatures significantly under 200°C (400°F) occur on the rear side after 30 seconds.

"This will adequately protect a neighboring cell against the destruction of cathode material or the separator," says Freudenberg expert Peter Kritzer. "The exact boundary values admittedly depend on a multitude of specific parameters such as the chemistry and geometry of the battery cells."

Consideration has even been given to the heat shield's mounting. Since the air pockets adhere well to the smooth metallic surface of a prismatic cell – thanks to a suction effect – an individual shield can be precisely positioned. It would even be possible to expand the function of the heat shield with additional development steps. If this flexible formed part were extended over the top of the cell, it could enclose and seal the rupture disk there. In the event of overpressure in the battery cell, the rupture disk ensures that the resulting partially toxic gases escape in a controlled way.

"Even more than energy density, safety is the most important characteristic of future battery generations in terms of quality," Kritzer says. "It can be significantly increased with the help of relatively nondescript components like our heat shields."

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INQUIRY NO. 530

Crimping HV terminals

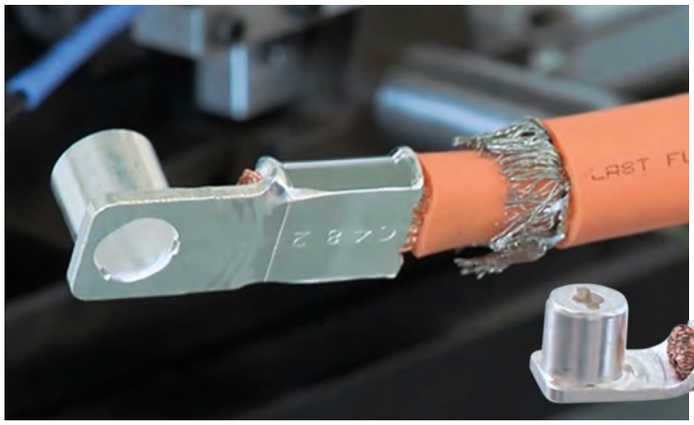
Proper crimping of wires to terminals is essential to system integrity, and requires a step-by-step approach that ensures the assembly performs to required specifications

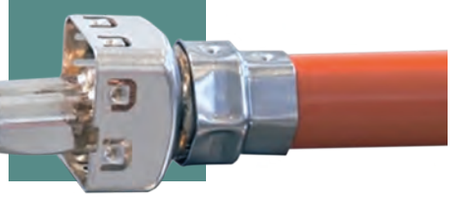
Few things in the world of electrical assembly seem more straightforward than crimping wires to terminals. Insert or place a stripped wire into the short metal barrel (open or closed) and tightly compress to form a homogeneous bond. Needing no solder, heat or flux, the simplicity and speed of the process is why, after more than 70 years, the solderless terminal continues to be one of the most popular and cost-effective connection systems available.

However, there's more complexity to the solderless terminal than meets the eye and the failure of an undetected bad crimp can seriously undermine the integrity of the whole product. An improper crimp can overheat, affect electrical connection, increase scrap, lead to product reworking, and possibly even lead to catastrophic failure.

With the high-voltage cable assemblies used in electric and hybrid vehicle systems, achieving a good crimp is a serious issue and industry leading manufacturer TE Connectivity's authorized distributor in the UK, Dalroad, is keen to spread the word.

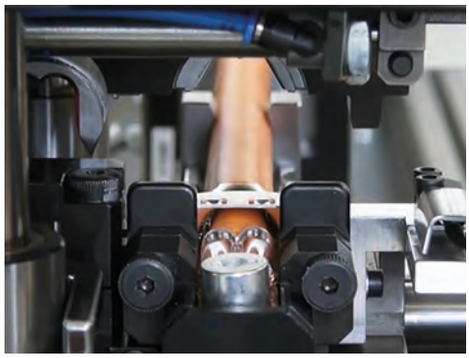
A common misconception is that any tool can be used to crimp a terminal. On the contrary, crimping solderless terminals is a carefully engineered solution. Tool and terminal are designed to act in tandem, creating crimps that optimize electrical and mechanical performance. Too loose a crimp will result in poor mechanical performance and electrical conductivity. Too tight a crimp may improve electrical performance up to a point, but can damage the terminal body or wire strands, reducing tensile strength and/or vibration resistance. Any of these issues can cause the product to malfunction or fail, resulting in lost production time, damage, repairs, and potential injury and/or litigation.





The solderless terminal remains one of the most commonly used bonding techniques, but improper crimping can lead to serious system failures

Photos: TE Connectivity



Correct tooling and terminal selection is essential to creating bonds that optimize mechanical and electrical conductivity in the high-voltage cable assemblies used in electric and hybrid vehicle applications

To consistently achieve quality terminations, TE Connectivity advocates a step-by-step, systematic approach – which covers quality training, wire, terminal, tooling, documentation and inspection – and cautions that failure to address any one of these issues can, and often will,undermine the effectiveness of a crimp.

HV assemblies must consist of the correct cable, stripped and matched with the correct HV terminals and connectors which have the features needed to take the system to production. Critical to the crimping process, the tooling must be designed specifically to accept the precise terminal and wire combination. Documentation specifying the measurements and parameters must be carefully observed and followed by close inspection of the finished crimp.

This advice is underpinned by industry safety and certification agencies such as UL and CSA which, as part of the process of certification, conduct tests on solderless terminals for crimp height (a non-destructive method of checking the quality of a good crimp), vibration tests, thermal testing, tensile strength, dielectric strength, and voltage drop in controlled laboratory conditions, according to manufacturers' instructions. Often misinterpreted, approval depends on the product being used in accordance with the certification criteria, which in the case of solderless terminals, involves crimping using only the specified tool. For instance, a UL-certified crimp requires a UL-certified terminal and the associated UL-certified tool.

Available from Dalroad, TE Connectivity's ever-expanding portfolio of high-voltage products designed specifically for hybrid and electric vehicles includes five classes of wire – from 2.5mm^2 to 120mm^2 (20-400A) – and terminals and connectors. Stripping and crimping tools range from handheld for smaller wire cross-sections and low production runs, handheld pneumatic for mid-range wire cross-sections, and hydraulic presses for forming larger products. In the UK, TE holds quality training courses on all aspects of crimping solderless terminals, either at its base in Swindon, Wiltshire, or at customer premises at sites across the country.

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INQUIRY NO. 531

Battery supplier choices

Establishing secure supply chains for battery production materials ensures that new products and chemistries can be reliably offered to customers designing electrified vehicles

Industry experts often report on the development of new chemistry or process changes that deliver improvements in battery performance. Historically, these improvements have seen performance gains in lithium-ion batteries, with average improvements of 5-10% per year becoming commonplace. Cell cost, however, is still an issue. Currently, pricing is still around US$250-300/kWh, although this is widely projected to drop below US$100/kWh by 2025, or even earlier. These forecast improvements have seen lithium-ion batteries become the choice for product developers and tech designers. In addition to performance gains and forecast cost reduction, there is also a forecast of global overproduction, making it a key time to negotiate supply terms.

However, are supplier choices really available? Is overproduction likely? Are product costs tumbling – is it merely hype, or are real-world commercial realities coming home to roost?

Production economics still see batteries representing the single largest cost for EVs, making it more important than ever that demand increases the choice of cell supplier.

Development of a national supply chain will enable advances in new cell designs and chemistries

Supplier choice, however, is a myth. It is extremely difficult for smaller companies (those without billion-euro-balance sheets) to establish new supplier relationships – as these companies find it hard to guarantee supply or even, in some cases, to get larger producers to answer the phone.

Worldwide production is growing, but placing multi-billion-euro orders has put the largest OEMs at the front of the supply queue. The larger vehicle manufacturers are playing a tune for cell manufacturers to dance to – Volkswagen recently called its battery tender one of the biggest purchasing initiatives in the automotive industry.

AGM Batteries is working with UK-based suppliers on a niche materials supply chain

Asian producers have committed to building new production facilities that, in turn, should help with long-term supply shortages. However, this still does not address the increased transportation costs that are associated with Class 9 Miscellaneous Dangerous Goods. Shipping cells manufactured so far from EV production plants only adds to spiraling vehicle costs.

Smaller producers are filling the supply gap created by the dominant players – who chase the bigger ticket orders. This market behavior is seeing the smaller producers becoming more important than ever.

Furthermore, Far Eastern dominance of materials adds to issues of product supply security, with the wider material supply chain feeling the strain of the growing market. UK-based AGM Batteries recognized that growth and security of products can only be guaranteed once the materials supply chain is established. Historically, the company has sourced base-line materials offshore, where established supply chains exist, supporting the dominant market players. This position has had to change, and having secured recent UK government grant funding, AGM is working in partnership with UK-based industrial material suppliers to establish a niche material supply chain. This initiative is making new suppliers aware of the material supply requirements of AGM's new and growing cell production facilities at its Thurso plant in Scotland.

The supply chain initiative will enable AGM to continue its work bringing new and exciting products to market. As the company works with the inventors of technology, the chemistries and products offered will provide customers with real choice and product security, as AGM produces quality cells onshore in the UK.

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INQUIRY NO. 532

E-propulsion expertise

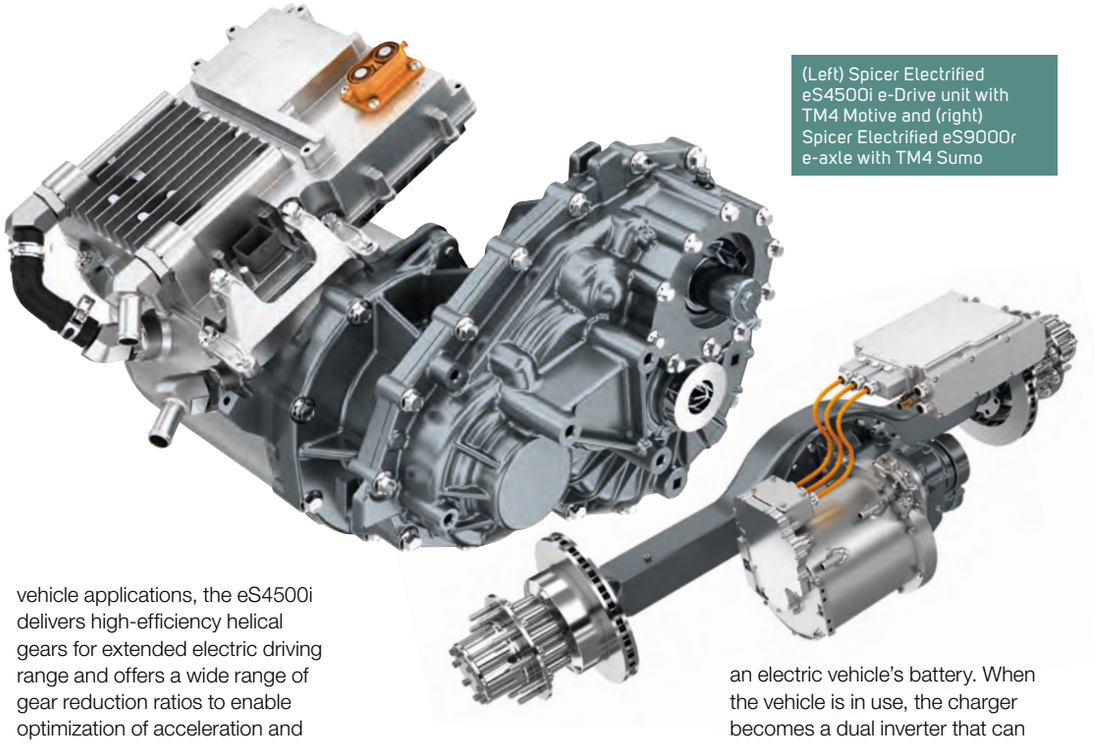
Advances in electric and hybrid vehicle power generation and conveyance can deliver improved performance, optimized packaging and reductions in system weight

The evolution of mobility is here. Emissions regulations and government policies are manifesting at an increasing pace. Combined with an upward trend in urbanization and a continued commitment to a 'greener' Earth, the transportation industry is embarking on a focused trajectory of decarbonization.

On this journey of technological sophistication, auto makers will look for trailblazing companies to help revolutionize power generation and conveyance. Dana Incorporated, a leader in highly engineered solutions for improving the efficiency, performance and sustainability of powered vehicles, is one such company. Dana offers a systems-focused approach to e-propulsion, guiding EV and HEV development for enhanced performance, packaging optimization and reduced system weight.

Ranging from complete systems and modular solutions to individual subsystem components, Spicer Electrified with TM4 solutions is able to meet the diverse architecture and platform requirements of the light vehicle, commercial vehicle and off-highway markets. From fully integrated e-propulsion systems that include electric motors, inverters, gearboxes and thermal management designed to meet the individual requirements of a customer's vehicle, Dana's electrified product offerings are revolutionizing power conveyance and positioning Dana as a leader in electrified drivetrains.

Ideal for the light vehicle market, Dana offers its Spicer Electrified e-drive units with integrated TM4 Motive electric motor and gearbox. The eS3000i, with torque output of 3,000Nm, is perfect for the ruggedness of the sport utility vehicle market. For light commercial vehicle applications, the eS4500i delivers high-efficiency helical gears for extended electric driving range and offers a wide range of gear reduction ratios to enable optimization of acceleration and top speed that this important industry segment requires.



(Left) Spicer Electrified eS4500i e-Drive unit with TM4 Motive and (right) Spicer Electrified eS9000r e-axle with TM4 Sumo

Spicer Electrified e-axles, with TM4 motors engineered to fit within the gearbox or axle for reduced driveline complexity, offer the versatility required to accommodate a variety of applications. With output torque ranges of 4,500-9,000Nm, and architectures featuring integrated motor/axle power systems or integrated motor/transmission/axle power systems, the Spicer Electrified e-axle lineup is ideal for light commercial vehicles, minibuses, medium-duty trucks and buses.

An additional offering in the Spicer Electrified e-axle portfolio is the eS13.0Xr. Designed to meet the requirements of zero-emissions zones such as those in China, this integrated e-axle with centralized motor and driveshaft architecture offers weight reduction, lower energy consumption and improved vehicle packaging, resulting in an optimal driveline system.

With the recent acquisition of TM4, Dana's electrification capabilities now include in-house design and manufacturing for electric motors, power inverters and control systems. The TM4 Sumo MD, HD and HP families of motors and inverters are designed to interface directly with standard rear differentials and/or gearboxes and/or e-axles. With a torque output ranging from 700-3,500Nm, the TM4 Sumo motors ideally serve rear-wheel drive light commercial vehicles, medium-duty trucks and buses, large buses and heavy-duty trucks, as well as vocational vehicles.

Recent additions to the TM4 portfolio include the BCI20 bidirectional charger inverter and the Neuro 200 vehicle controller. In charger mode, the BCI20 converts AC to DC power to efficiently charge an electric vehicle's battery. When the vehicle is in use, the charger becomes a dual inverter that can provide two independent three-phase outputs of 9kVA each to power various auxiliary loads. The Neuro 200 is designed to be used as the central control unit of an electric/hybrid vehicle, seamlessly managing the information flow between all the components. Its fully programmable design enables customer development of multiple control features by interacting closely with the man/machine interface, traction system and other components.

Leveraging more than 20 years of electrification experience, and more than a century in conventional drivetrain innovation, Dana is able to support OEMs' needs wherever they are in their electrification journey.

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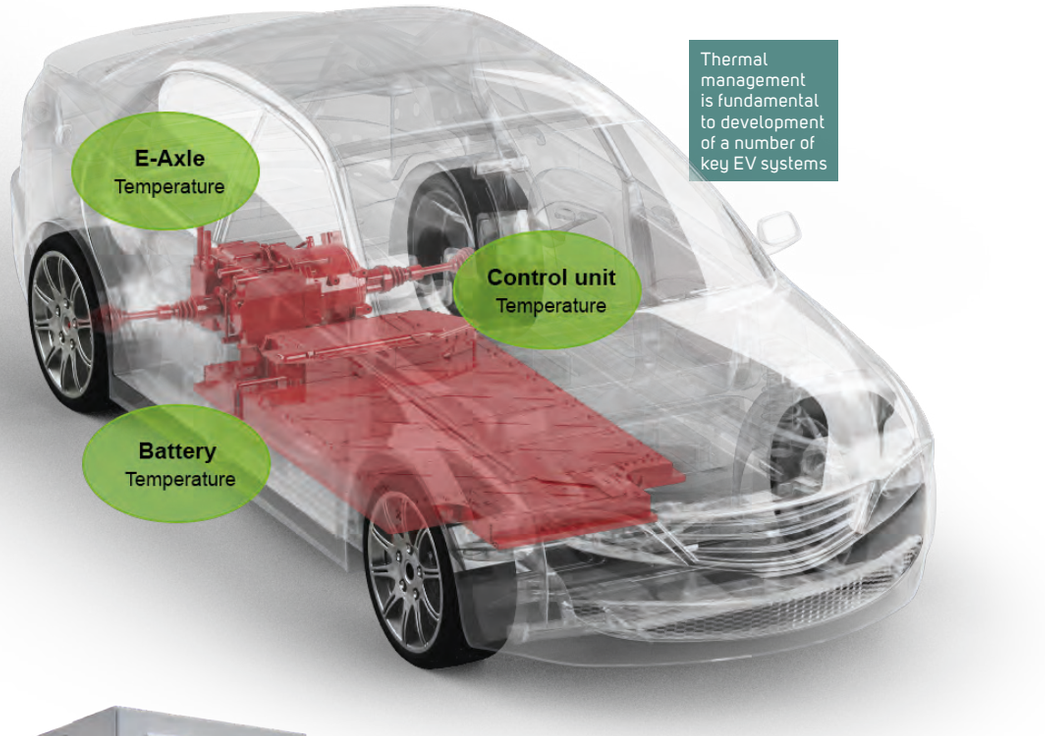
INQUIRY NO. 533

Testing cooling technology

The increasing importance of thermal management in electric vehicle powertrain development calls for sophisticated and precise testing equipment



Thermal management is fundamental to development of a number of key EV systems

In the rapidly growing e-mobility market, the rapid development of e-axles for electric vehicles, hybrid drivetrains and high-density batteries is of the utmost importance.

Thermal management is a key element in the development of electric vehicles – the performance levels, safety and service life of the battery and the electric motor are highly dependent on it. Batteries and electric motors are subject to repeated thermal shocks, which can see their performance levels suffer very quickly. Consequently, designers of an electric powertrain unit must also pay close attention to the cooling system.

For the same reason, defining the battery management system (BMS) and energy management system (EMS) control laws becomes essential to optimize the use of the electric motor and battery according to the temperature. Therefore, bench tests must manage the temperature variable precisely in order to reproduce driving conditions as faithfully as possible, so that the information used to calibrate the calculators is highly accurate within strictly defined tolerance levels.

Thanks to FEV's long-standing expertise in managing coolant conditioning, acquired from years of bench testing for internal combustion engines, the company has developed an innovative range of conditioning units – called eCoolCon – dedicated to the development and testing of electric powertrain units.

The conditioning units dedicated to e-axle and hybrid powertrain unit test benches facilitate ultra-precise temperature regulation with two or three different circuits for the electric motor and the control electronics. The temperatures covered range from -40°C to 150°C (-40°F to 302°F). The coolant flow covered ranges from 1 l/min to 40 l/min and is controlled precisely.

FEV's eCoolCon conditioning units are dedicated to the development and testing of electric powertrain units

In the race to increase power density while making batteries lighter, and to avoid thermal runaway, numerous tests – which require precise regulation of battery temperatures – must be run on test benches. The conditioning unit created especially for battery test benches boasts the same temperature and flow control qualities as the e-axle/hybrid powertrain applications, with a single conditioning circuit.

This device can reduce the time during which the test cell is used. High levels of precision, repeatability and reliability create stable test conditions that faithfully reproduce real-world environments – fewer measurement points are required and a stable, constant level of the desired temperature is achieved more quickly.

The FEV eCoolCon features a number of attributes and design features that guarantee excellent durability and ease of use. For quality assurance purposes and to increase the efficiency of each conditioning system, FEV-STS has its own test facilities where each conditioning unit is adjusted, calibrated and thoroughly tested in all respects.

The eCoolCon is a key part of the FEV product range dedicated to electric powertrain unit tests. It contributes to the quality of FEV test bench solutions for e-motor, e-axle and battery.

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INQUIRY NO. 534

NVH in plug-in hybrids

A major Chinese OEM has achieved low noise and vibration levels in its hybrid vehicles thanks to the application of highly targeted development loops during benchmarking

China has established itself as one of the world leaders in PHEVs, representing 15.7% of the global light-duty plug-in market. BYD is one of China's pioneers in hybrid and electric vehicles. To maintain a leading position in EVs and meet ever-increasing customer expectations, BYD's management has committed considerable effort to improving the overall NVH performance of the company's plug-in hybrid vehicle fleet.

Zhang Rongrong, manager of the NVH technology research division of BYD, knew that the key to improving the overall NVH performance in BYD hybrid vehicles was an in-depth understanding of the requirements. Knowing exactly where and precisely how much a car lags behind the competition is crucial for resolving any discrepancies.

The Chinese OEM contacted Siemens PLM Software's Simcenter Engineering and Consulting services to benchmark the Qin vehicle. The BYD prototypes were put nose-to-nose with comparable competitor models, providing all required data to execute a targeted optimization campaign, and were analyzed using Simcenter Testlab software. After considering the impact on the subsystems, BYD reached a verdict regarding the solutions it wanted to implement while taking particular care to ensure that other vehicle performance attributes, such as handling and durability, did not deteriorate.

BYD and Siemens PLM Software collaborated to benchmark NVH levels on the Qin model against competitor vehicles

Highly targeted development loops helped BYD boost the NVH performance of Qin model prototypes. "The results we got were staggering," says Rongrong. "Not only did we succeed in complying with our prior-defined targets, sometimes we even managed to surpass the NVH performance of the benchmark. For the Qin, idle noise in HEV mode came in at 0.9dB(a) (A-weighted decibels) less than the target. This result was also 3.7dB(a) less than the starting level, and 3.4dB(a) less than the competing vehicle."

Figure 1 shows wind noise measured in Articulation Index (%) versus road speed. The before and after performances of BYD's Qin vehicle are portrayed by the blue and red curves respectively. The green curve depicts the performance of a competitor vehicle. As demonstrated by the solid black line, BYD managed to exceed prior set target values at all measured speeds between 95km/h and 125km/h (60mph and 78mph).

"Fifteen versions of the Qin were praised for NVH performance by our customers," says Rongrong. "Working together with the Simcenter Engineering team for NVH optimization has helped us position ourselves as the top seller in plug-in new energy vehicles. We managed to save a considerable amount of time and resources. We were also able to boost our overall brand value and reputation."

At present, the company is rethinking its vehicle development process, which is largely based on prototype benchmarking and troubleshooting. Instead, BYD wants to move into the world of model-based systems engineering, where requirements can be frontloaded in the very early phases of product development at a much lower cost. Initial benchmarking will soon be part of a larger, more advanced optimization process.

"With Simcenter services and tools, our NVH performance development and control process has significantly improved," adds Rongrong. "The majority of noise- and vibration-related issues are now dealt with early in our product development process. The entire procedure is much more integrated."

With this fundamental change in philosophy, BYD has allocated NVH performance its rightful place within the design cycle of future vehicles. The company has taken an important step in the race to compete with other hybrid luxury car manufacturers outside China.

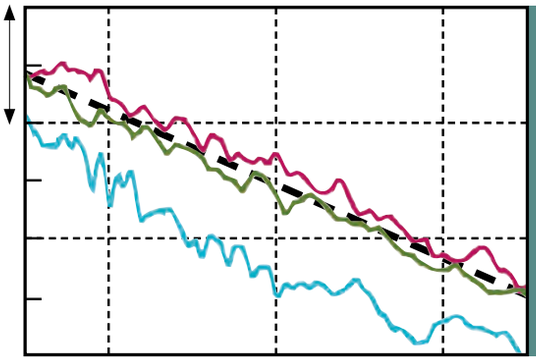

Figure 1: This graph shows wind noise Articulation Index (%) versus road speed. BYD managed to exceed its targeted values at measured speeds from 95-125km/h

After optimization | Competitor vehicle | Before optimization | BYD targeted values

Efficient EV transmission

A 4-speed transmission features traction motor-synchronized shifts and a deep-ratio first gear for difficult launches, and can offer improvements to a range of performance markers

With the upcoming introduction of its new 4-speed EV transmission, Eaton is taking what has long been considered standard in the electric commercial vehicle industry and turning the concept on its head. The new transmission promises increased performance in range, grade capability, acceleration and efficiency.

Since the advent of electric commercial vehicles, direct-drive transmissions have been the norm, much as they are on electric passenger cars. But the much greater weight typical of commercial vehicles means that this solution is largely inefficient.

The new 4-speed transmission, part of Eaton's eMobility portfolio of electrified vehicle components, solves the primary issue related to single-speed drives: contradictory requirements for high efficiency at top speeds and increased torque at launch and low speeds.

Eaton's new 4-speed automated manual transmission (AMT) is a lightweight, efficient countershaft gearbox with torque capacity up to 1,200Nm and electric gearshift actuation that enables OEMs to use smaller, more efficient motors.

Fine-pitch helical gears ensure smooth, low-noise operation, and the Eaton Transmission Control Unit's shifting strategy is designed for fast gear changes and maximum efficiency, extending both range and battery life.

Road tests have shown a 20-30% efficiency improvement under normal driving conditions compared with a direct drive transmission, and a 10-15% improvement compared with current 2-speed solutions.

Eaton's 4-speed EV transmission for commercial vehicle applications

The 4-speed EV automated transmission is based on traditional, robust and efficient lay shaft architecture typical of AMTs, but is designed specifically for EV commercial vehicle applications. Unlike traditional commercial vehicle transmissions, Eaton's 4-speed EV gearbox does not have a clutch, and shifts are synchronized using the traction motor.

It also operates at higher speeds than its traditional ICE gearbox counterparts, and gears are optimized for typical electric motor performance and power curves for maximum efficiency.

Eaton's deep-ratio first gear has been designed for launches under difficult conditions that would stress the driveline. The transmission's second gear is used to deliver smooth launches under normal road or load conditions.

The new design allows for a smooth launch on grades of up to 30%, compared with the approximately 10% grade limit of direct drives. On grades of 5-7%, the transmission can maintain speeds of 80km/h (50mph), and at grades around 3%, the vehicles can hold steady at 95km/h (60mph).

The 4-speed EV transmission also provides higher output speed capability and torque range than a direct-drive system. This enables the use of a smaller, lighter electric motor for large commercial vehicles, which cuts down on the cost; a major buying point for commercial EV operators.

The latest gear technology is ideally suited for 7- to 18-ton applications and provides 5,000rpm input speeds and up to 9:1 overall ratio coverage. The transmission improves acceleration by keeping the vehicle in lower gears, which provides maximum motor power while maintaining efficient operation at cruising speed.

The new 4-speed EV transmission can be tailored to the specifications of a customer's application, and is available as a standalone AMT, or as a complete EV powertrain system.

Eaton, which has been in the hybrid transmission business for 15 years, is already under contract to supply the new transmission to a major bus manufacturer.

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INQUIRY NO. 536

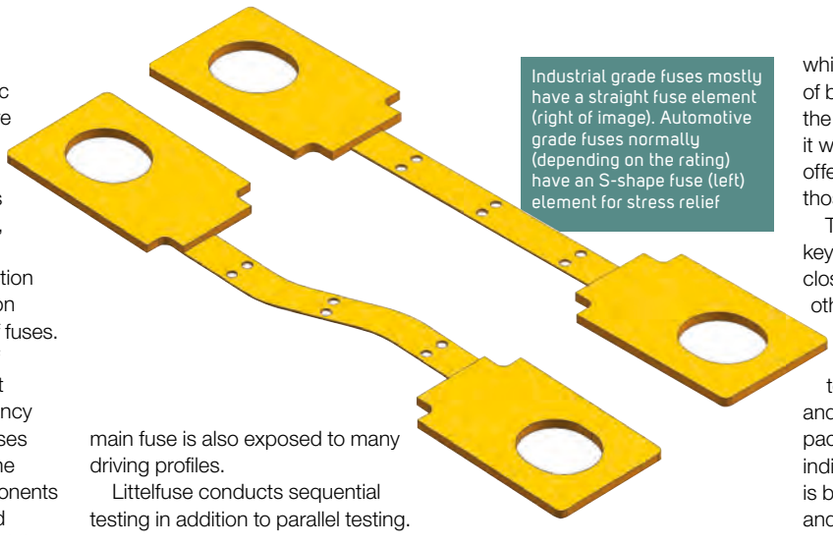
Overcurrent protection

With the level of electrification in vehicles increasing, it is vital to ensure a high level of robustness in the fuses used in current and future electric and autonomous vehicles

Modern vehicles are crammed with electronic systems. Legacy vehicles were essentially mechanical systems, supplemented by hydraulic or electrical systems for functions such as steering, ignition, lights and audio entertainment. System protection was focused on wire protection provided by a small number of fuses.

Not only has the number of fuses increased over time, but their purpose and life expectancy has also expanded. Today, fuses are used to protect not only the cable harness, but also components such as relays, pyro fuses and electronics. HEV/EVs require higher voltage ratings than legacy vehicles, from 48V up to 1,000V. In addition to the electrical parameters, greater robustness is required, particularly since functional safety (ISO-26262) has to encompass the increased complexity and higher risk of failure in autonomous vehicles.

In comparison with other industry standards, automotive requirements are more severe and tested under harsher conditions. For example, PHEV fuses must sustain 35,000 hours of EV charging stress added to the regular 8,000 hours from the driving cycle. Emissions regulations foster increasingly efficient electrical and electronic systems. Electrical loads are tailored to be turned on and off only when needed. Fuses protecting selectively switched loads must be more robust against pulse stress as well as DC operation. Pulse load leads to a higher degree of thermal expansion, resulting in a mechanical disconnect of the fuse if the design is not rugged enough. The main fuse is also exposed to many driving profiles.



Industrial grade fuses mostly have a straight fuse element (right of image). Automotive grade fuses normally (depending on the rating) have an S-shape fuse (left) element for stress relief

Littelfuse conducts sequential testing in addition to parallel testing. Over its lifetime, a fuse faces a variety of stresses that can influence one another. Thermal and vibration stress complement higher degrees of stress. Littelfuse has therefore developed a test plan in which the same fuses are tested, and are not replaced by new fuses for each subsequent test stage.

Electronic components are qualified according to AEC with its different standards for semiconductors and passives. An SMD fuse is a passive component. Although similar to a resistor, the stress tests defined in AEC-Q200 are not fully applicable to fuses. This allows electronic fuse suppliers a certain degree of freedom in regard to a fuse being considered automotive grade. Environmental conditions regarding temperature and humidity in particular require an improved design.

Littelfuse's next-generation circuit protection products

Littelfuse stress tests are more rigorous than other validations: with 1,000 hours versus 504 hours in humidity (85°C [185°F], 85% RH), 1,000 cycles versus 5 cycles in thermal shock (-55°C to +125°C [-67°F to +257°F]) and 1,000 hours versus 0 hours in operational life (with de-rated current applied). They additionally include testing at minimum, room and maximum operating temperatures for overload. Regular short circuit tests are performed at room temperature only. Specific customer requirements can be considered in the test plan.

With its experience in many other industries, Littelfuse supports customers' designs in the automotive space in accordance with worldwide automotive safety standards. By contributing their own experience to the development of new standards, Littelfuse engineers help to ensure the safety and reliability of the next generation of circuit protection products. They help customers understand which standards apply in terms of both the application itself and the geographical location in which it will operate. In addition they offer guidance on how to meet those standards.

The process control – including key parameters such as Cpk or closed loop control – is similar to other standard processes, such as electrical and visible testing. This also includes some regular testing, such as opening times and breaking capacity. Blister packaging is used for better and individual protection. The design is based on customer, functional and environmental needs, to ensure a high safety performance. Automated and controlled production lines ensure reliable and safe manufacturing.

With electronics controlling an increasing percentage of vehicle functions, the circuit protection devices that prevent hazardous overcurrents will continue to evolve to higher integration, combining switching and protection function using semiconductors. In some areas, melting fuses and electromechanical relays are transitioning to devices such as smart MOSFETs.

Sophisticated electronics are now integral to vehicles at every price point. For the manufacturers of electronic components, it is important to meet the increased requirements regarding availability and reliability since these systems are safety critical. For the future, it is important to evaluate hybrid solutions with passive and active protection as well as pure semiconductor-based overcurrent protection.

Advanced battery testing

Continuous development of hardware and software has resulted in battery testing systems that are fast, accurate, customizable and capable of testing multiple units simultaneously

Now recognized as a pioneer in the modern battery test industry, Maccor started operations in Tulsa, Oklahoma, in 1986. With a core team of engineers experienced in emerging battery technologies and computer control systems, the company is dedicated to the development of high-performance battery test systems.

In the past, the only commercially available products to evaluate battery performance had been designed and built specifically for lead-acid vehicle battery applications. These units were relatively high power, lacked a high degree of accuracy, had limited test programming capabilities, and collected data relatively slowly. In the mid-1980s, when there was a growth in new battery technologies, it became clear that the available battery test systems were inadequate.

The founders of Maccor imagined an entirely different design for a battery test system. The result was a system that provided extremely accurate results, collected test data quickly, tested large numbers of batteries simultaneously, and could be programmed to perform almost any test sequence required.

Over the past 32 years, Maccor's technology has become the standard solution for many organizations involved in the research, development, quality control and evaluation of cells and batteries.

Today the company has a share in excess of 80% of the US market in its product area, and a major share of the European market, and has an expanding business in Asia. Maccor has more than 2,000 systems in regular operation in more than 50 countries.

Most Maccor systems are customized to suit specific testing application requirements

Maccor designs all its own hardware and software. This is an ongoing process. Most systems are customized to meet specific requirements, while some customers additionally request bespoke features in the software. The experience gained is used to develop future systems, with better performance and additional advanced features and capabilities using new computer technology.

Maccor is confident that it offers the widest range of features and capabilities of any manufacturer for this type of equipment.

Over four years ago, Maccor announced an exclusive agreement with the Scientific Instruments business unit of Ametek Advance Measurement Technology. Scientific Instruments comprises the Princeton Applied Research and Solartron Analytical and Signal Recovery businesses of Ametek Advance Measurement Technology. 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. This provides greater data integrity with more reliable and reproducible test results and reduces idle time and in-test waiting caused by operators having to move test devices from one instrument to the other.

In 2017, Maccor and Voltaiq announced a joint marketing agreement. Voltaiq is a supplier of data analytics, providing the informatics platform and expertise for optimizing energy device performance throughout the product lifecycle. The Voltaiq Battery Intelligence software platform integrates seamlessly with Maccor's test equipment, providing a complete end-to-end solution for battery testing, analysis and optimization.

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INQUIRY NO. 538

Precision manufacturing

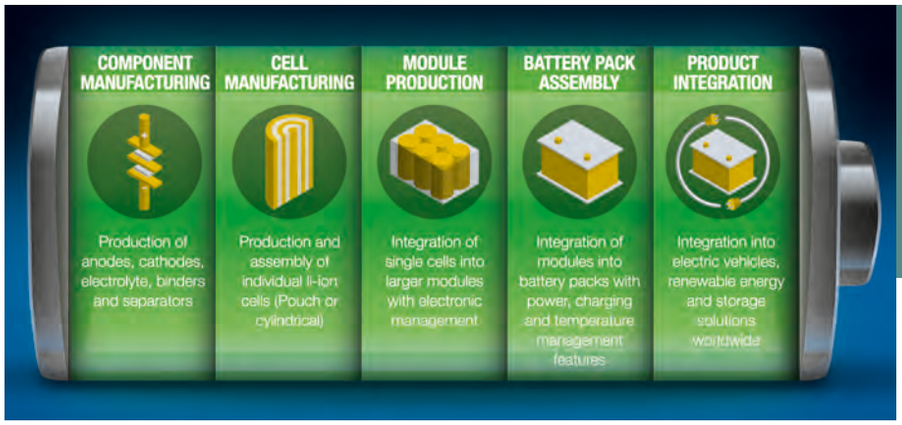
Each phase of battery production – from component and cell production to module production and final assembly – requires the use of other sophisticated technologies

Decarbonization, increasing electrification of transport, the expansion of renewable energies: the efficient and safe storage of energy plays a central role in the scenarios of the developing energy revolution. Battery production is becoming a key technology, and whether it is a matter of manufacturing the smallest components or the largest energy storage solutions, other highly specialized processes are used in every phase of battery production.

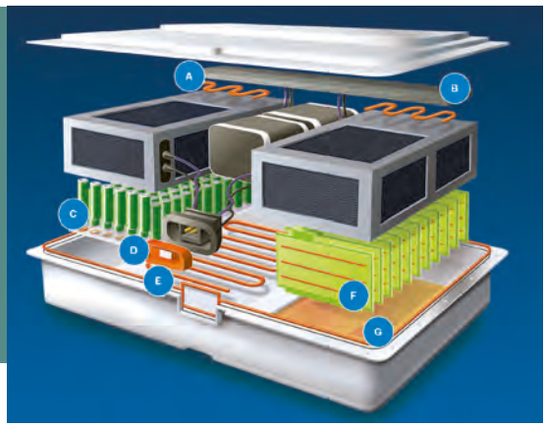
As a leading supplier of precision metering and processing of adhesives, coatings, polymers and plastics, sealants, bio- and other materials, as well as liquid management, Nordson offers the technologies required at all stages of production from a single source. R&D startups use the innovative processes and in-depth materials knowledge of the USA-based company, as do the world's largest manufacturers. Lithium-ion battery suppliers rely on Nordson extrusion and coating technologies, while electric vehicle battery developers benefit from knowledge of the release of thermally conductive adhesives. More than 70% of the world's battery producers belong to Nordson's customer base.

The component manufacturing stage is characterized by the melting, extruding and pelletizing of polymers. To this end, Nordson provides its battery customers and OEMs with tailor-made extrusion and tooling systems – for example, for the production of separators and soft-pack outer housings.

Cell production places the highest demands on reliable, precise liquid dispensing of anode and cathode coating and bonding, electrolyte filling, electrode cell bonding, coil friction prevention, cell edge protection and separator fixation.



From the smallest components to the largest energy storage solutions, Nordson technology plays a crucial part in every stage of battery manufacturing



With the right technology on board, assembling cells into modules is quicker and more accurate, with less chance of error. Minimized overflow and cleaner pack assembly mean less waste and reduced rejects

The technologies offered deliver highly repeatable, uniform liquid separation while reducing material waste, scrap and rework. Depending on the size of the production, coordinated components such as benchtop dispensers, dispense and spray valves, innovative jetting technologies and automated dispensing robots are available.

For the assembly of cells into cylindrical, prismatic or soft-pack modules, flexible solutions are available for every size and speed of the production process. These help to improve the accuracy of module assembly, cell stack, component bonding, battery cell bottom, solder paste dispensing, module lid sealing, structural bonding and encapsulation. They also minimize the chance of errors when bonding, securing or applying materials for heat management, regardless of whether manual or fully automated production is involved.

To adapt to the end product, battery cell modules often have to take on complex shapes. However, it must be ensured that the module supplies sufficient power. For such applications, solutions are available that enable precision dispensing of the material, even in difficult-to-reach places, while preventing material overflow and ensuring clean packaging arrangement. Such precise potting and gap-filling solutions to support power distribution and heat management throughout the battery pack require years of experience and expertise.

Nordson's battery production offering is rounded off by a system of sophisticated quality assurance measures. Testing and inspection technologies integrated throughout the manufacturing process include overhang measurement and layer count verification, weld and bond destructive testing, or pull and shear testing. These proven technologies ensure the highest quality standards and consistency from cell to cell.

As a systems provider, Nordson benefits from the combination of years of experience in tool design and manufacturing with in-depth know-how. Complete integration of manufacturing processes not only improves product quality, but also optimizes production itself and maximizes its efficiency.

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INQUIRY NO. 539

EV charging standards

International standards have an important role to play in improving production of electric vehicle charging infrastructure, and encouraging system compatibility

Founded in 1994, Intramco Europe (Dutch Electrical Driving Solutions) has, in recent years, developed a comprehensive range of high-quality and progressive EV charging products. Electric mobility is the future and as a result, much of the technology is still relatively young and subject to further development. Intramco continues to research, develop and innovate to facilitate the mobility transition, and is poised to expand its product portfolio.

Although ultra-fast charging and inductive charging continue to garner more attention, the market for AC charging will be the first to experience major growth for a number of reasons. Charging at home will remain the far cheaper option, and electricity storage for multiple uses will become increasingly common. Furthermore, charging can be done at home without having to wait for a charger and without having to travel to a charging location.

However, DC charging will be available at every gas station along the highway within 10 years.

The level of investment required in infrastructure and supply of the grid is substantial. Who will invest? Primarily the gasoline and energy companies. The question remains what the expected ratio of fast, public and private charging will be in 10 years' time, but Intramco believes that AC charging will represent the largest proportion.

AC and DC charging will therefore coexist and share the market without conflict. The industry faces a challenging future as the EV market is just a fraction of what it could become in the next few years. When starting from zero, every growth figure looks impressive – although explosive growth is yet to be seen and expectations keep on being adjusted. China sales are now exceeding those of Western Europe and the USA combined.

A comprehensive range of charging products is key to capitalizing on the vehicle and infrastructure variety typical of the developing EV industry

One of the most obvious benefits of charging standards is that they facilitate trade. Intramco believes international standards will make an important contribution to improving production and international trade.

The IEC/EN 62196 series of standards applies to electrical connectors and charging modes for electric vehicles. IEC/EN 62196-1 is applicable to plugs, socket outlets, connectors, inlets and cable assemblies, while IEC/EN 62196-2 is specific to EV dimensional compatibility and interchangeability product requirements for AC pin and contact-tube accessories.

Intramco's current range of EV products (charging cables, sockets, actuators and other components) are more specifically applicable to: IEC/EN 62196-1:2014; IEC/EN 62196-2:2012, A11:2013 and A12:2014; and its US charging cables adhere to UL2251 by SGS USA/CANADA (Type 1 AWG10/30A to AWG8/50A). The company's DC CCS2 Combo 60-150A conforms to IEC 62196-3, IEC 61851-23 and -24 and ISO 15118. Combo CCS 1 technology for the USA and Canada is under development.

Both vehicle and charging station plugs are designed with a long, bend-resistant cable tube. All plastics are level V-0, non-flammable material. Plugs are filled with epoxy to ensure natural heat spreading, and are water resistant. The shells can therefore withstand pressure against breaking, ensuring that wiring will not be exposed.

Intramco is legally obliged to provide proof of the safety of its products. CE marking is the standard for the European market. SGS's Center for Quality Engineering conducts safety tests of Intramco's products in accredited test laboratories, ensuring products are compliant with international standards through certification.

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INQUIRY NO. 540

Battery pack insulation

A patented dynamic insulation system can keep lithium-ion battery cells in their optimum operational window for extended periods, without requiring active cooling solutions

Besides the driver and passengers, the battery is the most valuable asset in modern electric vehicles. It dictates their ability to move, availability, price, durability, resale value and recyclability. These are the most critical factors for buyers when deciding between a PHEV or a BEV.

The battery is particularly sensitive to temperatures changes, which is why battery designers and automotive OEMs strive to find innovative ways to warm or cool it using complex, heavy and costly fluid-flow networks.

The increase in the number of new electric vehicle models looks set to continue, and will require modular battery packs with variable geometries, optimized weight, high efficiency and suitability for fast-charging modes.

Hutchinson's expertise in insulation applications and fluid management systems for automotive as well as aerospace industries is enabling it to develop creative solutions in its thermal management-dedicated laboratory, answering current and future vehicle requirements.

The Dynamic Insulating System (DIS) is one such solution. The patented technology has been designed by Hutchinson to meet changing customer needs. The DIS's combination and specific layout of formulated materials builds a dynamic thermal barrier between the battery pack and its surroundings. This keeps all the Li-ion cells at their optimal operating temperature of 20-35°C (68-95°F), whatever the weather conditions. The DIS represents a new approach to managing thermal energy transfer between the battery pack and the ambient environment.

During cold periods, DIS insulating properties reduce the transfer of calories to the outside, and boost the operability of the battery. During heat peaks, DIS prevents battery overheating and reduces the amount of energy needed for rapid cooling.

The formulated materials, their specific combinations and the design of the system have been simulated and tested to maintain a standard battery pack in a temperature range of 20-35°C during a 12-hour period with the vehicle parked and unplugged, and with outside temperatures from -20°C to 45°C (-4°F to 113°F).

The vehicle battery management system typically uses safety and wait protocols in such temperature ranges to condition the battery – with a detrimental effect on mobility. The DIS from Hutchinson offers a wider operational range, longer service life and higher battery pack efficiency. Consequently, it therefore offers a lower TCO for the end customer. Furthermore, it increases the end value of the battery pack for a potential static second life. DIS is specifically designed and adapted to various use cases.

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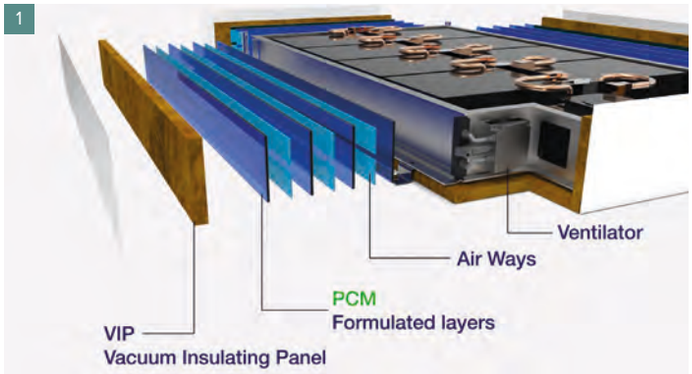

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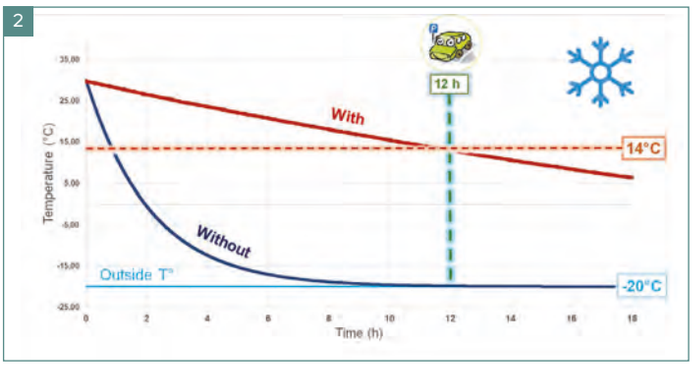

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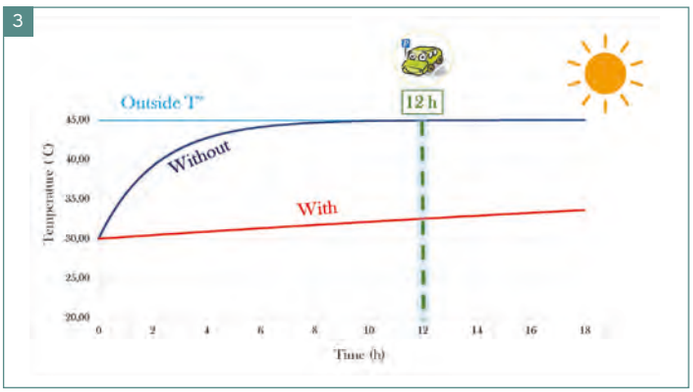

Figure 1: The DIS integrates several phase-change materials with different melting temperatures. Each material type and quantity is tailored to different climatic conditions

Figure 2: With low outside temperatures, the battery pack should be preconditioned. The use of the DIS maintains the battery temperature, even during a long static period

Figure 3: During high temperatures, the system limits the temperature rise in the battery pack, without any active cooling. The phase change materials with high melting temperatures increase the thermal inertia

High-efficiency power electronics

Ever-stricter emissions requirements and increasing environmental awareness pose the same challenge to both suppliers and auto makers: to develop green vehicles, paving the way for a cleaner and more energy-efficient future. For this reason, hybrid and electric vehicles are increasingly in demand. BorgWarner supports international auto manufacturers by covering four out of five key technologies for electric mobility – e-motors, transmissions, thermal management and power electronics.

Taking a closer look at BorgWarner's portfolio of power electronics, customers will find high- and low-voltage controllers as well as DC/DC converters for commercial vehicles. All of the motor controllers include a fully integrated set of inputs and outputs designed to handle a wide range of vehicle requirements. With operating voltage ranges of 50-800V, BorgWarner offers its customers a wide spectrum of power electronics, suitable for numerous hybrid and electric applications – in the commercial and the passenger vehicle market. By doing so, the company contributes to more powerful and eco-friendly mobility. Customers looking to find out more information on BorgWarner's high- and low-voltage motor controllers – namely the AC Motor Controller, the AC Motor Controller Gen4, the AC Motor Controller Gen5-S9 and the High Voltage Low Power Motor Controller should contact the company.

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www.ukimediaevents.com/info/ev
INQUIRY NO. 542

Hybrid vehicle trial program

Revolve Technologies is a UK-based company, world renowned for providing expertise in a number of low-carbon technologies. In 2017, Revolve was asked to join a consortium of partners to work on a multimillion-pound trial project, designed to help improve air quality in London as part of a global electrified vehicle push.

The project, headed by Ford Motor Company and the APC, and supported by Transport for London, features a 12-month trial of 20 new plug-in hybrid (PHEV) Transit Custom vans, in which Revolve offered program support, geo-fencing and vehicle telematics. The purpose of the project, supported by a £4.7m (US$6.4m) grant from the UK, is to explore how partners can contribute toward cleaner air targets while boosting productivity for operators in urban conditions. Revolve's engineering expertise was deemed essential in the fight to reduce emissions and costs in London.

With the breakthrough project now in its trial stage, Revolve's involvement since the completion of the vehicle builds has centered on the creation of geo-fencing technology and datalogging abilities, which will ultimately be invaluable resources for the future of low-carbon transportation.

Electric and hybrid technologies is just one area of expertise offered by the Essex-based company, together with its state-of-the-art involvement in hydrogen systems, dual-fuel technologies and fuel cell range extenders.

This project demonstrates once again that Revolve is at the forefront of green technology, pushing boundaries for the deployment of low-carbon technologies.

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INQUIRY NO. 543

Integrated e-axle test solutions up to 1,400V

Founded in 1967, Unico has been manufacturing high-performance inverters and drive systems for the test stand industry for more than 20 years. With the rapid move toward electrification in the automotive sector, Unico's AC and DC modular drive platform is proving to be ideally suited to electromobility testing.

In the case of electric motor or e-axle testing applications, Unico is able to provide an integrated solution: a DC battery emulator to power the unit under test, as well as a single AC dynamometer, or a pair, to load the e-motor assembly.

The battery emulator and AC dynamometer inverters are housed in a single cabinet to save floor space. Power is recirculated internally between the battery emulator and the AC dynamometer, meaning that very little power is actually drawn from the mains. This saves on installation costs, since it reduces current draw. It is also much more efficient to recirculate power across the internal DC bus than it would be to recirculate it across the AC power grid.

With power ratings from less than 100kW to more than 3MW, Unico is able to provide systems for the smallest of powertrains right up to the largest systems used by off-highway machines.

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www.ukimediaevents.com/info/ev
INQUIRY NO. 544

Shielded connections

Ideally suited for power conversion applications between 100kW and 200kW, Aptiv's RCS Direct Mate is based on proven 8mm Round Contact System terminals known as RCS800 and RCS890 – the terminal used depends on the cable exit orientation. The RCS Direct Mate is a shielded connection system which uses a simple unshielded terminal holder to replace complex, traditional shielded headers. A single screw fixes the female connector on the device. Thanks to the innovative screw position assurance, the Direct Mate provides an easy and safe connection. As the market requirements for compact solutions increase, the RCS Direct Mate is a perfect match for applications with space constraints. The Direct Mate has a female connector with no lever needed. In addition to the simple, unshielded terminal holder, this innovative feature delivers a cost-effective solution meeting current and future e-mobility challenges.

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www.ukimediaevents.com/info/ev
INQUIRY NO. 545

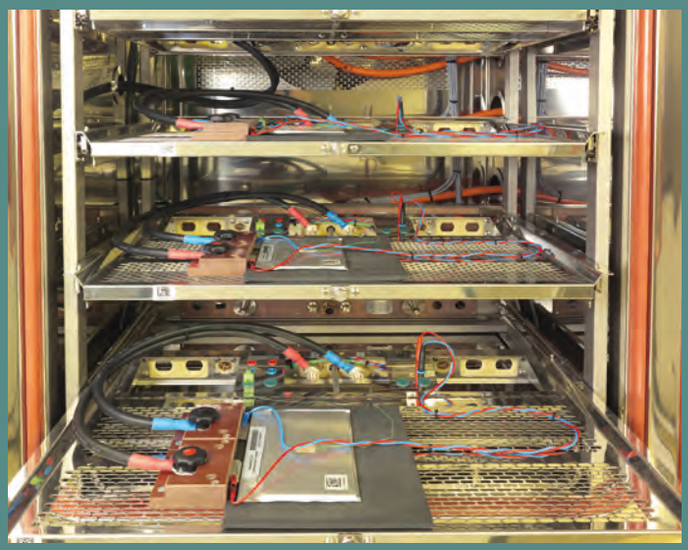
New testing solution for electric engine and battery

The CRITT M2A electrical department is equipped with 96 single battery cells and five battery module test systems to characterize the electrical and thermal behavior of batteries used in various applications in the automotive, motorsport, railway and aeronautic industries. It will also soon be equipped with six battery pack test systems up to 750kW to characterize complete EV batteries, and a 4WD test bench for tests on electric, hybrid or ICE vehicles or powertrains.

CRITT M2A has recently been equipped with a battery simulator (AVL E-storage) to perform battery characterization tests (32kW/ 0-60V/±600A).

This equipment offers measurement and control accuracy with maximum dynamic performance, and can be adapted to suit the specific needs of the company's customers.

CRITT M2A can use Emulator modes (for example, to simulate the battery of a consumer) and Tester battery to characterize the performance of the battery.



The equipment can be used on engine test benches to perform tests on hybrid engines.

Thanks to E-storage, CRITT M2A can now complete its range of turbocharger tests, including electric compressor tests, recovery system tests, and turbo compound tests (turbo and electric engine).

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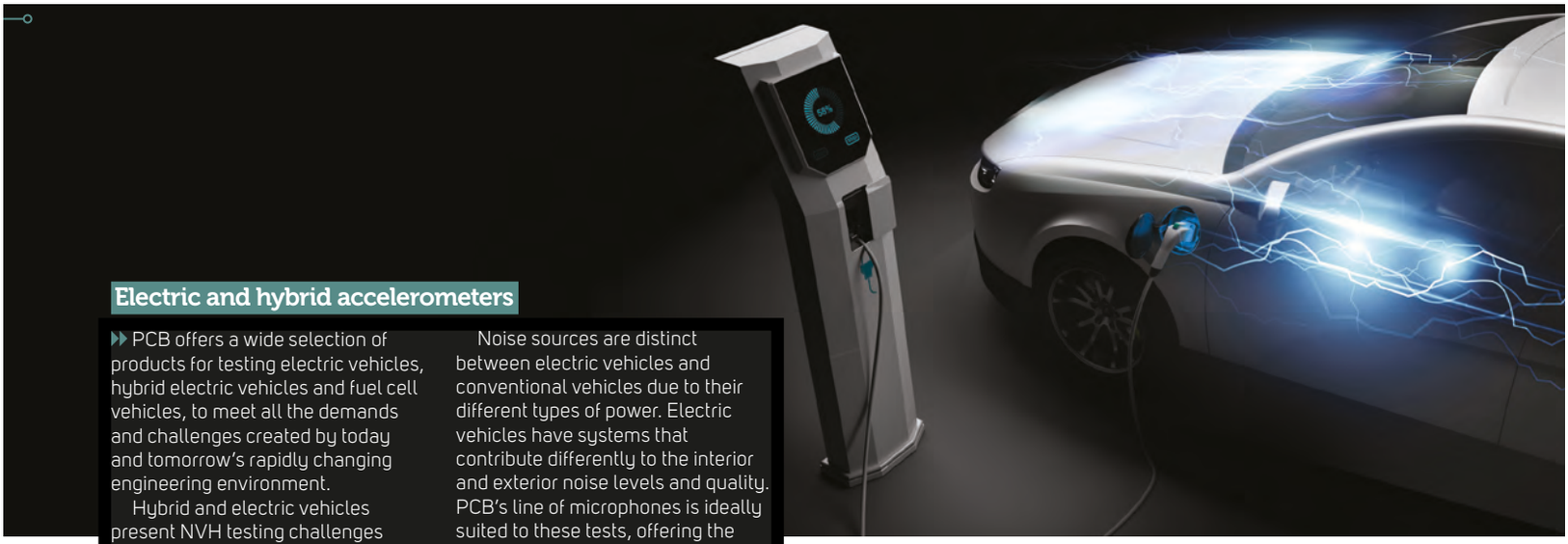
INQUIRY NO. 546



Electric and hybrid accelerometers

PCB offers a wide selection of products for testing electric vehicles, hybrid electric vehicles and fuel cell vehicles, to meet all the demands and challenges created by today and tomorrow's rapidly changing engineering environment.

Hybrid and electric vehicles present NVH testing challenges due to vehicle complexity, characteristics and potential problems with electrical isolation. NVH issues related to the addition of new electrical devices, gear whine and vehicle resonance increase the number of NVH areas to be tested. PCB's broad line of accelerometers is engineered to meet these challenges, with ground and case isolation. These accelerometers are ideal for use in strong electrical fields generated by electric and hybrid vehicle drive systems. Electrical isolation reduces noise in these fields and eliminates ground loops.

Noise sources are distinct between electric vehicles and conventional vehicles due to their different types of power. Electric vehicles have systems that contribute differently to the interior and exterior noise levels and quality. PCB's line of microphones is ideally suited to these tests, offering the precision needed to take accurate measurements in electric and hybrid vehicles. PCB's model 378A04, the industry's first pre-polarized low-noise microphone and preamplifier system, enables users to measure extremely low amplitudes found during electric and hybrid vehicle testing. The ICP design significantly improves ease of use and lowers per channel cost when compared with externally polarized models.

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INQUIRY NO. 547

Precision metal forming

A J Rose Manufacturing, with two plants in the Cleveland, Ohio area, and one in Nasik, India, is a top precision metal forming company in the automotive industry. AJR specializes in powertrain products for either electric or combustion powertrain systems, including components for motors, engines, brakes, transmissions, differentials, converters and more. Having been in business since 1922, AJR has amassed expertise, capabilities, patents and more, enabling it to integrate this know-how with today's technological manufacturing systems.

A J Rose Manufacturing then utilizes premium raw material grades, enhancing this expertise and yielding virtually defect-free components for critical-functioning applications within the powertrain.

The oncoming electric, hybrid electric, and newer combustion powertrains are bringing an entirely new range of precision metal formed products and capabilities, and AJR will be one of the few producers able to meet these new requirements.

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INQUIRY NO. 548

Smart solutions for test benches

Voltage, current, power: these three parameters are the first things that come to most users' minds when they are looking for an industrial power unit for testing rig applications. These are immutable parameters when it comes to designing a power unit, but there are many other properties that decide whether users have actually found the right power unit for their particular area of application. Signal quality is another crucial parameter: if a DC source/sink is needed for an EMC testing rig, it is in fact *the* deciding criterion for the output voltage. To simulate a battery with real DC voltage, a minimum residual ripple is essential too.

For Heinzinger's energy recovery systems, this is a typical application: with a residual ripple of less than 0.2% U_{nom} over the entire range from 0-1MHz, and with exceptional temperature stability, the ERS series is designed for battery simulation, and has been used successfully for more than 10 years in sophisticated testing processes.

Innovative technologies and short delivery times are necessary in order to defend a leading industry position. Heinzinger is well prepared to cope with the actual increasing demand situation.

The company's portfolio features different bidirectional DC sources in all power classes. With special software packages, Heinzinger can realize all applications for battery tests and simulations.

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INQUIRY NO. 549

Self-triggered hybrid pyro fuse

A global expert in electrical power and advanced materials, Mersen has developed a new line of self-triggered χp-ST Hybrid Fuse technology, specifically designed to provide optimum overcurrent protection for demanding battery-related applications in e-mobility platforms.

Today's overcurrent protection requirements of DC batteries on board electrified vehicles has brought new challenges that traditional fuses may not be able to address effectively. Fuses must guarantee fast protection for a wide range of fault currents and must withstand an elevated sequence of charging and discharge cycles, accelerations and regenerative braking, all while being subjected to harsh environmental conditions such as vibrations and wide temperature variations.

At the heart of Mersen's χp-ST hybrid fuse is an ultra-fast-acting pyro element with self-triggered ignition capacity. The self-trigger ignition mechanism can detect overcurrent faults and can clear high fault currents at 1,000V DC in less than 1ms while maintaining a 2kA minimum breaking capacity and very low power loss (20W@400A) over the entire DC voltage range. The integrated trigger eliminates the need for an external trigger sensor with related electronics and power.

Mersen's χp-ST hybrid fuse has a compact footprint and is built to handle large inrush currents of up to five times nominal current. With its adjustable time-current performance curves and tunable minimum breaking capacity, the χp-ST hybrid fuse is a flexible and high-performing overcurrent protective device for the next generation of e-mobility applications.

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INQUIRY NO. 550

High-conductivity copper

For designers of high-performance permanent magnet motors, the opportunity to forget the worries of rotor demagnetization, or the ability to conceive a high-field stator with liquid cooling integrated directly into the conductor itself, is worth exploration.

A high-conductivity copper conductor, combined with efficient thermal management inside, is just one product Luvata has recently introduced to the electric vehicle market. Luvata hollow conductors are available with cross-sections as small as 3 x 2mm with a 1.2mm round hole inside, right the way up to larger dimensions as required.

In battery pack design, copper hollow conductors enable efficient heat transfer, while keeping cells within optimal temperature ranges and providing the opportunity to use the same component as a current-carrying conductor. To boost motor manufacturing efficiencies, Luvata hollow conductors are delivered on long-length level-wound coils.

Luvata offers a wide range of other copper-based products for electric current carrying, thermal management and power generation and distribution purposes, as well as high-current connectors and all-copper rotor components for induction motors. Luvata is also a leading manufacturer of resistance welding electrodes for automotive robotic welding.

Luvata operates 11 plants internationally and is a Mitsubishi Materials group company.

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INQUIRY NO. 551

Thermal interface materials

Fujipoly Europe specializes in the supply of thermal interface materials (TIM) for cooling of electronic systems, as well as elastomeric connectors and rubber extrusions for the automotive industry. Fujipoly's parent company, Fuji Polymer Industries, was established in 1978 as a manufacturer specializing in the secondary processing of industrial silicone rubber products. Thanks to the technical knowledge within the Fujipoly global group, the company is able 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 requirements. Fujipoly understands the time pressures on projects where prototypes are required urgently, and has invested in finishing machines that require no tooling. This enables the company to respond extremely 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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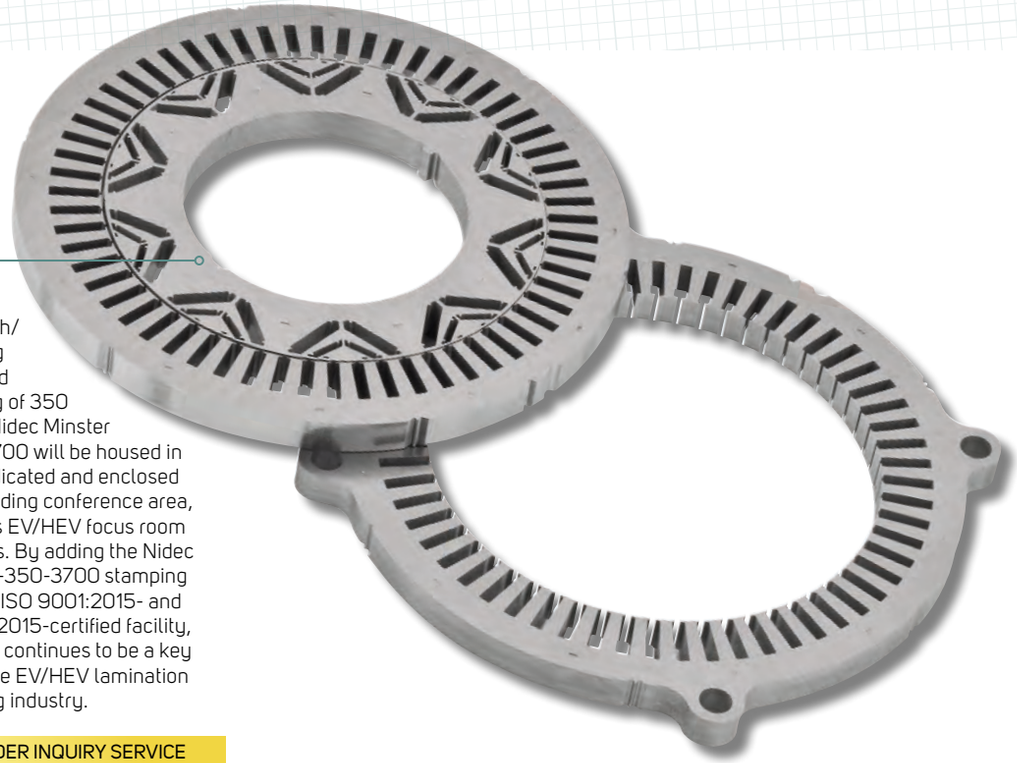
INQUIRY NO. 552



Die tryout press introduction

Based in the USA, LH Carbide is a leading company in the design and manufacture of high-precision carbide lamination stamping dies, and is expanding its breadth of die tryout capability. After conducting an extensive study of the projections of future EV/HEV needs published by major automotive manufacturers, LH Carbide determined that an additional tryout press would be required. The company chose the Nidec Minster EV-350-3700 press based on decades of Minster's proven technologies and stamping experience with extremely thin materials specific to the hybrid and electric vehicle market.

Handling the most complex programs with ease, the Nidec Minster EV-350-3700 is outfitted with a bed length of 3.7m (12.1ft), a Nidec Vamco push/pull feeding system, and has a rating of 350 tons. The Nidec Minster EV-350-3700 will be housed in its own dedicated and enclosed room, including conference area, making this EV/HEV focus room world-class. By adding the Nidec Minster EV-350-3700 stamping press to its ISO 9001:2015- and ISO 14001:2015-certified facility, LH Carbide continues to be a key player in the EV/HEV lamination die-building industry.

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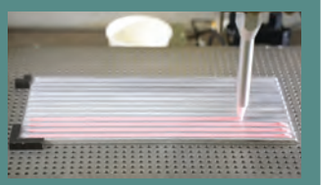
INQUIRY NO. 553

Thermal interface materials

Battery manufacturers are typically drawn to two types of products for thermal interface materials (TIM): a liquid-dispensable gap filler or a thermal pad. So, how do they differ? Lord Corporation did a study of the thermal impedance of CoolTherm gap fillers against commercial thermal pads with equivalent bulk thermal conductivities.

Despite having a high thermal conductivity and thin bond line, a TIM may have high thermal impedance and poor heat transfer because of the material's poor contact with one or both substrates. The study shows that thermal pads have considerably higher impedance values when compared with gap fillers. When comparing the key attributes of each, the relative cost for using thermal pads is high due to the costly scrap that results. Gap fillers



are the answer for design flexibility since the hardness and working time can be adjusted using the mix ratio of its two parts. Lastly, when applied, thermal pads can be difficult to apply without trapping air and automation is difficult. On the other hand, gap fillers are well-suited for high volume production.

When searching for the best solution for a battery pack, Lord's CoolTherm liquid-dispensed gap fillers can offer customers a valuable solution.

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INQUIRY NO. 554

Reliable solder interconnects in IGBT power modules and PCB assembly

With stricter regulatory requirements, the key to achieving lower CO_2 emissions is increased vehicle electrification. The auto industry has seen a rapid increase in 48V mild hybrids, HEVs, and EVs. Increased electrification with higher voltages poses specific challenges and demands on the solder paste used in PCB assembly, as well as the solder preforms used in IGBT power modules.

In PCB assembly, with higher voltages and the increased use of power components (FETs, DPAKs), it is critical that the flux in the solder paste can meet enhanced electrical reliability requirements, including minimum surface insulation resistance (SIR) of 5,000MΩ for 1,000 hours versus 100MΩ for 168 hours. Low voiding (under 20%), especially for low-standoff power components is also critical. Indium Corporation's Indium8.9HF solder paste has been proven to consistently achieve low voiding with no electrical dendritic growth.

For IGBT power modules and double-sided cooling modules, bond-line control – especially between the DBC and baseplate – is key for improved thermal and power cycling reliability. Indium Corporation has developed InForms – a new solder-matrix composite preform.

Compared with the traditional wire-bond stitch and trim technique, InForms have significantly improved bond-line control and, in addition, benefit from the creep resistance offered by the matrix. This directly translates to twofold improved thermal cycling reliability, without any change in the alloy or process. InForms also reduce the cost of ownership as they eliminate the extra process steps associated with the wire bond stitch trim technique.

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INQUIRY NO. 555

Pick-and-mix power electronics modules

A leading manufacturer of drive solutions for mobile use, Lenze Schmidhauser is focusing on its Mobile system of modular products specially designed for commercial vehicles. This system comprises double inverters, DC/DC converters and various combination modules.

Manufacturers can put these products together from a catalog to quickly and easily create a custom-made system for the drive control of auxiliary units and the provision of energy for the onboard power supply in their individual applications. This means the user can cover a large range of applications efficiently and economically with only one family of products, and react flexibly to new demands. The Mobile set of modules is tested and proven in series production, and it is continually being refined and extended – for example, the new DCU Single Inverter S for the control of air-conditioning systems and compressors. Lenze Schmidhauser offers its customers the best combination of expertise and series-product competence for the electrification of specific vehicle tasks.

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INQUIRY NO. 556

Pressure die-cast copper rotors for motors

Vehicle manufacturers always look for maximum power out of the smallest possible motor volume; most of them have turned to permanent magnet synchronous motors to achieve this goal. But this leads to very high demand on the market, where the sources of the rare earths necessary to magnet production are highly concentrated in a small number of countries. This leads to strategic issues such as uncertain long-term availability of rare earth permanent magnets and high cost volatility. Last but not least, the extraction of rare earths is not environmentally friendly.

This makes alternative, magnet-free motor architectures of great interest, and among these, induction motors with copper rotors are one of the best performing, as showcased in Tesla's Model S. A new development including Favi die-cast copper rotor enabled one of the company's customers to deliver 120kW continuous power from a 40kg (88 lb) induction motor, therefore achieving a power density of 3kW/kg.

Since 2002, Favi has been producing pressure die-cast copper rotors for high-performance induction motors, offering a reliable (more than 2.5 million copper rotors have already been produced) and affordable solution for high-performance, magnet-free motors.

Favi is a Tier 1 automotive supplier, IATF TS 16949-certified, specialized in production of aluminum pressure die-cast components and subassemblies.

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INQUIRY NO. 557

Powerful and fast battery state-of-health evaluation technology solution

Chen Tech Electric (CTE), a battery test solution provider from Taiwan, has developed a rapid and precise battery state-of-health (SoH) evaluation technology known as SBT.

In just 30 seconds, SBT achieves a reading with precision of more than 92%. In 2012, CTE first developed SBT for evaluating retired EV batteries in second-life applications. Now, SBT has been adopted by some used car dealers in Taiwan for repurposing hybrid EV packs.

CTE provides an efficient and easy way to sort battery modules among retired packs. On average, the repurposed packs deliver approximately 90% capacity compared with the fresh pack.

In addition to retired batteries, SBT is also used in new battery QC sorting processes. SBT is capable of detecting more than twice as many potential failure batteries as traditional methods.

Having successfully realized the aforementioned case studies, Chen Tech Electric believes it can provide an efficient and powerful solution for battery SoH inspection. The company is also willing to work on multiple collaborations with worldwide partners on battery SoH evaluation applications.

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INQUIRY NO. 558

Dynamic automotive test laboratories

Increased vehicle complexity and new power sources require advanced testing capabilities in the automotive industry. The demand for hybrid and fully electric powertrain and EV battery testing is rapidly increasing.

Proventia offers a dynamic approach with completely modular test laboratories and centers. Proventia Test Solutions enable customers to rapidly increase the capacity, change the setup at any time, or expand the capacity in stages, without disturbing operations in other test cells.

Not far from a plug-and-play laboratory, Proventia Test Units are manufactured and pre-commissioned before delivery. They are surprisingly fast and convenient to deploy. This leads to a quick and optimized testing capacity increase for the customer. Each Proventia Test Unit is an independent and highly integrable test cell that can be equipped with a customer-specific combination of key equipment.

The competitive advantage of Proventia Test Units lies in the modularity. It offers the true flexibility that today's continuously changing testing requirements demand. Proventia's scalable test center concept does not require heavy investment in the main building facilities. It enables the test center to grow step by step, spreading the investment over a period of time as the center grows.

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INQUIRY NO. 559

Tolerance-compensating connector system

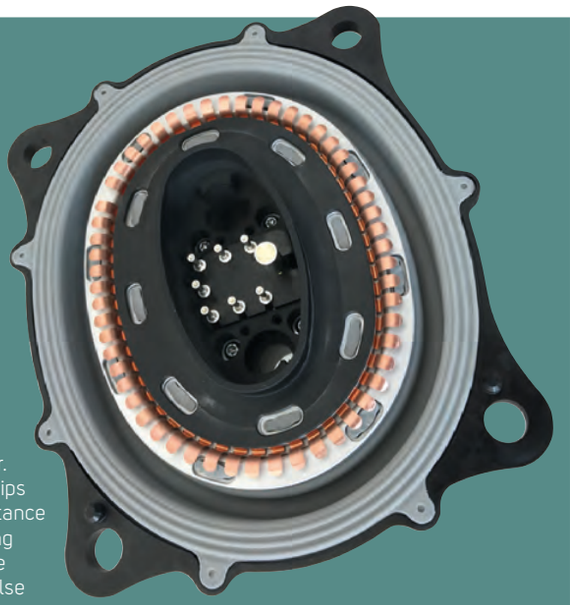
Sophisticated contact and connection technology that fulfills the highest quality standards, covers additional requirements and offers innovative solutions – this is the goal that continuously drives ODU's research and development work and opens up new technical approaches for further product development and optimization.

The latest example of ODU's development work is the Docking Mate, a new plug design with tolerance-compensating features, which is already experiencing strong demand from customers.

ODU is responding to the increasing degree of automation in production. In the future, automated production will be required to work independently, without any manual intervention. In this context, the company's tolerance-compensating plug systems will play a key role. ODU believes that an increasing number of devices or systems will feature a self-locating contact in future. The new innovation from ODU offers the required degree of precision, safety, reliability and robustness for the demands of industrial environments.

As early as 2009, ODU Automotive showed its innovation in the form of the first high-voltage battery-boosting system in a Mercedes S400 BlueHybrid, the first hybrid vehicle from a German manufacturer.

Thanks to sophisticated simulation software, constantly optimized development processes and a high degree of vertical integration internally, the company's development cycles for new products are becoming ever shorter. Its international partnerships are also growing in importance in the context of generating new products and creative solutions. The initial impulse for the new self-finding connector was generated at the first international ODU eMobility workshop in Mühldorf am Inn. The concept was then perfected in close collaboration with a global network of specialist teams.



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INQUIRY NO. 560

Drive system components for demanding duty cycles

The United States Forest Service recently announced its commitment to the introduction of clean, sustainable electric transportation to help preserve the environment and enhance the visitor experience at Sabino Canyon, Arizona. To facilitate the introduction of environmentally responsible transportation, the Forest Service announced it was awarding a five-year contract to Regional Partnering Center (RPC), to provide a fleet of zero-emission, open-air, 62-passenger trams. RPC teamed with Trams International, a leading USA tram manufacturer, on the project, which included a demanding duty cycle on a route featuring steep grades and several water crossings. Trams International worked closely with Transfluid to provide key drive system components for the project. Transfluid is a 60-year-old company that designs and produces hybrid and full-electric transmission systems. The complete transmission system installed on trams is fully electric, features a permanent magnet e-machine supplied through a dedicated traction inverter, has a high-energy $LiFePO_4$ battery, and is managed via CANbus and control systems developed in-house. The e-machine is mated to a gear and a clutch to transfer the power to the wheels.

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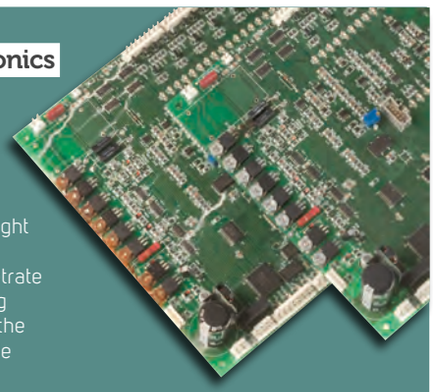
To learn more about Transfluid, visit:
www.ukimediaevents.com/info/ev
INQUIRY NO. 561

Reliable protection for electric and hybrid electronics

Manufacturers have long relied upon various methods to protect electronic systems, but newer, more advanced electronics are requiring advanced levels of protection that must be light weight, achievable on any component size, survive harsh environments, and cannot interfere with the sending or receipt of control signals.

Ultra-thin and light weight, Parylene conformal coatings offer excellent moisture, chemical and dielectric barrier capabilities to protect electronics used in EV/HEV technologies. 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. Parylenes provide a level of protection that is unmatched by many conformal coating materials.

RoHS and REACH compliant, Parylenes are also proven to provide metallic whisker mitigation in lead-free solder applications. The polymer coatings are ideally suited for protecting sensors, circuit boards, MEMS, LEDs, elastomers and other surfaces and components that need reliable, long-life performance in harsh automotive operating environments.



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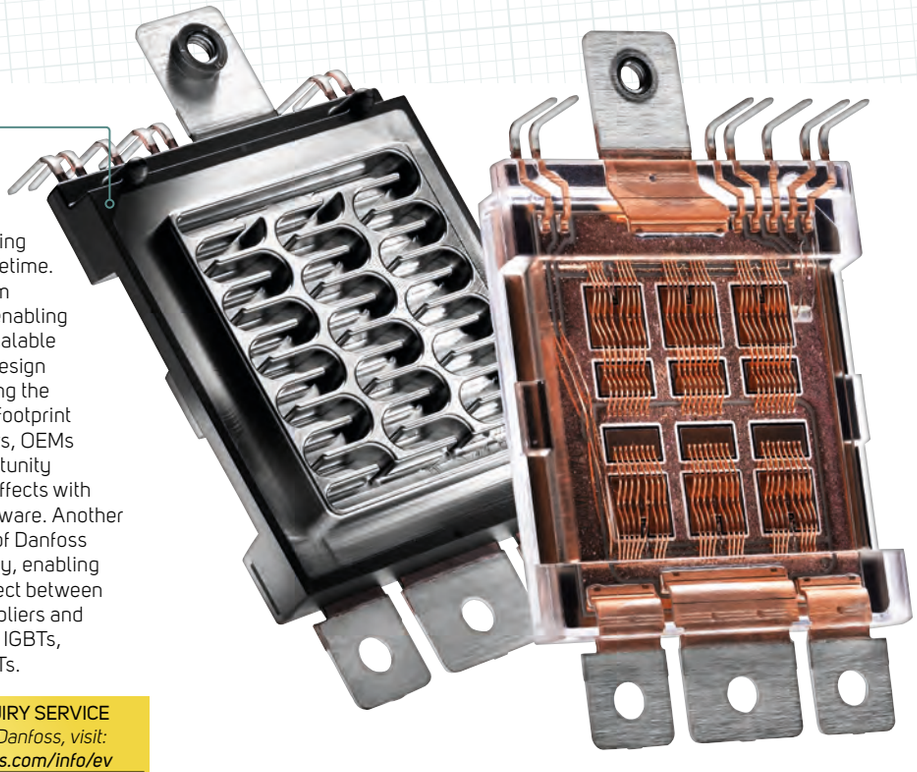
Power module technology platform

For decades, Danfoss has enabled the world's leading automotive manufacturers to deliver solutions that are designed to meet stringent efficiency, reliability and cost targets. Now, Danfoss is introducing the Direct Cooled Molded (DCM) power module technology platform for traction applications in hybrid and battery electric vehicles.

DCM 1000 can accommodate up to 1,000mm² of semiconductor area and the platform is truly flexible, designed to utilize Si, SiC or Si/SiC hybrid semiconductors. The DCM 1000 is designed to meet the drivetrain power requirements, while being scalable in terms of different voltage classes of up to 950V blocking voltage, and output currents ranging up to 700A.

The DCM utilizes a specific transfer mold package. In combination with the Danfoss Bond Buffer and direct liquid-cooling technology Shower Power 3D, DCM reaches a superior power cycling performance and lifetime.

The DCM platform ensures flexibility, enabling customers to use scalable drivetrain inverter design approaches. By using the same package and footprint for different inverters, OEMs now have the opportunity to achieve scaling effects with the supporting hardware. Another main differentiator of Danfoss is chip independency, enabling the company to select between a wide range of suppliers and offerings of suitable IGBTs, diodes and MOSFETs.



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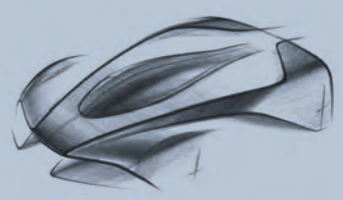

Aston Martin confirms Project 003 hypercar

Aston Martin has confirmed its next step into the mid-engined electrified market with a vehicle code-named Project 003. The mid-engined vehicle is the third hypercar developed by the OEM, following the Valkyrie and Valkyrie AMR Pro (formerly projects 001 and 002). The new vehicle will feature technology showcased in the Valkyrie. Project 003 will be built around a lightweight structure and will be powered by a turbocharged petrol-electric hybrid engine.

Project 003 is also being designed and engineered to offer more practical concessions to road use, including space for luggage. Fully homologated and available in all markets in both left- and right-hand drive, production will be limited to 500 coupe cars, with the first vehicles arriving to market in late 2021.

Inverter technology for vehicle control applications

For vehicle control applications, Curtiss-Wright's WTI-Traction Inverters operate with multiple motor technologies, including AC induction, permanent-magnet synchronous (PMS) and interior permanent-magnet (IPM) types. Major components – insulated-gate bipolar transistors (IGBT), 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 7,000,000.

Curtiss-Wright's technology features high levels of self-protection, with both current and transistor temperature measuring locally to the IGBTs, rather than through remote components. This technique delivers fast and accurate temperature measurements, offering effective protection against adverse high-current conditions including short-circuit or thermal overload.

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 the inverter 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 DC bus voltage mode, the inverter can moderate adverse and damaging voltages resulting from situations including regenerative braking from high speed.

The 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; 360-650V DC supply and 90-530kVA 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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INQUIRY NO. 564

Impulse magnetizing and measurement

With 40 years of experience in impulse magnetizing, Magnet-Physik Dr Steingroever is well equipped to meet the demands of modern electric motor production. The family owned and operated company from Germany develops and produces cutting-edge technology used by major manufacturers in a wide variety of industrial magnet applications.

From the magnetization of loud speakers, through power tools and auxiliary drives, all the way to large electric traction motors and wind turbines, the company's products cover a wide range of market requirements. Additionally, magnetic measurement technology supplied by Magnet-Physik is used to check quality and performance of both hard and soft magnetic materials.

In a world where energy efficiency, even in production processes, is becoming ever more important, the multichannel, liquid-cooled magnetization technology from Magnet-Physik based in Cologne on the river Rhine excels. Even the biggest traction motors can be magnetized in assembled form with one impulse. Thanks to highly efficient cooling of the magnetization fixture, mechanical and thermal stress are minimized so that the cycle time between magnetizations can be kept short, while maximizing system durability.

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INQUIRY NO. 565

Automation expertise for high-voltage cables

The fast-growing market for electric and hybrid vehicles is generating increasing demand for high-voltage cables. Currently, production is largely carried out manually. To ensure efficient and economical processing of the rising quantities of shielded cables, automating processes is becoming ever more important.

Komax provides suitable solutions for automating the desired process steps. Building on the flexible, modular Lambda platforms, the individual solutions add various processes for cable- and component-specific assembly including the required quality assurance checks.

The platform-independent process modules are freely configurable and can be set up in accordance with the manufacturing requirements. The degree of automation can be selected in keeping with the production volume – from a manual work station to a fully automated system.

In order to meet the growing market demand in the future, the company's current site near Budapest in Hungary will be significantly expanded. The new plant, which is currently under construction, will have an overall surface area of more than 4,000m² (43,000ft²), and will become Komax's global competence center for e-mobility.

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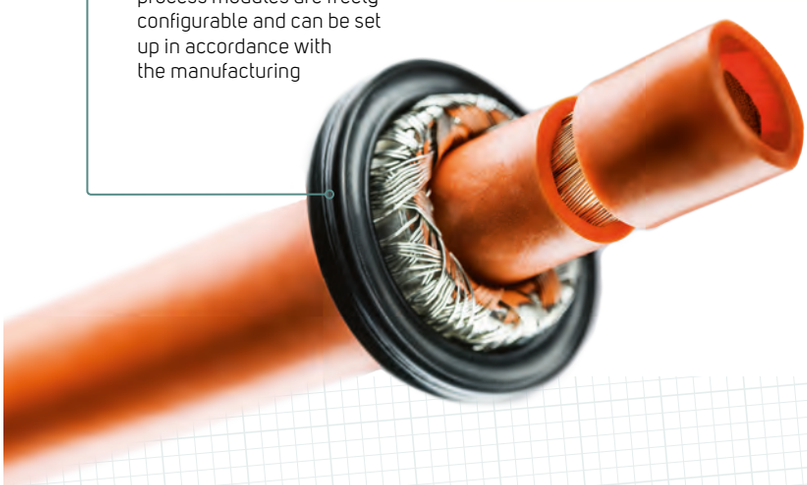
INQUIRY NO. 566



Robotic testing systems for use in climate chambers

Kübrich has more than 15 years of experience in automated test systems for R&D, durability and end-of-line (EOL) testing under different climatic conditions (-40°C to +125°C; -40°F to 257°F). The company produces a range of test products, from doors and flaps, interior and small electric motors, up to electric drives and components such as inverters and chargers.

With its Actere software, Kübrich has developed a turnkey test system individually designed for laboratories, test facilities and end-of-line systems. Based on long-term experience and an idea to create test sequences that are as easy as possible, Actere is ideally suited for testing, documentation and report generation.

Testing of e-mobility components such as starter generators, e-drive motors, inverters and charging systems, as well as pressure pulsation tests, have become a major focus for Kübrich, as has component testing for development of autonomous drive systems – for example, electronic steering, self-parking and electric-driven aerodynamic components. All components interfaced with the Actere testing software enable users to create their own test sequences, displays and reports.

The DuT Adapter Modular offers a wide range of measurement possibilities and simulations via CANbus or LINbus, and is also suitable for usage applications in climate testing chambers. Kübrich's latest development features the inverter EOL test system complete with conditioning system.

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INQUIRY NO. 567

Precise battery management for reliable range

To accurately determine the remaining range of an electric vehicle, precise battery management is essential. Shunt-based measurement methods provide the most precise information about the battery's state of charge, so the driver can rely on safely reaching the next charging station.

With precision shunt resistors, the electric motor can be optimally controlled and run at maximum efficiency. Compared with magnetic sensors, shunt-based measuring modules have a higher accuracy and provide digital measured values. The shunt resistors with an electron beam-welded copper-manganese strip enable high-precision measurements of the electronics over a wide temperature range, and establish the connection to the power electronics of the stator in the drivetrain.

Electrical energy storage devices for energy recuperation in hybrid drive technology work with lithium-ion batteries, providing high energy and power density. To guarantee safe cell chemistry, the cell and module connection in a battery pack require special copper-aluminum bimetals used as bus bars.

The special process of laser welding, together with a cladding process, makes it possible to combine the properties of different metals in a composite pre-material with excellent contact strengths. The process implies a high degree of freedom in flexibility and dimensioning. Also in direct cell contacting, specific copper spring connectors are a must for reliable, efficient bonding.

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INQUIRY NO. 568

Shunt-based measurement technology

Designed for high dielectric strength in traction batteries and stationary energy storage devices, Isabellenhütte's shunt-based IVT-S measurement technology sees the company responding to the market, which now favors specified functions in current measurement systems. The main focus is on achieving dielectric strength that is as high as possible in line with the intended application. High dielectric strength must be guaranteed in battery-powered vehicles, for example.

To this end, Isabellenhütte offers the IVT-S high precision current measurement system, featuring a maximum dielectric strength of 1,000V based on the DIN EN 60664-1 specification. Its functional range includes the precision 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.

A variety of components are used in the IVT-S. A 16bit AD converter guarantees precise transformation of the voltage drop into digital signals. Data is transmitted through a CAN 2.0 interface. Through this module, the internally developed firmware is provided with information on charge and discharge.

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INQUIRY NO. 569

Mild hybridization with high power

Due to savings in weight, package space and cost compared with high-voltage alternatives, 48V mild hybridization has recently become an attractive and commercially viable option. The safety considerations for vehicle maintenance are also a key factor in the adoption of 48V architectures.

For maximum benefits, high power capability is required for maximized recuperation during deceleration events in order to capture all of the braking energy available. The cost and installation package should be reduced by minimizing the storage capacity of the 48V battery. These conflicting requirements lead to a small battery pack capable of repeated high-power charge and discharge events.

Analysis for a typical C-segment vehicle application suggests that a charging capability of 20kW enables the majority of available braking energy to be recovered. Power deployment at the next acceleration event following a recuperation cycle is a particularly effective control strategy; therefore only a modest electrical storage capacity is required.

A new 0.5kWh, 48V battery pack using novel chemistry and a high-performance cooling system has now been designed to address these challenges. Capable of 10kW continuous discharging and charging power, and a peak performance of 20kW, this pack opens up significant opportunities for 48V mild hybridization.

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WORDS: **DEAN SLAVNICH**

Game **changers**

A few months ago, I was lucky enough to be one of the first journalists to get behind a wheel of a Jaguar I-Pace on UK roads. At the time of driving it, I thought to myself: what a BEV game-changer this car is! How can one not be impressed with these kinds of numbers? The I-Pace has 470km (292 miles) of driving range, 400ps, 696Nm torque, and sprints from 0-60mph (0-97km/h) in just 4.5 seconds. And all this in a car that's super stylish on the outside, beautiful on the inside, oozing with tech, and a pleasure to drive. And three months later, I still think it's a BEV game-changer.

But I'm writing this column on a plane flying back to the UK, having spent three days with Kia in Korea learning about the company's electric vehicle ambitions.

Kia has 51,000 employees worldwide and 15 manufacturing plants. It's gone from selling around 1.4 million cars in 2008 to 2.8 million today, making it the eighth-largest OEM. And not only is that growth drive not slowing down, Kia execs have now locked in on making important inroads in the BEV arena.

Peter Schreyer, Kia's president and chief design officer, told me, "Over the past few years, we've changed the perception of Kia. And now we have new possibilities with EVs too."

He added, "With no combustion engine, we have a better chance to rearrange the package and it gives us a chance to create a new type of product."

Having launched the Soul EV a few years back, this new battery electric drive within Kia is taken to a higher level with the e-Niro, which I was (again, lucky me!) one of the first to drive ahead of its international launch in 2019. An embargo means I can't tell you how it drives on the road yet (watch this space in the next issue of *E&H Vehicle*!), but what I can say is that, like the I-Pace, the e-Niro is another BEV game-changer. In fact, in many respects, it might be an even more important BEV development than the Jaguar crossover.

The reason I believe this is not rooted in some deep engineering setup of the e-Niro – far from it. Quite simply, e-Niro is Kia's attempt to bring battery electrics to the masses. And coming in at £33,000 (US$42,900), you get a lot of car, tech and range for your EV money.

That UK showroom sticker price is backed up with a wonderful real-world range of 301 miles (484km), with a 64kWh lithium-ion polymer battery that can be recharged to 80% in as little as 54 minutes.

Let's just repeat that driving range: 301 miles! And no matter how hard I drove in Korea – high speeds, uphill and on testing windy country roads – I got the sense those 301 miles actually meant 301 miles. And on the WLTP city cycle, Kia says the electric crossover can even cover 382 miles (615km)!

That high-tech battery pack is paired with a 150kW motor that produces 396Nm, powering the e-Niro from 0-60mph in an impressive 7.5 seconds.

The car is packed with clever technology, like a coasting guide control system that alerts the driver when it's the best time to lift off the accelerator and coast toward a junction, allowing the battery to regenerate under engine deceleration. There's also an eco driving assistance system and predictive energy control tech function.

In what's a really neat touch, the e-Niro also has paddles behind the steering wheel – although, with this being a BEV, these paddles don't shift gears but rather allow the driver to choose from three levels of energy recuperation. It's little things like this that make the e-Niro even more user-friendly.

And like all other Kia vehicles, this BEV comes with that solid seven-year, 100,000-mile warranty. Told you it was a BEV game-changer.

With an impressive range, sophisticated performance and an abundance of tech, the Kia e-Niro – like the Jaguar I-Pace – is a genuine game-changer for mass-market EVs

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No need for the car to stand still while charging

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