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July 2017

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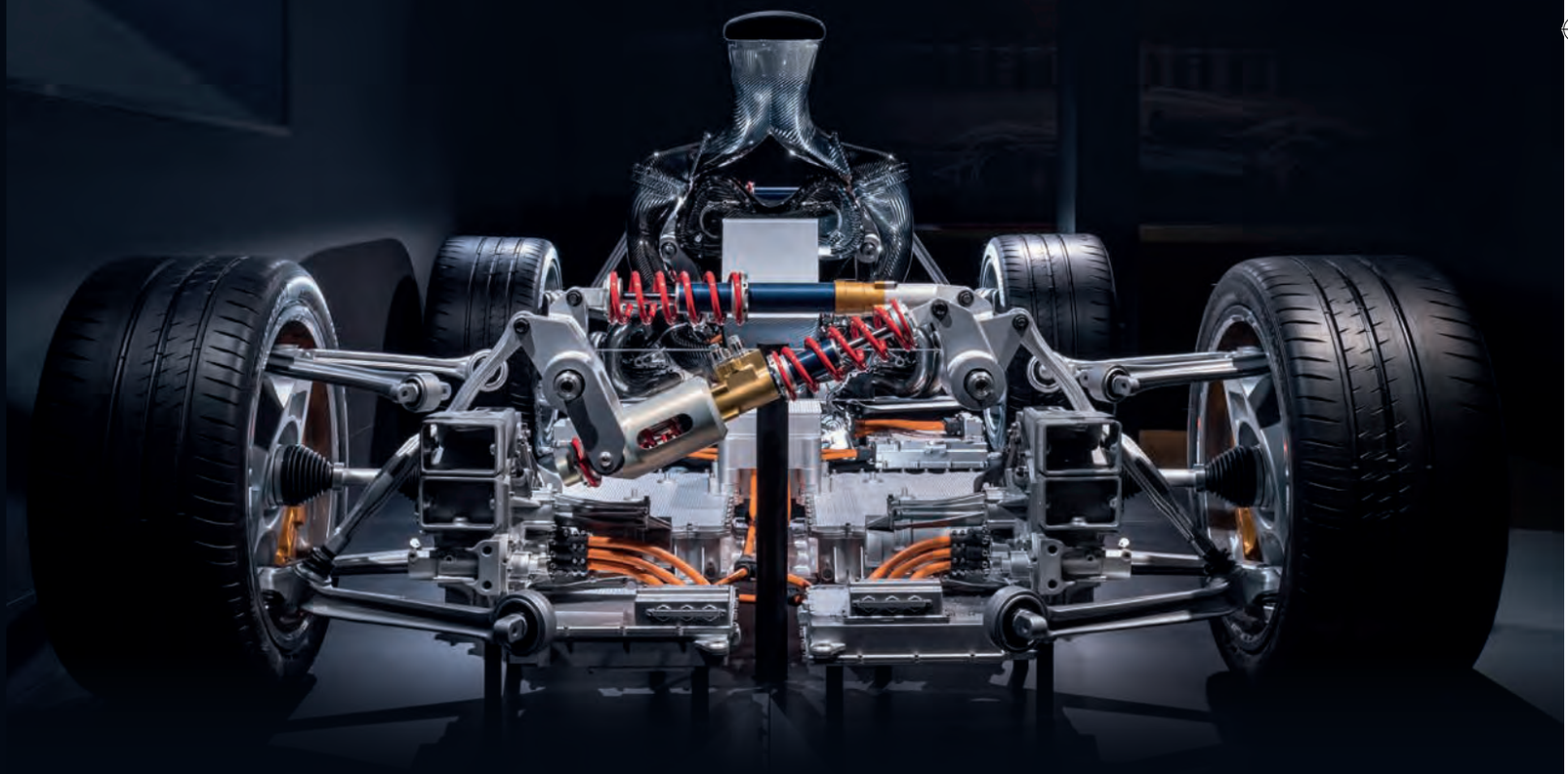
MERCEDES-AMG
Project One

Transforming a Formula 1 racer into a street-legal hybrid supercar



SECOND-LIFE CRISIS
More electrified vehicles means more batteries. Is the industry doing enough to plan for these spent power sources?

THE FUTURE ACCORDING TO BMW i
The i3 and i8 have taken the industry by storm. Stefan Juraschek, head of electrified powertrains, discusses the OEM's next steps

GO WITH THE FLOW
Could the sustainable transportation movement change the way that auto makers design vehicle aerodynamics?

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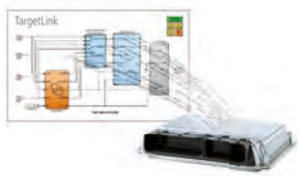

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EDITOR'S NOTE

At the start of this year I was in the press center at the Detroit Motor Show, drinking my umpteenth cup of Motor City coffee in a desperate bid to get warm (even for a Brit, Michigan in January is a little cold), when I overheard a pair of journalists at the table behind me lamenting some of the vehicles being presented in the nearby halls: "Don't they realize this is an auto show, not a tech show?" griped one to his colleague. Perhaps he was having a bad morning – I had myself just been unceremoniously moved on by the security entourage of a visiting Joe Biden – but it still struck me as a rather outdated mindset. Sure, a healthy percentage of the stands I visited had given significant focus to the latest in interior gadgetry or explaining how smartwatches can improve the driver-vehicle interface, but I was surprised nonetheless – in 2017 – to hear two journos bemoaning the encroachment of technology into the automotive industry.

Having staved off the shivers, temporarily at least, I then managed to catch a few minutes of an Automobil Q&A session with Renault-Nissan's Carlos Ghosn, during which he was asked if he was worried about the impact of new EV startup companies on the business of major OEMs. His response, and I'm paraphrasing a little here, was that car makers and tech companies "are not pursuing the same objectives".

It was a rather cautious, diplomatic answer, so I asked the same question to BMW's head of electric powertrain, Stefan Juraschek, when I interviewed him later that day. (You can read more from Stefan on page 98.) Equally diplomatic, his response was that it was one thing for a new company to bring a single vehicle to market, but quite another to build, maintain and continually improve an entire model range – and also to maintain a relationship with a customer base that is, at the end of the day, being asked to part with considerable amounts of money. For all the headlines about how quickly the latest EV startup supercar can cover a quarter mile, there is no shortcut to the decades of experience, R&D and industry nous that some OEMs have accumulated.

However, despite this, the industry (and the aforementioned pair of technophobic journalists) cannot afford to simply dismiss these young companies out of hand. If nothing else, the disruptive impact of startups on the automotive establishment is worthy of examination. Would OEMs be sinking such large sums of cash into electrified programs without the likes of Tesla nipping at their heels? Would we be seeing massive tech brands like Apple moving in to the automotive industry if others hadn't shown there was a demand to be met?

What's particularly interesting is that a lot of these companies don't even view themselves as car makers – as Elon Musk told *E&H Vehicle* back in 2015, "we're a technology company making electric cars" – nor do they feel obliged to do things the way they've always been done. Personnel at some startups have some pretty strong opinions on what OEMs have achieved in the electrified vehicle market so far – our feature on page 40 goes into this in more detail and makes for a fascinating read.

I am, perhaps, painting an unfair picture. OEMs are not exactly lumbering giants being forced into action by a bunch of young upstarts. As you'll see throughout this issue, companies that have been around for many years are more than capable of producing vehicles and technologies that are, quite frankly, stunning. For example, take a look at Mercedes-AMG's Project One or the all-new Lexus LS 500h (p12), read more about Ford's massive investment in new electrified vehicles (p54), and hear what PSA Peugeot Citroën's takeover of Opel/Vauxhall means for the French auto maker's future powertrain strategy (p136).

But startups, and their potential to needle and disrupt the OEMs, look set to remain a talking point. How many will still be around in a decade? Who knows. But if their presence means the entire industry has to keep on its toes, I reckon that's a good thing. Enjoy the issue.

Matt Ross

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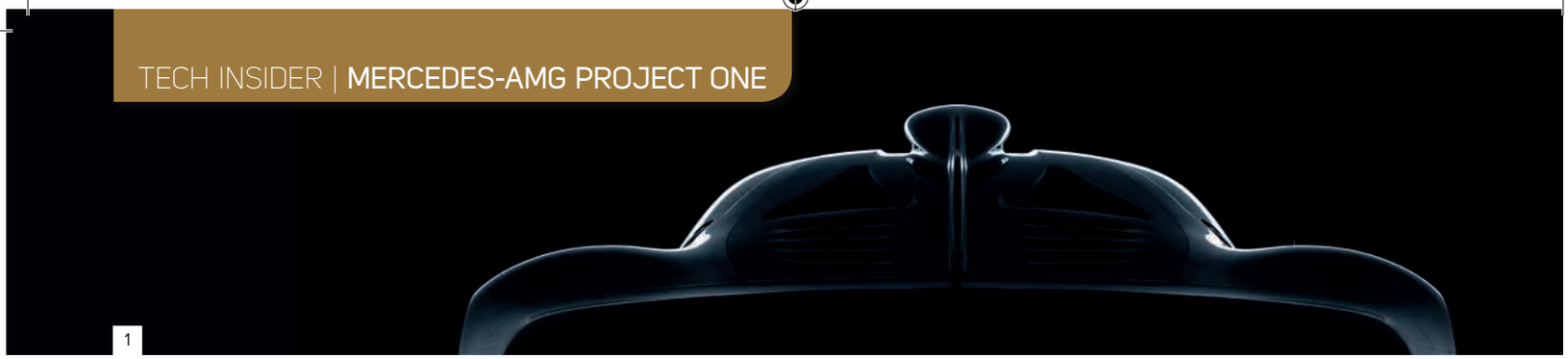
Winning FORMULA

Mercedes-AMG's new hypercar – the Project One – brings pure-bred Formula 1 technology to the road

WORDS: **MICHAEL TAYLOR**



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Supercars and modern hypercars have always been about drama, shapes and exclusivity, all painstakingly draped over a bedrock of astonishing performance and, virtually above all else, evocative noise.

That's part of the reason why people decried the complexity, the cost, and the technology (but mostly the noise) when Formula 1 moved into its current hybrid era. Unlike every previous era of F1, more of the technology transfer went from production cars to the racing cars than the other way around – even so, the costs of development were astronomical, especially when Mercedes-AMG effectively reinvented the turbocharger.

Unlike its current competitors, Mercedes-AMG has developed a street-legal descendent of its F1 car – Project One is derived directly from the W08 EQ Power+ F1 that is the chariot of choice of Lewis Hamilton and Valtteri Bottas.

AMG chairman Tobias Moers insists the 1,000bhp hypercar will use a detuned F1 powertrain, complete with the 8-speed, computer-controlled manual gearbox, the split turbocharger, the two electric hybrid systems, and the 1.6-liter V6 engine.

Unlike the F1 car, however, the Project One will use a pair of electric motors sitting on the front axle line to make it an all-wheel-drive car. It's also capable of running as a zero-emissions electric car for 25km, because its ABC-supplied lithium-ion battery runs the same chemistry as the F1 battery, but with four times the capacity.

Also unlike the Formula 1 racer, the componentry inside the Project One will be 'lifed' to 50,000km, which Moers insists is enough, after which its powertrain will either be refreshed or replaced.

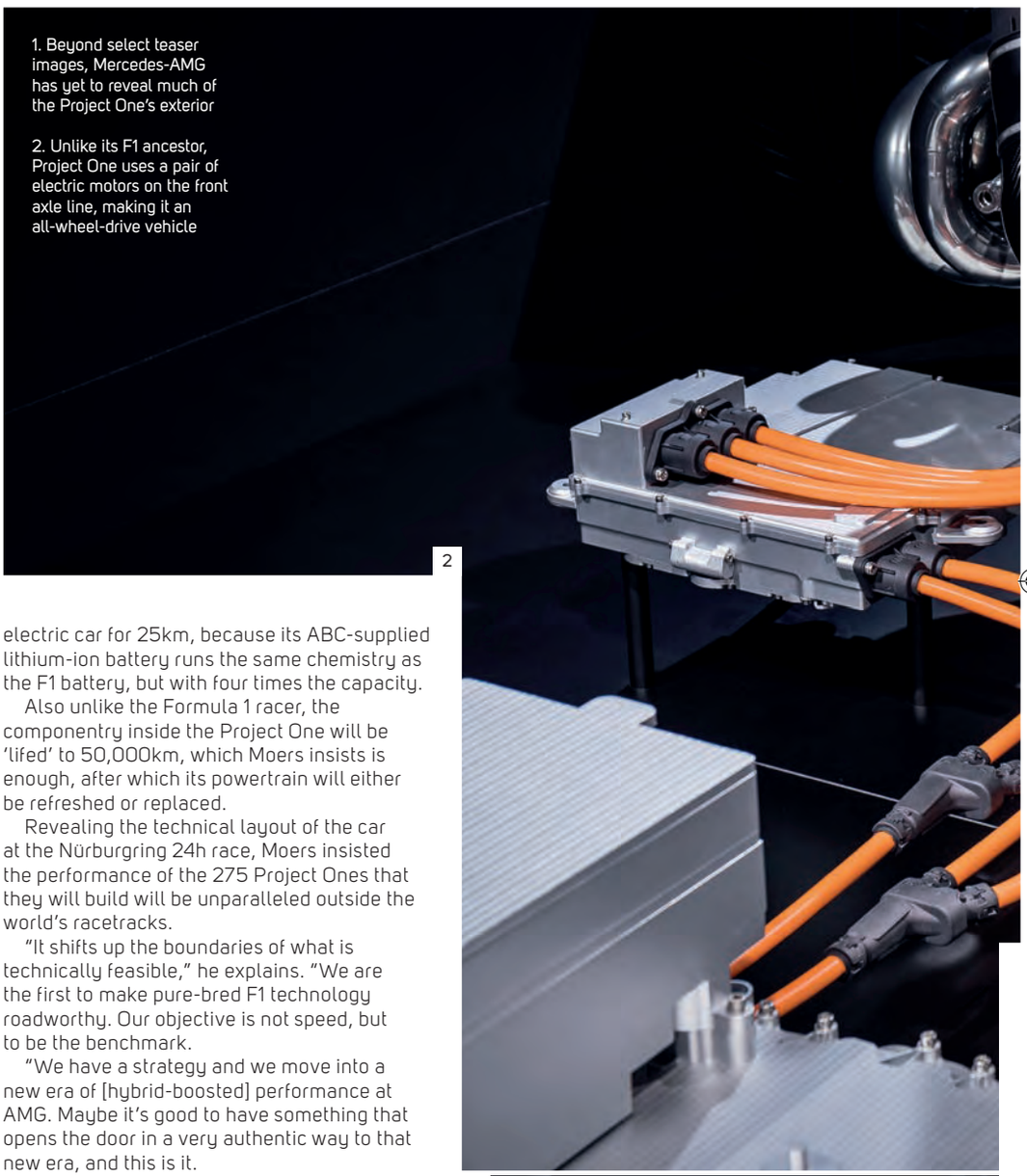
Revealing the technical layout of the car at the Nürburgring 24h race, Moers insisted the performance of the 275 Project Ones that they will build will be unparalleled outside the world's racetracks.

"It shifts up the boundaries of what is technically feasible," he explains. "We are the first to make pure-bred F1 technology roadworthy. Our objective is not speed, but to be the benchmark.

"We have a strategy and we move into a new era of [hybrid-boosted] performance at AMG. Maybe it's good to have something that opens the door in a very authentic way to that new era, and this is it.

1. Beyond select teaser images, Mercedes-AMG has yet to reveal much of the Project One's exterior

2. Unlike its F1 ancestor, Project One uses a pair of electric motors on the front axle line, making it an all-wheel-drive vehicle



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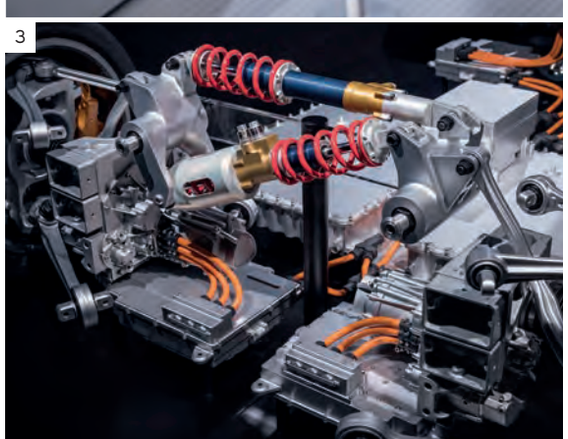

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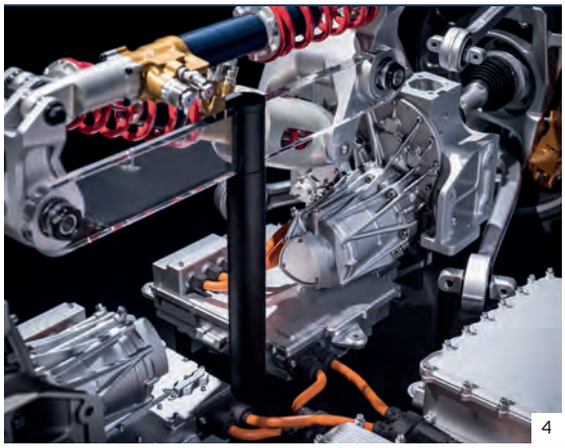
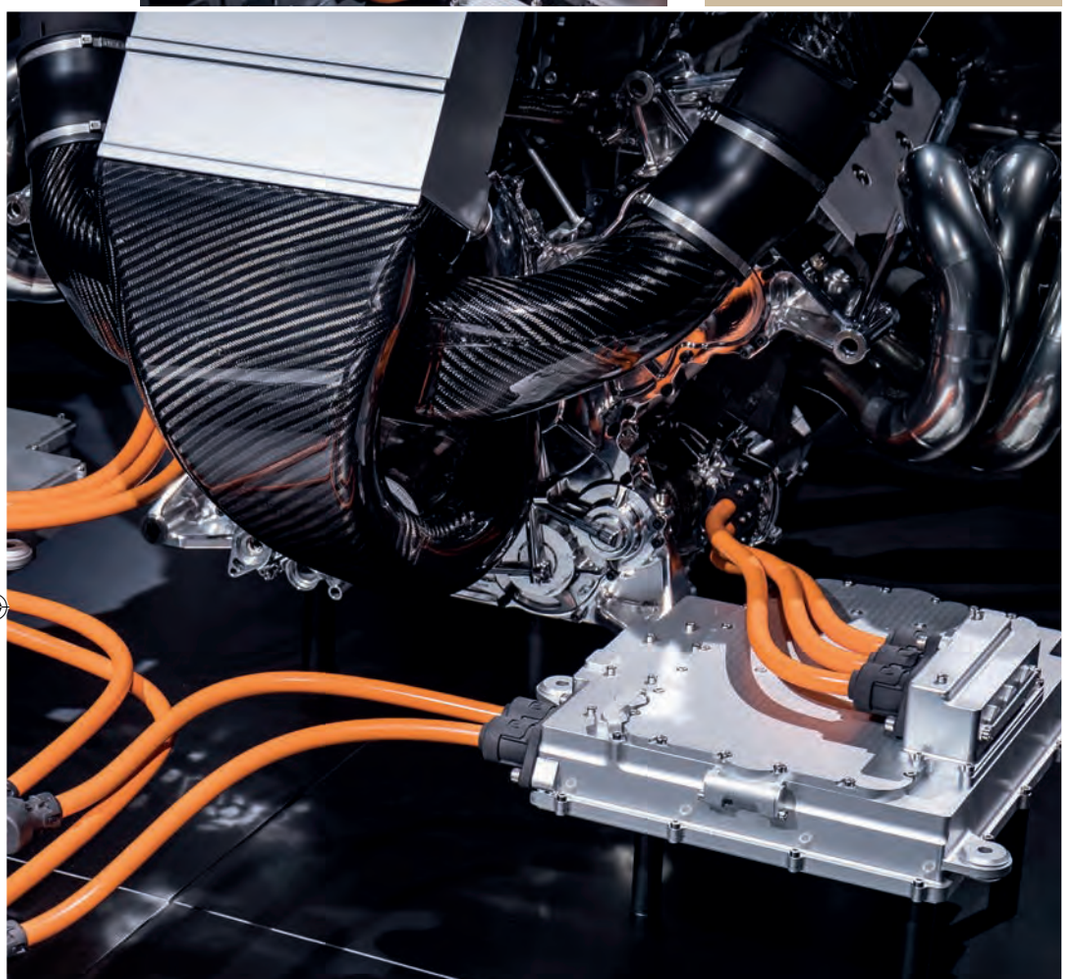
3. Componentry inside the Project One should be good for 50,000km, at which point the powertrain will be replaced or refreshed





4. The powertrain of the Project One, Mercedes-AMG insists, is pulled directly from the auto maker's F1 program

5. Unlike the Formula 1 car, starting up the Project One doesn't require a complete race team and a series of high-end computers

"Plug-in hybrid is going to be the future for AMG. We get more performance and more efficiency, and what's wrong with that?"

The Project One won't be the first road car to use Formula 1 technology beneath the skin, though. Ferrari did it as recently as 1995 with the V12-powered F50.

"We are talking about a high-performance hybrid, with one combustion engine and four electric motors," Moers says. "The combustion engine comes from Brixworth, from the same people who delivered three consecutive Formula 1 World Championships for drivers and manufacturers.

"The redline is at 11,000 and it has a high-tech turbo, which is driven by an 80kW electric motor. We have reached thermal efficiency of 43%. Nobody else has managed anything like that, street legal."

By comparison, AMG's 4.0-liter biturbo V8 has a thermal efficiency of around 25%.

Direct descendent

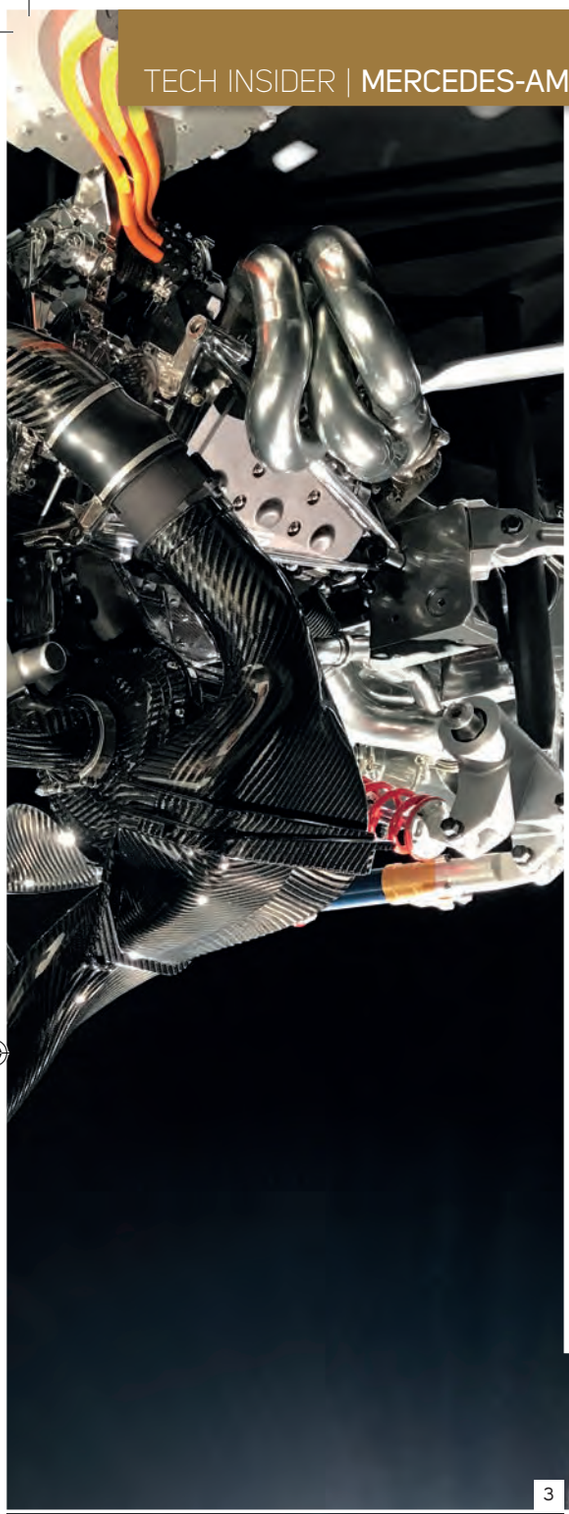
The two-seat, US$2.54m coupe follows the standard Formula 1 practice of basing the entire car around a central core of a carbon-fiber chassis tub, and stressed engine, gearbox and differential.

Even though the first deliveries of the car are due late next year, Moers is pushing to finish its production run before 2021 kicks off, and AMG already has one 'mule' prototype running to help with initial verification of the powertrain and chassis concept.

But the key part of the technology is the Project One's powertrain itself, which AMG insists it pulled directly from the F1 program.

"The idle speed is 1,100rpm and in F1 it's 3,800 or 4,000. It revs to 11,000rpm, but in F1 it's 13,500rpm," says Moers.

"We have to move combustion ratio, for example, that's what changes. In Formula 1, they run Lambda that's way more than one, but we can't because of emissions. We have the same cylinder head, same crank housing, but a different crankshaft."



For all that, though, Moers insists that Project One customers won't need the usual array of Formula 1 race engineers and laptop computers to start the engine.

"Prospective buyers have been asking if they will require a support crew or dedicated lubricants to run it. My answer is always 'no'. It will be a street car. You keep it plugged-in in the garage. You fill it with 98 [RON fuel]."

Among the most complex elements of the powertrain is the way it combines electrified and internal-combustion power.

The AMG V6 stunned Formula 1 by splitting its single, large turbocharger, with the exhaust turbine moved to the back of the engine to be closer to the exhaust system, while the compressor wheel sits at the front of the engine where the cooler air is. A shaft runs through the engine's V angle to join them together.

AMG won't talk about the power output from the tiny 1.6-liter V6, but back-of-a-napkin calculations put it somewhere around 350kW. There's also a 100kW electric motor (the MGU-K – for 'kinetic' in Formula 1 parlance) directly attached to the engine's crankshaft and another 80kW electric motor (the MGU-H – for 'heat') that spins up the turbocharger to eliminate turbo lag.

"The 80kW from the MGU-H is not so important to rev the turbocharger compressor up, but it's important for regeneration," Moers insists. "It could be a lot smaller to rev and still spin it up."

Any excess energy harvested by the MGU-H can be sent directly to the MGU-K to punch more electric torque directly into the crankshaft.

Then there's a 120kW electric motor for each front wheel. These have essentially the same construction and design as the MGU-K, but have different housings and are connected to their own individual gearboxes.

While Moers will not be drawn on the car's target weight, he does confirm that, even with a 100kg lithium-ion battery, the entire powertrain would weigh about 420kg.

What makes the Project One particularly complicated is that all of its electric motors act as both motors and generators to recharge the fast-discharge battery, which has a 800V-12V converter sitting on top of its housing.

The all-wheel-drive Project One hypercar has torque vectoring at both ends, and eliminates the packaging difficulties of anti-roll bars via five-link suspension systems.

AMG has separated the vertical bump and roll tasks in the suspension with two springs in series sharing a single damper, while what looks like the longest rear pushrod in the car industry is mounted directly to the upright and, in large part, defines the car's aerodynamic package.

It will use a variable ride height and a variable aerodynamic package, to get the best from its custom-developed Michelin Pilot Sport Cup 285/35 19 front and 335/30 20 tires, which ride on center-lock wheels.

The transmission, too, will be similar to the Formula 1 car's 8-speed unit, strengthened for longevity, and using the electric motors to 'fill in' any acceleration holes during gear changes.

Moers insists that the car will have different driving modes, ranging from the zero-emission front-drive BEV mode, to a mode so aggressive it will be similar to that of an F1 Grand Prix qualifying setup.

1. AMG currently has a mule prototype to verify the chassis and powertrain

2. The vehicle avoids issues with anti-roll bars by using five-link suspension systems

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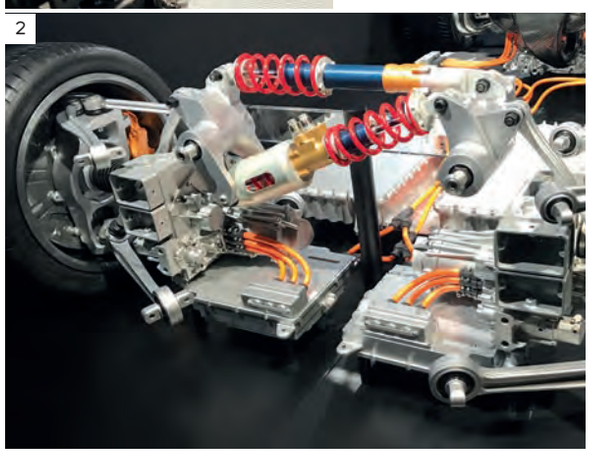

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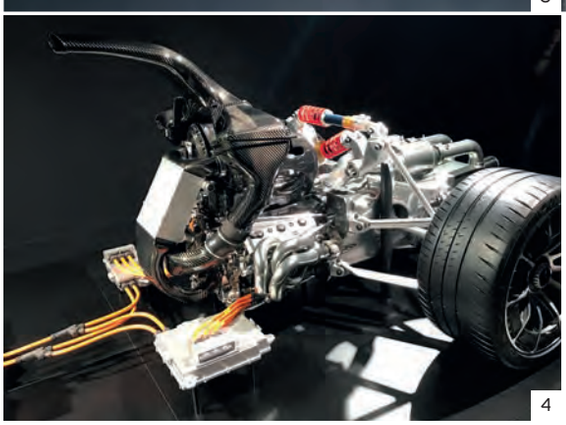

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3. Many of the Project One powertrain's more complex elements result from the combination of hybrid IC engine power

4. The vehicle's rear suspension uses a pushrod system reminiscent of a Formula 1 race car setup

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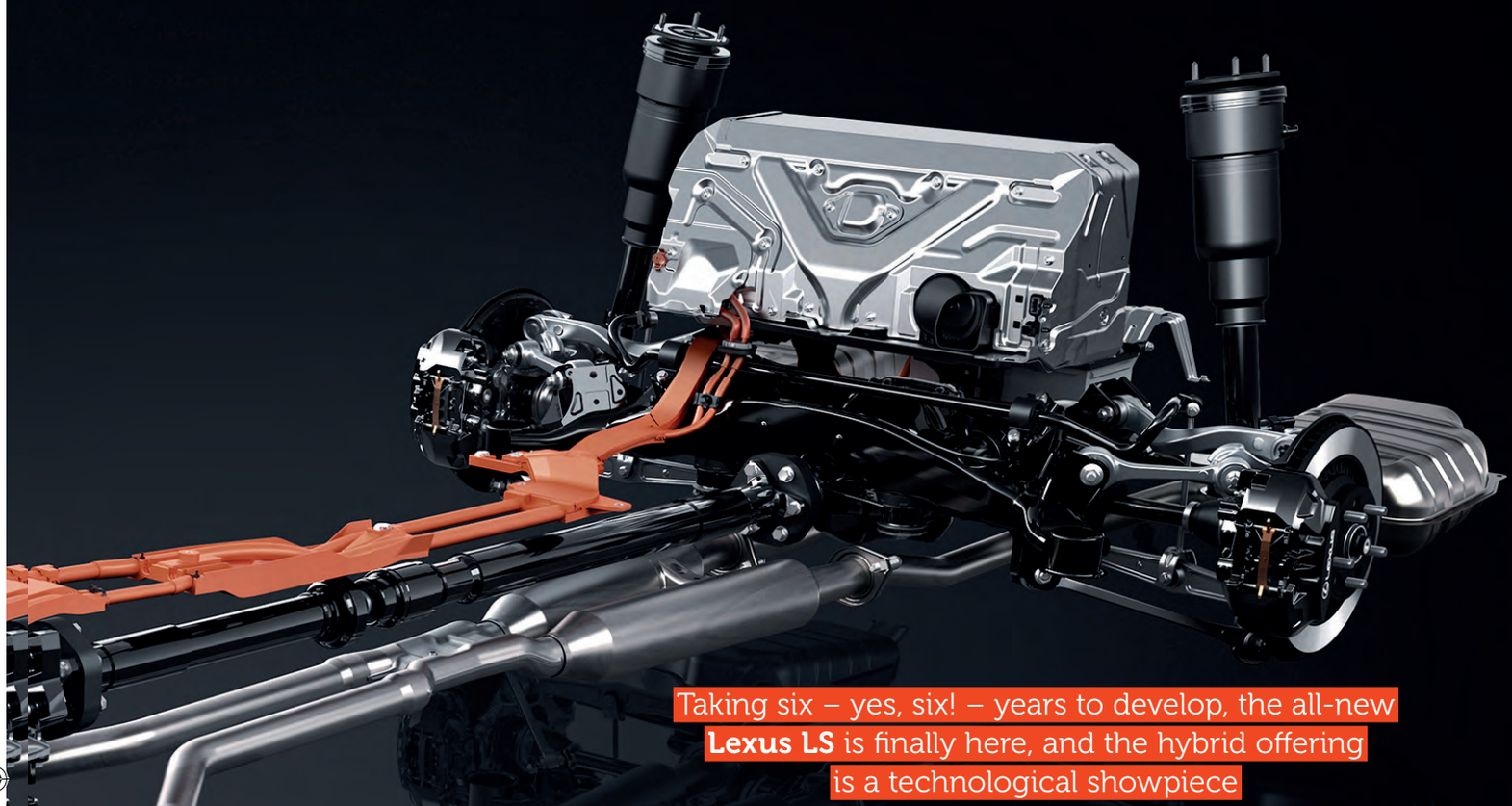
TIME goes by

WORDS: **DEAN SLAVNICH**

The new LS 500h is equipped with Lexus's multistage hybrid system, a breakthrough technology that transforms hybrid powertrain performance



Taking six – yes, six! – years to develop, the all-new **Lexus LS** is finally here, and the hybrid offering is a technological showpiece

Unsurprisingly the all-new Lexus LS 500h is oozing with state-of-the-art technology; in fact it literally is a vehicle for highly advanced next-gen automotive systems and breakthrough innovation. That in part is down to the fact that this is, after all, Lexus's flagship product – the star that sits at the top of this particular tree – but also playing a crucial role is just how long this car has been in the pipeline for the Japanese auto maker.

Development of the LS started in the second half of 2011 and, admits chief engineer Toshio Asahi, the program took far longer than anybody at Lexus HQ expected.

"That timeframe really isn't normal for us," he says with a wry smile. "But the LS is a flagship car for us, so it had to be perfect, inside and out, and that's challenging. It took us around two years to clear planning and design because we wanted advice from many aspects of the organization. We didn't feel obliged to have a model change because the time was 'right', but rather we wanted to hit the market with a perfect car that matched the needs and expectations of our customers."

As such, work on the powertrain was not only detailed and intense, but was critical for the end product to meet its lofty goals.

Better hybrid technology

The previous LS also featured a hybrid offering – the LS 600h – marrying a large 5.0 V8 with first-gen powertrain electrification technology. The all-new LS 500h, part of the fifth generation of LS, moves things forward significantly on that front, thanks chiefly to a next-gen multistage hybrid system and a twin-turbo dual-VVT-i V6.

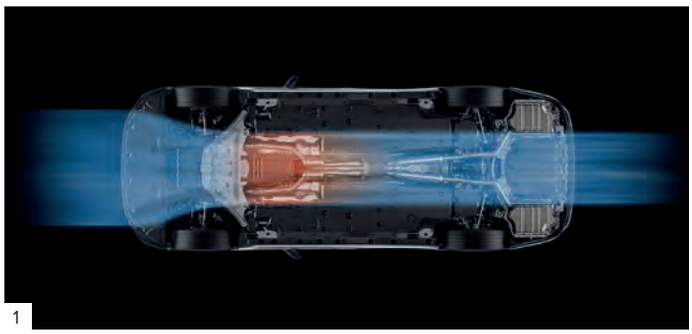
"At the beginning of the development of this car, the first question we asked was: what would the powertrain be like for this type of vehicle in five years? Would it allow us to have such a large [displacement] hybrid engine?," explains Asahi, when pressed about the V8 not making the cut this time around.

"At Lexus we want to be the frontrunner, so a review of the original system was a must," he continues. And that led to "smart-sizing the powertrain", essentially combining efficiency, luxury and performance in a single package.

"We really didn't want to spoil the premium drive comfort that the LS stands for, so we aimed for a better premium drive, a downsized [IC] engine and better hybrid technology."

For Asahi, the first place to start when justifying "better hybrid technology" is with the multistage hybrid system developed in-house.

The technology essentially adds a four-stage shifting device to the hybrid drive combination



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1. LS 500h is fitted with a compact, lightweight, lithium-ion battery that is 20% smaller than the nickel-metal hydride unit featured in the outgoing Lexus LS 600h, yet has a higher power density

2. LS 500h combines a 3.5 V6 dual VVT-i engine with two electric motors, together delivering a total output of 264kW

of the 3.5 V6 and two electric motors. The result, says Asahi, is more direct response to driver inputs, while balancing dynamic performance with efficiency and smoothness – the latter being so important to Lexus and especially the LS.

Unlike conventional hybrids, where engine output is boosted by the e-motor via a reduction gear, the Lexus multistage hybrid system sees output from the V6 and battery amplified by a four-stage shifting device, allowing much greater drive power to be generated. This means that the 500h hits 100km/h (62mph) from rest in 5.4 seconds. It also means high-speed cruising can be achieved at lower engine RPM, and 140km/h (87mph) is possible with the gasoline engine in shut-down mode.

The challenge to developing such a powertrain – with total combined output of 264kW – was twofold, explains Asahi: "First was the hybrid system itself and then, on top of that, was the complex transmission. To have full control of this system was a real challenge."

This meant that the design of the entire system places the multistage shift unit behind the power-split device, on an axis aligned with the crankshaft. Although the unit has four speeds, the D range has a simulated shift control pattern that delivers the feel of driving with a 10-speed automatic. As the vehicle's speed rises, engine speed increases with linear, direct and continuous acceleration feel – all free from the 'rubber band' effect that plagues so many CVTs.

The transmission further benefits from an improved version of the AI shift control found in conventional autos, in the process enabling optimum gear selection to be made in line with driving conditions and inputs.

Battery upgrade

Another big change from gen-four to gen-five LS hybrid models is in the battery technology. Where the LS 600h made use of a nickel-metal hydride pack, the 500h boasts a compact, lightweight lithium-ion creation that's 20% smaller – enabling the new LS to increase luggage capacity by 25%. This is also the first time a Lexus hybrid battery features a 'satellite' construction design, in which the cell voltage monitoring function has been made separate from the ECU. Asahi says this enables the efficient use of what would otherwise be empty space inside the pack to house stuff like the wiring harness and cooling blower, thus reducing overall dimensions.

But that's not to say the entire hybrid powertrain is small – it's not! Asahi estimates it accounts for a hefty 15% of the entire sedan's mass.

On the V6 side of things, along with intelligent variable valve timing, other efficiency measures include the adoption of narrow, lightweight roller rocker arms and low-friction timing chains.

VITAL STATISTICS

Engine: 3.5-liter V6 hybrid
Capacity (cc): 3,456
Valve mechanism: 24-valve DOHC with Dual VVT-i
Max. engine output (kW): 220
Max. engine torque (Nm): 350
Battery type: Lithium-ion
Battery voltage (V): 310
Total hybrid system output (kW): 264
Transmission: Multistage hybrid system

FROM V8 TO V6 TO I4 TO BEV?

If downsizing and emissions are so important to Lexus – after all, here's a premium car maker that's fashioned a solid reputation on being green – why didn't it dare to go further with the LS, employing a four-pot instead of a V6 for the hybrid?

Asahi smiles at the concept: "Considering the NVH and also that premium acceleration feeling we wanted for LS, we opted for a 3.5 V6."

But given Lexus's strive for complete efficiency, will a not-too-distant-generation LS totally eliminate the IC engine, therefore becoming a complete BEV? Asahi is unsure about this: "When we talk about the future, of course that's possible, but we need to be realistic, too. We need to compete with rivals in this field, so a hybrid powertrain for now and for the future is the way to go with a vehicle like this."

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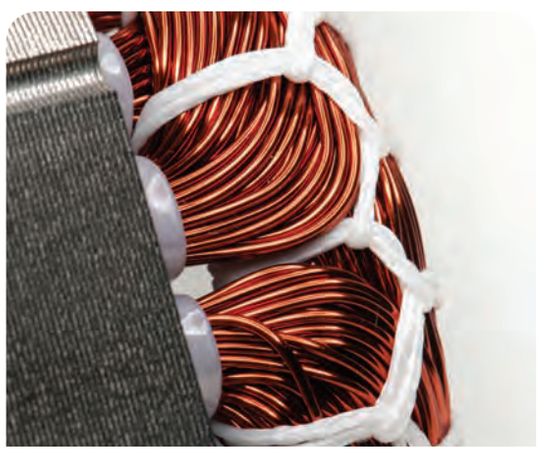

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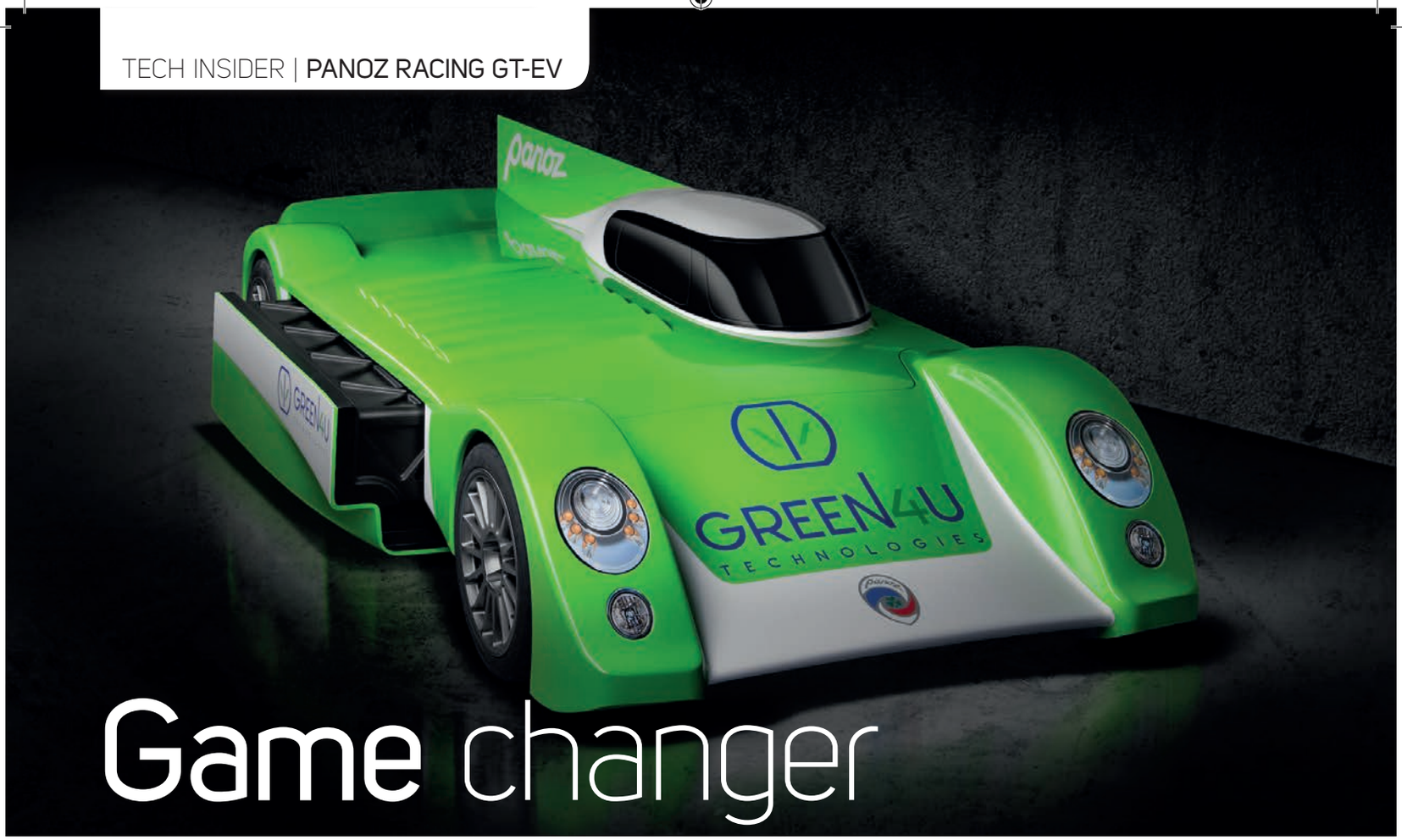

Game changer

The electrification of motorsport continues unabated, with a number of championships now featuring electric power to some degree. Panoz hopes to move the game on further

WORDS: **JOHN O'BRIEN**

Since 2012, the Garage 56 moniker has helped a variety of left-field, obscure and true prototype race cars take to the field and see if they can endure the full Le Mans 24 Hours. Beginning with the DeltaWing, other concepts have looked into using hydrogen, cryogenically frozen biomethane, and of course forgoing the ICE completely in favor of an all-electric powertrain.

The latest car aiming to join the fray is Green4U Technologies' Panoz Racing GT-EV, which was unveiled at the 2017 French endurance race.

The Panoz name is already synonymous with motorsport and traditional V8-derived muscle cars in North America, but in late 2016 its founder, Don Panoz, expanded his business interests by forming Green4U.

"We're debuting the GT-EV here at Le Mans because of the history of this iconic race, where the brightest and most ambitious and tenacious competitors always push the motorsport and automotive boundaries," explained Panoz. "We pushed the boundaries when we brought Sparky [the 1998 Panoz Q9 GTR-1 Hybrid] and the DeltaWing to Le Mans, and we'll do the same with the all-electric GT-EV. The goal is to run our car in a race, perhaps even go for a future Garage 56 slot, and apply what we learn to our Green4U EV vehicle designs."

Its mid-2017 unveiling at Le Mans is, perhaps, surprising, given Panoz's own admission that the project was started 'around' three months earlier, with the first tests predicted to run in another six to eight months' time.

Quick draw

Perhaps the biggest differentiator to any previous form of electric motorsport is the GT-EV's battery system, which has dictated the unusual visual appearance of the car. The offset, narrow cockpit has been used to reduce the car's overall frontal area, as well as to enable the large battery pack to sit next to the driver.

The original brief for the car called for a vehicle that could deliver performance and range similar to those currently achieved by both pure IC-engined and hybrid competition cars – particularly the GTE category of endurance and GT race cars. This translates to a predicted range of 90-110 miles (145-177km) in racing conditions, with a top speed cited as 180mph (290km/h).

These performance stats are to be achieved through the aforementioned battery pack. Unlike other championships, such as Formula E, which require drivers to change cars mid-race, the GT-EV's battery pack can simply be exchanged during pit stops, thus eradicating the need for lengthy stops during the race to recharge the existing battery. While technical details on the battery are still sparse at this stage of the project, Panoz is predicting around 50 minutes of racing time between battery change stops.

Beneath the car's surface is a bespoke carbon-fiber monocoque, designed to form a spine down the center of the vehicle and to which the battery pack and driver cockpit are attached.

The predicted 450kW total power output is generated by two motors that are mounted on either axle, giving the car all-wheel drive. The race car also features regenerative braking on all four wheels, as well as active aerodynamics to reduce drag down straights, ultimately increasing range and overall performance.

Road racer

In addition to the conceptual race car, Panoz also unveiled sketches of a proposed street-legal version of the car, visualized by renowned designer Peter Stevens. The design capitalizes on the narrow, offset cabin and arranges the passenger seats in tandem. The road car also retains the racer's long Kamm tail, and shark fin aerodynamic attributes, suggesting that any road-legal variant would be as potent as its race-car relative.

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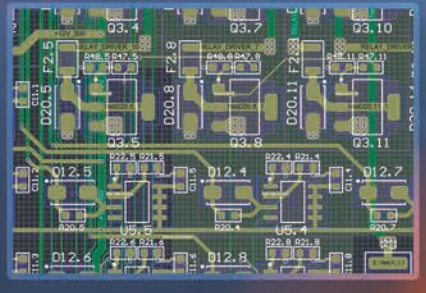

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City slicker

The revised 2017 Yaris Hybrid is the latest addition to the Toyota hybrid family. The package might be new, but there's an awful lot of familiarity in its powertrain

WORDS: **JOHN O'BRIEN**

The Yaris nameplate has been around since the turn of the millennium, and despite its manufacturer forging the way for mass-market hybridization, an electrically assisted version of the Yaris city car didn't appear until 2012.

The second-generation Yaris Hybrid made its debut at this year's Geneva Motor Show and is based around the Generation 3 hybrid synergy drive powertrain. At the center of the system is the second-generation 1NZ-FXE 1,497cc IC engine, which made its debut in the original 1997 Prius. Revisions to the engine between generations have been largely to increase its efficiency, and were incorporated when the engine was reintroduced to the Toyota range in 2012 for application in the Prius C.

The most significant of the engine revisions is the move toward the unit being free of drive belts. Now devoid of belt-driven ancillaries such as the starter motor, overall losses are reduced and the efficiency of the IC engine is increased. An increased 13.4:1 compression ratio in tandem with a delayed closing of the inlet valve also gives the unit a simulated Atkinson cycle, rather than an Otto cycle.

In removing the belts and ancillaries from the block, Toyota now uses the hybrid synergy system to start and support the IC engine. By incorporating a separate planetary gearset, Toyota uses one of the two motor-generator units (MGUs) on board to crank the IC engine and to act as a battery-charging alternator to both the high- and low-voltage batteries.

The second of the two MGUs acts as the drive device to the car, providing the car with propulsion as well as helping charge the high-voltage, nickel-metal hydride battery through its regenerative braking capacity.

The third-generation hybrid synergy drive system also marks a move away from a chain drive. Internally, the new system uses helical gears, allowing unit packaging to be reduced. Despite the integration of the electrical drive system, the Yaris Hybrid weighs just 50kg more than the IC-engined range.

Sound of silence

One area in which Toyota worked extensively during the Yaris's development was its NVH levels. Following what the OEM refers to as 'a thorough review', engineers worked on the powertrain to ensure that vibrations and harshness were reduced, particularly under acceleration. As a result of the review, the 2017 Yaris Hybrid makes use of new engine mounts and a larger diameter engine pitch restrictor, and the integration of the 1NZ-FXE IC engine required new driveshafts and a new subframe. In addition, a new intake system and revised exhaust with a redesigned sub-silencer ensure that the new car meets Toyota's revised targets.

Changes under the hood are complemented by notable revisions to the car's suspension. Toyota has made alterations to the damping force and valve design for a more comfortable ride, and the electrical power-steering system has been reprofiled to offer less friction and an overall smoother response to driver input.

Customer feedback

The Japanese OEM is keen to highlight the input of its existing customers in the Yaris Hybrid's development. In addition to all the regular feedback channels, Toyota has also deployed a data-gathering tool, which it says will help retailers demonstrate the benefits of hybrid drive to consumers more clearly than ever before. Automatically gathering data on journeys, the Driveco box has already logged more than 500,000km of driving from its inaugural trial. The trial period, which saw participation from 900 users across Europe, showed that owners used the car's EV mode more than 54% of the time and achieved an average of 56.5mpg – down somewhat on the manufacturer's claimed 85.6mpg...

COMMENT

Is Toyota getting left behind?

BILLY WU, LECTURER, DYSON SCHOOL OF DESIGN ENGINEERING AT IMPERIAL COLLEGE LONDON

Two decades after the Prius launched, has the industry overhauled the Japanese OEM that helped popularize the mass-market hybrid?

Widely regarded as the first mass-produced HEV, the Toyota Prius has championed low-carbon transport technology since it was introduced in 1997. According to Toyota, cumulative global sales of its HEVs exceed nine million, with approximately six million units attributed to the Prius family. However, since 2012, sales numbers have stalled at circa 1.2 million units per year, suggesting that its market share is being eroded.

With the rapid growth of the EV market, the question arises as to why Toyota's HEV sales have slowed down? An obvious reason is that there's simply more competition; during the early years of HEVs, consumer choice was extremely limited and Toyota's first-mover advantage gave it a significant market share. From a technological perspective, the earlier Prius versions were built using a nickel-metal hydride (NiMH) battery, as lithium-ion battery technology was still in development. It was not until the fourth generation of Prius in 2015 that a Li-ion battery was introduced. This highlights one of the major challenges of being a first mover – early design decisions can slow down future innovations as manufacturing lines are optimized for older technology.

In contrast, other companies who released HEVs or BEVs later could design around the superior Li-ion battery chemistry, which has improved at a much more rapid pace. These new competitors also offer different business model approaches to capture growing customer groups. The emergence of China as a global EV force is driven, in part, by emissions regulation, which make it difficult for Chinese OEMs to sell their vehicles in North American and European markets, leading to considerable investment in growing China-based EV companies. By comparison, Tesla offers relatively high-end products with equally high-end marketing. Such has been their success that press releases from Elon Musk are received in the same manner as those about the latest iPhone.

The landscape for EV technology continues to evolve at pace. Where this will end up remains to be seen, however it is evident that picking a winner still appears to be a lottery due to the shifting consumer perception of the technology and appetite for the product. The only reliable forecast that can be made at this stage is that the EV industry will increase and thus attract a more diverse market. Companies that aren't agile enough to adapt to the changing landscape risk getting left behind – innovation will be at the heart of success.

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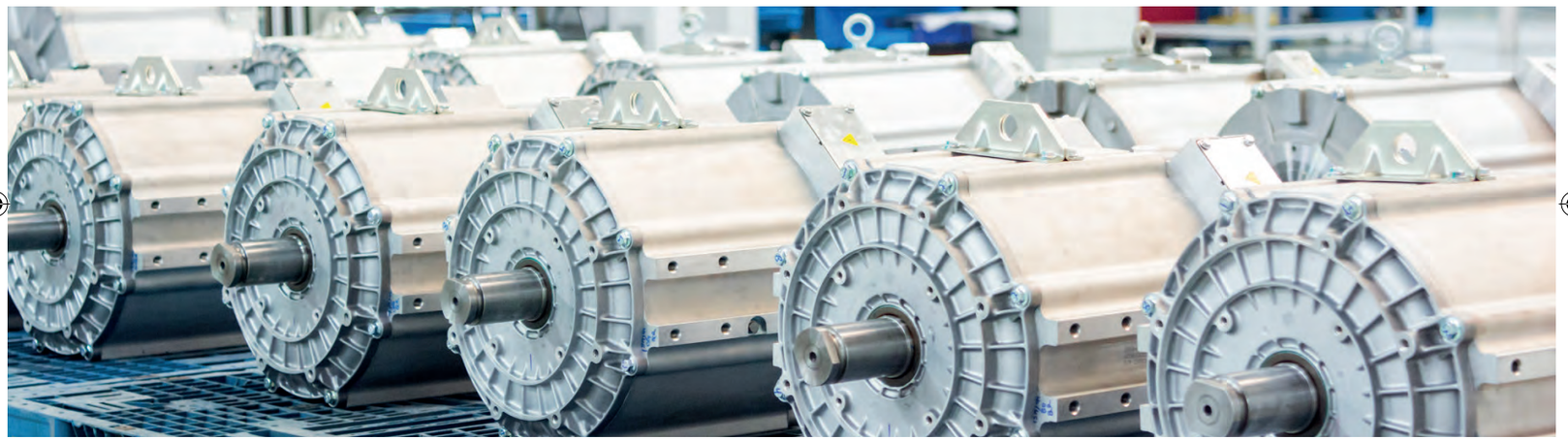

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Fare game

From 2018, all London cabs presented for license must have zero-emissions capability. The London Taxi Company has been hard at work preparing its all-electric vehicle

WORDS: **MATT JOY**

Taxis are some of the hardest-working vehicles in the world. London cabs can travel as much as 112,000km (70,000 miles) in a year, frequently in stop-start traffic and on poor-quality urban roads.

With such a specific set of demands and stresses on a vehicle, the development program needs to be more challenging to reflect this. This is the task facing The London Taxi Company (LTC) as it develops a new electric passenger service vehicle to suit forthcoming regulations; from January 2018, all taxis presented for license in London must have zero-emissions capability for at least 48km (30 miles) and overall emissions below 50g/km. With a substantial investment of over US$374m from parent company Geely and access to existing EV technology from Volvo, LTC has to ensure the end product is built to cope.

City slicker

Testing of the new EV taxi began early in 2016, with a program more extensive than that carried out on LTC's previous TX1, TXII and TX4 vehicles combined. Mofid Elkemiri, director of quality for LTC, explains the breadth of scope required for a vehicle of this nature: "The central ambition of this project was to create a taxi for which no city is off-limits. That means not just developing a car that can withstand one of the most demanding duty cycles of any vehicle, but one that can operate in any climate and meets the diverse regulatory requirements of cities worldwide."

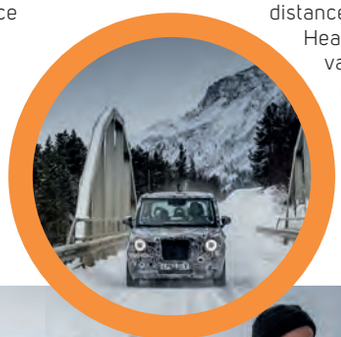
While a conventional car must meet varying regulations across the globe, passenger service vehicles like this have an even greater number of rules and codes to comply with – even varying within a country – which can focus on very small

1. During hot weather testing in the Arizona desert, the taxi completed journeys of 482km (300 miles) – the equivalent of 20 trips from Heathrow Airport to central London

details, as Elkemiri explains: "There are a large number of city-specific rules – mainly aimed at ensuring taxis meet the needs of those who need help with accessibility. Meeting London's tight turning circle requirement is probably one of the most famous examples, which ensures that wheelchair users can always board from the pavement with minimal effort from the driver. Meeting this requirement used to mean proving the turning circle on the roundabout outside the Savoy hotel, but now it is a wall-to-wall test."

Beyond such specific service vehicles tests, the new taxi is also undergoing high-speed durability cycles; abuse tests; cold, warm and humid climate testing; accumulation of between 400,000 and 800,000km (249,000-498,000 miles) per car; corrosion testing; and extensive crash testing. In early 2017, a set of development prototypes underwent cold weather trials in Norway's Arctic Circle, with a particular focus on heating and ventilation – a crucial factor as passenger comfort is a high priority, as is rigorous examination of battery performance, something much more sensitive to ambient temperature.

Most recently, the taxi underwent hot weather testing in the desert heat of Arizona. During the trials, the taxi undertook journeys of 482km (300 miles) – the equivalent of 20 times the distance between central London and Heathrow Airport – and provided valuable data regarding the battery performance in extreme heat.



Tough targets

Durability is possibly the most important vehicle attribute, with any time spent off the road incurring considerable cost for the owner and operator of a taxi. LTC has been forthright in its focus on quality and endurance as a priority. "Most of our components are specifically designed for taxi requirements," Elkemiri continues. "For example, the doors are designed to last for more than one million openings and closings, in comparison with a standard passenger car, which needs to pass approximately 150,000 closings. This demonstrates that most of the components will have to withstand tougher test standards."

Such are the specific demands of a passenger service vehicle that LTC enlisted the support and input of an experienced driver, with Steve McNamara, general secretary of the Licensed Taxi Drivers Association, providing knowledge and insight to the program. "It was truly amazing to witness the new London black cab being tested in such an extreme climate and performing so well," McNamara says. "This new, clean, 21st century vehicle will ensure that the world's best cab drivers now have the best tool for the job."

Compared with a conventional passenger car designed for series production and sale to the general public, a taxi may have fewer overall targets to achieve. But the targets it must reach are more exacting and demanding, covering the same mileage and enduring the same use in a much-reduced period of time.

Quality director Wolfram Liedtke explains the mindset of LTC when it came to testing its latest work: "Our new taxi is being developed according to two key engineering principles – quality and endurance – to meet the needs of the demanding taxi duty cycle. We understand that drivers will want to be sure that our range-extended electric vehicle technology works in all conditions, which is why we have gone to such efforts to test in these extreme environments. It will be, without doubt, the highest quality and most resilient product in the London taxi's history."

2. Testing in the Arctic Circle included rigorous examination of the taxi's battery performance in extreme temperatures

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Strong, silent type

A famed Czech motorcycle brand, dormant since the 1960s, has been reinvented as a new state-of-the-art electric vehicle

WORDS: **MATT ROSS**

The new Type 506 electric motorcycle retains the body design of the original scooter, but underneath it features all-new technology. The vehicle's battery pack is provided by Panasonic, and built in to packs by the Czech Republic-based team

The history of the automotive industry has no shortage of fallen icons – famous names that have struggled to keep up with economies of scale, fallen out of fashion, or simply been left behind by advancing technology. But for the Čezeta – a famous motor scooter that was manufactured in what was Czechoslovakia in the 1950s and 1960s – the decline was down to a broader paradigm shift, and its reinvention is altogether more niche.

"Motorcycle production wasn't a thing for the communists," explains Neil Smith, the man bringing Čezeta back to life. "They thought socialism's future was on four wheels, so they started investing everything in cars." Smith, a British expat and the CEO of the relaunched Čezeta, is a long-time fan of the scooters. In 2013 he was retired and took the opportunity to revive the iconic brand as an electric bike – the Type 506. "I was doing it for a hobby, working on scooters just like I had done when I was younger. I had time and, luckily, a bit of money, and I wanted to bring this part of the country's history back."

Surface appeal

Smith built the first prototype bikes himself, in the same barn from which he's now talking to *E&H Vehicle*. "We kept the look of the old bike because that was the best thing about it," he explains. "But only the surface looks the same, everything else is different." The Type 506's motor comes from China, but goes through retuning at the Čezeta facility in Prostějov – Smith's first choice was to build the Type 506 in the original Čezeta factory in Strakonická, but soon found that any interest, expertise and molds relating to the old vehicle were long gone. Smith had originally hoped to source every part of the Type 506 from the Czech Republic, but the desire to fit the new bike with a hub motor made Chinese supplier QS Motor a more logical choice. "A bike with a separate motor has a belt or chain. The nice thing about a hub motor is that it's silent – with a separate, you can do something with the gearing and the teeth, but there's still a whining."

The Čezeta team opens up the QS Motor, upping the power and adding in safety elements. "The most powerful one they could deliver was 8kW continuous, so we toyed around with it and got it up to 9.6kW and added a thermistor – unbelievably there isn't one included – which is vital because, once the temperature gets high, you need some way to communicate that to the regulator so that you can drop the amps to allow the motor to cool."

Panasonic lithium-ion 18650 cells – the same ones that are used by Tesla – are built into packs by the Čezeta team, while the Type 506's BMS is proprietary. In fact, aside from the untuned motor and the individual battery cells, most of the new Čezeta has been developed in house. The Type 506's braking system, which includes KERS, is a combined assembly developed by the Čezeta team, consisting of an electromagnetic brake on the throttle and a mechanical brake.

The new Čezeta motorcycle is available in two variants – the 506/01 accelerates from 0-50km/h in 4.5 seconds and has a top speed of 85km/h, while the 506/02 does the same sprint in 2.7 seconds and tops out at 120km/h. The Type 506's maximum range is 150km (a touring trailer, planned for 2017, will increase this to 250km).

Production is underway, and the first bikes should ship out toward the end of July. Smith aims to scale up production, but is keen to stress that the new Čezeta will be a thing of quality, not quantity. "The plan is that we would like to sell 300 next year, 600 the year after and 900 the year after that, until we get up to around 1,000 bikes a year. We can't flood the market; it would lose its cachet and its position. You can't just put the Čezeta name on something that isn't the best of the best. The time to move into this market is now, and it's important to do it in a way that makes this country proud."

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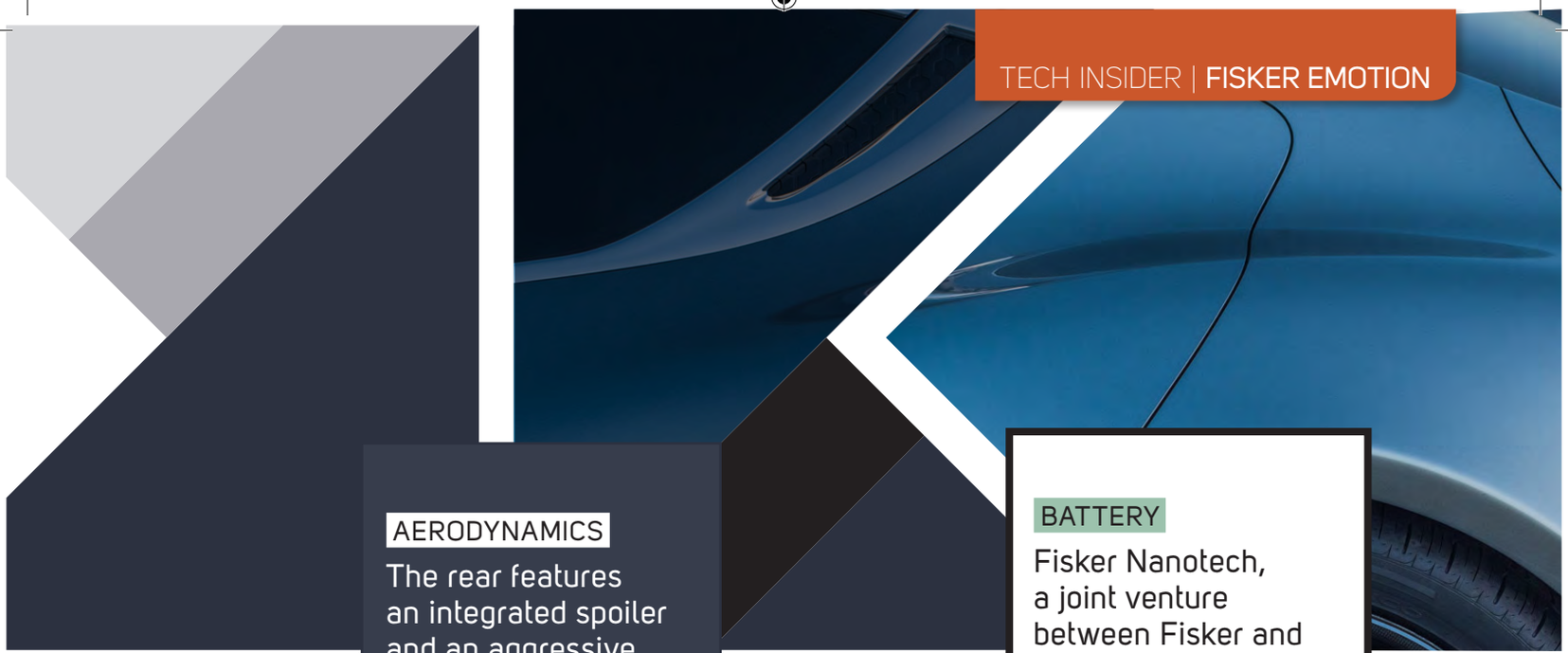
Fisker returns with the new EMotion, a luxury sport sedan with a claimed range of 640km

AUTONOMOUS DRIVING

The front of the EMotion houses a lidar sensor, and the vehicle will be equipped with hardware for autonomous motoring

RANGE

Fisker claims the EMotion will have an electric range of 640km (400 miles)



AERODYNAMICS

The rear features an integrated spoiler and an aggressive functional diffuser

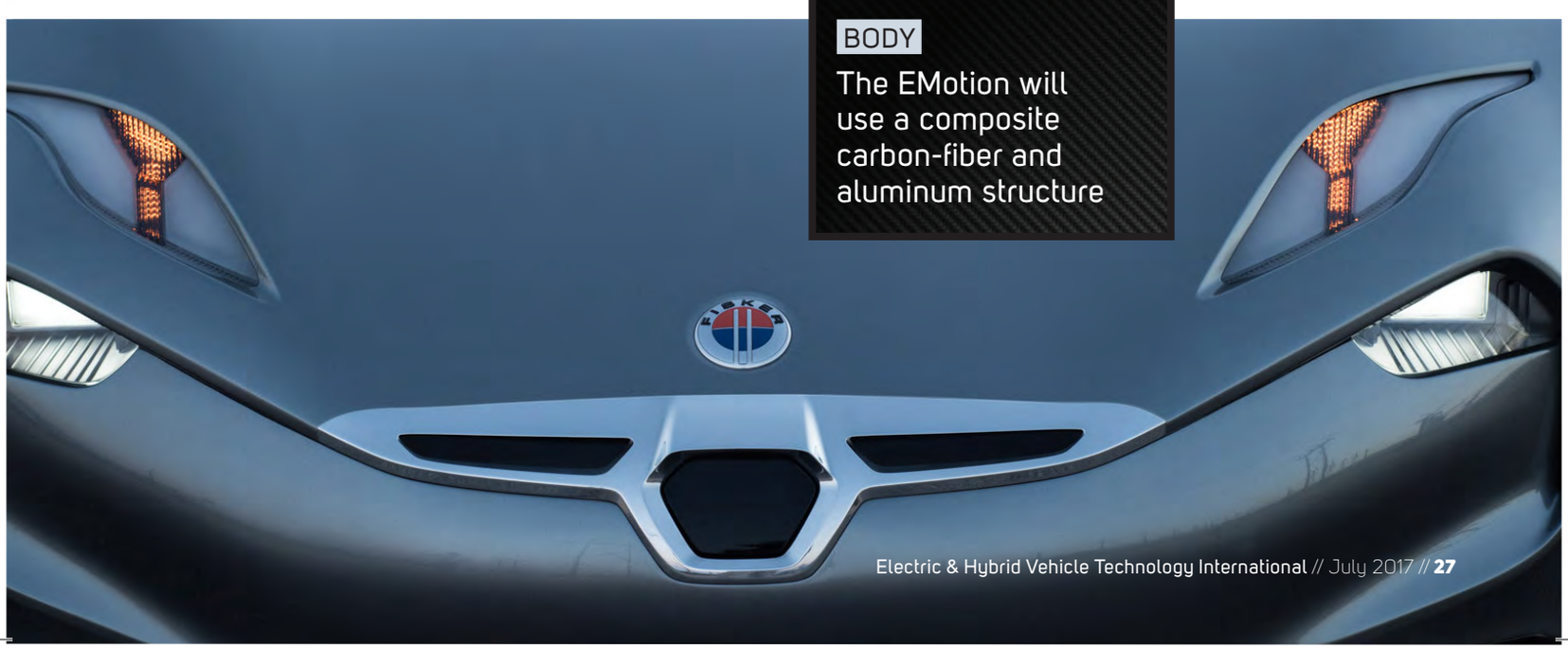
BATTERY

Fisker Nanotech, a joint venture between Fisker and Nanotech Energy, will produce the vehicle's graphene-based battery packs

After a tumultuous few years, the first car from Henrik Fisker's relaunched auto maker will be the all-electric Fisker EMotion. The luxury sports sedan will, according to its manufacturers, feature a range of 640km (400 miles) and the electric drivetrain will power the vehicle to a maximum speed of 260km/h (161mph). Produced in the USA, the EMotion will be equipped with all the hardware required for fully autonomous driving, waiting only for self-driving to be approved.

BODY

The EMotion will use a composite carbon-fiber and aluminum structure



ELECTRIC POWERTRAINS **ON TEST**

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

TOYOTA PRIUS PLUG-IN

Rolling off Toyota's TNGA platform, the all-new Prius Plug-In rocked up to *E&H Vehicle* HQ with much green-living promise. And having spent a full week with the car – and in every type of traffic scenario you can imagine – it was clear that the PHEV not only fulfilled said potential, but went beyond it. For daily commutes to and from work – in our case around 32km (20 miles) – the 1.8 four-cylinder VVT-I, codenamed 2ZR-FXE, was left virtually untouched. Here is a PHEV that's very happy to do its business in e-mode only, thanks chiefly to powerful electric motors (two) and an advanced lithium-ion battery. So impressive, in fact, is the Prius's pure EV drive capacity that for the most part we were averaging 2.825-plus l/100km (100mpg-plus) on the way to and from the office. This really is BEV territory for a PHEV. A lot of that comes down to the large-capacity pack under the rear load space. Its capacity has doubled from 4.4kWh to 8.8kWh, but that has come at a price: volume has increased by two thirds – from 87 liters to 145 liters – while the 120kg weight means it is 50% heavier than its predecessor. The other impressive bit of tech playing an important role in the engineering setup of the Prius Plug-In is the dual motor drive system. It's the first Toyota hybrid application to feature such an innovation. The DMDS (as we're calling it) increases EV power by around 83% over the outgoing Prius. A highly compact, one-way gear within the transaxle allows the hybrid system generator to act as a second electric motor. Not only does this boost power, but also gives a super-impressive maximum EV speed of 135km/h (84mph).

Away from the powertrain, another equally impressive feature of the Prius Plug-In is the solar panel roof, which generates electricity to charge the battery. On one particular day when we had the vehicle, the June sun contributed some 6km (4 miles) of EV range to the pack. Amazing in every respect.

VOLKSWAGEN PASSAT GTE

We've said it before and we'll say it again: VW's GTE powertrain technology is supremely impressive, and that conclusion is no different for the latest Wolfsburg hybrid test car we sampled – the Passat GTE. Already powering the Golf as well as Audi A3 plug-ins, the Passat GTE powertrain package consists of VW's flexible but always remarkable 1.4 TSI gasoline, an electric motor, DSG and a 9.9kWh lithium-ion battery that's placed within the vehicle floor surrounding the rear seat bench. Such a combination of technologies means the Passat GTE can travel 31 miles (49.8km) on electric power alone and, like the Prius Plug-In, this is an e-driving mode that really does shut off the IC motor completely at all times, even if air-con, heated seats and satnav are switched on. Perhaps just as impressive as the real-life frugality of the GTE is how engaging the car is to drive on everyday roads – it really is like any other class VW product in setup, feel and dynamics, except with the added e-powertrain tech. The EA211 turbo engine, weighing 102.8kg, serves up 156ps from 5,000rpm and 250Nm of torque between 1,500rpm and 3,500rpm, while the 35kg e-motor adds maximum torque of 330Nm and continuous torque of 170Nm. The result is that the Passat never feels underpowered or overwhelmed, having a combined 218ps and 400Nm on tap. Such figures become even more impressive when combined with efficiency of 1.5 l/100km (156mpg) – like the Prius, we couldn't quite match the official NEDC but we did consistently experience 100mpg-plus – and emissions of just 40g/km of CO_2.

HONDA NSX

When *E&H Vehicle* was given the chance to drive the Honda NSX at the Goodwood Festival of Speed, we jumped at the chance. The 2017 NSX takes a very different approach from its forebear in achieving the same outcome – engineering perfection that delivers a sublime driving experience. The new car utilizes electric motors in conjunction with a 3.5-liter biturbo 75° V6 to deliver over 567ps and 645Nm in what feels like an instant, at any rpm, in any gear. It's a bizarre driving experience, brought about mainly by the NSX's flexibility. At low speeds, the compact supercar feels no more difficult to maneuver than a regular hatchback, with light steering and a responsive throttle that never lurches the car forward despite its power reserves. And when in 'quiet' mode the surrealness increases, as the IC engine falls away to silence and the car operates over short distances on the battery's 1kWh power alone. When in Sport+ mode, however, all three of the car's e-motors are working in conjunction with the gasoline IC engine, delivering ballistic performance. Honda quotes a 0-60mph sprint of around three seconds, and thanks to a rapid DCT that feels entirely believable.

TOYOTA C-HR

The C-HR (Coupe High-Rider) caused quite a stir when it arrived at *E&H Vehicle*. The striking vehicle uses the same 1.8-liter in-line four-cylinder engine as the Prius, working with the electric motor for a total system output of 121ps at 5,200rpm. Power is sent to the front wheels via the CVT, which is standard on the hybrid model. Throttle response at low speeds is crisp, though the IC engine is overly keen to take over from the electric motor, and the gearbox requires little encouragement to send the ICE revs rocketing. EV mode delays the 1.8-liter unit's contribution, but hit the gas with much purpose and the C-HR deselects electric-only mode and resumes dual operation. The gasoline engine has a distinctive note to it, though the CVT's fondness for revving can make drivers feel a little self-conscious – particularly as EV mode is pleasingly silent. The transmission does make for higher efficiency levels, however. Over a weekend we recorded real-world mpg figures in the high 60s, and the hybrid C-HR boasts CO_2 emissions levels of 86-87g/km, depending on wheel size.

KIA NIRO

The Niro is an important car for Kia, not least because it's the company's first dedicated hybrid product – a big step toward catching the likes of VW and Toyota. Unfortunately, though, Niro remains some way off the likes of Prius and Passat GTE, even when favorable price differentials for the Kia are taken into consideration. Granted, the use of a 6-speed DCT over a CVT is a positive note, but that really is a standout technical feature. The gasoline engine – a refreshed version of the 1.6 Kappa – has been specifically developed for hybrid cars, and in this guise it develops 108ps and 147Nm. An electric motor adds 32kW and 170Nm torque to the package. Kia claims the HEV is capable of 3.8 l/100km (74.3mpg) but we couldn't get anywhere near that mark, while CO_2 emissions are at a super-impressive 88g/km. Aside from our real-world economy, there are no major issues with this first version of Niro. The real hope, though, is that the next Niro derivative – a PHEV – will not only be more real-world 'green' but will also give Prius and Passat GTE a good run for their money.

BMW i8

We're long-time fans of the i8 here at *E&H Vehicle*, and a recent spell in BMW's hybrid sports car has only reinforced that admiration. With a 1.5-liter three-cylinder ICE that works seamlessly with the e-motor setup, the i8 has absolutely no right to offer the kind of performance it does with such a small engine. Total system output of 363ps from such small displacement sounds like massaged figures, but put your foot down in the i8 and it suddenly seems very, very believable. The electric powertrain is in no hurry to call on its IC partner, even when driving aggressively, and when the two powerplants are called on to work in concert, the switchover is barely noticeable. Even if you do find yourself between charging points – and the i8 will run for more than 20 miles (32km) in EV mode – the 1.5-liter engine is more than capable of offering impressive acceleration and an abundance of available power by itself. The production version of the i8 might be more than three years old, but it's still putting many of its competitors to shame.

PROFILE: JASON MARCH

Job title: Director of powertrain systems and McLaren programs
Company: Ricardo Performance Products

What career did you want when you were growing up, and what was your first job?
I always wanted to be an engineer and was very interested in Formula 1 – even at a young age I tried to attend as many F1 events as possible. Then that was transferred into building go-karts out of lawn mower engines and wooden frames – which was very dangerous – learning the hard way about materials and engines. I was sponsored through university by Austin Rover and was lucky enough to be involved in the concept design for the K series engine, which was applied in the Metro. We were also based in the office area where the Issigonis was developed, so I had two opportunities to work on a state-of-the-art product of the time. That fired my enthusiasm for being involved in new engine development and that's why I came to Ricardo, where I started in the NVH field.

Please describe a typical day.
On a typical day I would be looking at what we achieved the previous day in terms of engine deliveries, because we run a two-shift manufacturing operation and I don't work both shifts myself. Then the day can be quite mixed – it could be meeting with McLaren or a supplier from an operational or commercial point of view, or working with the engineering team on new products.

What are the best and worst elements of your job?
My favorite part is that there is always a challenge, usually created by something out of my control. In a manufacturing environment with a cycle time of 45 minutes, you have to respond very quickly to those challenges. It's that constant element of surprise that is very enjoyable and the fact that I've learned a lot about manufacturing but also have to apply engineering skills. The worst are tasks that take an extended period of time, such as getting contracts in place. But it's very enjoyable when they are eventually signed.

What would be your dream engine specification for today's eco-friendly world?
In today's world we're almost always looking at a hybrid powertrain, but we have to recognize that what makes cars exciting

> In today's world we're almost always looking at a hybrid powertrain, but we have to recognize that what makes cars exciting is their engines

is their engines, particularly in the supercar segment. For me that's the challenge – developing high-revving, exciting hearts of the machine powertrains, surrounded by complex electrical systems that play an equal part in the experience of the driver.

In your opinion, what is the greatest engine that has ever been produced?

First of all it's a Ferrari flat-12 engine from the 1980s. I remember as a teenager going to Brands Hatch and experiencing the sheer sense of performance and ear popping when the car drove past. That spurred my enthusiasm, in the same way that I hope F1 engines do today for young engineers. Then I would say the Honda VTEC engine family, particularly the 2-liter with balancer shafts. It's a very high-revving, sophisticated engine for its time and oozes fantastic performance.

Lastly I must say that my respect for engine engineering and manufacturing continues to grow, and the fact that we can build in a short period of time something that goes from being an inanimate object to one that produces the power of a McLaren engine still stuns me every day. So there's place in my heart for that engine, too.

What car do you currently drive?

A Volkswagen Phaeton, which is very rare in the UK, but I do a lot of commuting on motorways and it's perfect for smooth luxury. I do also get my hands on the keys to Ricardo's McLaren every now and again!

Which OEMs do you have an engineering respect for?

I joined the automotive industry when it was probably at its worst point in the UK, so my respect goes to the entire UK industry and UK OEMs for how they clawed it back.

What will be powering a typical family sedan in 2030?

With quite an aggressive look forward into that period of time, we see about 30% of vehicles in the segment being fully electric – vehicles with the infrastructure and range that will be developed over the next 10 years – and then the biggest C segment market will be a downsized gasoline engine, maybe a 1.5-liter with high efficiency both in cycle and off-cycle. Technologies such as Miller cycle operation will be applied. Vehicles will also take advantage of connected and autonomous driving, which means they will be much more aware of the traffic conditions and the environment in order to raise that efficiency to the next level.

Volvo's Environmental Concept Car featured a turbine-electric hybrid powertrain, aluminum body and responsibly selected materials

Proof of concept

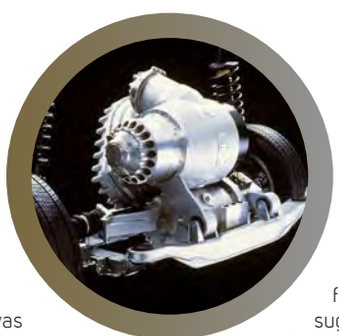
A look back at Volvo's Environmental Concept Vehicle, a turbine-electric hybrid car built 25 years ago that offered a glimpse into the OEM's vision for the future

WORDS: **MATT ROSS**

Car makers have never been shy when it comes to speculating on what the 'Vehicle of the Future' might look like. For decades, concept cars have been used to offer up fanciful ideas of what the vehicles driven by future generations might look like. Nor was such forward thinking limited to the automotive industry – Fritz Lang's 1927 classic movie *Metropolis* imagined the dystopian city of 2026 to be populated by heavily stylized versions of then-current cars crammed onto elevated roads, while *The Jetsons*, which originally ran in 1962, had the average family zipping about in flying vehicles.

It's fair to say that the personal hovercraft is probably still a little way off, but it is possible, if you look hard enough, to pick out trends and design cues from conceptual vehicles that have made it into the cars on today's roads. On balance, concepts have tended to be more miss than hit in terms of predicting the future of decades-away personal transportation, but in the shorter-term, car makers have, on occasion, been remarkably prescient.

Unveiled in 1992, the Volvo Environmental Concept Car (ECC) was the result of the OEM's study into what a safe, environmentally optimized, comfortable family vehicle might look like in the year 2000. Looking at the ECC now, 25 years on, it's clear that the design is a little dated and the powertrain – a hybrid system featuring a series-connected gas turbine and electric motor – hasn't become *de rigueur* across the modern Volvo model range. But there are elements of the ECC, which was developed at the Volvo Monitoring and Concept Center in California, that hinted at the Swedish car maker's (not to mention other OEMs') future direction.



One focus for the project was on matching an efficient powertrain with an aluminum body – yielding a low gross weight of 1,580kg. Though turbine-electric power isn't widespread nowadays, the quest to make greater use of aluminum in vehicle body design certainly is. For example, in early 2017 one of Tesla's aluminum parts suppliers announced investment to increase output ahead of the Model 3.

Materials for the ECC were selected based on their low environmental impact during vehicle production and with recyclability in mind, while the generously proportioned interior was designed with a focus on ergonomics. Technology known as Dynaguide provided the latest traffic information, via a display on the instrument panel. Even a look at the drive selection will be, for modern hybrid drivers, surprisingly familiar. A series of switches suggest the modes available: full-electric, hybrid and turbine.

More immediately for Volvo, the ECC had a substantial impact on the design of the S80, which was introduced in 1998 – the softer nose, integrated bumpers and V-shaped bonnet were something of a departure for the OEM in the early 1990s, but are design cues that have endured to this day.

The ECC might not have offered hover car technology or other such fanciful speculation, but the vehicle does provide a fascinating insight into Volvo's thought processes a quarter of a century ago. And though current vehicle applications of a turbine-hybrid powertrain are few and far between, the ECC nonetheless proved to be an important milestone in Volvo's vision for the future.

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The Renault Zoe has benefitted from extremely rapid advances in battery technology over the vehicle's relatively short lifespan

I remember hearing predictions seven years ago about how the electric vehicle market might expand by 2025. Maybe 5% of new cars would be electric by then, said the forecasters. For someone who had become convinced that electric vehicle technology was superior, this was fairly depressing to hear. The same kind of predictions were made about the growth of renewables – maybe 5-10% of generating capacity by 2020.

A famous quote by William Gibson is apt at this point: "The future is here, it just isn't evenly distributed."

Over 30% of drivers in Norway now sit behind the wheel of an electric car and the numbers of new EV sales are through the roof. China and India are adopting electric vehicles with a vengeance, Japan and Korea are miles ahead, and the UK and Ireland are adopting electric vehicles at an above-global-average rate.

Of course, in other parts of the world there are no electric cars, no charging infrastructure, and little or no knowledge of the developments taking place. But it's in the field of renewables that the changes are most apparent and widespread.

The United Kingdom has 13GW of solar installed, combined with massive offshore wind – this is the main reason behind the recent days of zero coal use in the UK, the first time since the industrial revolution.

There are advances taking place around the globe, and solar PV and small battery systems are growing at incredible rates across sub-Saharan Africa and India. The solar cell is a close technological relative of silicon wafers developed by the computer industry. The growth in energy generating capacity in solar cells and the drop in cost per watt is in line with similar developments in size, speed and energy use in computer chips.

The two technologies of renewables and electric cars are inextricably linked. Electric cars are just computers on wheels and are developing at a rate ICE vehicles have no chance of competing with.

> "Electric cars are developing at a rate ICE vehicles have no chance of competing with"

Anyone who drove the original Renault Zoe, and has had experience of the latest version, has witnessed these developments first hand – Renault has almost doubled the capacity of the Zoe battery pack, and everyone I spoke to at Renault was surprised at how quickly this development took place. Engineers and managers at the OEM have suggested they might bring out a larger-battery-capacity Zoe at the end of 2018. They began manufacturing them in late 2016.

I've recently been around the massive Renault plant at Flins outside Paris and witnessed the construction of the two battery options. One has a 22kWh capacity, the other 41kWh – yet they are the same size. The only way to differentiate them is through the barcode on the side. This increase is partly to do with packaging, but much more to do with improved energy density. The same will hold true with the new longer-range Nissan Leaf. The recently released Tesla Model S 100D has the same sized battery pack as my Tesla 85, but with 15kWh more capacity and an increased, genuine, all weather, all-terrain, 300-mile range – I recently drove a 100D from London to Orkney and back, and the one thing that wasn't even a passing thought was range.

So range, charging infrastructure, choice of models and constantly improving energy efficiency and reliability are all ticked boxes. It's now all down to cost – as always, it's the initial purchase that we consider, not the running costs over the life of the vehicle.

Anyone who's driven an electric car for any length of time knows they're cheaper, but that's a difficult argument to get across. However, the news is spreading and adoption rates reflect this. We are entering the age of the electric car.

Greg Offer

Battery technology will play a major role in future advanced economies, and competition for investment is likely to be extremely fierce

The battery industry is predicted to grow to an industry worth between US$50bn and US$200bn a year by the end of the next decade, and battery packs are set to replace IC engines as the most expensive part of the vehicle. So it's not surprising that competition is growing to attract the investment of major cell manufacturers. Tesla is building the Gigafactory in California in partnership with Panasonic, but there are a host of battery factories being built elsewhere – such as Samsung's in Hungary and LG Chem's in Poland – which will create the supply and could be scaled up quickly if vehicle demand increases as expected. To that end, AESC, LG Chem, Samsung and Panasonic, the giants who dominate the battery industry, are investing in strategic partnerships around the world.

There has been a realization that the economics of batteries are driven by scale. Ten years ago, many road maps assumed progress from hybrids to plug-in hybrids and eventually battery electric vehicles, or perhaps a leapfrog to fuel cells. However, engineers realized that battery electric vehicles are actually the easiest application – the huge packs mean the cells last a long time (as they are not stressed) and fewer vehicles constitute enough demand to justify investment in scaling up cell manufacturing.

> "Battery packs are set to replace IC engines as the most expensive part of the vehicle"

High-performance cars like the Tesla and the BMW i8 generate the most hype, but electric buses are probably already a bigger market in terms of demand for cells, particularly in China. The effect this has had on the price of cells has been dramatic, and could see cell costs fall below the US$100/kWh barrier for large volumes in a few years. The transition seems well underway.

Many countries are positioning themselves to be at the forefront of this opportunity. I was at a battery conference in Aachen, Germany, a few months ago where Kai Vuorilehto from EAS highlighted that Germany had invested a lot in cell development yet still had no significant indigenous cell manufacturing. He suggested that the country should focus on more profitable high-quality manufacturing and systems engineering. This would create demand for cells, attracting inward investment to counter the uneconomic shipping of large numbers of cells or packs. Germany's car makers have been doing this for a while.

In March 2017, the UK announced investment of £246m (US$318m) into battery technology over the next four years – peanuts compared with the US$5bn for a Gigafactory, but the hope is to nurture the seeds of a large future battery industry. China started investing in batteries a long time ago and is now going head-to-head with South Korea and Japan.

It's probably too late for Europe and the USA to make a similar move into existing cell technology – better to focus, as Vuorilehto suggests, on attracting investment from the international battery companies. For next-generation battery chemistries, however, the playing field might be more level.

Failure to do anything could lead to countries losing a large percentage of their advanced manufacturing industries when the last combustion engine-powered vehicle rolls off the production line. Although that might be 10 or 20 years in the future, laying the foundations for what will replace them must start soon, as it will only get more expensive to join the club. Batteries are going to be a key distinguishing feature of future advanced economies, and attracting this international investment is going to become a cut-throat geopolitical game – if it hasn't already.

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

EV startups are keen to have a disruptive impact on the industry. But can they really change the way things are done?

WORDS: **LEM BINGLEY**

"I think in the automotive industry in general, we're ripe for some disruptive technologies to come in. I think maybe in the niches, that's where things could be interesting"

Mark Vinnels, head of engineering, McLaren

Illustration: Sean Rodwell

German manufacturer Daimler uses the term 'CASE' to summarize the four big challenges facing established OEMs. The acronym stands for connected cars, autonomous driving, shared mobility and electric vehicles.

Speaking at the recent FT Future of the Car Summit in London, Daimler's head of strategy, Wilko Stark, told delegates, "All four have the potential to be completely disruptive for the automotive industry, so we have to balance our investment. This is a very, very difficult task. Because we as a company – and this applies to all OEMs – have to be self-disruptive. And to be self-disruptive is the most challenging management task."

Ripping up your own rulebook is hard for any company, but the alternative is to risk being supplanted by somebody else. Business history is littered with toppled giants.

"Nokia had 80% market share and then they were gone, two years later," observes Lewis Horne, chief executive of Swedish automotive startup Uniti, noting the impact of Apple's 2007 iPhone. "I have friends and advisors and teammates that were at Nokia and Sony at the time," he adds. "They were in those discussions where they had rooms of people saying, 'Well, we like the plastic-button interface.'"

Horne founded Uniti in January 2016 to try to bring iPhone-like disruption to the car market. The company is deliberately avoiding traditional automotive approaches, aiming to create cutting-edge, highly computerized processes to build a city EV in the European L7e quadricycle category. Last December it crowdsourced €1.2m (US$1.3m) in seed funding to pursue its goal.

Of course, Uniti's budget is a sliver of the €10bn (US$11.2bn) Daimler is spending to develop a platform for its future EVs, but Horne argues billions aren't necessary. "We avoid huge amounts of nonsense. If you came along today and gave me a billion dollars and said, invent the stupidest electric car possible, I don't think I could come up with anything worse than today's futile EVs."

As Horne explains, Uniti is targeting the L7e category not for cost reasons, but because the

"We have to recognize that Tesla did a great job, because they pushed the whole industry into electromobility. But in the long term I think it will be quite tough for them because all other OEMs will come up with electric cars that have a similar driving range to Tesla"
Wilko Stark, head of strategy, Daimler

"At the end of the day, it's very easy to set up one vehicle, and make a single product type. The secondary issue is to make a company out of them"
Stefan Juraschek, head of electric powertrain, BMW

rules governing M1 vehicles are a straitjacket. The more lightly regulated quadricycle niche gives Uniti freedom to reexamine everything including design and construction, drivetrain, materials, safety measures, instruments and controls. "We need to free ourselves from the old machine," Horne explains. "I'm sure that Volkswagen and Daimler and everyone else think they use human-centric design, but that's nonsense. They're designing around the mechanical properties of the machine. If we remove the mechanical limitations, you can actually design around the driver. That's fundamental to our whole project."

In the business of disruption

It remains to be seen if a small startup like Uniti can create the shockwave its founder envisages. For now, the disrupter troubling OEMs is Tesla. At the time of writing it has a stock market capitalization of almost US$62bn, having surpassed General Motors and BMW to become the world's fourth most valuable car maker. This is despite losing money on a turnover of only US$7bn last year. BMW, by contrast, made profits of almost US$7bn on revenues of US$94bn.

"The concept of Tesla is really clever but it's actually conventional technology for low-volume production. I think this can be done by many [companies] but they did it at the right time, at the right place with the right products, targeting the right people"

Alain Raposo, Renault-Nissan global VP, powertrain and EV engineering

"The stock market evaluates what will happen in the future – or it tries to," notes Dr Timo Möller, head of the Future Center for Mobility at consulting company McKinsey. An engineer by training, Möller has guided OEMs and Tier 1 suppliers in their response to the four CASE challenges.

As Möller explains, Tesla's valuation reflects the belief that the electric vehicle market will become huge in the future, and that Tesla will claim a considerable chunk.

A roster of other startups aims to follow suit, focusing on the high-value niches of supercars and luxury vehicles. Prototypes from the likes of Faraday Future, Lucid Motors, NIO, Rimac and Vanda Electrics have grabbed headlines and secured investment cash. It seems unlikely that all can succeed, however.

"We have to recognize that Tesla did a great job, because they pushed the whole industry into electromobility," concedes Daimler's Stark. "But in the long term I think it will be quite tough for Tesla because all other OEMs will

"There is a shift from powertrain engineering to marketing and customer understanding, and there might be companies out there who have that more in their DNA than traditional OEMs"

Timo Möller, head of the Future Center for Mobility, McKinsey

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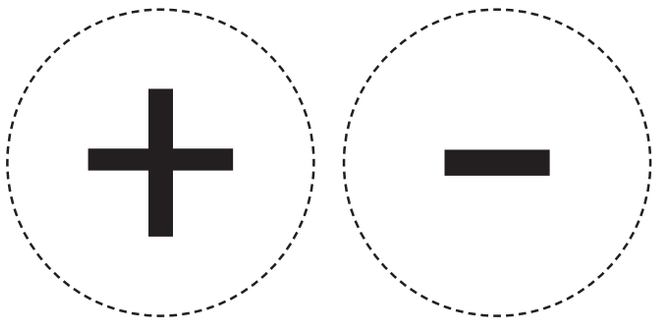

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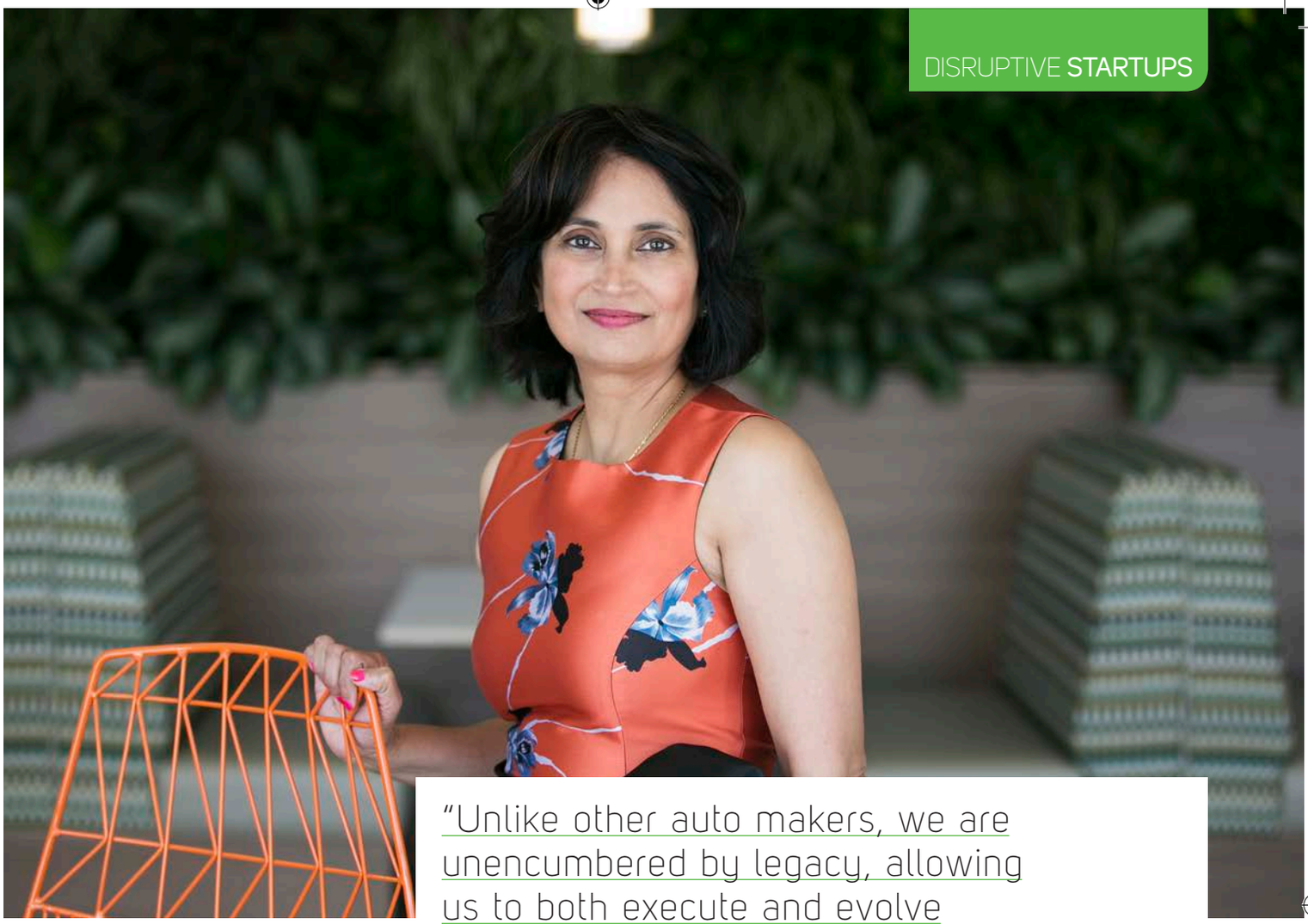

come up with electric cars that have a similar driving range to Tesla, which will have a similar power to Tesla. So Tesla, for the time being, really has a USP in the market, but in a few years this USP will no longer exist."

However, Möller suggests that simply parking on Tesla's lawn is unlikely to scare it off. "In the traditional world, you always needed a highly complex powertrain in your vehicle, which relatively few companies could create from scratch," Möller says. "An EV is obviously much less complex ... so the entry barriers are less. Secondly, getting closer to the customer and having a better customer understanding is becoming more important. There's a shift from powertrain engineering to marketing and customer understanding, and there might be companies out there who have that more in their DNA than traditional OEMs."

A customer-centric ethos is the first topic raised by Padmasree Warrior, chief development officer and US chief executive of Shanghai-based NIO. "We start with the user," she asserts. "Cars are no longer a mode of conveyance; they are becoming people's living space on wheels. As a startup, we are manically focused on this vision. And unlike other auto makers, we're unencumbered by legacy, allowing us to both execute and evolve quickly as the market transforms."

"Unlike other auto makers, we are unencumbered by legacy, allowing us to both execute and evolve quickly as the market transforms"

Padmasree Warrior, chief development officer and US chief executive, NIO

"[Startups] have a clean sheet advantage, for sure, but they don't have the experience of what it actually means to be an established car manufacturer in the automotive industry"

Rolf Frech, head of engineering, Bentley

While legacy can be a hindrance, it's also a strength, Möller counters. "You'll still need a vehicle to go from A to B, even if it's connected, even if it's shared," he observes. "Those guys are not at all in a bad position. They have 100 years of experience in bringing a high-quality product to the street. They have a huge customer base and surveys show there is quite some loyalty to traditional OEMs when it comes to innovation. People say they really want to sit in an autonomous vehicle from a traditional OEM, but they're not so sure if it's from a tech player."

But Warrior predicts such advantages will be short-lived. "As more EVs hit the roads, many of the issues and concerns – real or imagined – will fade away," she argues. "There is a big transformation happening in the automotive industry where the car of the future is really going to be a computer and a robot. Like other industries, there will be winners and there will be losers."

Power struggle

While OEMs hope to dominate via muscle and economies of scale, startups will fight

"We need to free ourselves from the old machine. I'm sure that Volkswagen and Daimler and everyone else think they use human-centric design, but that's nonsense. They're designing around the mechanical properties of the machine"

Lewis Horne, chief executive, Uniti

back with low overheads and agility. "More important than anything is our culture and our governance structure and our lack of hierarchy," says Horne. "The team has a lot of experienced people, but we are new-ideas dominant, not old-experience dominant."

Hugo Spowers, founder of British hydrogen vehicle startup Riversimple, believes that modest scale can be a blessing. "We can break even at a tiny fraction of the volumes of an existing manufacturer," he notes. "That allows you to not give a monkey's about what 95% of people want; if you've got a product that meets the needs of 5%, you're in business."

Like Uniti, Riversimple is rethinking a lot of fundamental assumptions. It plans to lease rather than sell its vehicles, with all costs including fuel and insurance covered by a monthly fee. This is a fundamental shift, because the costs of wear and tear, the impact of fuel efficiency and questions of residual value all move from the customer's lap into the supplier's.

"People won't pay extra for efficiency, but it costs you as a manufacturer to make the car more efficient," Spowers observes. "Therefore the only driver for efficiency is regulation, and as we've seen that's a very blunt instrument."

By contrast, Riversimple's business model means it benefits directly from investment in efficiency. "That aligns our interests not only with regulators, but also with customers," Spowers says. While OEMs profit from obsolescence and maintenance costs, mobility service providers will profit from longevity and minimized maintenance. "We are rewarded by resource efficiency rather than resource churn," Spowers notes.

As long as entrepreneurs come up with new ways of seeing the world, no amount of spending by OEMs will shut out the threat from startups. "Nobody knows which specific companies will be successful in the long run," notes Möller. "But there is a good opportunity for newcomers in the EV segment to be successful, and to really establish themselves among the top OEMs."

INSIDE A STARTUP

Dr Nico Sergent is the powertrain architect of Riversimple's Rasa, a hydrogen car under development in the UK. With a background in F1 engineering at Williams, he joined the startup in 2010.

The two-seat, carbon-bodied Rasa resembles a gnat next to the elephantine fuel cell cars from established OEMs. "We're trying to design a vehicle that will be as efficient as possible," says Sergent. "A fuel cell provides the core power and it's sized for cruising, and we have a buffer of supercapacitors that provide the power to accelerate and get energy back under braking, and also to provide energy to go up hills and get energy back downhill."

Off-the-shelf JSR supercapacitors store a modest 0.5kWh, while a Hydrogenics fuel cell designed for forklifts provides only 8.5kW. Toyota's Mirai fuel cell, by comparison, offers 114kW. "The fuel cell output is only linked to top speed, and not to acceleration because that comes from the supercaps," Sergent says. "Each motor is about 15kW, so overall we have 60kW (81.5ps) in a 580kg car. That's quite fun." Rasa can go from 0-60mph (96.6km/h) in about 10 seconds, using about a third of the supercap capacity in the process.

Light weight enables a virtuous circle, Sergent says. The low mass of the hub motors, bespoke designed by Printed Motor Works, helps them shrug off pothole shocks, for example.

Sergent notes that none of Rasa's components are cutting edge – it's their combination that delivers a breakthrough. "We don't need to push to the extreme limits of lithium batteries or supercaps or motors or fuel cells. The car is already more efficient than lots of others, so the process of optimization – the stage that really costs a lot – doesn't need to be done now."

"As engineers, we always like competition, and these new products that come into the market show us that we should never believe in the constraints we give ourselves"

Gerald Killman, head of powertrain, Toyota Europe

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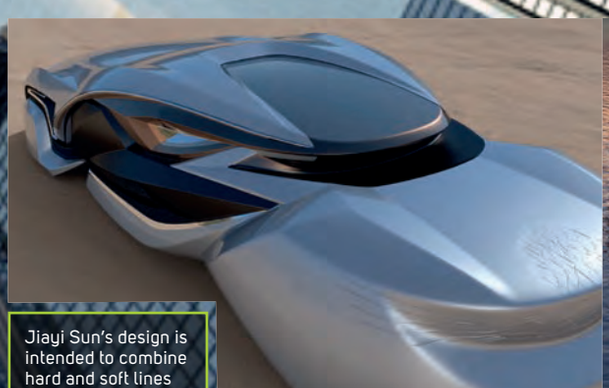
Xinyu Bob Wang's six-rotor mobility system of 2030 combines a 320kW vertical take-off and landing capability with a cruising output of 70kW

All images are supplied by CCS and are in no way associated with the respective OEMs

Located in downtown Detroit, the College for Creative Studies has been around since 1962, and the institution's alumni can be found working at auto makers and Tier 1s around the world. Here, a trio of CCS students from the Transportation Design program offer their take on the vehicles of the future

WORDS: **MATT ROSS**

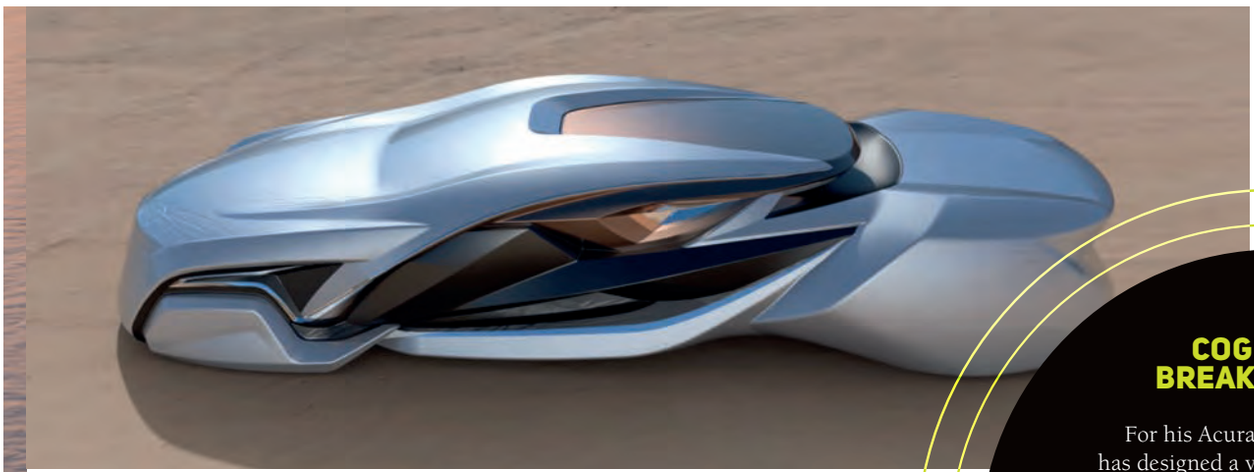


Jiayi Sun's design is intended to combine hard and soft lines with harsh, dark crystalline motifs

Cesar A Olivera Latorre's Evocador 2025 features a long hood and a short front overhang, while the vehicle's lines evoke a bird's feathers in the wind

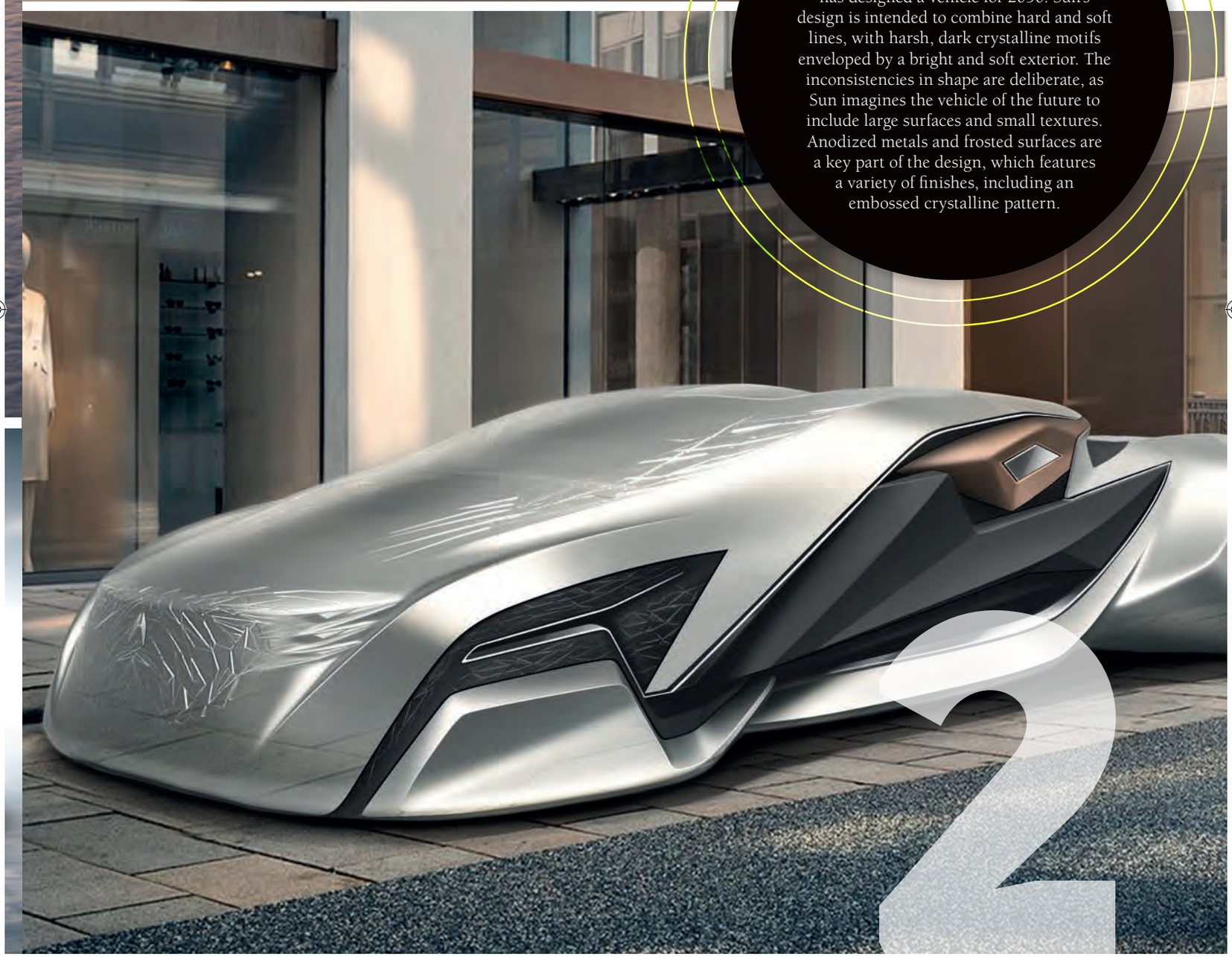
ADVANCING IDENTITY

Cesar A Olivera Latorre has blended the familiar and the futuristic in his Buick design. The Evocador 2025 features a long hood but a short front overhang, while the vehicle's lines evoke a bird's feathers in the wind. Transparent chrome dots resemble stars, glowing during the daytime and illuminated by LEDs at night. Laser headlights and tail-lights are designed to 'hide' within the vehicle's form, while a range of materials are used in the front fascia and rear end, which also include acid-etched textures.



COGITATIVE BREAKTHROUGH

For his Acura concept, Jiayi Sun has designed a vehicle for 2050. Sun's design is intended to combine hard and soft lines, with harsh, dark crystalline motifs enveloped by a bright and soft exterior. The inconsistencies in shape are deliberate, as Sun imagines the vehicle of the future to include large surfaces and small textures. Anodized metals and frosted surfaces are a key part of the design, which features a variety of finishes, including an embossed crystalline pattern.



3

THREE-DIMENSIONAL MOBILITY

In the face of increasing traffic congestion in megacities, Xinyu Bob Wang has followed trends of autonomous operation, shared mobility, increasing battery capacity and lightweight composite materials through to a conclusion that sees electric aerial drones integrated into the transportation infrastructure. Operating as a premium transport service for daily commuters and business travelers, Wang's six-rotor mobility system of 2030 combines a 320kW vertical take-off and landing capability with cruising output of 70kW, reducing traffic and improving cityscape efficiency.

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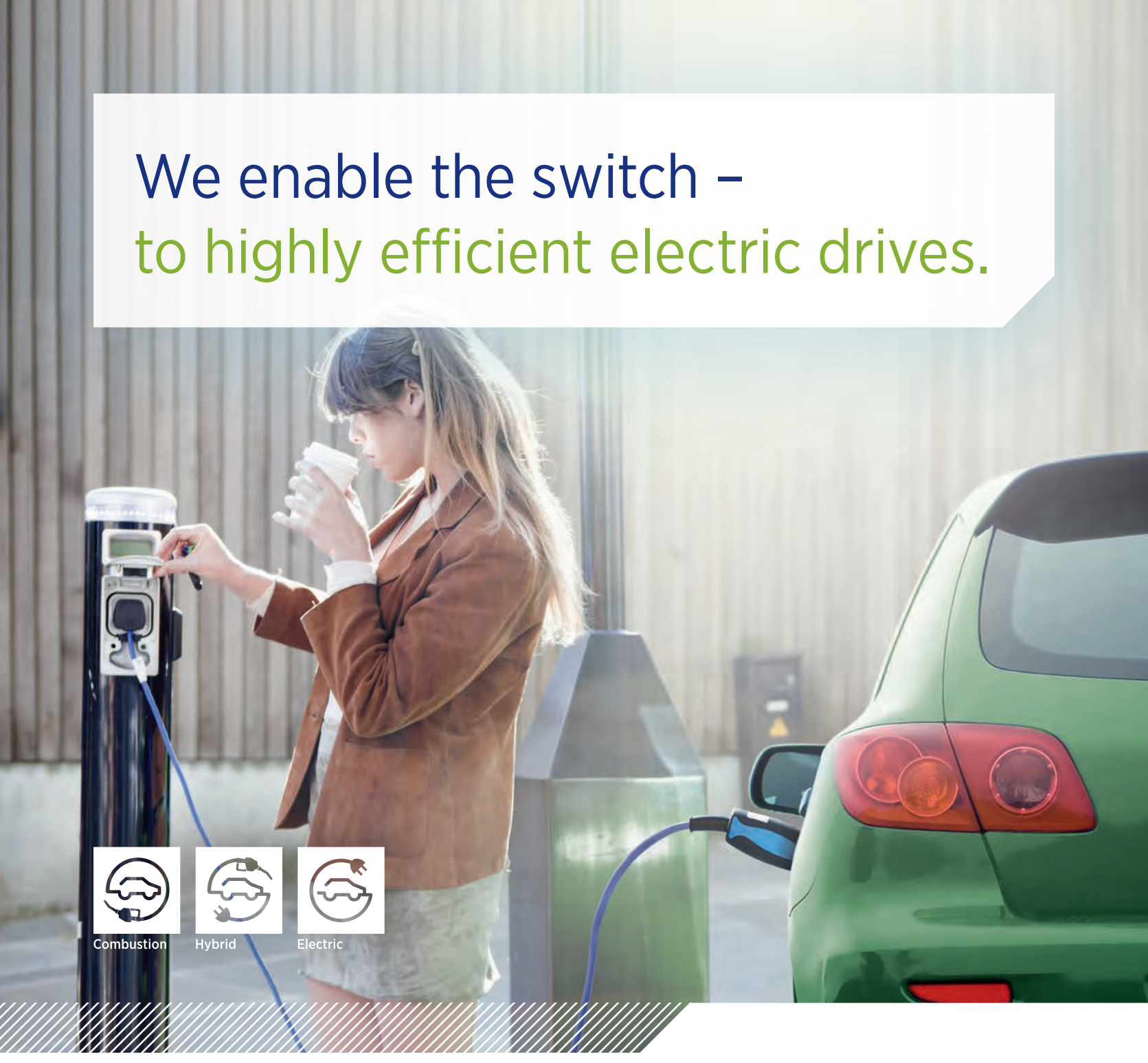

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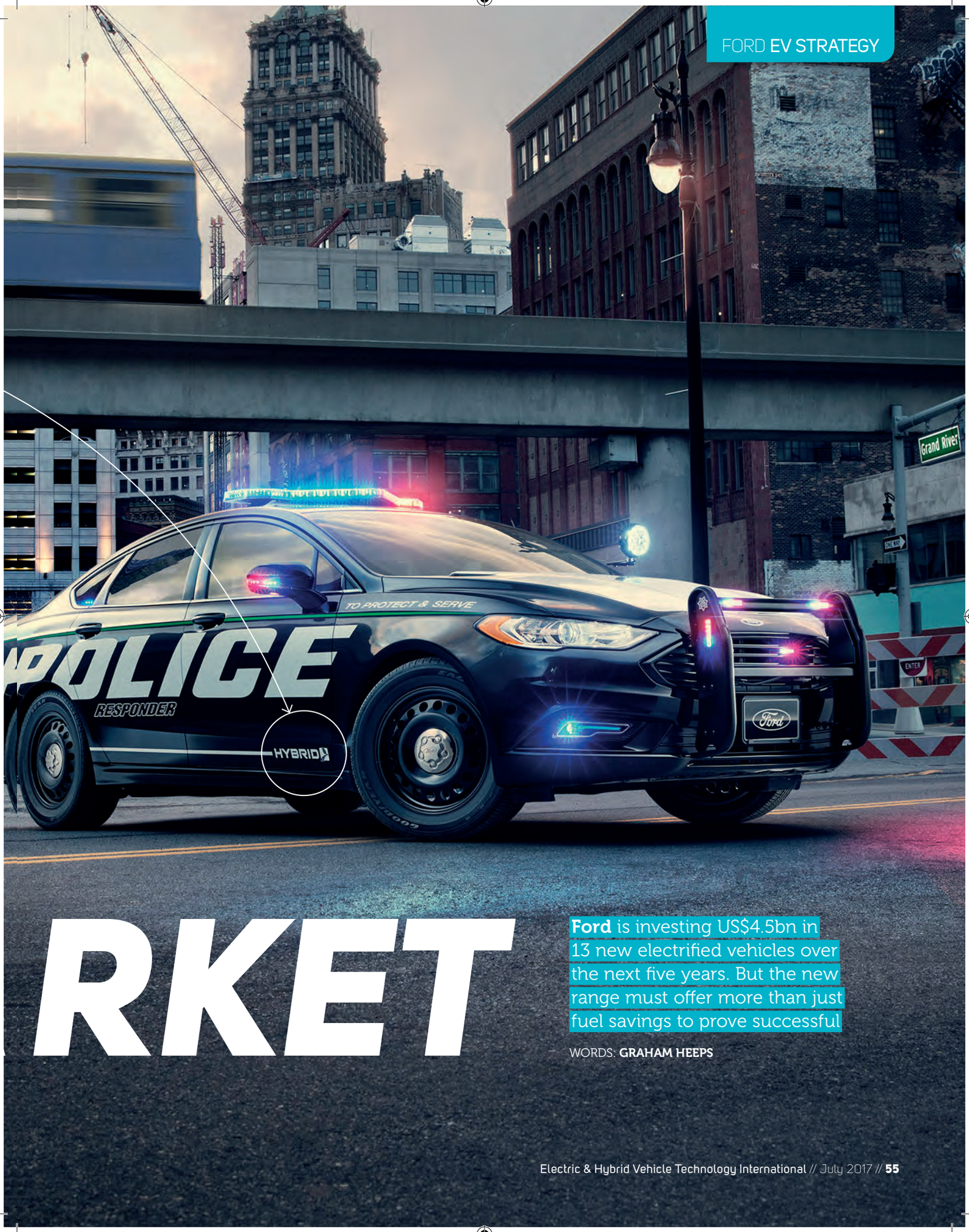

RKET

Ford is investing US$4.5bn in 13 new electrified vehicles over the next five years. But the new range must offer more than just fuel savings to prove successful

WORDS: **GRAHAM HEEPS**

Having had a small number of electric and hybrid models on sale for more than a decade, Ford is now jumping into the vehicle electrification market with both feet. Beginning last September, a series of announcements reveal a commitment to 13 new electrified vehicles over the next five years, a US$4.5bn R&D investment to achieve that goal, and US$700m of modernization at the Flat Rock, Michigan, assembly plant to build some of the new range.

The identities of seven new models have been confirmed. An all-electric SUV with a 300-mile (480km)range will take the fight to the Chevrolet Bolt, Tesla Model 3 and others who join the affordable-EV party. A "high-volume", Level 4 autonomous hybrid will be made available to ride-sharing fleets. Two Blue Oval icons, the best-selling F-150 pickup and the Mustang muscle car, will get hybrid powertrains, while electrified working vehicles will include a Transit Custom plug-in hybrid and two pursuit-rated hybrid police vehicles, one of which has been confirmed as the Fusion-based Police Responder Hybrid Sedan.

More than just efficiency

If your first thought is that fuel efficiency isn't at the top of a Mustang-buyer's shopping list, then Brett Hinds, Ford's chief engineer of

1. The Transit Custom PHEV trial in London also involves Prodrive and Revolve Technologies

"We work closely with our suppliers to make sure we understand what's on the leading edge so that when we launch our vehicles they'll be best-in-class for EV technology"

Brett Hinds, chief engineer of electrified powertrain systems, Ford

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electrified powertrain systems, would agree. He says that in order for this next generation of electrified vehicles to be successful – and in particular, to achieve the kind of mass-market penetration for which Ford is best known – the new EVs and hybrids must offer more than just lower emissions and better fuel economy.

"There's a limit to the fuel-economy market, particularly with the price of fuel at its current level," he says. "Electrification is important to the CO_2 compliance plan that we have committed to deliver. But to achieve it we're going to have to sell lots of electrified vehicles and we recognize that there are all kinds of consumer needs, so it's important to be able to provide a full range of products.

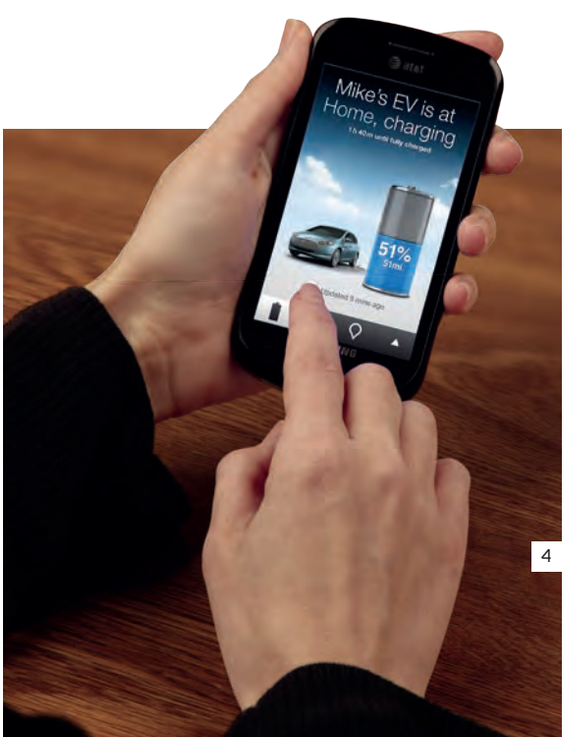
"We then want to use the enhanced attributes of the vehicles to sell them – people will choose that particular F-150 because it can tow better, as an example, whereas performance is key for a Mustang buyer, so we are looking at how to use electrification to give it more spirited performance and better response. At the same time, we'll give you the better fuel economy that hybrids are known for."

How the hybrid powertrain in the F-150 or Mustang will look isn't yet clear. One could speculate that both vehicles might use versions of the same setup, which could be based on an EcoBoost I4 or V6, either of which could deliver the V8-level performance of which Ford has spoken, depending on how powerful the V8 in question might be…

What Hinds will confirm is that the battery technology and electric motor efficiency of this new generation of vehicles – the Mustang is due in 2020 – will be a clear step forward from what Ford currently has available.

"We work closely with our suppliers to make sure we understand what's on the leading edge so that when we launch our vehicles they'll be best-in-class for EV technology," he says.

Hinds adds that not all the supply contracts for the future programs have been awarded yet. "We're not going to get into battery cell manufacturing, because that expertise lies with the battery manufacturers," he explains. "But when it comes to assembling and testing a battery pack, the same with motors, we have full capability to do that in-house. For us it's a business decision whether we make it in-house or buy from an external source, depending on volumes, manufacturing locations and the like."



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2. Ford will start testing a fleet of 20 Transit Connect hybrid taxis and vans in major US cities this year

3. As more vehicles in Ford's EV strategy are revealed, there will be a discernible global outlook

4. Current electrified Ford vehicles in North America provide the OEM with vital real-world feedback

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GREEN TRUCKING

Like all major truck makers, Ford has close ties to the upfitter industry that builds buses, ambulances and other specialty vehicles on OEM chassis. Here too, the market for electrified vehicles is growing and Ford recently expanded its Advanced Fuel Qualified Vehicle Modifier (QVM) program – which previously encompassed vehicles running on CNG or propane – to include companies that develop and install electric- and hydraulic-hybrid powertrains in Ford trucks and vans.

The new eQVM program means that electric and hybrid work trucks modified by vehicle developers who pass Ford's assessment process will retain their original powertrain warranty. Initially three companies are part of the program: XL Hybrids, which offers a hybrid electric drive system for a variety of E- and F-Series trucks; Motiv Power Systems, which performs all-electric conversions on Ford E-450 and F-59 chassis; and Lightning Hybrids, which has developed a hydraulic-hybrid energy recovery system for a number of E- and F-Series vehicles.

1. Analysis of data from Ford's existing electrified fleet will play a key role in determining future vehicle specifications

"It's about doing a full portfolio of vehicles and enhancing their performance with attributes that customers want, all at an affordable price that customers are willing to pay"

Brett Hinds, chief engineer of electrified powertrain systems, Ford

Real-world feedback

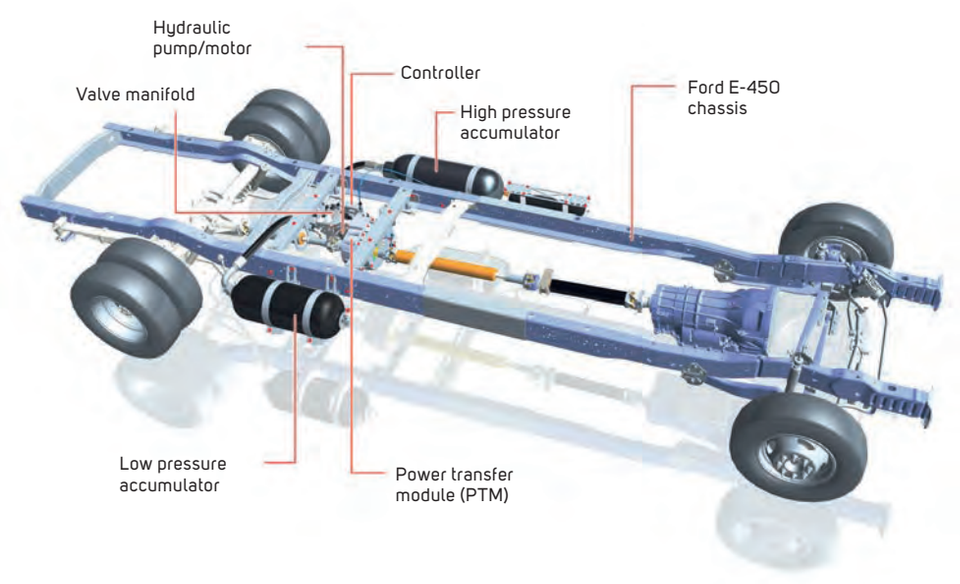
The Transit Custom plug-in hybrid could be the first of the 13 new products to reach the market if the launch goes ahead as planned in 2019. From this autumn, a fleet of 20 Transits will be tested by a cross-section of businesses on the streets of London – not far from the vehicle's engineering center in Dunton, Essex.

At around the same time, a similar number of Transit Connect vans and taxis, which are already being tested internally by Ford, will hit the streets of US cities, including New York, in the hands of key account buyers.

"We know what we think they should do, but we want the customers to tell us their experiences," says Hinds. "Real-world feedback is incredibly important to us. Our current vehicles in North America [the Fusion and Lincoln MKZ Hybrids, the C-MAX Hybrid and Energi, and the Focus Electric] are equipped with the MyFord Mobile application. Through it we log everything that happens to the vehicle and to date we have tens of millions of trips' worth of data.

"We analyze it for trends," he continues, "How far people are driving, when they are recharging and how many trips they make before they start recharging, for example. We use that information to optimize the size of the battery, the chargers and how much EV range people want or need."

When it comes to battery capacity, Hinds stresses the need for rightsizing, particularly given Ford's position as a mainstream



Ford's Police Responder Hybrid Sedan is the industry's first pursuit-rated police car. The vehicle was launched in New York and Los Angeles. A second hybrid police vehicle for the North American market will follow as part of the OEM's new EV strategy

PAYING THE EV PRICE

Mark Fields' surprise departure as Ford CEO in late May was touted as a 'retirement' for the high-flying 56-year-old, and while that's what both parties vigorously maintain, rumors swirling around Dearborn seem to suggest otherwise.

According to said rumors, Fields, who had led a long and largely successful career within the Blue Oval, was politely told to leave Ford HQ by the exec team, headed up by chairman Bill Ford. The company denied this, however, insisting Fields was retiring.

Ford's official statement regarding the appointment of Jim Hackett as new CEO used key phrases such as 'sharpening operational execution', 'modernizing Ford's business' and 'transforming the company to meet future challenges'. And that, in the real world, suggests a previous lack of key decisions on some core products, including PHEVs, BEVs and autonomous vehicle tech, especially when you look at what GM is doing with Lyft and FCA with Google's Waymo. GM has hugely pushed ahead with its e-powertrain program too, offering US consumers an array of hybrid and plug-in hybrid vehicles, as well as full electrics, like the Bolt, Spark, Volt and Ampera, all towering over Ford's current range.

Prior to the promotion, Hackett was chairman of Ford Smart Mobility, a subsidiary of Ford formed to accelerate the company's plans to design, build, grow and invest in emerging mobility services. Before joining Smart Mobility, Hackett was a member of the Ford Motor Company board of directors, and was actively involved with the Ford senior leadership team in launching the company's Ford Smart Mobility plan.

manufacturer. "We're trying to give customers what they want without driving the price into the high end. We're a mass vehicle manufacturer and want to sell lots of cars. Looking forward, however, we are doing a 300-mile BEV SUV that will deliver all the performance you'd expect from a high-mileage EV, but at Ford-level pricing."

Such developments will be made possible, Hinds believes, by technology maturity and scale effects in the battery market, as well as by the design efficiencies that come from having done it before: "We understand what customers want and value, and can better tune our designs to provide the features people need while leaving out the things they don't."

Global outlook

Ford hasn't revealed when the remaining six of its 13-vehicle portfolio will be announced, but expects them to have less of a North American bias than those revealed so far.

"There are pressures around electrification in Europe and China too," notes Hinds. "As the other six vehicles are filled in, you'll see more of a global perspective."

It's already confirmed that the Mondeo Energi plug-in hybrid, sold in North America as the Fusion, will be manufactured in China from next year alongside the Mondeo Hybrid at Ford's Changan Ford JV in Chongqing. The all-new BEV SUV will also go on sale in China within five years.

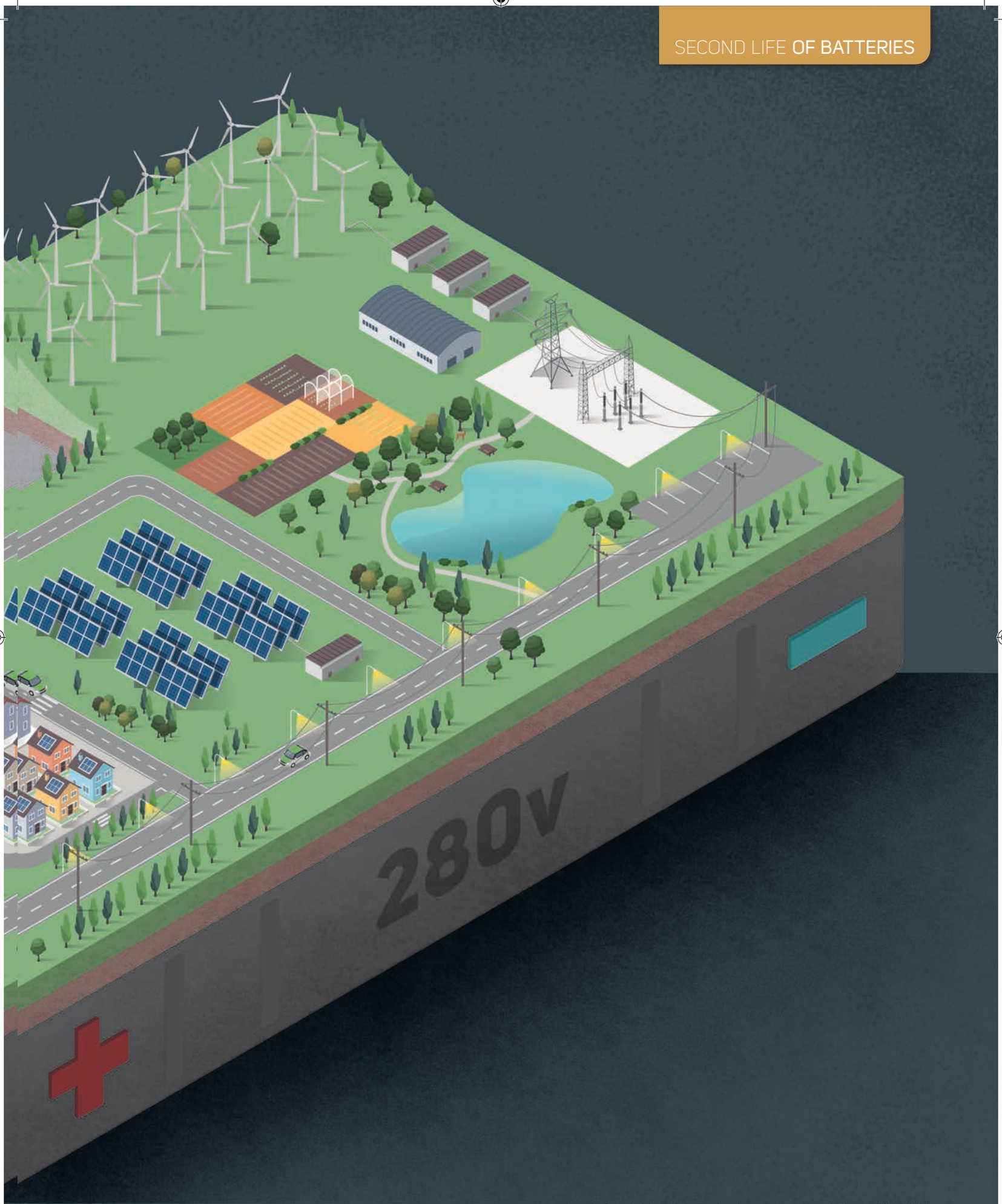
With other major manufacturers, such as Volkswagen, also now fully committed to electrification, the prospects for the wider adoption of hybrids and EVs look brighter than ever. Hinds, for one, has high hopes that Ford can repeat the trick it performed with its EcoBoost ICE downsizing technology.

"That same storyline is there and we expect customers to buy the best product," he adds. "It's about doing a full portfolio of vehicles and enhancing their performance with attributes that customers want, all at an affordable price that customers are willing to pay. That's Ford's core business. We think that we'll be a major player in electrification for the masses."

REUSE OF POWER

The industry is facing the prospect of millions of used electric vehicle batteries in the next few years. The question is, what should it do with them?

WORDS: **CHRIS PICKERING**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Right now, the global EV population is growing at an exponential rate, with numbers now in excess of two million. That's great for the car industry, but it does pose a question: What do we do with those batteries once they have reached the end of their life?

It's not an easy problem to solve. The cost of lithium-ion cells has halved over the past eight years, due in part to the reduced use of expensive metals such as cobalt. Unfortunately, that means that the value of the recoverable materials has dropped too. In some cases, the net cost of recycling a single EV battery pack can be in excess of €1,000 (US$1,118).

On the other hand, a battery pack deemed to be at the end of its life for EV applications may still have plenty left to give. Most OEMs state that an EV battery pack should retain 70-80% of its charge at the end of its intended life. A recent study by Lux Research estimated that, by 2035, this could equate to 65GWh-worth of EV batteries being retired from service each year.

This is somewhat complicated by the non-linear nature of a battery's cycle life, though. Beyond a certain point, the aging process accelerates rapidly and the capacity plummets. So it's likely that the battery would indeed be nearing the end of its automotive life at 70% capacity. Transferred to a less demanding application, however, it could have many years of useful service left.

This is where so-called second-life batteries come in, with scores of companies – including most of the major EV manufacturers – now evaluating the concept. Last year, Daimler announced the opening of the world's largest second-life battery storage facility in Lünen, Germany. Comprising around 3,000 battery modules taken from the Smart Fortwo Electric Drive fleet, it provides 13MWh of grid storage, helping the local energy network to balance out fluctuations in supply and demand.

Creating a second-life market for EV batteries could dramatically improve their residual value too. Daimler estimates that it has doubled the economic value of the cells used in the project.

"If the aging of the battery is too advanced to meet car requirements, we can now give it a second purpose in stationary storage and use the battery for another period of time in a profitable operation," comments Frank Spennemann, director of business innovation at Daimler. "Based on our simulations, we

1. Daimler's industrial-scale lithium-ion unit uses modules taken from Smart Fortwo EVs

2. The Lünen facility is the largest second-life battery storage facility in the world, and provides grid stabilization and smooths load peaks

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3. Battery research at the University of Warwick, UK

4. Mercedes-Benz energy storage solutions, which reuse spent electric vehicle batteries, are also suitable for private use

"If the aging of the battery is too advanced to meet car requirements, we can now give it a second purpose in stationary storage"

Frank Spennemann, director of business innovation, Daimler

expect much less aging of the batteries during stationary operation as the operational pattern is rather soft. The batteries stay in a certain state-of-charge range and within a quite narrow temperature window, both of which support a long battery life."

Batteries developed for automotive already exceed the highest requirements for quality and safety in stationary applications, he points out. And for Daimler, which produces its own batteries in-house, both the expertise and the production equipment were already in place.

"It's more than just taking the batteries and putting them into storage," says Spennemann. "For the automotive battery pack itself, it's mainly testing to make sure everything is working and to define the aging status. For building a stationary storage system connected to the grid, you then have to add an inverter. But the highest level of complexity comes with developing the controllers, including communication of all the functions. We went through a lot of software development and testing."

Daimler is by no means alone. Nissan and US power management company Eaton are joining forces to take on Tesla's Powerwall with their xStorage Home residential system, assembled from second-life EV cells. Renault, meanwhile, has just announced a tie-up with Powervault to create a similar home system, which it claims will reduce costs by 30% compared with using the equivalent first-life cells. Interestingly, it also puts a figure on the life of the system – estimating "up to 10 years of useful life" in the stationary application.

Varied uses

A lot of independent technology businesses are also investigating this concept. Hyperdrive Innovation, based just down the road from Nissan's battery plant in Sunderland, UK, is one such company.

"Even once they've aged, Li-ion batteries can compare favorably with other chemistries," comments Hyperdrive managing director Stephen Irish. "And it's not just a question of capacity. Their ability to handle high charge and discharge rates opens up additional possibilities such as frequency regulation."

Arguably the most vital part of repurposing batteries is assessing their condition. Irish envisages this as a triage system, where the batteries could be assigned different onward uses depending on their condition.

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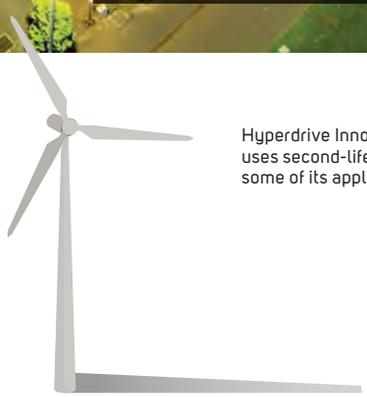
POWER TO THE PEOPLE

In addition to the xStorage Home technology, Nissan has teamed with Eaton and The Mobility House on xStorage Buildings, an energy storage system to provide backup power for the Amsterdam Arena. A 10-year deal at the 55,000-seat stadium sees 280 repurposed Nissan Leaf batteries stored in racks and Eaton's bidirectional inverters providing backup power for major events, assisting utilities during periods of high demand, and grid stabilization. Technology company The Mobility House will operate the system, which will provide power for the surrounding neighborhood in addition to serving as the stadium backup.

"There may be some [batteries] with a very high energy density remaining. On the other hand, there may be some that are quite low, which could be used for off-grid applications"

Stephen Irish, managing director, Hyperdrive Innovation



Hyperdrive Innovation uses second-life cells in some of its applications

"We see the cells being graded for different applications," he explains. "There may be some with a very high energy density remaining. On the other hand, there may be some that are quite low, which could be used for off-grid applications – perhaps donated to charity for remote areas with no continuous power supply. It's about understanding all the opportunities."

A large part of the intellectual property of second-life batteries comes with this grading, he adds: "It's far from straightforward. Being able to do it on an industrial scale is also very different to doing it as a one-off in a laboratory. That's where the value really comes in."

Making the grade

The Advanced Propulsion Systems group at the University of Warwick is also looking into battery grading. Much of the research focuses on assessing the batteries at a pack level rather than as individual cells, says Prof. David Greenwood, who leads the group.

"The business case for second-life batteries is borderline at present, so it makes things more difficult if you have to put a lot of cost in," he says. "Generally, what we're trying to do is keep the battery at the highest level of aggregation possible to maintain the value within it."

The simplest way to assess cell performance is to run a complete charge-discharge cycle, but with a full-scale EV battery, this can take many hours. Greenwood and his colleagues are looking at the use of electrochemical impedance spectroscopy (EIS) as an alternative. Here, current is applied to the battery across a range of frequencies, which activates different areas of the cells.

"This is an established technique for testing single cells," Greenwood explains. "At high frequency, the area of the cells that works

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hardest is closest to the terminals, whereas at lower frequency it's more the body of the cell. By measuring the impedance across this range we can generate a trace that characterizes the whole cell. As the cell degrades, this pattern will change."

The next challenge is to apply EIS testing at a modular level, he explains. Part of the complexity is that stronger cells in one area of the battery could mask issues in another, but it's hoped this can be overcome. If so, it could provide a very fast, convenient way to assess the state of the battery.

Testing the batteries – at least to that level of detail – may not be necessary, though. Another suggestion is to use the battery management system (BMS) to collect data that can characterize the battery over time. The hardware required for this is already present in most BMSs; it simply needs to be recorded and stored in an accessible format. However, there can be intellectual property tied up in the BMS algorithms, which the manufacturers are understandably keen to protect. There are potential solutions, though, such as creating a secure partition within the BMS or feeding the data to an external module.

"The valuable part of the intellectual property that manufacturers will want to protect generally relates to the second-by-second management of the battery," explains Greenwood. "What the second-life producer needs is a more general overview of battery usage over time, such as total throughput and average operating temperature. It would be difficult to infer any sensitive information from that sort of high-level data, but it would allow the battery to be graded for its future use."

The group is also looking into how batteries could be designed to better facilitate reuse, and indeed recycling.

"Right now, very little of the content in an EV battery is recycled, because it doesn't make economic sense," says Greenwood. "Part of what we're doing is to look at ways to recover materials and reuse them with relatively high value. Rather than stripping down a cell and breaking a cathode into its elements, for example, could that be used as a cathode material in a lower-performance battery?"

Production methods are also coming under scrutiny. At the moment, manufacturing techniques such as welding and adhesive bonding are commonplace, but these can make it particularly difficult to break the battery down into its component parts.

"We've been working with Axion to eliminate those issues, and we've found that, if you design the recyclability in sufficiently early on, you can do so at remarkably low cost," notes Greenwood. "In fact, it can have benefits. Eliminating the processing and curing of adhesives, for instance, can significantly improve cycle times."

There's also a logistical element to consider. Recycling or repurposing locally incurs lower CO_2 and transportation costs than extracting the materials at source. And while there are no imminent signs of material shortages, the increasing demand for Li-ion batteries in both the EV and consumer electronics markets means we're going to have to think carefully about what we do with them in the future.

SECOND-LIFE CRISIS?

Granting spent EV batteries a second life beyond the vehicle is, clearly, better than consigning them to the scrapheap, but increasing numbers of electrified cars will still need an increasing number of new batteries – and several issues surrounding the production process remain.

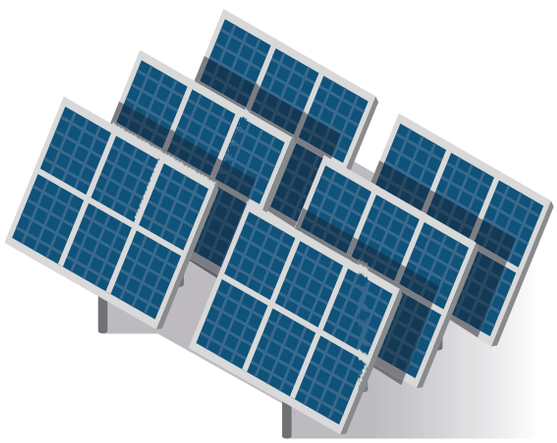
"While electric vehicles pose an excellent opportunity to mitigate climate change down the road, the production of the batteries does require quite a bit of energy and materials input which, in today's economy, produces a not-insignificant environmental footprint," explains Prof. Anders Hammer Strømman, director of the industrial ecology program at the Norwegian University of Science and Technology. "It is difficult to produce any green product in a dirty economy."

After all, lifting the used battery from an EV only makes sense if a new one takes its place.

"We embrace the emerging battery industry and the electrification of transport, but we need to work hard on making this production green and lean, if you will," continues Strømman. "If we don't talk about this, and address this issue, electric vehicles will not be as effective a mitigation option as we would like them to be.

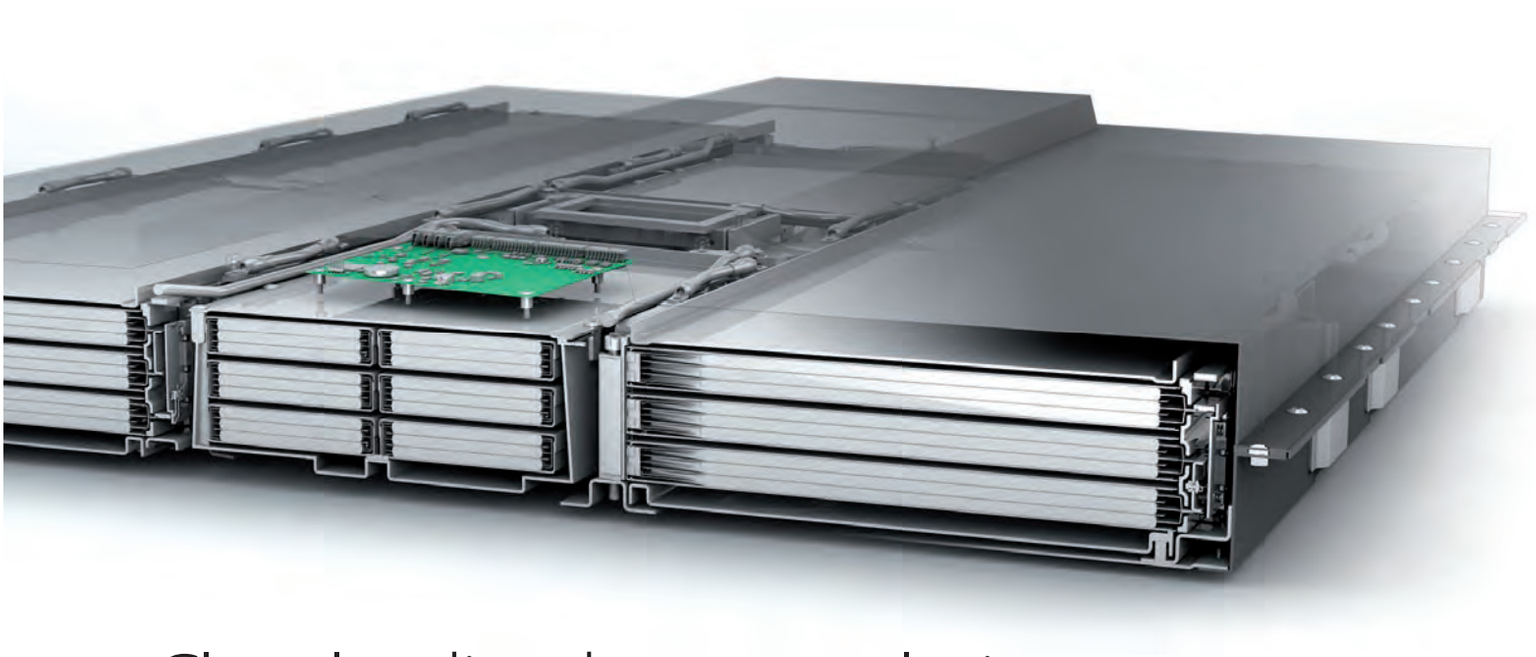
"We're in a very early lifecycle stage of the emerging global industry for traction batteries. Discussions on the idea of a circular economy and the electrification of transport need to merge at some point, so we can design better concepts and systems for both reuse and subsequently recycling of the materials. Now we have the opportunity – we're designing technologies that are being phased in, and there's no reason why we shouldn't work hard [at this stage] to make sure that we create a circular economy of batteries."

1. Daimler and Enercity's facility, where used batteries are built into energy storage systems



"Right now, very little of the content in an EV battery is recycled, because it doesn't make economic sense"

Prof. David Greenwood, leader, Advanced Propulsion Systems group, University of Warwick



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Battery breakthrough

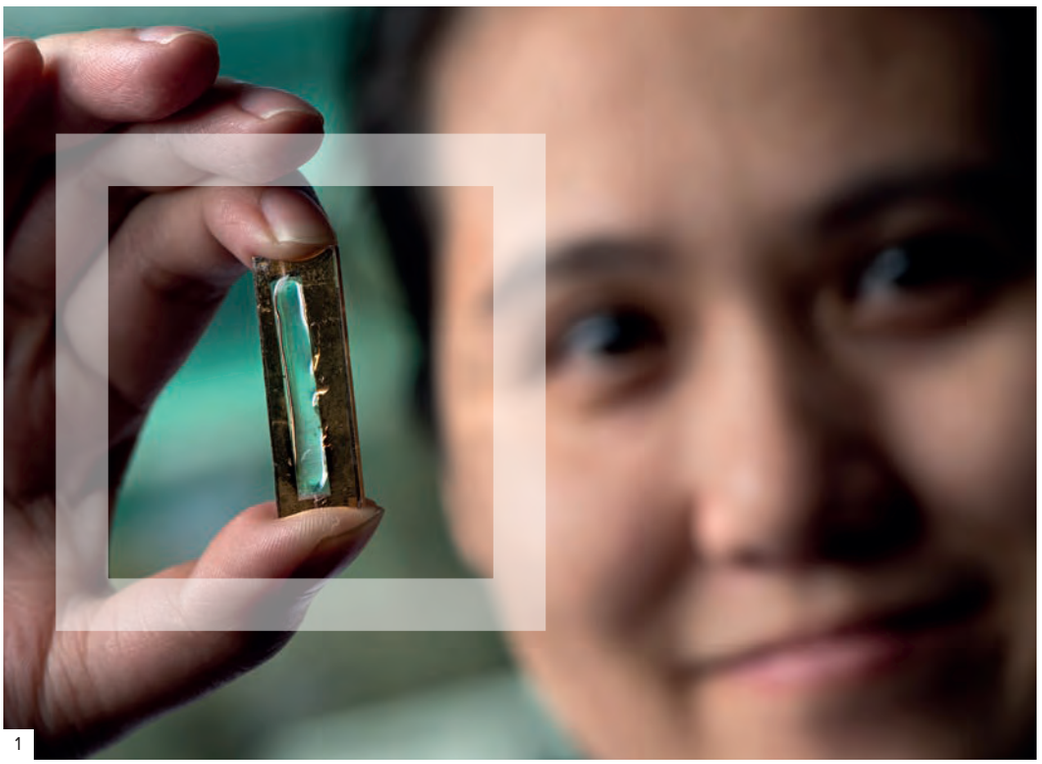
When it comes to nanotechnology, good things really do come in small packages

WORDS: **CHRIS PICKERING**

In 2016, a team of researchers from the University of California, Irvine (UCI) hit the headlines for a seemingly miraculous discovery. While investigating solid-state electrolytes for capacitors, they stumbled across the startling realization that the electrodes they'd created seemed to maintain their charge capacity almost indefinitely. This was not – as was widely misreported – the makings of an everlasting battery, but it still marked an important discovery.

The team, led by Professor Reginald Penner, constructed what they termed a Degradation and Failure Discovery Platform. This comprised two arrays of gold nanowires coated in manganese dioxide (MnO_2) and arranged on a glass plate. Together, the arrays look rather like interlocking fingers, with 375 nanowires on each side, separated by the electrolyte. When a potential difference is applied to the two sides of the platform it generates an electric field, creating a capacitor. As the name implies, the purpose of the platform is to charge and discharge the electrodes until they break down.

In UCI's test rig, the arrays were formed using lithographically patterned nanowire electrodeposition (LPNE). Developed by the university in 2006, this technique uses photolithography to prepare a sacrificial electrode on a piece of glass or plastic. This is then used to electrochemically grow nanowires (in this case, gold). Once the electrode is removed, the nanowires remain printed on the glass and a manganese dioxide shell is grown on top, encasing the gold core.



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Previous studies with conventional liquid electrolytes had shown that the electrodes usually degraded after about 6,000 cycles, leading to irrecoverable capacity loss. This is due to the manganese dioxide coating going brittle over time – simply through mechanical fatigue as the flow of ions causes the material to expand and contract.

With this in mind, doctoral candidate Mya Le Thai prepared a gel electrolyte based on polymethyl methacrylate (PMMA) mixed with a small amount of lithium perchlorate (a salt commonly used in the electrolyte for lithium-ion batteries).

"Mya began testing the capacitors and initially there was no apparent difference in performance, but they just kept on going," Penner recalls. "Mya would visit my office every week or two and say, 'They're still going'. We never saw irreversible capacity loss."

In the end, the team was able to demonstrate charge stability for some 200,000 cycles. It's thought that this is due to the PMMA acting as a plasticizer. And what's interesting is that the same technique could well be used to prevent degradation in batteries with metal oxide electrodes.

"The number of cycles this platform would typically achieve before it succumbed to capacity loss was quite comparable to what you'd see in a lithium-ion battery," says Penner. "The chemistry is different in a battery, but the key point is that the cathode is usually a metal oxide, so it's likely that the stabilization method we've discovered would work there too."

Nano benefits

Gold was utilized for the purposes of this research project because it's largely chemically inert, minimizing chances of any interaction with the electrolyte chemistry. In a practical application, something far more affordable, such as nickel, could be used just as easily, notes Penner. But what's extremely important is the nanostructure.

"You have to ask yourself the question, 'What limits power in batteries?' Essentially, it's the ability to get ions in and out of the charge storage material, whatever that may be. That ability is directly proportional to the surface area of the material. Nanowires give you a very high surface-to-volume ratio, so there's a much greater area available for ion intercalation," explains Penner.

The problem is that nanowires are very fragile, which until now has precluded them for practical applications such as batteries. So the upshot of this research is perhaps not to create everlasting batteries, but to extend the life of high-performance nanowire-based materials into a practical range.

"One of the biggest benefits of this technique is that it would allow nanowire-based materials at the cathode. That should increase power – both gravimetrically and volumetrically – without sacrificing cycle life," Penner explains.

Challenges ahead

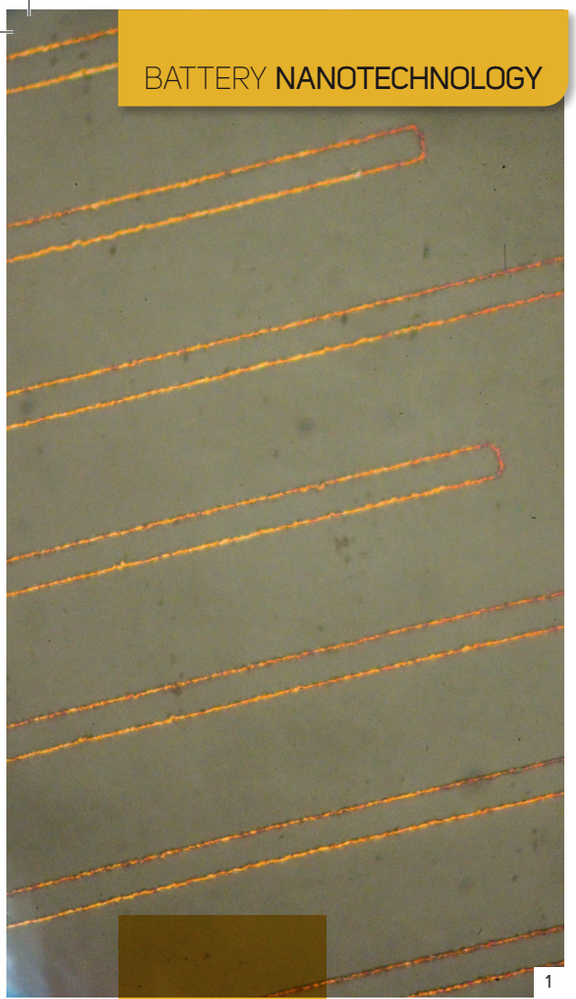
In theory, the UCI electrode design could be used as the cathode for a conventional cell, but there are a number of practical obstacles. For a start, you'd need millions of nanowires in place of a few hundred to operate at a useful scale. The issue here is that it's hard to fabricate cells with millions of nanowires.

2

1. A team at the University of California, Irvine has created electrodes that maintain charge capacity for extremely long periods

2. Mya Le Thai used a gel electrolyte based on polymethyl methacrylate, mixed with a small amount of lithium perchlorate

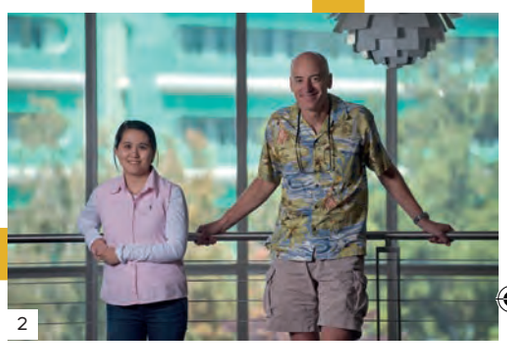
Steve Zylius, UCI



Steve Zylius, UCI

1. Gold nanowires were used because the metal is chemically inert, reducing the chance of interaction with the electrolyte

2. The University of California, Irvine's Mya Le Thai and Richard Penner



"To the best of my knowledge, there are no battery electrodes based on nanowires at the moment," says Penner. "Fabrication is a big problem, but nobody has really been motivated to solve that issue until the stability was under control. Now, though, it looks like we might have a solution."

That's not to say that there aren't potential fabrication options. During the late 1980s, a technique called template-synthesis was developed. This uses a thin plastic membrane with cylindrical pores punched through it to grow a carpet of nanowires.

"That's the sort of technique you could use to scale this into a practical application," notes Penner. "The length of the nanowires is quite limited – around 20µm – so you'd need billions of them, but that's basically what you'd want for a battery geometry."

Since the original findings were published in 2016, the UCI team has expanded its work on several points. Firstly, the PMMA layer, which was originally 180µm thick, has been scaled down to around 2µm in an attempt to see how much gel is really required, and what sort of packaging density could be achieved with the nanowires. Reducing the amount of gel reduces the overall volume of the battery, so the volumetric capacity should go up in inverse proportion to the thickness of the gel.

The other aspect they've looked into is the voltage range, which dictates how much energy the capacitor can store. Increasing the voltage by 50% has doubled the energy density of the capacitor. "That was an exciting discovery," explains Penner. "We've gone from 1.2V to 1.8V, and without the gel there'd be no way you could achieve this sort of voltage window. At 1.8V, with 2µm of gel, we're still getting more than 100,000 cycles. Those are just the first two ideas we've tried, and we think this technology has got a very interesting future."

There's still a lot left to do, he adds: "We think it's important to understand why the gel works so well, but we're not really there yet. We've only tried one electrode material and one gel material, so there's a huge amount of fundamental science left to do."

The extent of any practical gains would depend heavily on the battery architecture, so Penner is understandably reluctant to speculate on percentage improvements. Nonetheless, nanowire electrodes could offer considerable benefits in terms of both energy density and outright performance. If this research succeeds in enabling that leap, then it would indeed be a momentous discovery.

"One of the biggest benefits of this technique is that it would allow nanowire-based materials at the cathode. That should increase power – both gravimetrically and volumetrically – without sacrificing cycle life"

Prof. Reginald Penner, Chancellor's Professor, Chemistry, School of Physical Sciences, University of California, Irvine

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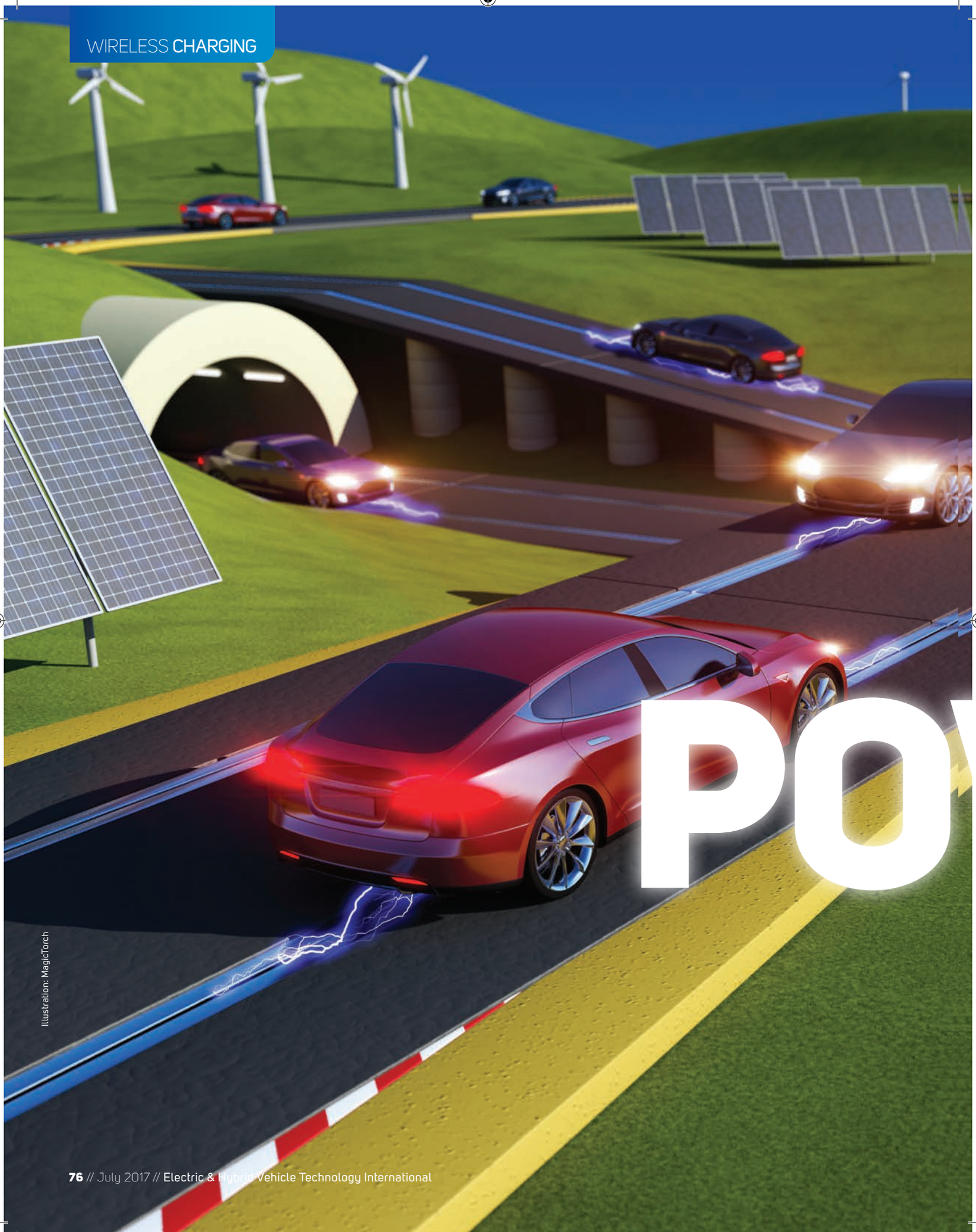


Illustration: MagicTorch

WERING the future

Testing of wireless charging technology is vital to ensure standardization – an important milestone in the journey toward a cable-free future

WORDS: **LEM BINGLEY**

The first wave of modern EVs – Nissan Leaf, Renault Zoe and BMW i3 – arrived in the absence of a global charging standard. As a result, the trio require quite different rapid-charging cable solutions: CHAdeMO for the Leaf, Combined Charging System (CCS) for the i3, and a Type 2 Mennekes connector for the Zoe. Consequently, today's rapid chargers tend to be three-tentacled beasts, carrying all the costs and complexities of doing the same thing three different ways.

As such, OEMs and infrastructure providers are keen to avoid a repeat in the emerging technology of wireless charging. This technique uses resonant magnetic coupling to transfer energy between a transmitting coil built into a pad fixed to the ground and a receiving coil carried on the underside of the vehicle, separated by an air gap. Several companies have brought their own such variations of this technology to production readiness, but the ideal scenario would be to have full compatibility, so that an EV fitted with any given receiver will be able to charge reliably from any manufacturer's transmitter.

"The introduction of EVs with wireless charging ability has been delayed – the technology was actually ready two to three years ago," says David Schatz, director of business development at wireless technology provider WiTricity. "One of our licensees – Toyota – was already field testing but chose to wait for standardization because this is a long game and the OEMs really feel the pain of the profusion of standards for conductive charging. They have to go through quite elaborate testing of every charging system that is on the market because of all the differences in standards and connectors and because of all the differences in behavior between the chargers."

One organization leading compatibility efforts is SAE International, through its J2954 working group, which was set up in 2010. The group has already reached agreement on a common frequency band for light-duty vehicles, from 81.39kHz to 90kHz (nominally 85kHz), and has also outlined four wireless power transfer levels dubbed WPT1 to WPT4. The first two are the focus of current standardization work, with rates of 3.7kW and 7.7kW. Work that began earlier this year is addressing WPT3 operating at 11kW, while WPT4 at 22kW and further levels beyond will be tackled in due course.

Efficiency of effort

Last summer a substantial project was undertaken at Idaho National Laboratory (INL) and funded by the US Department of Energy, to assess compatibility between rival systems using the standard frequency. INL research engineer Barney Carlson, a member of the J2954 committee, coordinated the work.

"We tested various coil topologies – circular and multicoil designs – in order to determine

"We tested various coil topologies – circular and multicoil designs – in order to determine whether they are interoperable from design to design"

Barney Carlson, research engineer, Idaho National Laboratory

1

2

1. WiTricity is working with General Motors to test an advanced wireless charging system prototype for maximum efficiency and interoperability across platforms

2. Idaho National Laboratory researchers and six companies achieved a major milestone in December 2016 by completing bench testing for wireless charging systems, a technology that eliminates the need to plug in electrified vehicles

AUTOMATIC FOR THE PEOPLE

Continental has developed automated wireless charging for EVs, a solution that complements cable-free power transfer with the Tier 1 company's micro-navigation technology.

As a vehicle approaches a parking bay equipped with inductive charging, an authentication dialog with the charging station is executed automatically. An in-car interface shows the driver when the vehicle has reached the correct parking position and confirms that charging has started.

Continental's inductive charging solution is capable of recharging the EV at a rate of up to 11kW, and begins the power transfer automatically and safely as soon as the authentication has completed and the vehicle is parked in the correct position over the system's ground pad. Furthermore, gap-monitoring technology interrupts the transfer if any foreign objects are detected.

ON THE MOVE

Advancements in wireless charging continue to come thick and fast, and dynamic charging – transferring power to a vehicle while it is in motion – is also interesting car manufacturers and technology developers alike.

Honda, which has targeted a fivefold increase in sales of EVs in the next four years, has been working on technology that will enable charging of 180kW (DC 600V, 300A) at speeds up to 155km/h.

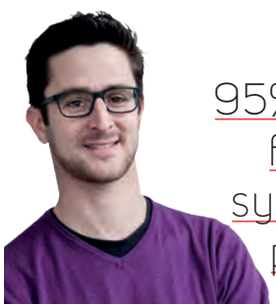
Qualcomm has demonstrated dynamic charging, based on the company's Halo technology, capable of charging an EV dynamically at up to 20kW at highway speeds. Qualcomm also demonstrated simultaneous charging, in which two vehicles on the same track can charge at the same time. Vehicles can pick up charge in both directions, and in reverse.

Following the demonstration, the Qualcomm Halo DEVC system was handed over to Vedecom to perform tests for FABRIC (FeAsiBility analysis and development of on-Road charglng solutions for future electric vehiCles). These will evaluate the operation, safety and efficiency of energy transfer to the vehicles for a wide range of practical scenarios including vehicle identification and authorization on entering track, power level agreement between track and vehicle, and speed and alignment of vehicle along track.

1

1. Dynamic charging demonstrations took place at a 100m-long test track built at Satory Versailles

2. The source part of Qualcomm's Halo DEVC system was integrated in the test track, while the receiving component was integrated onto two Renault Kangoos



"The objective is to reuse at least 95% of the work that has been done for cabled charging. A wi-fi-based system is currently emerging as the preferred communications carrier"

Sebastian Mathar, senior engineer, Qualcomm

whether they are interoperable from design to design, across different power classes and across different coil gaps," he explains.

Power transfer was the sole focus of the study. A deployed system also requires data transfer between transmitter and receiver, as is the case with cabled charging, but this need fell outside the test's scope.

"We're trying to avoid duplication of effort," notes Sebastian Mathar, a senior engineer at technology provider Qualcomm, who participated in the INL tests. "ISO 15118 standardizes communication for both cable and wireless charging. The objective is to reuse at least 95% of the work that has been done for cabled charging. A wi-fi-based system is currently emerging as the preferred communications carrier," Mathar adds.

In order to gather repeatable results, INL employed a non-metallic rig to hold the two pads apart. The frame allowed for precise adjustments to the vertical separation (z-axis) as well as horizontal displacements in the x-y plane. Rotational misalignment, to reflect skewed parking for example, was not assessed.

2

Prior work at INL had established that a pad bolted to an actual car behaved rather differently from a coil in isolation – as might be expected of a magnetic device positioned close to a ferrous chassis. Thus, the test rig included a flat steel backing plate to emulate the vehicle body as well as an aluminum shield between the plate and the receiver pad.

"The specifications of those two components were much discussed by the committee," notes Carlson, who adds that a battery emulator was used to receive the transferred power.

When it came to test subjects, Toyota provided a WPT1-level system that used circular coils, while WiTricity and Nissan brought more powerful WPT2 circular coils, and Qualcomm and Jaguar Land Rover evaluated another WPT2 system that employed double-D (DD) coils. According to Qualcomm, a DD configuration provides a more compact design for a given level of performance. "The coils are, on average, 30-40% smaller than a circular coil," says Mathar.

Mind the gap

As well as assessing whether rival coils could work together, INL's study measured power transfer efficiency across misalignments likely to be seen in the real world. The permutations of receiver and transmitter, various air gaps and a series of x and y deflections meant collecting tens of thousands of datapoints. The tests took several months to complete.

1

GETTING WIRED

Installation of charging infrastructure remains a major obstacle for uptake of wireless technology, but on a South Korean island, authorities are pushing ahead – albeit with wired solutions. In 2014, Jeju Island – a UNESCO World Heritage Site – hosted the International Electric Vehicle Expo, where officials of the Jeju Special Self-Governing Province mapped out plans for a completely carbon-free future.

In addition to a target of generating 100% of the island's consumed energy from renewable sources by 2030, officials want to make every vehicle on the island an EV. But how does a small island with a dense population of more than 605,000 people build the infrastructure to support such a vision?

"Until 2014, only the South Korean government was active in infrastructure development, but since 2015, we've seen private businesses join the effort," explains Dong-Hee Kim, head of the Strategic Industry Promotion Division. The island is undergoing a sharp increase in charging infrastructure – by the end of 2016, there was a total of 679 charging stations, and local citizens wanting to install home chargers could receive government funding. And that's just the start.

"Beginning in August 2017, we plan to expand our EV charging infrastructure and establish a parking tower that will ultimately solve parking-related issues," explains Dong-Hee Kim.

Naturally, the government has had to offer incentives to ensure Jeju residents remain enthusiastic about the vision. In 2016, locals received around US$18,800 per EV, and charger support reaches up to US$3,575. The EV purchaser receives up to a US$3,575 discount on taxes, including the island's individual consumption tax, acquisition tax, education tax, and more.

There is a 50% cut in the basic rate of electricity charges, and owners benefit from free parking at designated locations.

There remain obstacles to be overcome – due to the large number of apartments on the island, EV owners have problems installing home chargers – but Jeju's efforts could provide a roadmap for widespread charging installation.

Meanwhile, in Europe, London and Berlin-based Ubitricity is installing wired charging sockets in streetlights across the UK capital. The unique charging technology has been designed to fit inside ordinary light architecture – offering sockets that remove the need for additional, specific EV charging bays, and minimizing visual impact on the urban environment.

The low-power charging points are intended for use by local residents lacking access to off-street, high-power solutions. The sockets connect to the existing electrical supply, avoiding the need for civil works, and reducing installation time and overall cost. Richmond upon Thames is the latest borough to receive the sockets, joining Hounslow, Westminster, and Kensington and Chelsea.

Carlson oversaw engineers from each of the participating providers, who conducted each test scenario. Qualcomm's Mathar describes the process: "We'd set up our vehicle pad on the test rig, for example, with the agreed separation. We'd talk to the ground-pad engineers and agree a certain current, voltage or power that they needed to generate on their pad. Then we'd monitor the energy we received on our pad, to see what fraction of power we got – typically 91% or 92%. Then, once we finished one, we'd switch off the power and go to the next offset."

The results of the tests were encouraging, says Carlson: "There was a high degree of interoperable performance among all these systems, and across all test conditions," he summarizes. Meanwhile, Mathar's verdict is more quantified. "What we saw was 95% super, great results, and the remaining 5% were not unexpected. And we know how to solve those issues now. So, if we were to do it again it would work 100% smoothly."

The tests also provided confirmation of computer modeling. "For the first time we really saw it working," adds Mathar. "It was expected from our simulations, but we were positively surprised because you have to keep in mind that all three systems were developed completely independently. There was no communication during the development and interoperability was not the main focus. Nonetheless, interoperability was demonstrated and really worked very nicely."

Following the tests, the SAE working group was able to reach agreement in January on specifications for a test station, which manufacturers will be able to use to verify compatibility of production designs. The test station uses a circular coil but, as the INL tests have demonstrated, other compatible topologies are possible.

But as with any good working standard, the emerging SAE work will leave plenty of scope for innovation in other areas, such as system efficiency, cost, complexity, durability and longevity. As Mathar astutely observes, there is still plenty of work to be done before the automotive industry is able to create a fully formed standard. "Discussions on foreign object detection and living object protection are both on the agenda," he notes.

1. There are currently more than 8,000 EV chargers installed on Jeju

2. WiTricity is also working with Nissan to develop a wireless solution

2

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DRIVING FORCE

GM has built an imposing pickup demonstrator for the US Army to evaluate the benefits of fuel cell power on simulated missions

WORDS: **GRAHAM HEEPS**

General Motors and the US Army's Tank Automotive Research, Development & Engineering Center (TARDEC) have a cooperative R&D agreement for the joint testing of new fuel cell materials and designs. Now, in a separate collaboration, the Michigan-based organizations have completed a rapid development program – a year from concept to finished vehicle – to create the Chevrolet Colorado ZH_2, an off-road fuel cell pickup being evaluated by soldiers in 2017.

The US Army is keen to assess whether some of the benefits of fuel cell power – such as near-silent operation, high wheel torque at all speeds, and water as a by-product for field use – might be applicable to its needs. The ZH_2 will show where a vehicle like it would fit into soldiers' usage.

"We've been able to invest a relatively small amount compared with GM's US$3bn of total fuel cell investment to evaluate the technology very quickly from the Army standpoint," explains Brian Butrico, ZH_2 chief engineer and program manager at TARDEC. "As a result, the people who write requirement and capability documents for the Army will know that there's an alternative powertrain out there that's reliable, tested and can offer unique attributes. For silent watch or silent mobility for example, they will know what is possible and won't be asking for something that's not achievable."

Transformational technology

A pair of ZH_2s have been built: a development mule, and the fully clothed and finished vehicle that was handed to the Army in April 2017 for trials. The base is the new Chevrolet Colorado ZR2 body-on-frame pickup. The cab, doors and roof remain largely standard steel items; notable interior additions include a roll bar, different seats and six-point harnesses. New front and rear ends – styled by GM's North Hollywood design studio, which also creates vehicles for the *Transformers* movies – handled styling and packaging requirements.

Under the domed hood is a transversely mounted, proven GM Hydrotec fuel cell stack that has been carried over from the Chevrolet Equinox FCV, of which a 120-strong test fleet completed more than 3.1 million miles. The Colorado ZH_2 has the capability to operate particularly stealthily because the fuel cell powertrain gives it a much lower thermal signature than a diesel would, making it less visible to enemy thermal sensors.

A driving range of around 193km (120 miles) is expected, with acceleration from 0-97km/h (0-60mph) in around 15 seconds. A 39° departure angle, 48° angle of approach and ability to ride over a 12in curb provide the go-anywhere capability that will prove

JET PROPULSION

Were the Colorado ZH_2 or any other fuel cell vehicle to go into Army service, the question of a hydrogen fuel infrastructure would need to be addressed. According to GM's Joe Mercurio, studies have been done to reform the US military's widely used kerosene-based JP8 jet fuel to hydrogen. He says that you get about the same efficiency whether you put the JP8 in a vehicle with an ICE, or one with a fuel cell, because the fuel cell's efficiency compensates for the conversion losses.

The fuel-cell-powered GM Colorado ZH_2 was named as one of the US Army's top 10 modernization efforts of 2016

useful in Army operations. TARDEC's brief to GM was to meet or beat the mobility requirements of the Humvee.

The bespoke rear end is made of Kevlar-reinforced carbon fiber. A clamshell cover incorporates air intakes that feed radiators that are honeycombed behind the rear doors. GM says that moving the air intake nearer the roofline reduces the amount of dust and dirt ingested into the radiator during operation in extreme conditions.

New generation

The rear-mounted Exportable Power Take-Off unit (EPTO) transforms the ZH_2 into a mobile generator. "Fuel cells are about 10 times as efficient as combustion engines at idle speeds," explains Dr Joe Mercurio, manager of new business development for GM's fuel cell activities. "When you park the vehicle, you can run the cell to make around 300V DC power, which the EPTO will convert to 120V or 240V AC. It'll produce up to 25kW, enough to operate a temporary army camp."

A core of around a dozen TARDEC engineers worked with a larger GM team during the Colorado ZH_2's development.

"GM's been terrific about showing us how they do rapid development," notes Butrico. "We can now take some of GM's best practices and apply them to rapid Army modernization or prototyping."

In an initial test phase at the start of 2017, full performance characterization of the ZH_2 was completed at GM's Milford Proving Ground.

"We didn't run into anything unexpected for a prototype during testing and shakedown," adds Butrico, a former Roush engineer. "We had to relocate a wire harness routing and tune the shocks and chassis control systems to the new center of gravity and different tires. Adding a front and rear camera system was probably the biggest change, but that was implemented easily on the ZH_2's architecture. GM also added a separate, less sensitive throttle map and more regenerative braking for 'L' on the PRNDL shifter. This will aid us in off-road operation versus the standard 'D'."

Following the handover to the Army, 12 months of further testing and user evaluations are being run by TARDEC. The ZH_2 is being taken to military installations and bases including Fort Benning (Georgia), Fort Carson (Colorado) and Fort Bragg (North Carolina), for use by groups such as special and airborne forces, regular infantry, armor officers and field surgeons, to find missions for which it might be a suitable platform.

"One thing we'll do is bring it to a field hospital to power up a field surgical unit quietly at night – the surgical team could use the vehicle they arrived in to power the unit, rather than bringing in a separate generator," says Butrico. "We want to get a lot of people in it and get their honest feedback on how well its capabilities translate to their needs."

Unlike the engineering data and the results of the Milford tests, some of the data from TARDEC's testing, specifically the results of acoustic and thermal testing, would potentially remain classified.

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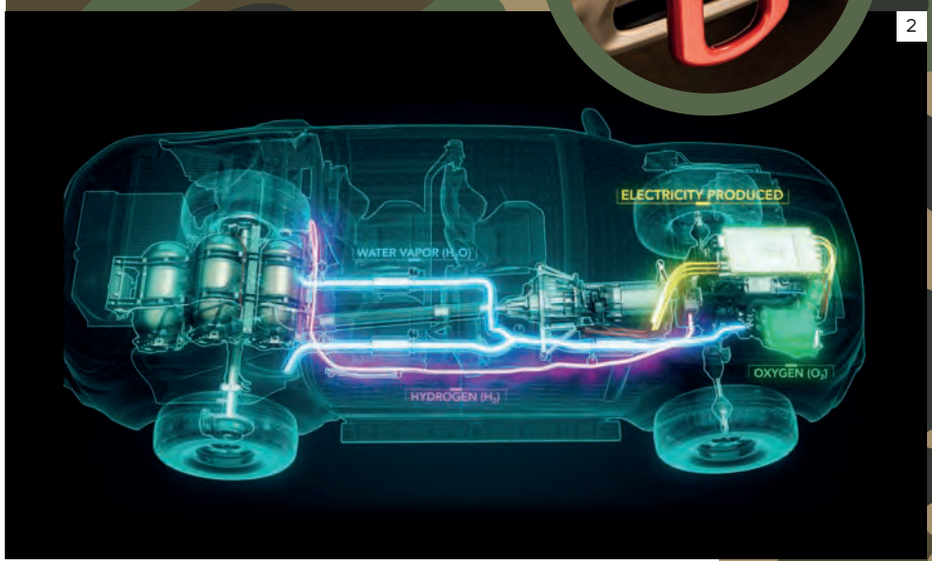

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1. A rear-mounted EPTO transforms GM's ZH_2 into a mobile generator

2. The ZH_2 is powered by a transversely mounted Hydrotec fuel cell stack

"A surgical team could use the vehicle they arrived in to power a field surgical unit, rather than bringing in a separate generator"

Brian Butrico, ZH_2 chief engineer and program engineer, TARDEC

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Fuel for thought

WORDS: **RICHARD N WILLIAMS**

For all the promise shown by FCEVs, a lack of hydrogen fueling infrastructure continues to limit vehicle sales – and those low sales make building infrastructure an unattractive proposition. So what's the solution?

The availability of stations providing reasonably priced hydrogen in places where vehicles will be deployed remains a key challenge to adoption of the technology

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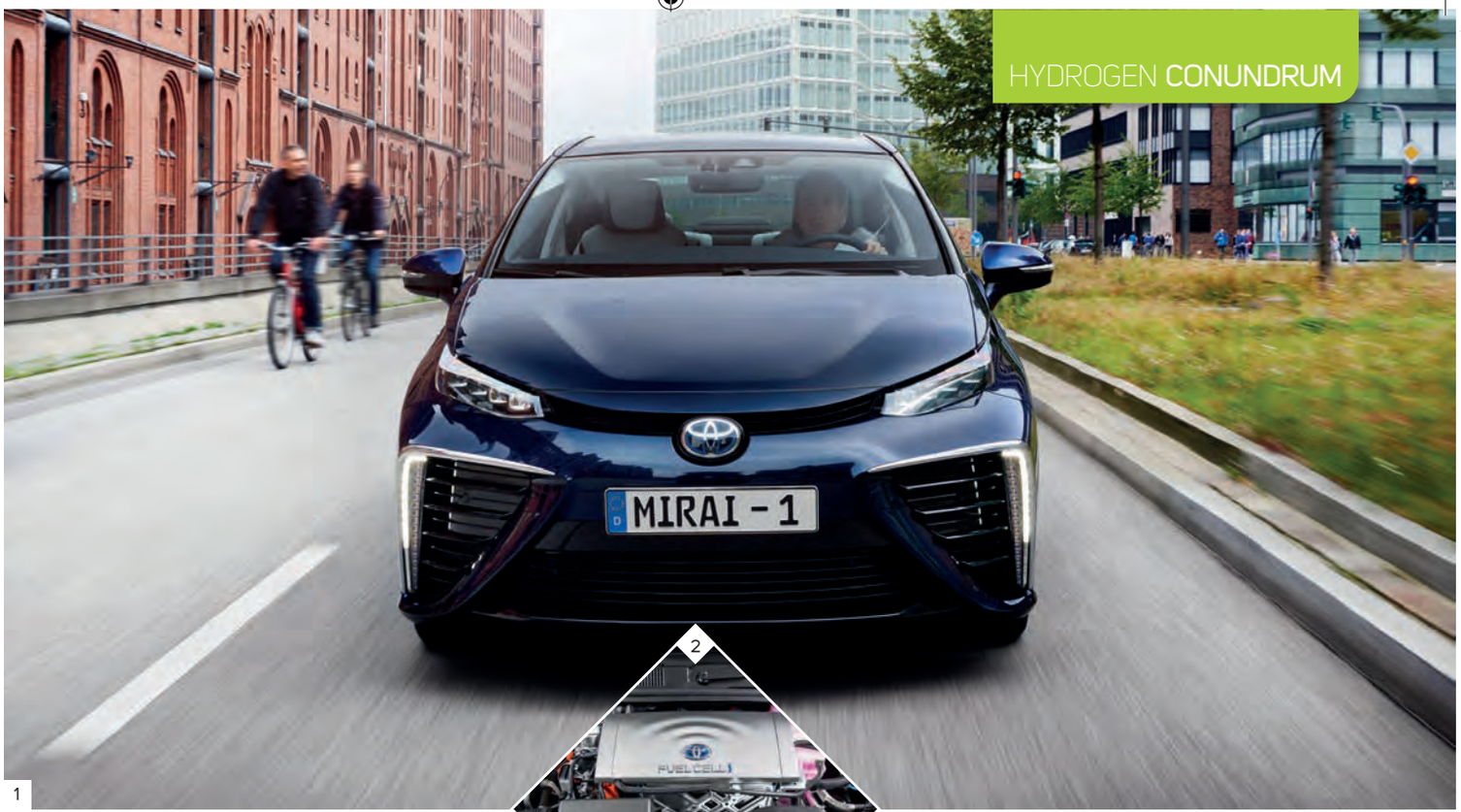

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In 2015, to much fanfare, Toyota released the Mirai, one of the world's first production FCEVs. On its launch, the company assured prospective car buyers that the infrastructure for these hydrogen-powered vehicles would soon be in place, but things haven't gone completely to schedule.

"From what we planned when we made the initial announcement in 2015, we do see a slight delay in the network," admits Stephan Herbst, technical general manager for business strategy and strategic planning at Toyota. "Primarily, this is because some companies want new spaces for hydrogen filling stations. Also, there are administrative challenges. Hydrogen is new, so the safety approvals and so forth take some time."

Sales of the Mirai have been steady, he says, and have been in line with Toyota's estimates.

"If you look at where infrastructure is the best, namely Germany, the UK and Denmark, then sales have been according to plan. The next step is to build up internationally. We are looking at 30,000 per year, globally."

Hyundai has also brought an FCEV, the ix35 Fuel Cell, to market, as has Honda with the Clarity, while BMW has toyed with an i8 FCEV concept – although has said that infrastructure is the main obstacle to a production version.

Indeed, BMW formed a group with Ford, Daimler and Nissan to collaborate on hydrogen technology – although Daimler has now abandoned its own hydrogen vehicle development.

1. To support development of fuel cell technologies worldwide, Toyota has released more than 5,600 royalty-free fuel cell related patents, including technologies developed for the Mirai

2. The US Department of Energy lists just 34 public hydrogen fueling stations in the USA; all but three are in California. By comparison, the US has more than 15,000 public electric charging stations

Circular argument

"It's a chicken and egg situation," says Herbst, who adds that Toyota is working with BMW to provide the hydrogen powerplants for the Munich-based auto maker. "People won't buy an FCEV if the infrastructure is not there, but equally nobody will install the infrastructure if there are no cars.

"The market is not very big," he concedes. "This is one of the reasons we went into partnership with BMW, and why we have opened up 6,000 patents. By sharing the technology and encouraging collaboration, it will bring more applications to market. We are willing to collaborate and to share."

Other OEMs, such as Hyundai, also believe that hydrogen fuel cell technology is here to stay. "Fuel cell technology is a fundamental part of Hyundai's current and future line-up,"

"People won't buy a fuel cell car if the infrastructure is not there, but equally nobody will install the infrastructure if there are no cars"

Stephan Herbst, technical general manager, business strategy and strategic planning, Toyota

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says Sylvie Childs, the company's product manager. "The ix35 Fuel Cell has been commercially available since 2014 and during that time we have delivered vehicles to a number of customers internationally, including more than 250 vehicles in Europe."

But what's being done to ensure that the infrastructure is in place to encourage growth in the FCEV sector?

Gathering support

"The main challenge for hydrogen fuel pumps is that of simple economics – without a high number of vehicles refueling, the stations simply don't make economic sense in the short term," Childs admits. However, she adds, OEMs have a plan.

"Hydrogen fuel providers will soon be able to bid for funding in partnership with organizations that produce hydrogen vehicles to help build high-tech infrastructure, which includes fuel stations. The funding will boost the creation of hydrogen fuel infrastructure and uptake of hydrogen-powered vehicles."

Some governments are also providing support to ensure sales of FCEVs don't stall. "A new £23m [US$29.3m] fund to accelerate the take-up of hydrogen vehicles and roll out more infrastructure was announced by the UK government in March 2017," says Childs.

"The EU's joint initiative has provided some €1.3bn (US$1.4bn) for infrastructure for cars and the UK is subsidizing programs, so it has political support," agrees Herbst. "In Germany, the plan is to have around 100 stations by next year, double the current 50. The UK is planning to have 65 – at the moment it has 14 or 15, so we are making progress in Europe."

1. The hydrogen tank of ix35 Fuel Cell stores hydrogen for the vehicle. Thanks to the 700 bar high-pressure hydrogen tank, ix35 Fuel Cell has an operating range of 594km (370 miles) per charge

2. In the UK, Hyundai is working with the Greater London Authority and the London Hydrogen Project to develop a hydrogen fuel infrastructure capable of supporting a mass-market uptake of the technology

"It's important to remember that this refueling infrastructure can easily be incorporated into our existing gasoline and diesel refueling network," says Childs, while Herbst reveals that Toyota is in discussions with Shell about implementing hydrogen into fuel stations.

Making a point

However, implementation of hydrogen into fueling stations, although taking time, gives FCEVs a distinct advantage over regular EVs, as Marcel Corneille, managing director at hydrogen fuel cell consultant Emcel, explains: "There is a big infrastructure problem with regular EVs. You need charge points. If you live in a city without a garage, you cannot have an EV, and there is simply not the space to build charging stations for everybody. With EVs, the more of them there are on the road, the worse the infrastructure problem is because you can have only a limited number of parking bays with charging points in the city.

"However, with hydrogen," he continues, "the more cars that are on the road, the more willing filling stations will be to implement hydrogen, so infrastructure problems lessen."

"When you compare the price of putting hydrogen into a filling station that can fill up hundreds of cars per day," adds Herbst, "to the

"It's important not to forget that this refueling infrastructure can easily be incorporated into our existing petrol/diesel refueling network"

Sylvie Childs, product manager, Hyundai

1

1. Issues surrounding the extraction of hydrogen must also be considered if uptake of FCEVs is to be successful

price of an EV charging point that can charge a handful, it is far, far cheaper to implement."

Finding fuel

A lack of filling stations is not the only infrastructure challenge facing the FCEV sector. Getting hold of the hydrogen in the first place is not that straightforward.

"There isn't any natural source of hydrogen on Earth," stresses Corneille. "But there are many different ways to generate it. The first is to extract it from the fossil fuels. Obviously, this is not very renewable, but because the efficiency of hydrogen is better than gas, it is better than running on gas alone. Secondly, hydrogen is a by-product of industry, so it is available there."

However, he admits this limited supply from industry would not be enough to satisfy road users if hydrogen were to become as ubiquitous as hybrids or EVs.

"That's when you have to start looking at electrolysis – separating hydrogen from water," says Corneille. "Okay, the infrastructure for this is not available yet, but the technology is certainly ready."

Childs believes the infrastructure network and take-up of FCEVs will definitely expand. "We have already proved there is a demand for these vehicles with the limited refueling capability that currently exists," she says. "Hyundai will continue to provide confidence for the infrastructure providers that vehicles are already here and will continue to grow in number, therefore ensuring continued growth of the infrastructure network at an ever-increasing pace."

And this is good news for FCEV owners, as Herbst explains: "Today, the price of hydrogen is about €10 (US$11) for 5kg. That can equate to 500km, which is a little behind diesel, but we expect, as production increases, the price will come down and be comparative with diesel by 2025."

Hydrogen society

"We have to de-carbonize the transport sector, and the advantage of hydrogen is that you can transport it, store it, and fill up like a gasoline car," says Herbst. "This is absolutely the way forward, and not just for cars. We would like to build up a hydrogen society so airplanes, the maritime sector and even power stations are running on hydrogen."

"This is an important point," agrees Childs. "Although we're talking about hydrogen-fueled vehicles, this sector is a tiny part of the overall hydrogen story. Passenger cars are only one customer for hydrogen. For 2020 CO_2 targets to be met, trucks and buses will also need to switch to alternative fuel, and hydrogen is perfect for them too."

"At the moment, in Cologne, we have a large chemical industry, which is able to provide hydrogen for 1,000 buses," explains Corneille. "That is more than the number of diesel buses in the city, so the infrastructure is ready for it.

"Obviously, bus companies have their own infrastructure, so this won't have much of an effect on the consumer market. It is a different world. But they do use the same technology, so it will help the market in that way. It will help to show off the technology and introduce it to the public."

"'Chicken and egg' is an often-used phrase in the world of hydrogen-fueled vehicles," says Childs. "But this phrase is no longer valid. We have the chicken and we have the egg; now the question is, how do we serve the omelet?"

"With hydrogen, the more cars that are on the road, the more willing filling stations will be to implement hydrogen, so the infrastructure problems lessen"

Marcel Corneille, managing director, Emcel

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WHAT'S NEXT FOR i?

In just six years, BMW i has become perhaps the most recognizable OEM electrification initiative in the industry. But for Stefan Juraschek, BMW's head of electric powertrain, the great strides that i and iPerformance have made are just part of a much bigger picture

WORDS: **MATT ROSS**

ILLUSTRATION: **MITCH GEE**

"It should be the case that we can put in a combustion engine, a PHEV or even an EV – and whatever you put in should be done on the same production line"

When you look back at what the i brand has achieved in its relatively short life, how does it make you feel?

I'm very proud of what we have achieved. Right now we have a total of 10 models. From the i brand we have the i8, the i3 EV and i3 REx, and then there is the 2 Series, 3 Series, 5 Series, 7 Series, X5, the plug-in hybrid X1 in China, and the Mini PHEV. We offer a lot of variety for the customer. Looking back at the past five or six years, we have done a lot of work on the BMW i program, as well as the start of PHEV development, which works in parallel with that. [You can also see] how fast we have brought vehicles to market though our modular approach. And also the quality of what we have produced. I'm very satisfied with the whole development.

So what's next for BMW i?

We are permanently increasing the fleet. Right now we have a good setup for different applications. Though it's not necessarily a part of the i brand, we have announced the battery electric Mini for 2019, and there is also the X3 – we don't know yet how it will be badged, whether it's part of iPerformance or part of the normal brand. But right now we are in a position where we can create models very quickly because the modular kit is available. In parallel, we are developing the basics, such as cells and modules, and we are in a position to bring them into series very quickly. If our board makes a decision on a new model, we are, I would say, normally between 24 and 30 months from market after the decision has been made.

Is that a result of the groundwork put in during the early days of the brand?

We do not stop. Right now we are preparing the next generation [of vehicles], which will start in 2020/2021. For this generation, mass production or very high production numbers is one of the key issues – to bring production costs down, to optimize production processes, requiring fewer parts in the electric drivetrain and so on.

Is the target still for BMW to produce 100,000 i and iPerformance vehicles in 2017?

That's the goal for this year. And we think that we will be increasing it for next year.

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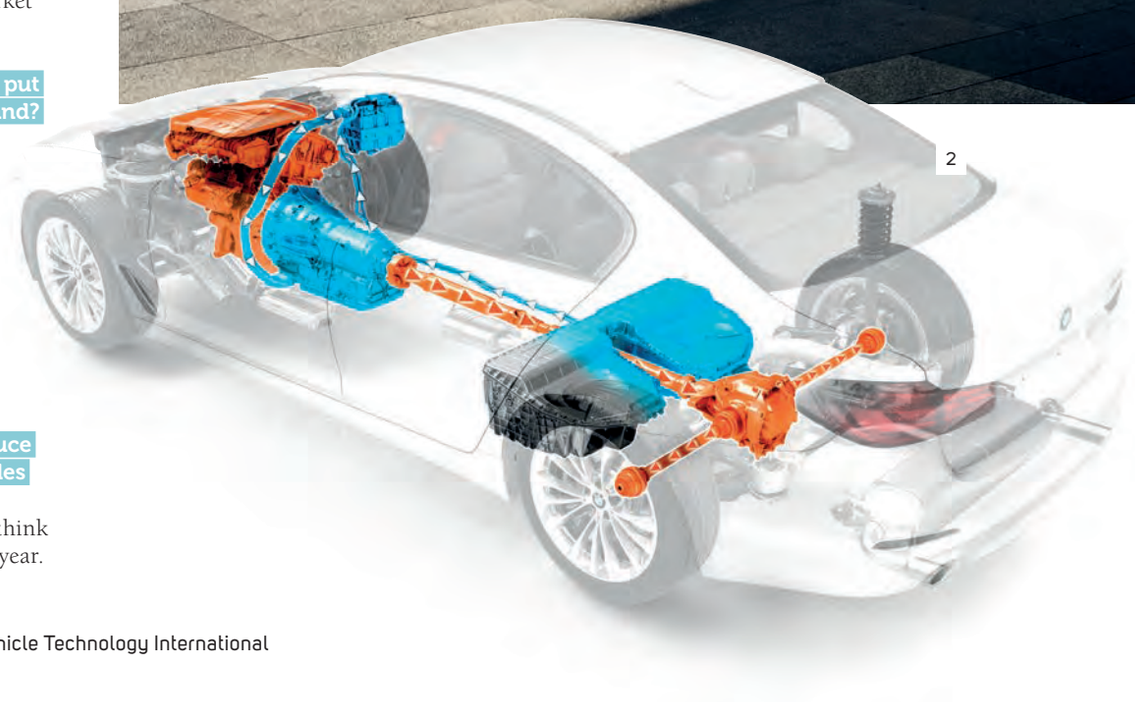

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Could BMW's target of 25% of its sales to be electrified by 2025 ever be revised up, or is that being too speculative?

[In terms of increasing the goal] I think no one in the world can predict, or make a presumption about where we will be in 2025. But what we're doing is creating the flexibility so that we are in a position where we can act. We won't have to react. Every development that is installed right now is set up to be able to deliver 25% in the year 2025. Not only the products themselves, but also the production side – and the flexibility in that production.

We have to take into account that we also want to install a worldwide production network. If we develop all these electric vehicles – whether that's pure EV, PHEV, or even fuel cell some years later – we need to get them to market. We should be able to build EVs and PHEVs in every single plant worldwide. That's what we're working on now – and it's a big task. We try to avoid having to remove production lines and setting up new ones, so we have to adapt our production lines and architectures so that the new components fit into these architectures very well.

1. The BMW i and iPerformance range is constantly being expanded, and the OEM's modular kit means new models and electrified variants can be added quickly

2. Hybrid architecture in the 530e iPerformance

It's about being ready for whatever comes?

It's so that we have a plan, and that plan is to be flexible. If you are looking at the new architectures coming in 2021 or 2022, it should be the case that we can put in a combustion engine, a PHEV or even an EV – and whatever you put in should be done on the same production line.

> "In 2014 only 2% of ICE drivers planned to look at hybrids. Right now it's 18-20%"

You once claimed that auto makers developing e-powertrains had to walk through "a valley of tears". Do you still feel that way or have things changed?

It is still hard work. I think it's very easy to build one dedicated vehicle – something like the i3. But if you want to go to the mass market, then you have to look at each architecture to make sure they are well prepared. This is hard work.

There won't be a new i model until the iNext in 2020/2021. Is that more a focus on autonomous driving rather than any new powertrain?

The new drivetrain for the iNext is what I mentioned earlier – the next generation of drivetrains, prepared for high volumes and cost-effective motors, batteries and so on.

Are the iPerformance models a good way to integrate i technology into the main BMW family – not least from a customer expectation point of view?

For six years we have been talking and writing about e-mobility, yet very few people are experienced in driving electric. That's still an issue for the market. We did a market survey

[in late 2016] and found that 90% of EV drivers intend to stay with EV and only 10% plan to go back to PHEV or normal ICEs. Of the PHEV drivers, 60% intended to stay with PHEV, 30% intend to look at pure EV, and only 10% are going back to ICE. In 2014 only 2% of ICE drivers planned to look at hybrids. Right now it's 18-20%. There is, in terms of plans for their next car, a change. But it's still not enough. With the iPerformance fleet, because it goes from the 2 Series through to X5, everyone who wants to try a hybrid has the possibility to get one. It's not limited only to the 3 Series, for example, or the 7 Series. I think it's a big opportunity for customers to get familiar with the technology, and [it will] help to increase sales in 2020 and 2025.

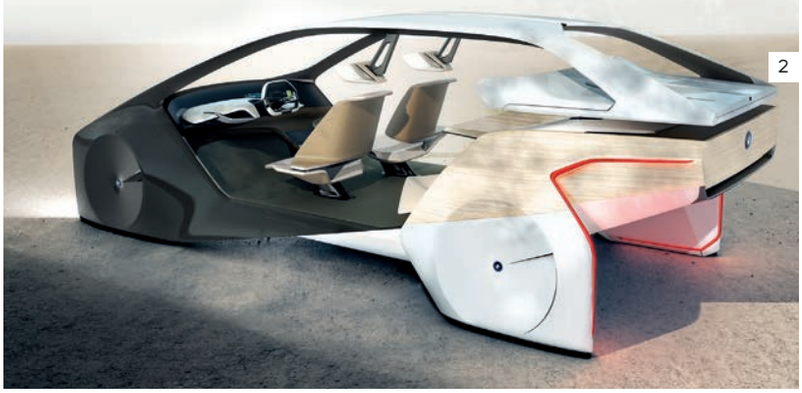
1

Do the development programs for, say, the 330e or the plug-in 5 Series, inform one another? Do you learn lessons on one project that you can apply to the next?

We are always finding new functionality and getting feedback from the field as to what needs to be improved. From every launch and LCI [life cycle impulse], we are improving the functionality. Even in cases where we update the battery, say from 60A to 94A, there is improvement in the battery management, in the temperature behavior, so that we can go more to the limits of the battery.

At the very beginning you do not really know what happens in the field. Feedback from the i3 told us more about the condition, temperature and charging state of the battery, and the charging conditions. With all this we are looking at really big data and we can improve our algorithms accordingly. We are always learning, and that leads to permanent improvements. This is very important if you want to be sure about the life of the battery and about safety – you need a deep knowledge of the cell, about how it behaves in the vehicle and in different environmental conditions. California is different from Norway, as an example, and they are both different from the UK or Germany.

> "If you want to be sure about the life of the battery and about safety, you need a deep knowledge of the cell, about how it behaves in the vehicle and in different environmental conditions"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1. A concept design for the i8 Roadster, due to be introduced in 2018

2. BMW's experience in the premium segment, Juraschek believes, will put the OEM in a very strong position for future vehicle technologies

Will electrification crossover from i to M?

We have to be prepared, at the end of the day, for every niche to have the ability to do a hybrid. I think we are in a position, because of our modular kit, to do that very quickly. So if there is a demand, we can do it.

Would you ever do an all-electric i8?

No. Next year, however, we will introduce the i8 Roadster.

Is BMW exploring diesel electrification?

Right now we are focusing on a worldwide solution, because of the numbers we are selling. It's not useful to make a split right now. A worldwide solution is the reason we are sticking with gasoline – so that we can offer it from Japan to California. Diesel development would mean, at the outset, you would have to separate out certain markets and that means a double development.

BMW was at CES this year, as were a lot of startup companies. Do you ever worry about competition from them?

If you want to go to the premium segment, it's very difficult to get there. We know very well how to build cars, how to build premium cars. And we will be going to the market with a premium EV-segment car. That's one of BMW's strengths, and I think maybe some of these startups, these competitors, are a long way from this.

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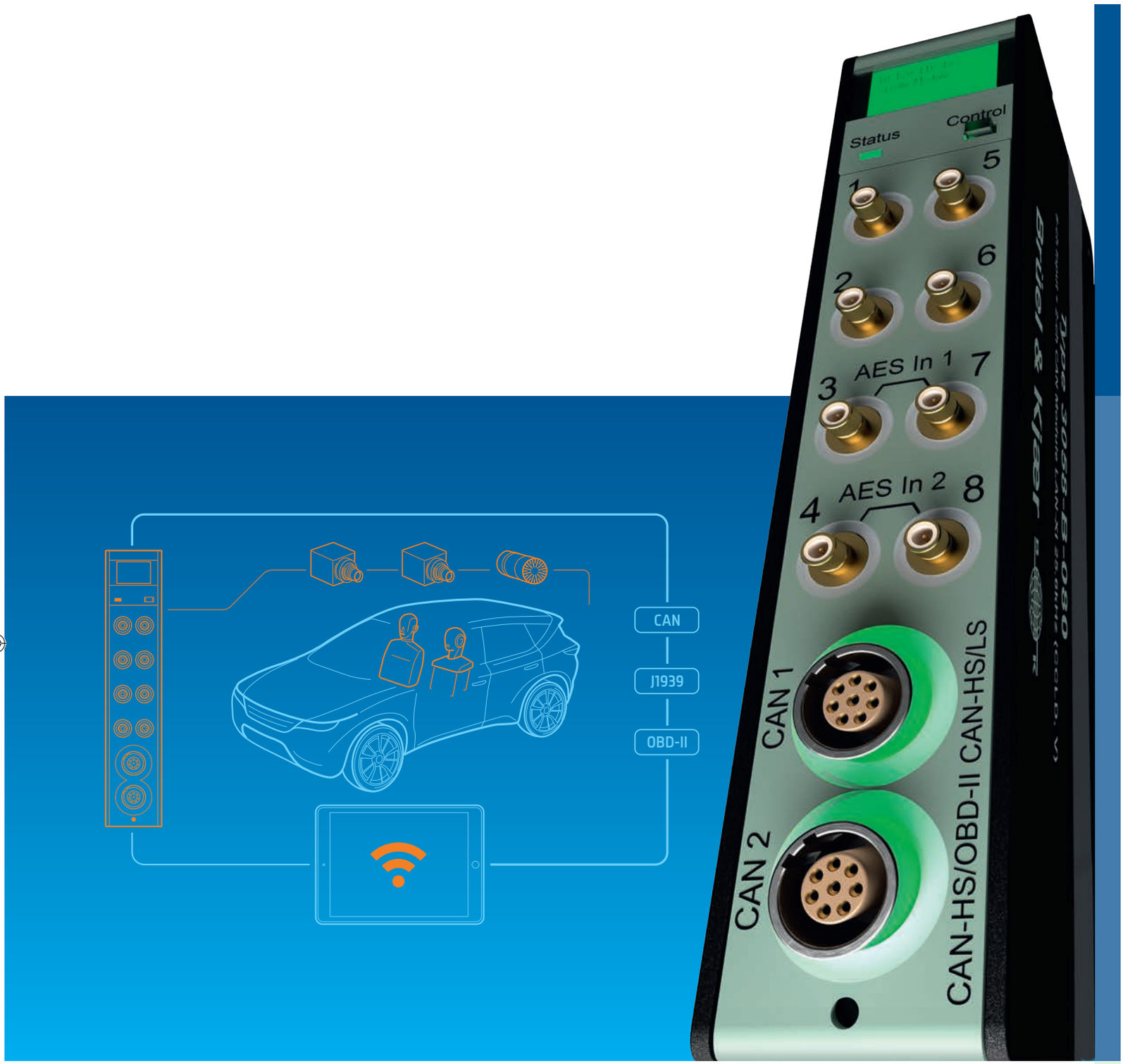

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RECOVER STORY

Multiple options of energy storage have been trialled, but lithium-ion batteries, such as those in the LMP1 above, remain popular, even in series that allow alternative solutions

How is the pursuit of increased efficiency levels shaping the development of kinetic energy recovery systems in motorsport?

WORDS: **LEM BINGLEY**

Cars with bright glowing brakes are a familiar sight in racing, as the hard-won momentum of a fast straight is shed going into a corner. But could those blistering discs become a thing of the past? If kinetic energy could be recaptured, stored, and reused to accelerate again, there would be no need for any red-hot rotors.

The prospect of race cars without friction brakes remains a long way off, but the notion of grabbing and recycling at least some kinetic energy has been around since KERS (kinetic energy recovery systems) landed in Formula 1 in 2009.

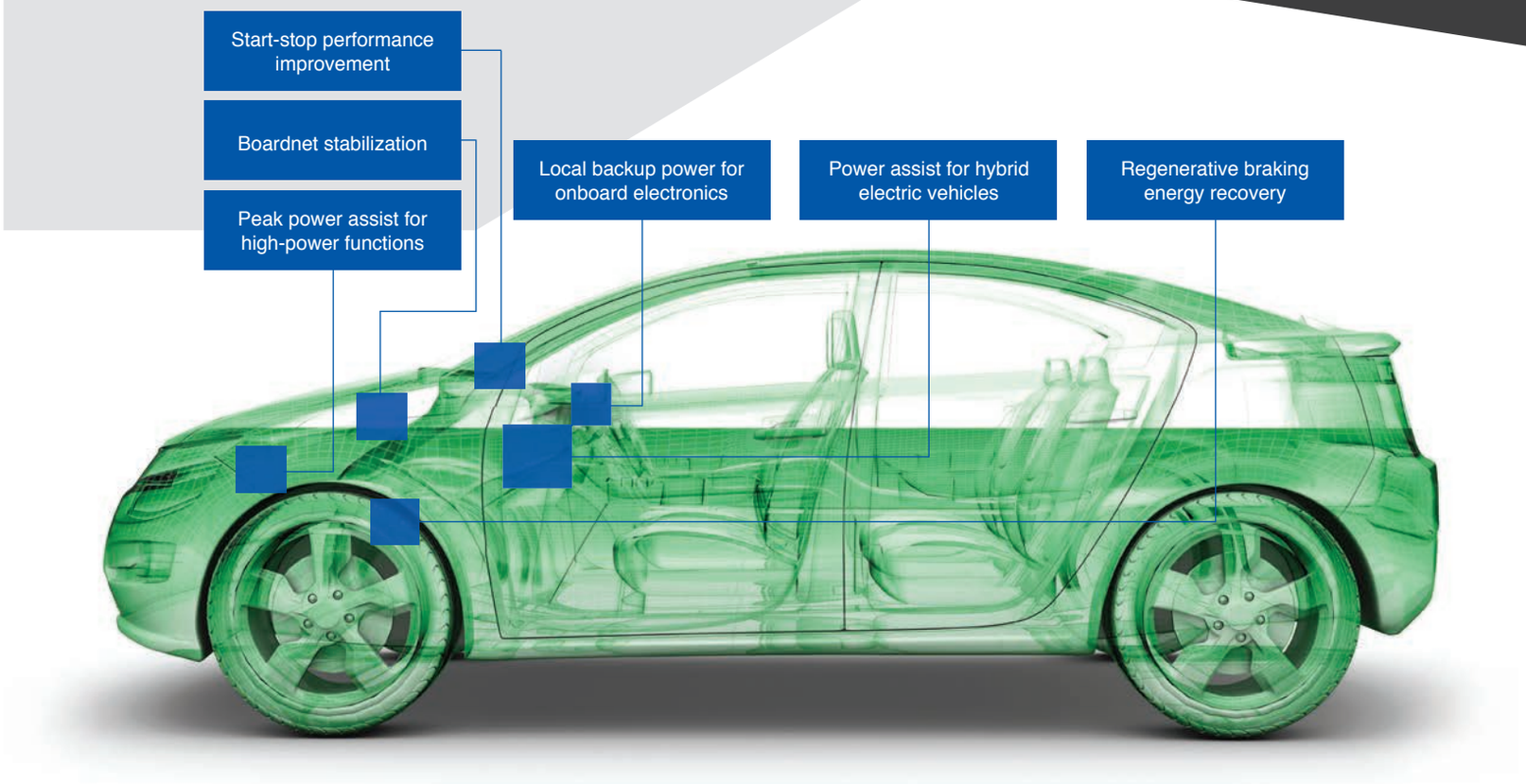
"If you can get hold of energy that's normally wasted as heat and reuse it then you're onto a winner," notes Paul McNamara, technical director at Williams Advanced Engineering. "The brakes are the biggest source of lost energy. That's how they work. They convert motion into heat."

When Formula 1 first introduced KERS, the best way to store captured energy wasn't immediately obvious. "We investigated putting it into a flywheel, because of the amount of energy you can store and release versus the weight," says McNamara. "But all the other teams went for electrical systems and so did we in the end."

KERS arrived in F1 with a battery to store energy and a reversible electric machine to act as both generator and motor. It would generate current on the approach to corners, and switch to motor mode to assist the engine on straights – typically during overtaking.

KERS technology evolved into today's MGU-K (kinetic motor generator unit), where an electric machine capable of 50,000rpm is geared direct to the engine's crankshaft. A second motor generator, MGU-H, connected to the engine turbo, also recovers energy from the exhaust.

Current F1 rules allow a 25kg battery as an energy store, fed by the two MGU systems. A maximum of 2MJ per lap can be captured by the MGU-K, while up to 4MJ per lap can be fed back to it from the battery. There are no limits on what the MGU-H can supply to either the battery or direct to the motor.



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Racing strategies

Despite the sophistication of today's F1 energy recovery systems, other options remain viable and alternative technologies could replace or supplement today's motors and lithium-ion batteries.

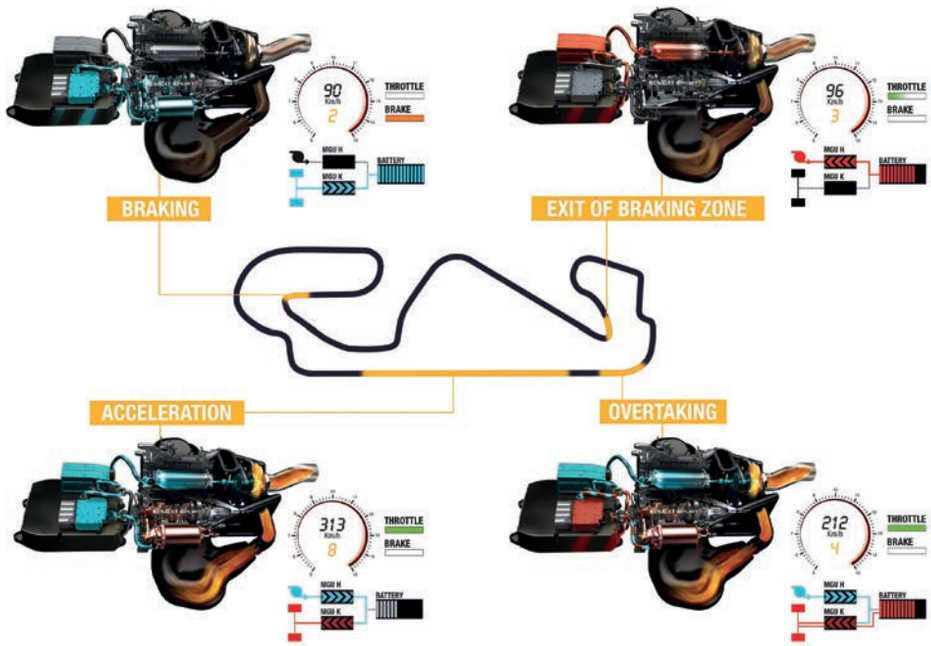
Although Williams's flywheel never raced in Formula 1, it did assist 2011's race-winning Porsche GT3R and helped Audi Sport's R18 e-tron Quattro to Le Mans victory in 2012 and 2013.

"Basically the choice of energy storage is a compromise between energy density and power density," observes Prof. Andrew Atkins, global technical lead and senior technologist at Ricardo. "The very transient high-power aspects of racing are attractive to flywheels. Speeding up and slowing down repeatedly can be deleterious for batteries but flywheels really like it."

Atkins notes that other purely mechanical systems might also be relevant. "We've looked at compressed air and hydraulic, and for applications outside automotive, we've even looked at clockwork," he says.

Capturing and storing energy is only half of the picture, of course. "The other interesting thing is where you put the energy back," adds Atkins. While the common approach is simply to reverse the route from wheels to battery, there are alternatives.

One scenario would be to use an electric motor, like F1's MGU-H, to overrun the turbo.



Operation of KERS in a Renault F1 engine at different stages of a lap

KERS in F1

Current F1 rules allow a 25kg battery as an energy store, fed by the two MGU systems. A maximum of 2MJ per lap can be captured by the MGU-K, while up to 4MJ per lap can be fed back to it from the battery

"That partially evacuates the cylinder, which reduces your pumping work, and at the same time rams more air in," Atkins notes. High-pressure air enables a Miller cycle (leaving intake valves open for part of the compression stroke), which cuts compression work. "By reducing both pumping losses and compression work for short periods, the net power output could be increased without increasing stresses on the engine," Atkins explains.

Another approach would be to use regenerated electricity to pump air into a high-pressure vessel, rather than charge a battery. A similar technique is used by Volvo PowerPulse engines, which release high-pressure air into the exhaust to speed up the turbo from low revs, improving response. Atkins says the more direct tactic of dumping high-pressure air into the intake manifold would also work: "It would be like having a solid-state supercharger."

With the right plumbing, compressed air could be generated direct from engine braking, like a truck's Jake brake. A secondary compressor and a carbon-fiber tank could create "some pretty interesting power densities", according to Atkins.

Arnaud Martin, director of powertrain at racing technology firm RML Group, also backs compressed air. "The components are very simple," he notes. "Energy density is likely to be an issue, but that's where I think motorsport can provide answers."

REBOUND AND RECOVER

Recapturing energy from a vehicle's suspension by making the damper into a linear generator is another way to recover otherwise wasted kinetic energy.

"Regenerative damping is talked about a lot, but it's not energy for free," says Williams's McNamara. "You see the car bouncing along and think it's going spare, but in the end, it's all coming from the motor."

Ricardo's Atkins believes that circuit racing offers little potential in this area. "Regenerative damping wouldn't be on my list until I was desperate for the last energy in the system," he says.

Rallies like the Dakar, where the suspension moves a great deal for long periods of time, provide the most promising opportunity. In 2011 suspension firm Donerre built regenerative dampers for Oscar eO, the first plug-in car to contest the Dakar, and the technology is likely to return in the future.

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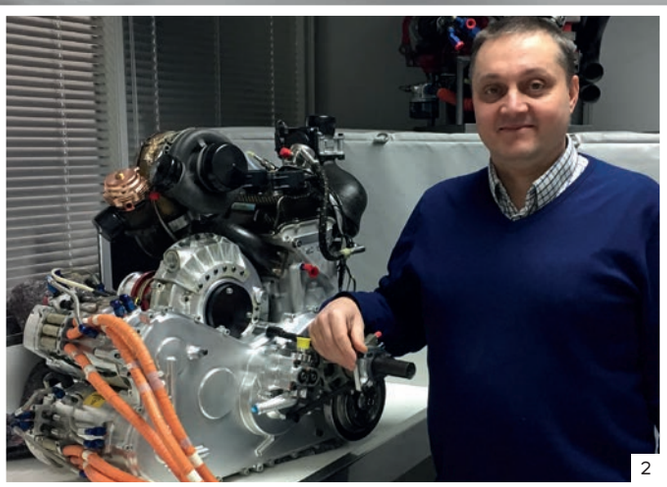

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1. RML Group designed Nissan's ZEOD RC Le Mans car to regenerate sufficient energy to do a full lap of Circuit de le Sarthe on batteries

2. Arnaud Martin, director of powertrain at racing tech company RML Group

Oversight obstacles

As Martin observes, the rules set by governing bodies dictate which options are worth pursuing. "They can stop a technology from developing by writing it out of the rules, or prevent one from being implemented because it doesn't leave enough freedom," he explains. "My feeling is hybrid air is something that should be allowed by regulations, and some sort of help given to people considering it."

McNamara, however, is less keen. "Storing compressed gas is always a bit worrying, because it has the possibility of being highly explosive," he says. "If you crack a gas cylinder, the energy is in a really raw form."

McNamara is far more enthused by the potential application of supercapacitors, as used by the Toyota TS040 Hybrid endurance race car in 2014.

"One idea is to create a hybrid battery that has both Li-ion cells and supercaps in it," he says. "The potential advantage is using the relatively lightweight supercaps to handle the peaks and not having to size the Li-ion cells for that, giving you an overall lighter package."

Martin can also see a wealth of potential in supercapacitors but thinks weight and complexity will rule out hybrid batteries. "I would say that in the next three to four years, supercaps will simply overtake batteries in racing," he says.

Atkins is skeptical, however. "Capacitors are great with power, but not so great with energy density," he says. "Graphene is making some inroads and energy densities are getting up to interesting levels, but going from a battery to a capacitor is a fundamental change. You go from a roughly constant voltage source to a constant current source. The voltage of a capacitor goes all over the place with the state of charge, so the power electronics are very different. It's not just a question of getting enough energy in a box.

"Race engineers have to learn an awful lot more stuff than before – high power electrics and electromagnetics on top of all the traditional stuff. We have to find a way to get more people into the system with a much wider understanding of the trade-offs between technologies."

> "Hybrid air is something that should be allowed by regulations, and some sort of help given to people considering it"
>
> Arnaud Martin, director of powertrain, RML Group

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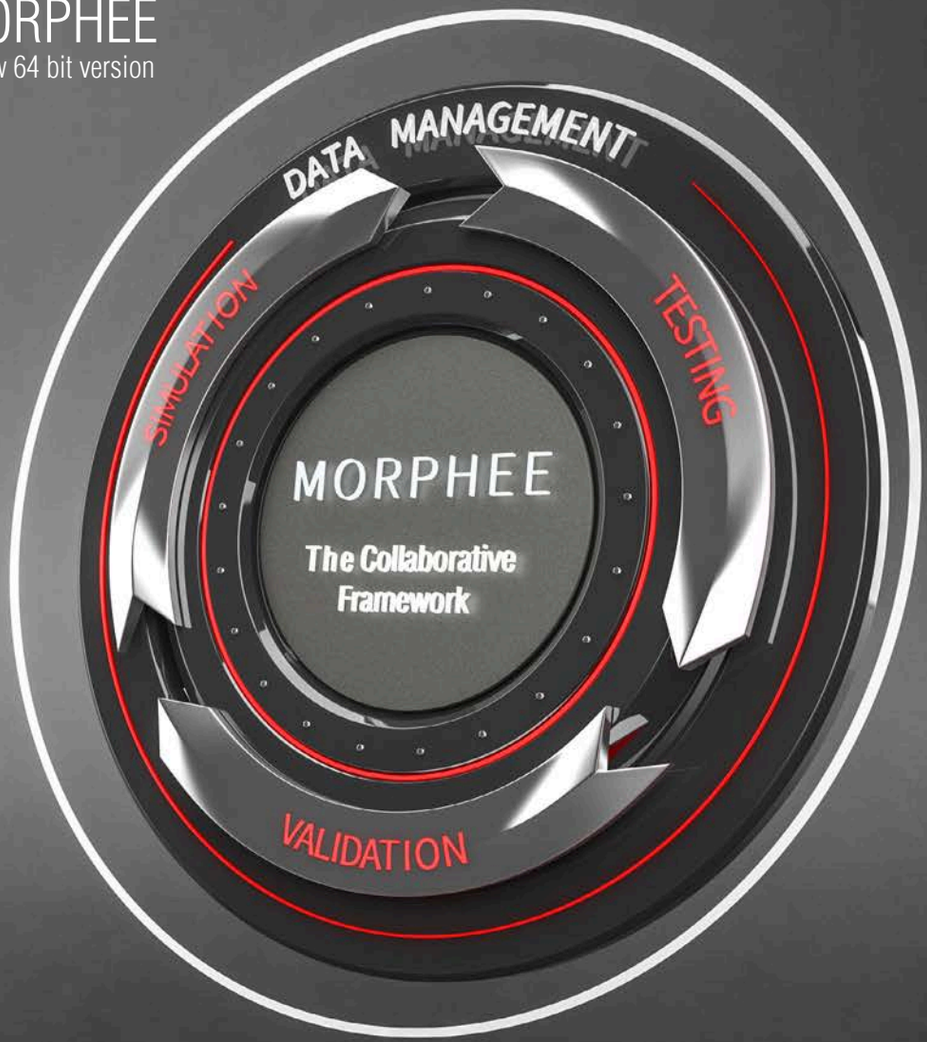

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Transfer of power

The growing number of hybrid powertrains means an increasing need for efficient and fast switching between power sources

WORDS: **JOHN EVANS**

GKN Driveline's eTwinster concept brings torque vectoring capabilities to EVs. It was first showcased to customers at its winter test proving ground in Arjeplog, northern Sweden

Above: Rising demand for EV technology has prompted GKN Driveline to boost the size of its eDrive production hub in Bruneck, Italy, by more than 60%, to create a new 18,000m² (194,000ft²) facility

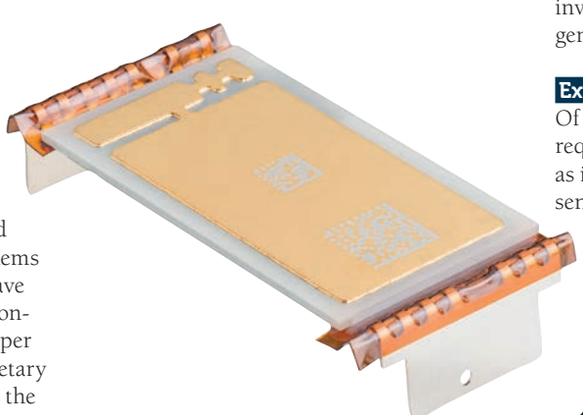
Below: Delphi's inverter power device can enable 30% more EV range as a result of its double-side cooling capability and wire bond-free design

Karl-Heinz Steinmetz, powertrain systems sector manager at Texas Instruments, is pondering a future dominated by ultra-high-power 800V systems and its implication for switching technologies in hybrid vehicles.

"It will be huge," he says. "With 800V, you need different power switch technologies, which will impact on the gate drivers."

Whether 400V or 800V, though, effective power mode shifting and energy control are all about faster operation and improved thermal management. In this regard, the industry is advancing on many fronts. For example, today's IGBTs are giving way to SiC (silicon carbide) wide bandgap semiconductors, offering much-improved conduction and switching performance.

SiC is difficult and expensive to work with, though, so until it can be developed cheaper and simpler, and until 800V systems are universal, over at Delphi engineers have gained a few extra valuable years for silicon-based semiconductors. The company's Viper range of six-switch inverters use a proprietary double-sided cooling system that enables the IGBT to deliver peak voltage.



"Instead of just one of the substrates in the semiconductor being cooled, both are cooled," says Robert Campbell, technical fellow, power electronics at Delphi.

"As a result, we can push the IGBT up to its peak electrical limit. We can use less silicon thanks to better cooling, so it's cheaper with six IGBTs for a three-phase motor controller, and very compact, too."

And much like Texas Instruments, Delphi is keeping an eye on the horizon. "Currently, we're looking at 800V systems and building inverters using SiC IGBTs to power the next generation of EVs," says Campbell.

Exploiting gains

Of course, improved switching performance requires equally strong gains elsewhere, such as in the precision of the microcontrollers that send out the PWM signals to the gate drivers that activate the switches.

"The role of the inverter is to control the electric motor and the key part here

"The biggest challenge for hybrids is that you have two power sources, and you have to know how to plan them and use them"

Theo Gassmann, vice president of advanced engineering, GKN Driveline

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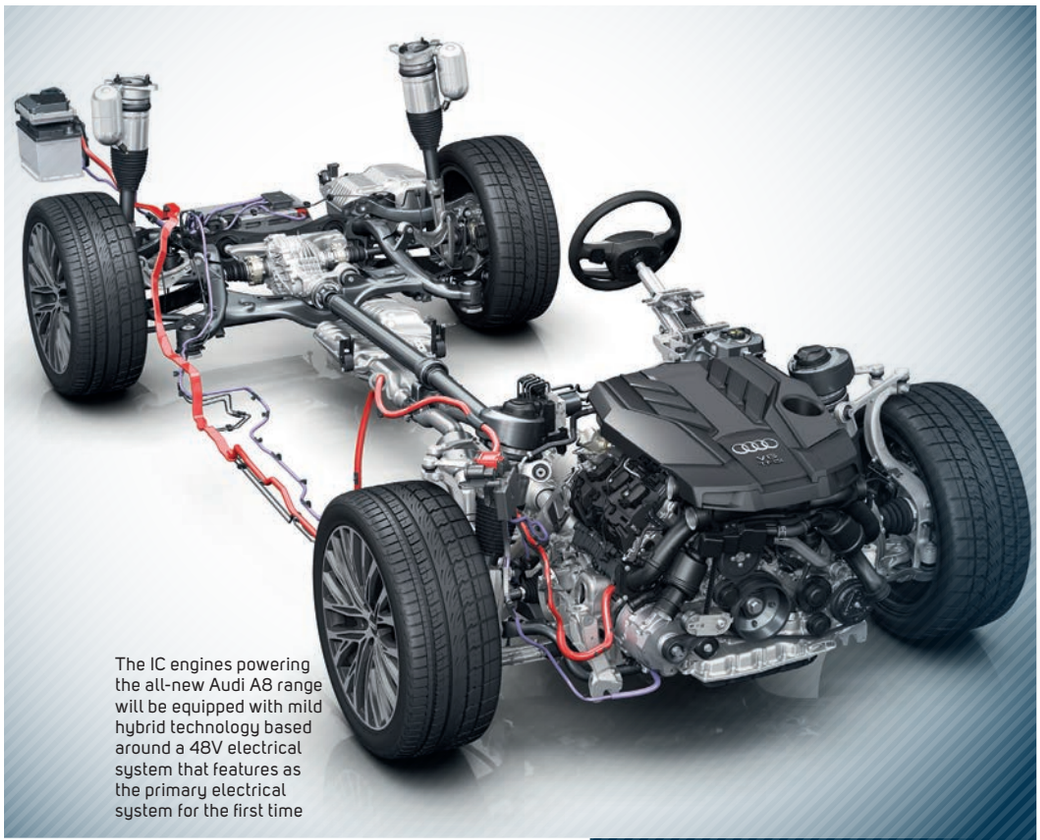


The IC engines powering the all-new Audi A8 range will be equipped with mild hybrid technology based around a 48V electrical system that features as the primary electrical system for the first time

is the controller, the actuator with its gate drivers, and the sensors that give feedback on the position of the car," says Steinmetz. "With these three components, you're powering the car, getting feedback on its position and also closing the loop in your controller algorithm.

"To exploit gains provided by, for example, SiC wide bandgap semiconductors, you need a fast, real-time optimized microcontroller capable of sending out precise, multiple PWM signals, and getting feedback from the sensors for the next cycle of calculations."

According to Steinmetz, this area is under "key development", the goal being one shared by all areas of the EV industry – specifically, to improve the cost-effectiveness and user experience associated with EVs.

On this last point, a seamless and timely switch from one energy source to the other and, where possible, a blending of both to maximize performance and reduce tailpipe emissions, is clearly desirable. From a control perspective, the whole energy management, distribution, and gen and regen processes must be synchronized. A smooth take-off or take-up from an IC engine, an electric motor, or both, requires super-accurate control of revs and torque. Fail to achieve either and you run into driving dynamics issues.

"From the control perspective, what's most important is that the whole system needs to be synchronized, especially revs and torque," says Steinmetz. "If you remove the power from the combustion engine and go to electric, the torque has to be the same. When 'sailing' at a constant speed using adaptive cruise control, the transition to pure electric propulsion must be seamless.

"In the same scenario, when slowing in response to the vehicle sensors, the control system must decide how best to achieve this and, as the forward vehicle accelerates, how best to accelerate in response. These are critical decisions and it is where Texas Instruments is working to improve efficiencies."

CASE IN POINT

A glimpse of the future of power management systems is promised by the new Audi A8. The 48V mild hybrid saloon uses its high level of connectivity to, for example, distinguish between different traffic situations. When the road ahead is clear, the belt alternator starter, which is permanently connected to the engine, starts the combustion engine promptly, allowing the A8 to drive off swiftly.

In addition, it provides 'predictive, convenient starting'. As soon as the vehicle in front moves, the engine starts, even if the brake is still pressed.

A spokesperson told *E&H Vehicle* that data for the powertrain management system is provided by the "many sensor and control units on the databus system, and information from the car's GPS navigation system".

Ready and willing

It's an area of focus for transmission specialist GKN Driveline, too. "The biggest challenge for hybrids is that you have two power sources, and you have to know how to plan them and use them," says Theo Gassmann, vice president of advanced engineering at GKN Driveline.

"It's tricky. You have pure electric mode, hybrid mode and sometimes just ICE mode, all of which have an impact on the way the car behaves."

Gassmann is referring to the way a hybrid can snap from rear-wheel (electric) to all-wheel (electric and ICE) to front-wheel (ICE) – and in the process, going from oversteer one moment to understeer the next.

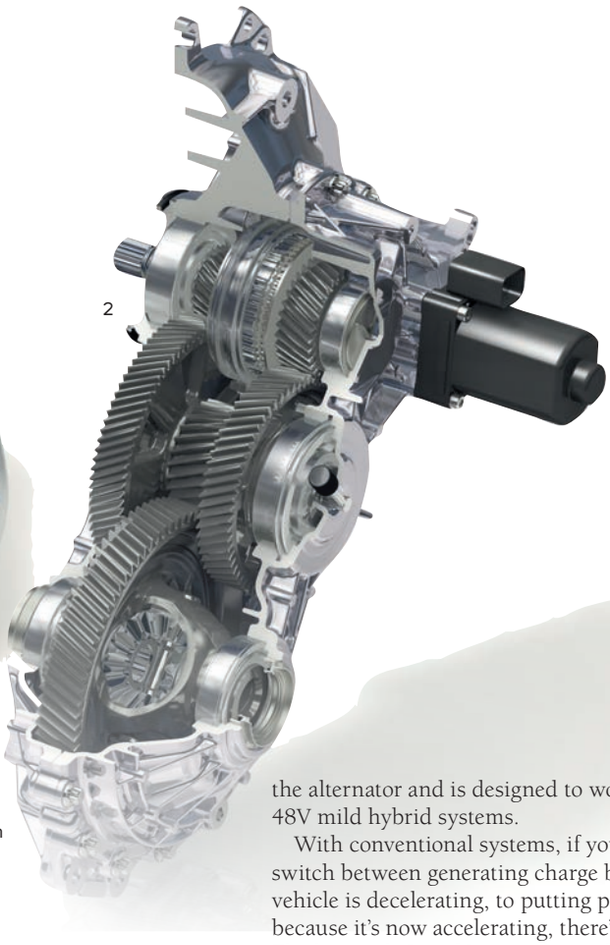
Even battery condition has an impact on the way the vehicle behaves and responds. When it's cold and you push the throttle, you may get less power because the battery is down. The same applies to recuperation. When the battery is fully charged and can't take more power, the system must use mechanical brakes instead. The control system must plan deployment of both the mechanical and electrical brakes to take into account the condition of the battery.

Fortunately, explains Gassmann, there are sensors – including those monitoring acceleration, yaw angle and yaw speeds, slip conditions and wheel speeds – that are capable of capturing the data required to make all the necessary power management decisions. More are required to take account of the IC engine, electric motor and battery. Their role is crucial in judging those energy-switching moments and how they're performed.

"You have to be careful when you switch mode, and check the slip conditions," says Gassmann. "We can bring a lot to the party with our 4WD and twin-clutch Twinster and eTwinster torque-on-demand systems, because you are seeing the same power transfers in 4WD from front to rear."

GKN is also working on 2-speed electric transmissions to avoid losing the electric motor when switching, for example, from four-wheel to front-wheel drive.

"Conventional systems that disconnect the electric axle are not very refined. Our 2-speed



system means you can stay in electric power, in four-wheel drive. We are also working on a seamless shift, 2-speed transmission for axle-split hybrids to smooth out the torque interruption during shifts. This product is now on the bench and we'll have it running at the end of this year in a car."

1. GKN's Multimode eTransmission enables vehicles to move between three drive modes from two power sources

2. Upon entering production on the BMW i8, the 2-speed eAxle from GKN was a world-first for hybrids and EVs

3. The SpeedStart belt integrated starter generator from Controlled Power Technologies has been validated to 1.2 million cranking events

Ready and willing

While GKN is developing more sophisticated systems for managing the effects of power switching, Controlled Power Technologies has released details of its new switch-reluctance machine called SpeedStart, which replaces the alternator and is designed to work with 48V mild hybrid systems.

With conventional systems, if you want to switch between generating charge because the vehicle is decelerating, to putting power in because it's now accelerating, there's a delay. The key with SpeedStart is that it doesn't take as much time as a conventional permanent magnet machine to flux up or down.

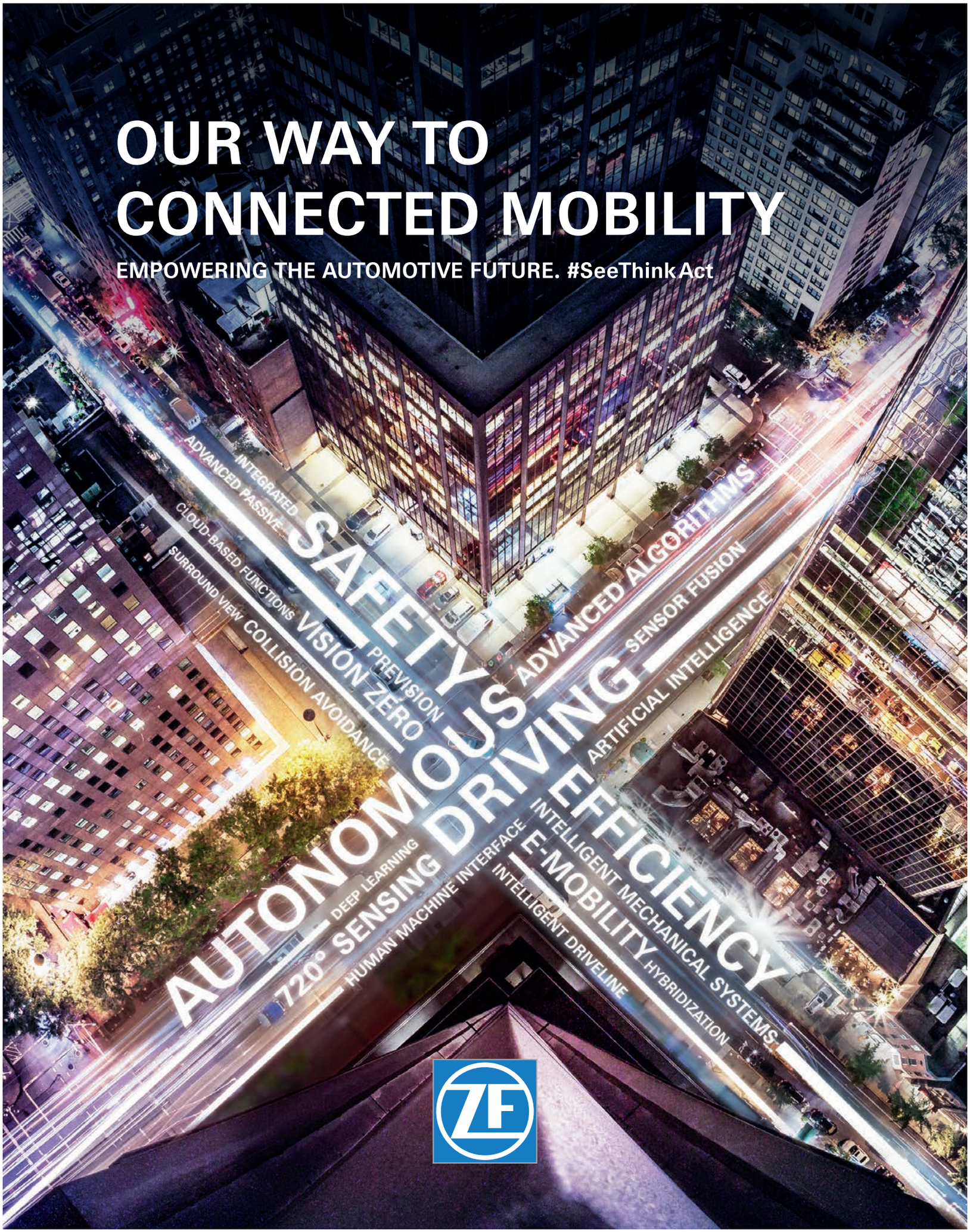
SpeedStart is primarily used as a starter generator. Tests performed with the Vienna University of Technology have yielded a 9% reduction in NO_x emissions, however Paul Bloore, a manager responsible for applications engineering and strategic projects at Controlled Power Technologies, explains that being built into the hybrid control system means that if it were to see a transient greater than a certain threshold, it could feed in power to fill as much of it as possible.

"Rather than blending the different power sources through electronics, we're using the responsive SRM to achieve the same effect without the inefficiencies associated with conventional systems," explains Bloore.

It's the reduction of inefficiencies, adds Steinmetz, that lies at the heart of EV power switch management and development.

"It's about the efficiency of motor control technology, gate drivers, inverters and converters, as well as developing better sensing systems to improve feedback for tighter control of the overall algorithm."

With that 800V future getting closer by the day, you can be sure he, and the rest of the EV industry, are working on it.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GOING PUBLIC

WORDS: **MAX GLASKIN**

With defined routes and operating times, battery electric buses seem like an obvious solution to reducing emissions. So what's been the holdup?

More and more electric buses are being bought by transit operators every year. Their predictable usage patterns make them ideal for battery technology, but why aren't their numbers rising more quickly?

Proterra is the largest electric bus maker in the USA, claiming 60% of the current market with sales of 60 units annually. The fall in the price of lithium-ion cells from US$1,000/kWh to US$150/kWh offers the promise of growth, and this could be supported by standards in charging technologies.

"Standardization is going to be one of the keys to unlocking charging infrastructure in depots," says Dustin Grace, director of battery engineering at Proterra. "There are a lot of different plug shapes out there, some driven by adoption in China, some in Europe, but in the last couple of years we have seen J1772 CCS taking over. It is the standard DC fast charge and capable of 62kW. By 2018 it will be capable of double that. We use two of those ports on our XR [extended range] bus, so today we can charge at around 120kW through the standard conductive system and by 2018 we'll be able to do roughly double that."

There's a different solution for en-route fast charging. For the past five years Proterra has been selling a proprietary overhead system that can be used at bus stands. Assisted automatic docking couples the charging unit

Catalyst E2 covers a nominal 560km (350 miles) with its storage capacity of up to 660kWh

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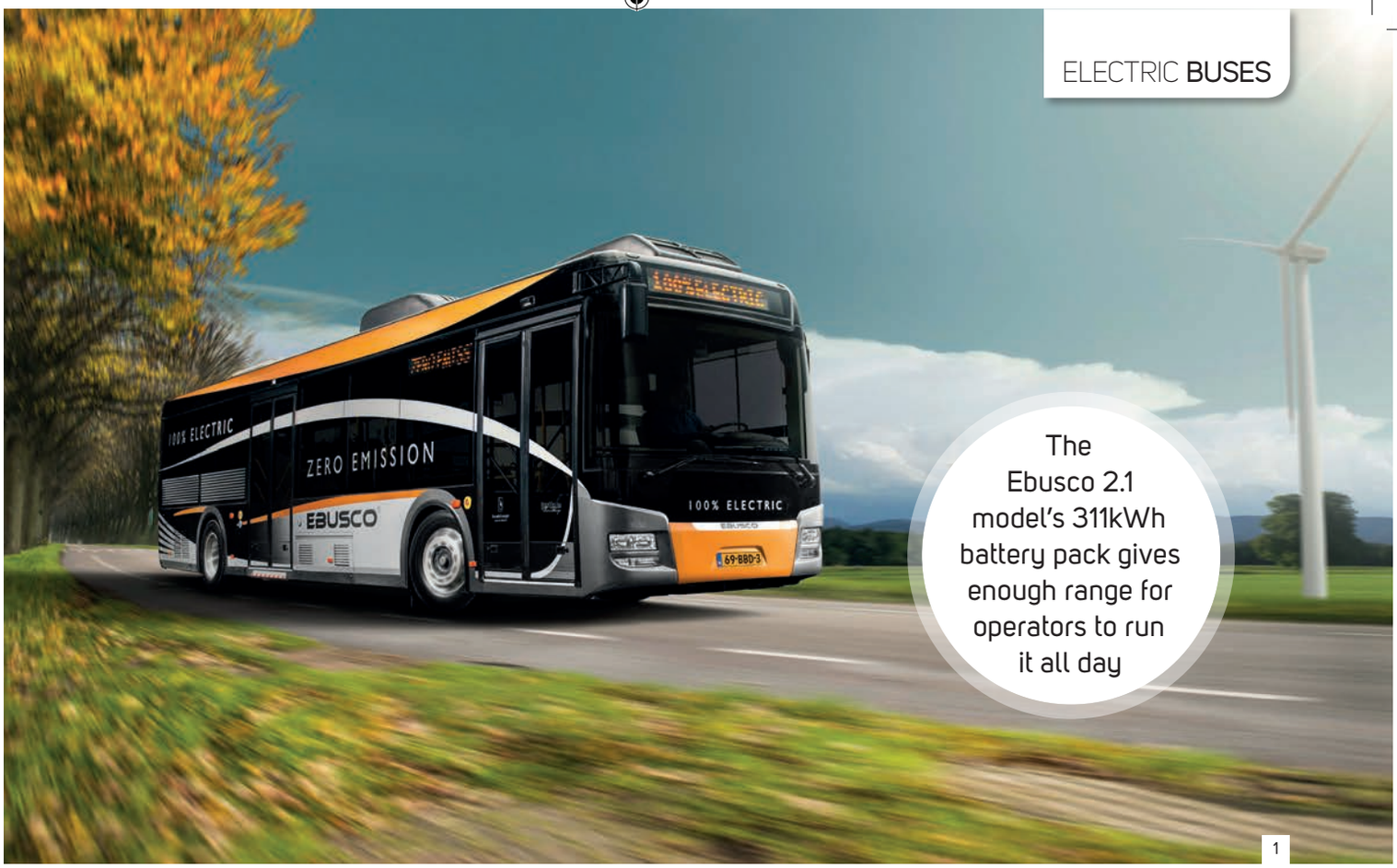

The Ebusco 2.1 model's 311kWh battery pack gives enough range for operators to run it all day

1

with a roof-mounted single blade to charge between 250V and 1,000V DC at a current of up to 1,400A. The company's own short-range TerraVolt FC battery pack, rated at 105kWh, is fully charged at 500kW in 10 minutes – enough for a range of more than 96km (60 miles).

Now though, rivals could start to use the same patented fast-charge system. "In order to increase the adoption of these charging standards, we've opened up all that IP to all our competitors," says Grace.

They can get royalty-free access in a move Proterra hopes will help accelerate standardization. It's a strategy similar to that deployed by Tesla Motors, which may not be all too surprising considering that Grace moved over from Elon Musk's car company in September 2015. In doing so he was following the trail set by Ryan Popple, formerly senior finance director at Tesla and now president and CEO at Proterra.

The California-based company has also launched a 12.8m (42ft) electric bus of unprecedented range. Its Catalyst E2 can cover a nominal 560km (350 miles) with its storage capacity of up to 660kWh. The average bus in the USA covers 210km (130 miles) a day.

Changing landscape

One of the largest capacity battery packs on a 12.8m bus in Europe is used on Ebusco's 2.1 model. "The 311kWh battery pack gives enough range for operators to run it without recharging because most buses do less than 200km [125 miles] in a day," explains Patrick Heuts, senior engineer at Netherlands-based Ebusco. The weight of the battery pack is kept down to 2,250kg, including the casing and battery management system, because the cells use energy-dense lithium iron phosphate chemistry.

1. The Ebusco 2.1 bus is able to run at least 300km (186 miles) with up to 95 passengers on board

"For buses you never use AC and I think it will disappear for cars as people want a range of 300km"

Patrick Heuts, senior engineer, Ebusco

"Battery management systems and battery technology are always developing," says Heuts. "There are so many researchers in the field that the landscape will change completely in the next 5 to 10 years, mirroring the changes in batteries for cell phones and for laptops over the past decade. So our advice is not to invest heavily now in infrastructure for fast charging."

Nevertheless his company has designed an overhead fast charger for its buses. "You don't want a pantograph on each bus because that's expensive, so we've located the pantograph in the charger," says Heuts. "It descends and couples with the four connection poles on the roof of the bus." It's limited to 300kW and it takes less than an hour to fully charge the Ebusco 2.1.

For charging at the depot, Ebusco currently uses the GB plug connector, which is standard in China. "They are better for buses than the European standard because those have been developed more for cars, which use AC charging," says Heuts. "For buses you never use AC and I think it will disappear for cars

1. A Volvo 7900 Electric Hybrid runs as an electric bus in selected areas but can perform as a hybrid on any route

2. The Volvo 7900's charging interface is located on the bus roof. A typical charge takes six minutes and usually takes place at the bus's final stop

as people want a range of 300km [186 miles], which requires a bigger battery pack and faster charging. I don't understand why, for buses, you'd want to use a bigger plug delivering less current and a complicated communications protocol."

Despite the fact that the working life of most buses can be forecast reliably, diesel IC vehicles continue to dominate because of their lower purchase price, Heuts believes.

"When inner cities want clean air, then investing in electric buses suddenly becomes attractive. That's exactly what's happening in China right now, so there are already many electric buses operating there."

The advances in electric bus technology in China is one reason the Dutch company sources several key components from there.

Window of opportunity

Elsewhere in Europe, Volvo Buses is part of a consortium that includes bus makers Solaris, Irizar and VDL, and infrastructure companies ABB, Heliox and Siemens, who together have agreed on an open interface for fast charging, called OppCharge.

"It has a pantograph in the overhead charge station, delivering between 150V and 450kW, with a voltage of 740V," says Edward Jobson, chief engineer of electric bus systems at Volvo. "A charge of approximately two or three minutes would typically be enough for half an hour of driving,"

OppCharge is compatible with both the present and the next CCS standard, due in Europe by 2020, and should work with other

"If you want to charge with 300kW then you have to have roughly a ton of copper on board to pick up the energy. It's a heavy weight penalty"

Edward Jobson, chief engineer, electric bus systems, Volvo

EVs. "Today, buses are dominating many of the most important EV discussions among politicians as they provide clean and silent public transportation for cities. However, this system is one of the few that's also compatible with trucks," says Jobson.

Inductive charging isn't attractive for buses because of the weight of the copper coil that would be needed, Jobson believes. "If you want to charge with 300kW then you have to have roughly a ton of copper on board to pick up the energy. It's a heavy weight penalty."

Also, cities are reluctant to dig the holes needed for induction chargers in established bus routes that may have several utilities beneath the asphalt.

PUBLIC SERVICE ANNOUNCEMENT

The ElectriCity group has announced the expansion of its electric bus operation in Gothenburg, Sweden, following two years of successful service on the city's route 55. The ElectriCity partnership – which includes Volvo Group, the Västra Götaland Region, Västtrafik, the City of Gothenburg, Chalmers University of Technology, the Swedish Energy Agency, Johanneberg Science Park, Lindholmen Science Park, Göteborg Energi, Älvstranden Utveckling, Ericsson, Keolis, Akademiska Hus and Chalmersfastigheter – will operate two electric, high-capacity buses on Gothenburg's route 16.

The route 55 service has seen 10 all-electric or partially electrified vehicles operating since 2015. The scheme was intended to conclude in 2018 but has now been extended until 2020, with additional vehicles due to join the program. In addition, plans are underway to expand the ElectriCity demo area, and for electric heavy vehicles to be added.

The world's first fully electric-powered double-decker bus launched in London last year. By 2020, Transport for London says all single-decker buses in central London will produce zero emissions

Advances in battery technology will be the most important technology enabler for Volvo Buses. "We can't shy away from the fact that battery price is an issue and it is going in the right direction, falling by roughly 15% per year," says Jobson, who adds that he would prefer policies that don't favor other eco-friendly energy systems, such as fuel cells.

"It's quite difficult to invest in charging infrastructure for battery electric buses when the EU is investing €3bn [US$3.4bn] over the next four or five years to promote fuel cells. That becomes an obstacle if you don't treat all alternatives the same," he says.

London calling

Five battery versions of what is probably the world's most iconic bus, the red London double-decker, are currently on trial in the UK's capital, supplied by BYD of China. Future versions will be made in partnership with UK bus builder Alexander Dennis Limited (ADL). Together they are already fulfilling orders for 51 single-deckers for London, to comprise Europe's largest electric bus fleet.

"We went into partnership [in 2015] because BYD is renowned for battery technology," says Ken Scott, group engineering director at ADL.

"The London buses run without opportunity charging," Scott adds, "The holy grail, which we've achieved, is for a full overnight charge to be sufficient for a bus to run all day, for 16 hours with up to 80 passengers on board."

So will electric buses fully replace diesel buses and hybrids? "Yes, absolutely, but it's not as simple as an overnight switch," claims Scott. "We sell buses all over the world, and there are many different solutions in a number of different markets, but for the UK I think there could be a full replacement within 10 years from now."

"The holy grail, which we've achieved, is for a full overnight charge to be sufficient for a bus to run all day, for 16 hours"

Ken Scott, group engineering director, Alexander Dennis Limited

STRADDLE NO MORE

Heralded by some as pure fantasy from the very start, but by others as a true sustainable public transportation breakthrough that could help keep future megacities connected and on the move, China's much-hyped straddling bus concept has reached its final stop.

According to widespread reports, the test site for the Transit Elevated Bus (TEB) in the city of Qinhuangdao in the Hebei Province is being dismantled, amid rumors that the project failed to overcome several major technical, engineering and financial problems.

Local reports say that Hebei Province authorities decided against renewing the contract for the feasibility study, which initially ran for three months last year, due to a series of issues that were not being addressed.

As well as seemingly being overly optimistic in how it could work in tight, congested urban areas, the makers of the near 8m-wide (26ft) bus also failed to take into consideration the knock-on problems the TEB trials would create for local residents, with the bus being described as a major traffic obstacle by concerned traffic authorities.

Furthermore, glitches in the technology and engineering of the vehicle, as well as problems in creating the surrounding track infrastructure, made matters worse for the project, but perhaps the knockout blow was nationwide suspicions that the entire thing was a stunt, funded loosely by a peer-to-peer lending program – many of which in the last few years have resulted in scams in China.

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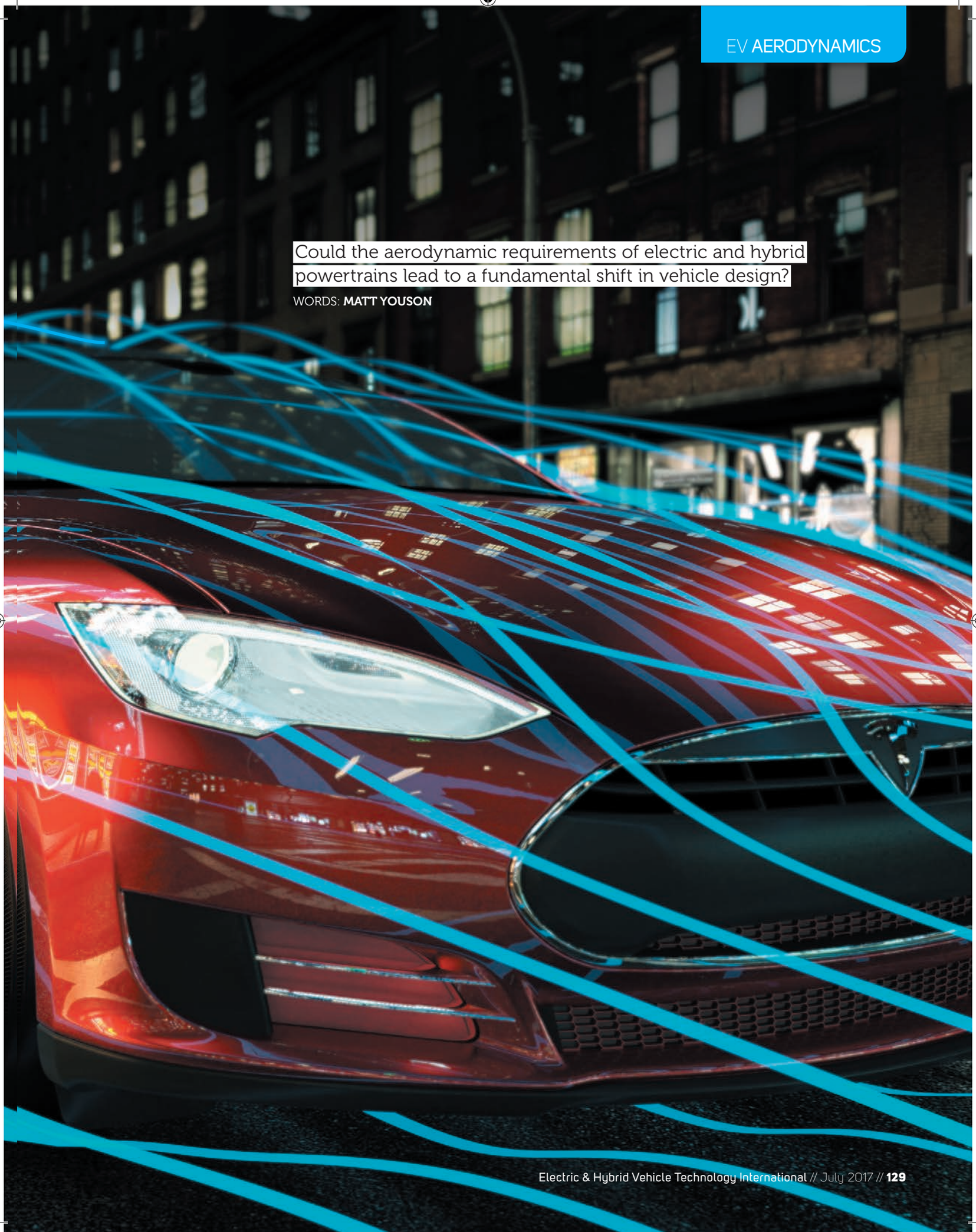
Freed of the constraints of IC engine packaging and architecture, could EVs usher in a new era of aerodynamic design?

SHAPE OF THINGS TO COME



Could the aerodynamic requirements of electric and hybrid powertrains lead to a fundamental shift in vehicle design?

WORDS: **MATT YOUSON**

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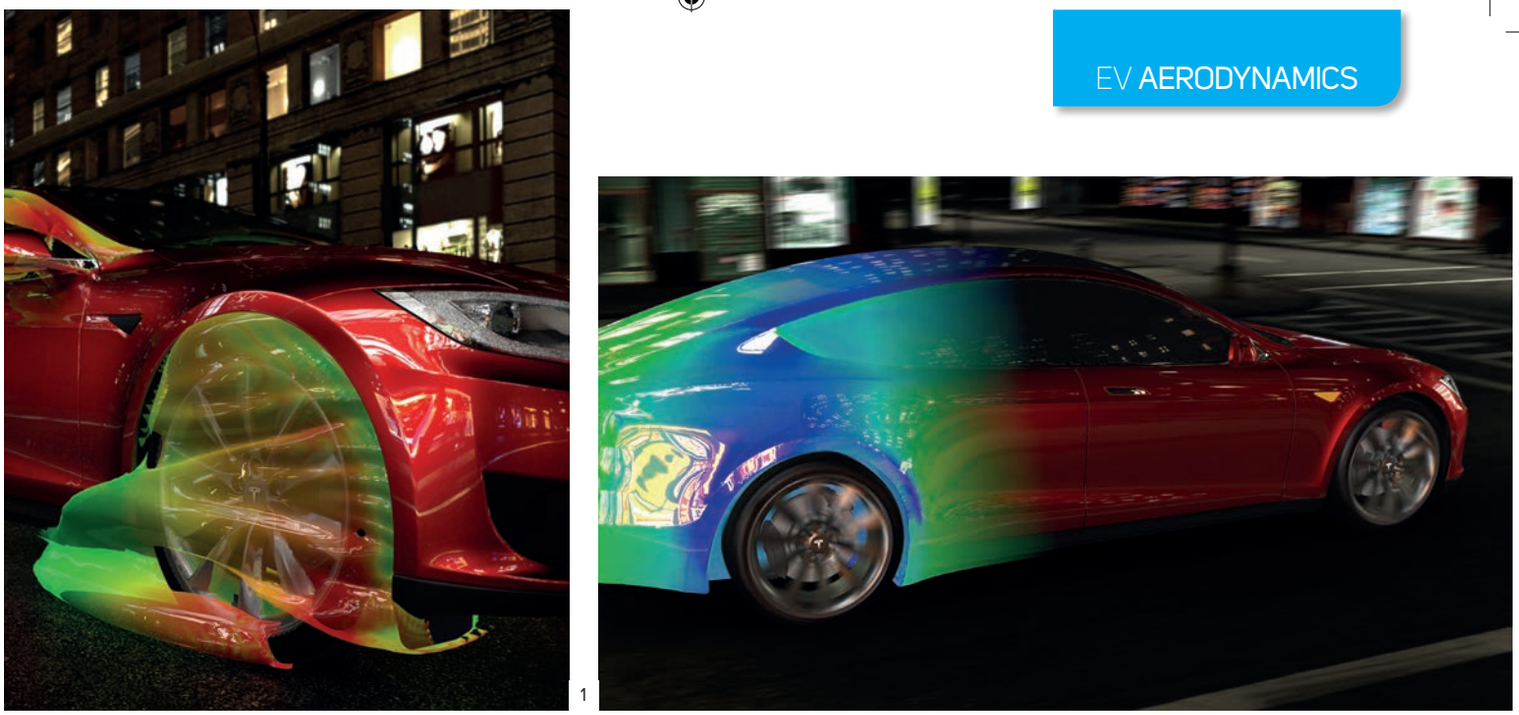

There's a century of design evolution behind the shape of modern cars – vehicles that have been built around the packaging of the powertrain and the need for a passenger cabin that seats X number of adults in comfort, while providing a driver with an acceptable field of vision. Aerodynamics has always been a part of the former requirement, providing cooling to the powertrain and latterly bringing performance benefits (in most cases drag reduction and thereby improved fuel economy), evolving the aesthetic and functional layout into the form seen today.

But what happens when one of those evolutionary factors is removed? Design studies and prototypes have always shown a radical interpretation of battery vehicles in which removing the large space taken up by the internal combustion powertrain presents an opportunity to adopt shapes with greater aerodynamic efficiency, lowering the drag coefficient to improve range – always the great bugbear of electric propulsion.

And yet, when it comes to production vehicles, major OEMs have shown a marked reluctance to deviate from the template of an ICE car. Indeed, many promote the idea that their EV derivative looks the same as a petrol or diesel model – even going so far as to include phony grilles. The industry has decided that, while perhaps not an optimal solution, there isn't a particular aerodynamic argument that precludes putting an electrified powertrain into a conventional package – albeit one that perhaps pushes conventional design to more aggressive extremes.

"In a lot of ways, the design parameters of the vehicle are not different," explains Brad Duncan, director of aerodynamics for simulation software provider Exa Corp, which numbers Tesla among its customers. "The car company that's trying to sell an electric vehicle wants to compete head-on with any other vehicle in, for example, interior space. You don't want the consumer to be making much of a concession when they buy an electric vehicle or an alternative powertrain.

"There may be different cooling requirements in the engine bay, or what's happening under the vehicle – but the thinking isn't very different in terms of the design itself," Duncan continues. "The goals may be different: dynamics are more important to electric vehicles and so you have to do aerodynamics much more aggressively. You have to find ways to improve the [vehicle] performance and that means touching on every area of design, and being willing to explore innovations that can perhaps improve drag but also improve styling."

> "You don't want the consumer to be making much of a concession when they buy an electric vehicle or an alternative powertrain"
>
> Brad Duncan, director of aerodynamics, Exa Corp

2

1. Several of the design considerations for electric vehicles are similar to those of cars powered by traditional powertrains

2. Despite having few of the powertrain packaging restrictions of an ICE car, Honda's Clarity adheres to the established design paradigm for vehicles

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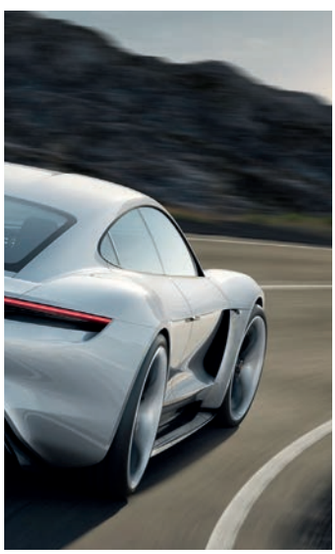
Design studies and concept vehicles offer up glimpses of what the cars of the future could look like. However, with relatively few exceptions, the auto industry seems reluctant to shed existing paradigms. *E&H Vehicle* looks at a few of the most striking (and important) designs that have done impressive things with the still-dominant vehicle form.

General Motors EV1
The EV1's fate has been well documented, but it's worth remembering that the now-infamous vehicle had a Cd of 0.19, and although its shape now appears a little dated, it was still something of a departure for 1990s car design.

Volkswagen XL1
First unveiled at the Qatar Motor Show in 2011 (the vehicle's first iterations included the VW 1-liter concept car in 2002 and the L1 Concept revealed in 2009), the plug-in diesel hybrid Volkswagen XL1 enjoyed a limited production run in 2013, and boasts a Cd of 0.186.

Porsche Mission E
Combining traditional Porsche design motifs and aerodynamics inspired by the OEM's motorsport heritage, the sleek, all-electric Mission E has done away with side-view mirrors – camera-captured images appear in a virtual display reflected in the lower corners of the windshield.

Renault Trezor
A fully electric concept, the Trezor's streamlined form includes a honeycomb-shaped air inlet on the hood, and distinct lack of lines across the body – a single seam connects the body of the vehicle to a clamshell-style roof.



(Clockwise from top)
The Renault Trezor;
Volkswagen's XL1;
Porsche Mission E

Stick with what you know

A good example of designing an alternative fuel car on the aerodynamic platform of a conventional vehicle is the Honda Clarity Fuel Cell. For the latest iteration of the vehicle, the Japanese manufacturer targeted fitting the powertrain under a conventional hood to leave space for a standard five-seat passenger cabin and trunk space. Honda targeted downsizing of the 103kW fuel cell stack, and integrated its electric motor, transmission and power electronics. The finished vehicle doesn't feature any eccentricities in its aerodynamic design.

Thomas Brachmann, chief project engineer – R&D and section lead, xEV Powertrain Research, Honda R&D Europe, suggests that this is very much in line with Honda's thinking with regard to alternative fuels. "In principle, we don't have specific aerodynamic requirements for our alternative powertrains, simply because the cooling performance provided in a conventional car will also cover the requirements of an alternative powertrain, whether that's natural gas, battery EV, hybrid or fuel cell EV."

Of course, just being able to package an electric vehicle in a conventional shell doesn't necessarily make that the most efficient option – but Brachmann argues that factors such as reducing the coefficient of drag do not particularly tie in with the requirements of everyday driving.

"Drag really becomes a factor at specific speeds, typically above 120km/h. If, in the future, mobility requirements from customers demanded speeds in excess of that, then a modified design will offer more efficiency – but if the focus is not on top speed, then we are relatively free on any form, whether that's the rolling cube, the gliding cube, a ball shape, or something yet to be defined."

The Renault EOLAB plug-in hybrid concept was styled to give the most attractive visual design for a given level of aerodynamic performance

Natural evolution

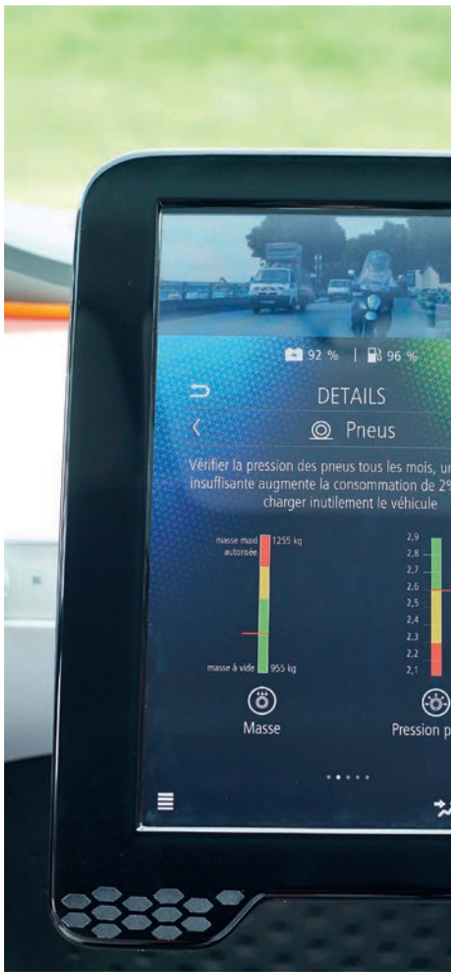
According to Exa Corp's Duncan, lacking a specific engineering demand, any change in aerodynamic requirement is likely to come as a natural evolution of concept and general downward pressure on drag. "It's a competitive marketplace and I think more of the OEMs will set their sights on more aggressive targets," he forecasts. "If the best in class achieves a Cd of 0.24, that will become the target for most manufacturers. Then someone like Tesla will have to build a car with a Cd closer to 0.2 to continue pushing the boundaries – but I don't think we'll see it done in a way that the consumer perceives to be outlandish. They're going to see it as something they really, really want – otherwise nobody is going to buy it."

It's a stepping-stone approach to a more aerodynamic vehicle design – something that sits well with Patrick Lecharpy, design director at Renault's Cooperative Innovation Laboratory. The lab has a remit to make a clean break from current technology and concentrate on the future. It is staffed by an interdisciplinary mix of stylists, designers, product and process engineers. Among other works, it is responsible for Renault's EOLAB plug-in hybrid concept.

"For years we have worked on aerodynamic optimization to minimize the gap between the perfect raindrop shape and something that you can sell," explains Lecharpy. "It does not mean that aerodynamics and styling are not compatible: a Cd of 0.19 is possible without styling; we can reach 0.22 today, but EOLAB was 0.224 in order to get the most attractive design for a given level of aerodynamic performance.

"Renault is pushing for more EVs in our vehicle [range], and that allows a lot of freedom in terms of design architecture. Downsizing the engine or placing the alternative wherever you want delivers a lot of opportunities for innovation – but it does not come in one shot. It's a question of merging engineering optimization and design. This is the key to the design of future cars."

This glide path to a vehicle with very different aerodynamic values is, of course, affected by factors other than the powertrain – most obviously, the potential for autonomous or connected drive cars doing away with the primacy of the driver position. Another factor, one more philosophical than technical, is the idea that ubiquitous EVs will bring about a change in how consumers perceive personal transportation and this, in turn, will influence aerodynamic design.



"It is difficult to integrate 90kWh of battery or a tank system with 700 bar containing 5kg of hydrogen for a fuel cell into a vehicle," says Brachmann. "That's a challenge of the future and maybe, with a combination of EV and autonomous driving, we will have a very different, more honest requirement for range. At present, the standard is to target what is possible with a 70-liter tank in a diesel car, and this gives us headaches. My wish is that society becomes more rational, and discards the notion that daily behavior requires a 1,000km range without pauses. If we can get beyond that, then maybe design – and aerodynamic requirements – will change."

What shape is the car of the future? Basically, whatever shape the market wants it to be.

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FAIR TRADE

PSA Peugeot Citroën's takeover of Opel/Vauxhall will lead to the creation of Europe's second-largest car maker. What impact will that have on e-powertrain development for the two organizations? In an exclusive interview, Gilles Le Borgne, the French car maker's head of engineering, maps out plans for partnerships, technologies and growth

WORDS: **DEAN SLAVNICH**

ILLUSTRATION: **MITCH GEE**

From an engineering perspective, how excited are you by the new joint portfolio that you now have at your disposal?

Well for us it's a huge challenge, of course. But let me go back almost five years, when we announced three major joint programs with GM Opel. These three programs are on our current platform – they are using our architecture, our modules, our powertrains, our axles and much more. We are now very close to launching these cars on the market, one of them being the Crossland X [from Opel]. This vehicle is in the global program, which also includes the Peugeot 3008, the new DS SUV [the DS 7 Crossback] and a future Citroën SUV. The Crossland X has been fully developed by engineers in Russelsheim, Germany, using our technology. The other two have been developed by the team in Sochaux, France. So we're fully integrated in that sense. The final program announced in 2012 is focused on an LCV, and this vehicle has also been developed by my team, but with Opel input.

So this shows that by 2019, with those three joint programs, we are going to have almost 20% of the total volume of Opel on PSA technology. We're not starting from zero – and that's something that must be understood.

Is that the most important thing – not starting this relationship from scratch? Especially when you think how long it takes to integrate platforms, powertrains and technology. Volvo, for example, only stopped using Ford engines last year!

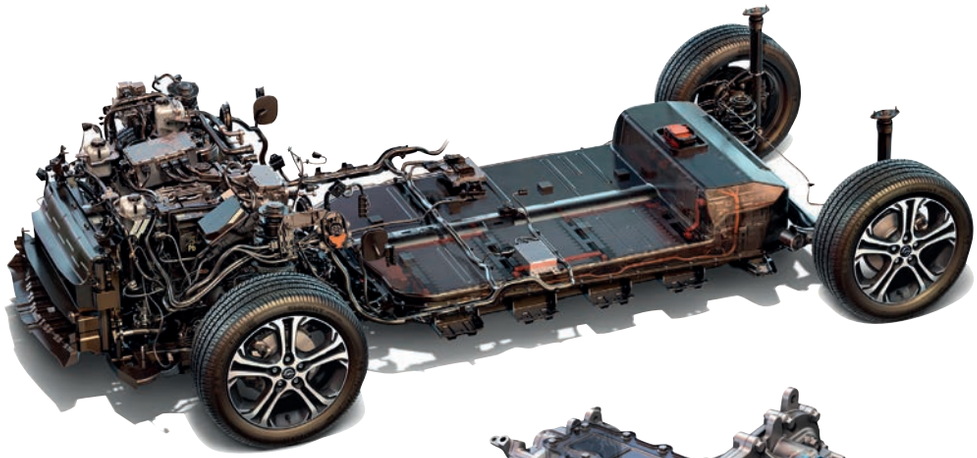
Absolutely, because it all takes time – so much time – and money, not just adapting the technologies and platforms but also regulations that you need to fulfill. Of course, our strategy will be progressive. We will switch to PSA technology for Opel but, as I said, not starting from point zero. Come 2019/20, 20% of Opel cars will be on PSA technology. It's exciting, it's challenging, but we know where we're going to stand and how we're going to do it.

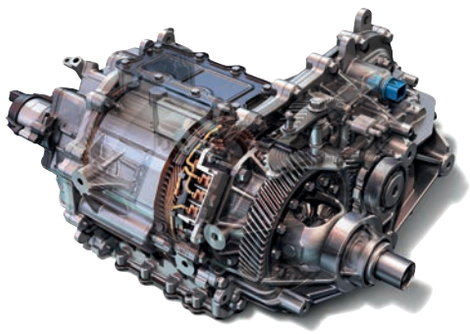
Is it a risk?

Well, there are always risks but I think for us it's a controlled risk.

Where are the engineering risks?

We're not sharing all the same platforms, we don't have the same tools for digital mock-ups and we don't have the same validation, integration and development processes. There's all that and more. We'll have to talk about that but – and I go back to my earlier point – we've already worked with Opel through those earlier three programs. What we now have to do is enlarge those foundations across the entire Opel line-up.



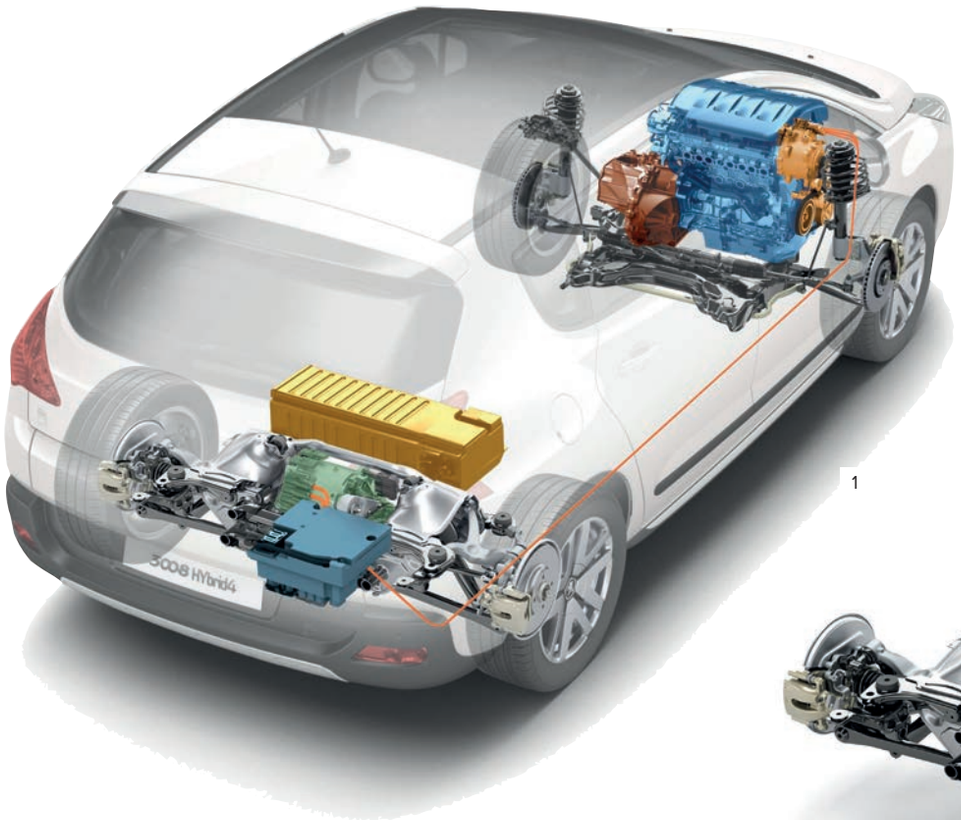


Is product similarity a risk?

It could be seen as a risk, but actually it is a chance. Why do I think that? Because we've proved ourselves with those earlier three programs. Along with the SUVs, we'll also have D-cars with Peugeot, Citroën, DS and Opel, and that will carry on across all line-ups.

Each time we'll take the one car at the root of the program – the mother car, if you like – and then adjust the content of each of the following cars to match the brand's DNA. You can see we're working like that already: 3008, Crossland X and then Crossback. All three vehicles are so different to drive, touch, feel and look at, but they fit perfectly within those brands' DNA, so I have no worries because that's why this risk is actually a chance for us. Corsa is not far off from a C3 or 208; Astra is the same. All of Opel's products are the same, so we can easily integrate Opel within PSA.

This page: As part of the takeover, PSA will gain access to the technology, underpinnings and the powertrain from GM's Ampera development



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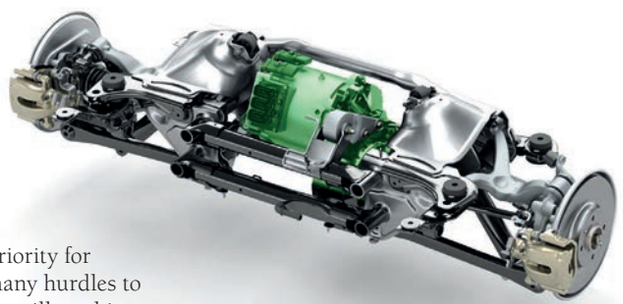
"Come 2019/2020, 20% of Opel cars will be on PSA technology. It's exciting; it's challenging"



You're also working together with GM on hybrid gasoline powertrains. Will you get access to that technology?

Actually, we're not really! In 2012 GM bought the IP for our PureTech engine, but currently, as far as I know, it hasn't developed anything with that IP. So today we are developing our own technology [in this space], but of course we will use it in future Opel applications.

Do you get the battery-electric and hydrogen fuel cell technology from GM as part of the deal?

Yes – that's part of our global agreement. So in certain conditions we have access to the Ampera – the technology, underpinnings, powertrain – and can rebadge it or do a reskin. But that's still yet to be decided. We also have access to fuel cell technology that GM is developing in the USA with Honda, but that's only to a certain extent. So for both Ampera and FCEV technology it is an open discussion, but there are real possibilities for us.

That's quite an added sweetener to the deal. Is it fair to say that on the BEV and FCEV front you are/have been behind rival car makers in terms of development?

That's not totally true. We've been working on both fronts. In fact in 2005 we did a fuel cell stack with 100kW output and we put it in several test cars. Testing was going very well but, as you know, most recently this hasn't been the number-one priority for development. There are still many hurdles to overcome, which is why we are still working on this technology but are focused more on other areas. From a PSA perspective, we do think fuel cells will come, but from premium brands first and then the rest will follow.

Another aspect of PSA innovation – which perhaps you pushed ahead too quickly with – was Hybrid4, the first diesel-hybrid powertrain for mass production. It cost a lot of money and didn't break into the market. How do you feel about that?

I was responsible for that platform at the time. It cost us €490 million (US$549m) in total. Why did we choose diesel? Because it was a full hybrid application but with a low energy content – it was 1kW per hour back then. As soon as we change to plug-in, the energy level will be up to 12.5kW per hour. At this level, the type of IC engine isn't as important because in urban conditions you use full electric. And as for the switch to gasoline for PHEV? It's because it's more global.

So is diesel dead? There have been rumors that Paris will ban diesel cars, and surely that will be the beginning of the end for this IC motor?

No, that's not true – Paris is going to ban older diesel cars only.

1. PSA's Hybrid4 diesel-hybrid powertrain cost a lot of money, but wider global use of gasoline technology caused the OEM to switch focus

2. The Crossland X is the result of a previous joint program between PSA and GM Opel, and uses the current PSA platform

2

1

But that's a slippery slope – first older diesels, then a different type of diesel and eventually all diesels. Do you agree?

This discussion needs to be based on figures and facts. Is the diesel decreasing in terms of market share? Well, that's yes. For us, diesels were 63% of sales in Europe in 2015, falling to 60% in 2016. But in France we're actually operating below that, with a 52% rate.

That's surprising – why is that?

Because of the diesel bashing here – that's the only explanation. But to go back to your point: is diesel decreasing in market share? Yes. So, our reaction is simple: we want to have a large bench of technologies, including IC engines with gasoline and diesel power. That's the start – we will introduce a new generation of diesel later this year to meet new regulations. In fact the aim is to decrease fuel consumption by 5-7% for both our gasoline and diesel cars. On the other hand, we're also working hard on PHEV, which we'll introduce in 2019 on the EMP2 platform, as well as battery electric vehicles later that same year on CMP platform.

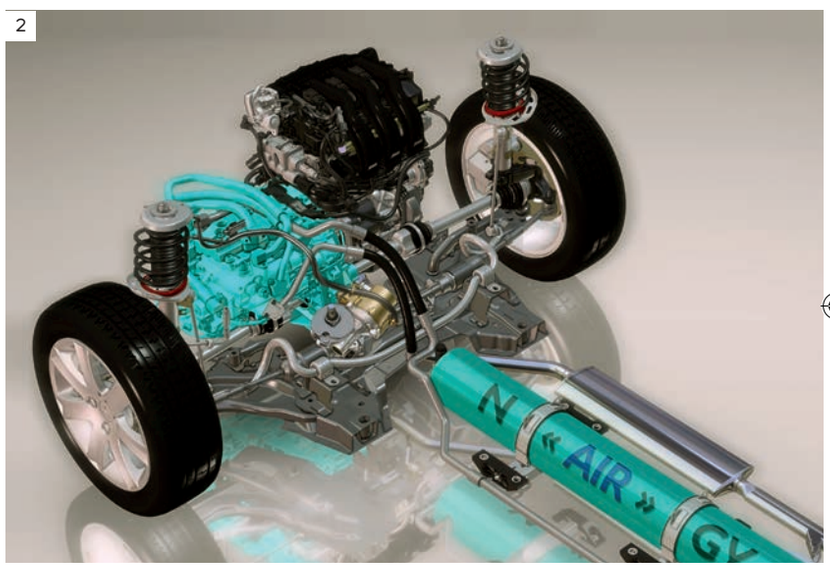
Do you hold Volkswagen responsible for the decline of diesel?

I can't comment on my competitors. My view is seen from PSA's perspective, and that is, we were always ahead of regulations. We invented the particulate filter back in 2000! We introduced SCR technology across our line-up – that was big. You know, when we made those decisions, especially the SCR commitment five years ago, it wasn't easy for us because it added extra cost – something like €100 to €200 per unit. Can you imagine how difficult it was for the company, which wasn't in good shape at the time, to make that decision? So I can say that we don't feel as if we're in the same basket as Volkswagen. Of course, the moment you mention cheating, I must say we have nothing to do with that. But if we're talking about regulation, that's another topic. We need to have more regulation that's very close to the car usage of our customers in the real world. For that reason, we're working closely with Transport and Environment on a new initiative that will enable us to be crystal clear with our customers about emissions and fuel consumption.

1. Previous programs with GM Opel mean that PSA has prior experience with its new vehicle portfolio

2. An earlier foray into alternative powertrain technologies – PSA's Hybrid Air system

3. Access to GM fuel cell technology could provide fresh impetus to PSA's developments in this area



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Might we eventually see a diesel-hybrid PHEV from PSA?

No. Today, and for 2019 plans, it'll be gasoline because of that high energy level I discussed earlier. It just doesn't make sense to do diesel because most of the time when commuting, the powertrain will be using zero-emissions energy in all-electric mode. As soon as you hit the highway, diesel is better but the difference between diesel and gasoline is less now.

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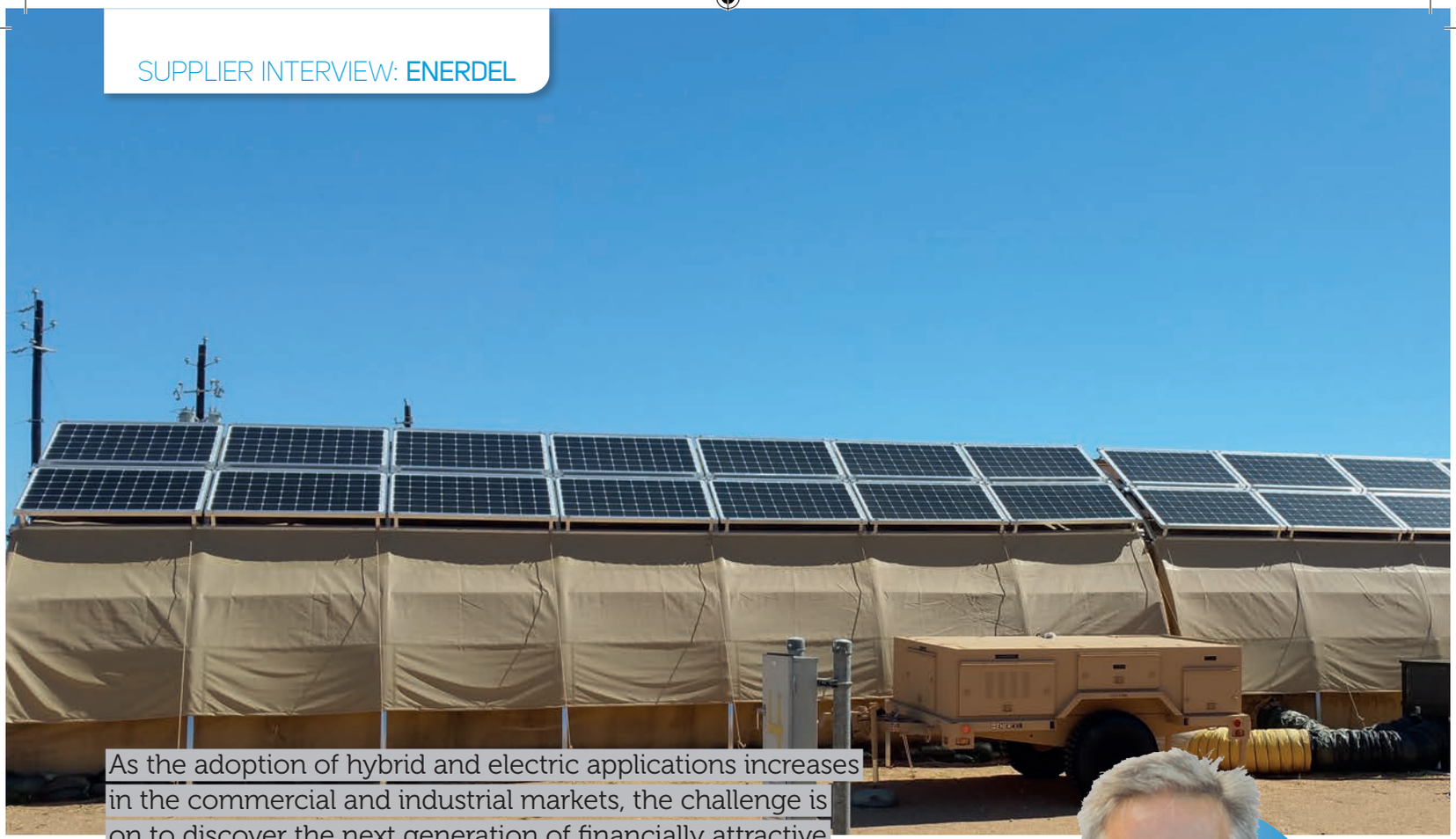


As the adoption of hybrid and electric applications increases in the commercial and industrial markets, the challenge is on to discover the next generation of financially attractive technology offering even greater power and energy density

Power ahead

WORDS: **KARL VADASZFFY**

The ability to offer its commercial vehicle customers quicker return on investment when it comes to electrifying fleets, both fully and hybrid, is the leading reason why EnerDel, a lithium-ion solution specialist based in Indianapolis, Indiana, offers products that are primed for transportation applications, ranging from industrial equipment to buses.

In the USA, the commercial bus market is rapidly adopting the company's PP320-738-LP Vigor+ lithium-ion energy storage system, and the recent growth of projects in Europe has demonstrated widespread interest in the technology.

This 21kWh energy storage system (ESS) is offered as an aftermarket product for buses using the Allison H40/50 powertrain. Nearly 500 of these have been installed in 13 North American municipalities over the past two years, and customers include the Washington Metro in Washington DC and the Maryland Transport Authority, with other users based as far afield as Seattle, Vancouver, New York and California.

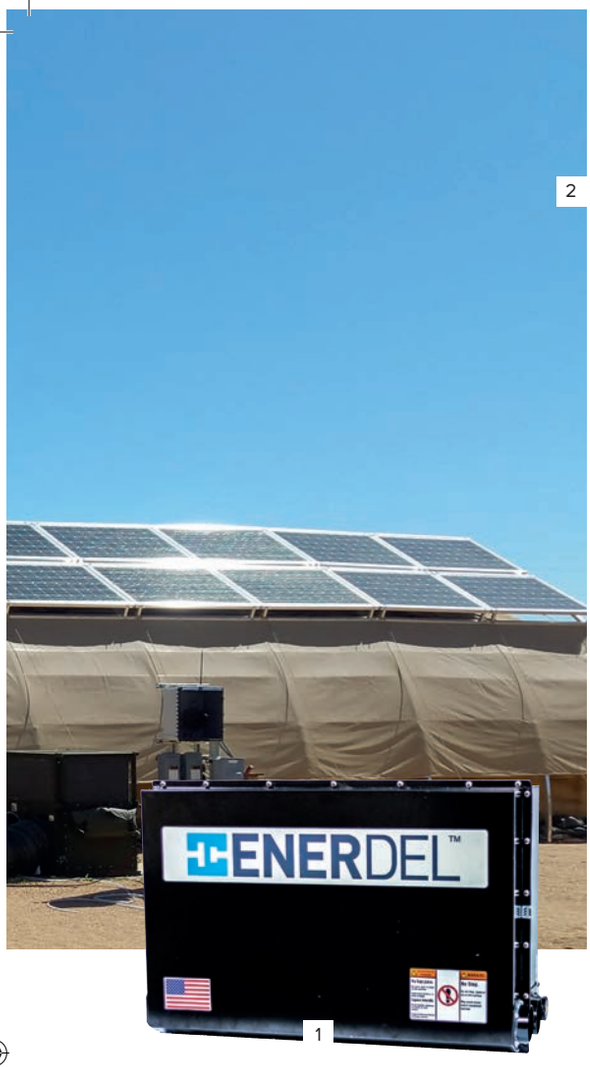
As Derrick Buck, EnerDel's director of product engineering, explains, "The Vigor+ ESS offers more than three times the energy of the original equipment product, and significant product life in the hybrid applications. Plus, the Vigor+ family of battery packs offers solutions starting from 11kWh, and can be used in parallel systems up to hundreds of kilowatt-hours."

Rapid payback

With commercial vehicles, Buck says, there is a much faster payback for the customer than with consumer vehicles – in some instances, just one-to-three years. So, as a result, "we're seeing a lot of growth in construction, mining and agricultural equipment, applications that typically have high fuel usage, which tends to be one of their main operating costs, as well as the bus segment. The Chinese bus market has exploded and we're seeing significant growth in both Europe and the USA, not only in the hybrid market, but in all-electric buses".

In a move that will support the evolution of all-electric buses, EnerDel's R&D team is working on developing a next-generation chemistry, expected in early 2018 and offering more than 40% improvement in energy density over the company's current cells. "This will provide a considerable improvement in cost per watt-hour," says Buck. "The new cell will remain the same physical size as the current cell, so it will be very easy to add it to our existing line of Vigor+ and Secure+ packs."

It will be an optimal fit in all-electric applications where large batteries are required



1. The 11kWh Vigor+ pack
2. EnerDel's SE44-390 Secure+ Mobile Hybrid Power System

3

> "Higher energy density is really an enabler to fit the amount of energy on the vehicle that is necessary to meet an application's usage requirements"
>
> Derrick Buck, director of product engineering, EnerDel

4

3. EnerDel's 21kWh Vigor+ pack
4. A 1.25MWh Secure+ Grid Energy Storage System

to satisfy the energy demands. Buck explains, "So higher energy density is really an enabler to fit the amount of energy on the vehicle that is necessary to meet an application's usage requirements. In addition, as we increase energy density, the price per watt-hour decreases, making for a very affordable ESS solution."

Recent initiatives, focused on introducing regulatory drivers in the USA to ensure some commercial and industrial applications start reducing emissions, are becoming "a major factor for many companies to see how they can remain competitive in the marketplace while fulfilling any emissions restrictions that get introduced".

Of course, there are additional benefits to electrifying these vehicles, including reductions in operating costs because, according to Buck, "Electrification results in reduced maintenance and service costs. Oil changes, tune-ups, and brake pad replacement all get reduced considerably when there's a transition to electrification."

Mobile technology

EnerDel has also developed a Mobile Hybrid Power System, which is a 40kWh energy storage system with inverter mounted on a trailer for remote military operations. EnerDel has successfully completed a one-year demonstration program with the US Air Force, in which 10 of these systems have been used for remote power for forward operating bases. "The US military is using them to reduce their reliance on diesel generators, so they're pairing up the battery with the diesel generator, and now the generator only switches on when battery power is low." The result, Buck reveals, has been a fuel saving of 40-50% over the course of the year.

Over the past decade, Buck says trends in the lithium-ion battery space have included costs dropping even faster than many of the technology's early prognosticators indicated. In addition, energy density has continued to increase steadily, and "perhaps most importantly, lithium-ion is moving from the early-adopter stages into the mass-market stage. In fact, today we're beginning to see cell energy densities reach the mid-200Wh/kg and beyond, which is the enabling factor in making electric-powered transportation more accessible to the general consumer". Energy density improvements will continue to encourage the boom that Buck says is also occurring in the maritime and unmanned vehicle markets.

Looking ahead, Buck argues that energy density, power and safety will continue to be the major areas of development. "Higher energy density will enable either longer electric drive range or smaller batteries," he says, suggesting that high power capability is needed to meet the growing demands for fast-charge applications. "Furthermore, safety is the basis of all development because the key is to try to make batteries safer while reducing or eliminating the effects of a failure.

"Electrolyte and separator development will be needed to achieve these improvements, and higher nickel content cathodes and silicon-based anodes are likely to be the major focus for most research and development groups in the immediate future."

Factory of the future

New thinking about technology use in manufacturing is afoot, but the widespread implementation of innovations such as AI and robotics requires a change of industry mindset

WORDS: **KARL VADASZFFY**

The role of manufacturing within the automotive industry is rapidly changing, believes Robb Black, the CEO of Omron Americas. He argues that the speed and breadth of today's innovation affects, and will further affect in the future, every job and skill set within the industry. "Automation, including robotics, AI, big data, the Internet of Things and mobile technology," Black explains, "are leveling and changing the playing field, not only geographically but across the spectrum of suppliers."

Innovation, therefore, creates new opportunities for manufacturing and the growth of the industry, but "To make the industry globally competitive," says Black, "manufacturers will need to leverage new technology, such as additive manufacturing. Automotive manufacturing is not monolithic, particularly when we look at the technologies required to put a connected, electrified and potentially autonomous vehicle together."

As a result of this, Black argues the critical challenge for manufacturers will be to approach footprint decisions in a more nuanced way, thinking about resources, prices, a looming shortage of highly skilled talent, a heightened global supply chain and regulatory risks. "Today," he says, "we've got many more complex needs, so in order to truly realize a return, we need to look at the system, which includes looking at the plant structure itself."

The difficulty, Black adds, is that archaic, pre-PC manufacturing concepts remain in widespread use. "The difference between manufacturing, equipment and processing tends to almost be inconsequential – everyone does things a little differently to serve the particular needs of a specific chemistry, market niche, or customer.

"However, the industry is now at a tipping point, where cost reduction and widespread product success are going to have to depend on a different model, perhaps manufacturing to design."

"In today's environment, it's optimal to benefit from working with a company that can offer the entire machine or line"

Robb Black, CEO, Omron Americas

1

Sense of the future

Founded in Osaka, Japan, in 1933, and responsible for innovations including the traffic light, ATM and proximity sensor, Omron is a global US$8.5bn corporation, with around 37,000 employees worldwide. Black leads its industrial automation business unit in the Americas, which consists of a sweeping portfolio covering controls, vision, safety, motion, robotics and services. "From sensing all the way through robotics, we offer the full spectrum of products in our portfolio," he says. "In today's environment, it's optimal to benefit from working with a company that can offer the entire machine or line."

Black refers to a "digital factory of the future", which will see "a small nucleus of connected people focusing on goals, ideas, innovations and strategies – everyone including the IT world – coming to the factory floor".

One of the keys to enabling such a factory, he predicts, will be AI and machine learning: "Machine automation controllers will achieve real-time integration between controller function, which controls the production lines and the equipment changing in microseconds on a factory floor, and the AI processing function."

Omron's portfolio of products is being primed to be 'the sixth sense' – able to monitor an entire line to spot any irregularity before one can occur. "We want to predict errors, prevent stoppages and prevent the deterioration of product quality before it happens," explains Black.

Although machine controllers have typically been used as data gatherers, Black believes that, in the future, they're going to be able to learn, predict and recommend options for an operator. "All of this together, through the IoT, will bring the factory floor to the office, and there'll be a seamless integration between them."

Indeed, Omron's AI machine automation controller will be on the market in 2018, with the aim of software to follow later the same year. Planned software will gather data, contextualize it and present it in a user-friendly way and in real time.

1. Omron's innovation in the development of controls, vision, safety, motion, robotics and services enables the company to offer its customers a full-spectrum portfolio

2. Technology from Omron is able to monitor an entire factory line, spotting irregularities before they even occur

2

Intelligent thinking

The company, with clients that include the top 10 global auto makers, also aims to develop the use of AI at the control level, a move supported by its recent acquisition of vision company Sentech Automation in April. As Black explains, "We will offer 2D or 3D vision systems that can make learning decisions and predict on their own."

Other future plans include increasing the capabilities of sensor products to make them more data-driven, so that they can reveal the inner workings of a unit – for instance, internal temperature and cycle count. "Smart sensors connected to AI machine controllers enable the operator, the floor and the entire facility to be much more in touch with the real inner workings of what's going on with the machines," Black says.

Two other recent acquisitions – robotics company Adept and motion-control company Delta Tau – have brought Omron to what Black describes as "a new level of automation". One product on offer is the LD unit, an autonomous mobile robotic solution, coupled with a true enterprise system, which has the potential to revolutionize industry thinking about capital equipment investment in a factory: "This moves away from fixed conveyors and stations toward a system where the factory floor can be readily reconfigured," explains Black. The LD unit is designed for moving material, particularly in challenging environments, and unlike with traditional autonomously guided vehicles, no facility modifications are required, potentially saving users 15% in deployment costs.

Also recently released is a new industrial PC platform. Omron's IPC meets strict quality standards for factory automation devices and offers stability on a long-term basis. "In the IPC, Windows can completely crash, but the controller OS will still run the machine," explains Black. "Other vendors of IPCs have their machine control non-partitioned and sitting on Windows, so if Windows crashes the controller crashes too." Indeed, Omron's IPC features high-reliability solid-state drives that have a mean time between failure of up to 23 years, while it's common for other vendors to offer CFast memory cards that have only a three-year warranty.

Through one evolving software suite, the company will be able to offer its customers one software environment to program their sensors, controllers, vision, motion, robotics and safety, so "no longer will customers need to work with different software packages", Black points out. And this is merely the beginning: in order to continue to innovate and extend its industry offering, Omron plans further exciting acquisitions in the years to come.

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TAKE CHARGE

Electric & Hybrid Vehicle Technology Expo, September 12-14, 2017, Novi, Michigan, USA

North America's leading show for e-mobility technology, supply chain and markets once again comes to Novi, Michigan, celebrating five consecutive years of success, growth and a spreading international influence. The halls at the Suburban Collection Showplace have once again sold out in record time, and well over 500 exhibitors are confirmed for what will be a truly amazing and pivotal event for all those involved in progressing the EV/HEV revolution.

Over 7,500 visitors from around 30 countries are expected at a time of notable positivity for the industry. The latest AAA study reveals that consumer interest in electric vehicles remains high, with the survey showing that more than 30 million Americans are likely to buy an electric vehicle as their next car. With rising sales, longer ranges and lower costs, AAA predicts a strong future for electric vehicles, and the expo has already proved itself the standout forum for the industry's foremost development programs.

"It's been a fantastic experience," explained Delphi's Randy Sumner at the last show. "We have had a lot of great contacts. It is a great way to network throughout the industry." These were sentiments backed up by Omron's Monika Minarcin, who commented, "It has been absolutely wonderful. I think the show is a great place to come, interact and explore new technology that is happening in the vehicle electrification space. You have everything here, from automation, to vision, to digital types of solutions for the modern vehicle."

Michigan continues to play host to the exhibition and rightly so. Auto makers and suppliers have invested over US$30bn here in the past several years, and more than 75% of all North American automotive research is conducted in the state, making it the epicenter of the future of transportation mobility.

The exhibition is now firmly embedded in the Detroit manufacturing scene and has built impressively on its status as one of the key influencers. Continental's business development manager, Christian Eder, says, "The show is really great. We want to show our products here. We have access to our whole portfolio, and people are interested in that. The companies that are passing by are very diverse portfolio OEMs, smaller companies and non-automotive looking for solutions that may lead to great discussions." This from a company that has just announced that it will

7,500 ATTENDEES

500+ EXHIBITORS

150+ SPEAKERS

invest an additional €300m (US$340m) by 2021 in electric- and hybrid-car technologies. It's clear to see which way the wind is blowing and it is reflected in the mounting enthusiasm for the show among executives from all the leading auto makers; component and material suppliers; research and development companies; design, simulation and engineering centers; testing and certification organizations; charging station companies; government and utilities.

Proving the point in Novi will be a range of product demonstrations taking place on exhibitor booths during the three days. This is another added feature as the organizers strive each time to deliver even more value to everyone, offering a panorama of this flourishing industry. "Every year it's getting much, much better, so it's a great show to be at," says Andrew Nowicki, president of DEWESoft.

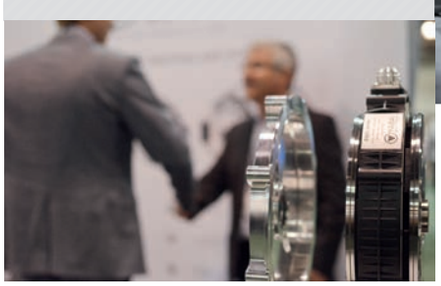
Once again, Electric & Hybrid Vehicle Technology Expo will be co-located with The Battery Show and Critical Power Expo – presenting three highly pertinent events that dovetail perfectly and continue to garner solid approval ratings from buyers, sellers, innovators and conference delegates.

In the years since these events have been established in Novi, the exhibitor base has broadened to such an extent that the leading HEV event is widely recognized as not only North America's premier meeting place for e-mobility professionals, but also as an important hub for international business and networking.

Over the following pages, we take a look at just a few of the technologies on display at Electric & Hybrid Vehicle Technology Expo 2017.

DESIGN, ENGINEERING, COMPONENTS, ASSEMBLY AND CONSULTANCY

At the heart of the expo, visitors will see every aspect of the powertrain – design, engineering, components, assembly and consultancy. Among the many majors showing this year are Valeo, MAHLE Industries, BorgWarner, TM4, Ecotrons, Future Technology Worldwide and MEDATECH. Also telling their side of this story are the leaders in motor, drive and transmission systems – and again the expo has attracted the top practitioners in the field, including Yasa Motors, EVergreen, ABM Drives, Parker Hannifin, UQM Technologies, Zytek, ATS, Protean Electric and TRANSFLUID.



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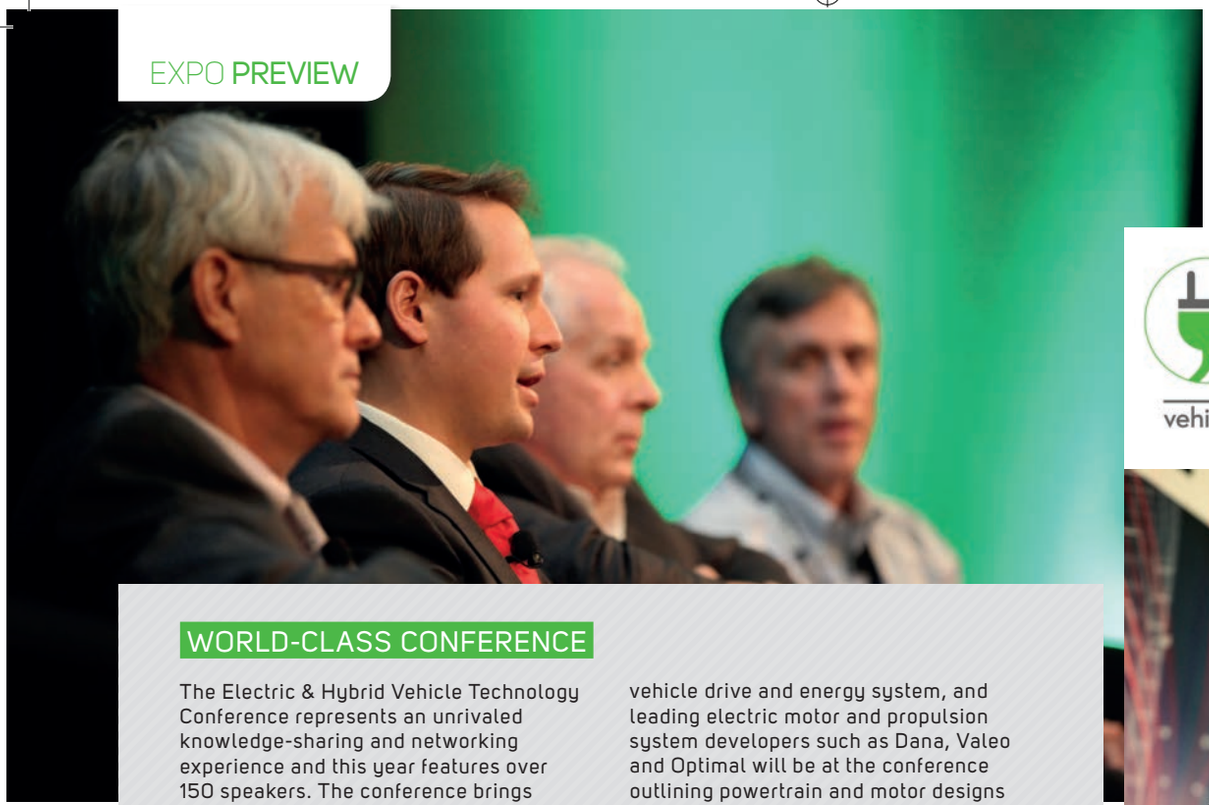

electric & hybrid vehicle technology conference

WORLD-CLASS CONFERENCE

The Electric & Hybrid Vehicle Technology Conference represents an unrivaled knowledge-sharing and networking experience and this year features over 150 speakers. The conference brings together electric, hybrid and plug-in hybrid vehicle technology experts, addressing the challenges throughout the supply chain including electrical powertrains and components, battery management systems, materials and equipment.

With over four years of dynamic growth, the conference is one of North America's leading events for cutting-edge EV/HEV technology and the only place that focuses on the challenges faced in different layers of the supply chain. Just one of many similar plaudits comes from Valeo's Matti Vint, who said after his presentation last year: "The conference went really well. In fact, the room was full, with people even standing at the back – and they turned up on our booth as well. We had a lot of foot traffic. A lot of people were interested – a lot of OEMs and other suppliers. It has been a great event."

The conference opens with a keynote panel session of OEMs sharing their views on the role of hybrid and electric vehicles in the future of transport as it moves toward electrification, autonomy and connectivity. Karma Automotive, Hyundai and Honda will be discussing the big picture issues such as the commercial viability of 48V hybrid technologies, the development of the plug-in, the evolution of fast-charging infrastructure, and the implications of intelligent mobility and autonomous vehicles for hybrids and EVs.

The conference also provides an excellent in-depth examination of the impact on components of development in hybrid and electric vehicles. The motor and generator are at the heart of the vehicle drive and energy system, and leading electric motor and propulsion system developers such as Dana, Valeo and Optimal will be at the conference outlining powertrain and motor designs and assessing them in terms of cost, robustness and torque.

Although the long-term future may be electric, in the short- and medium-term, automotive OEMs are increasingly looking to 48V systems for mild hybrids. The conference brings together Mercedes-Benz, General Motors, Valeo and Ford to discuss the key components, integration and cost implications of a hybrid powertrain design, how effective 48V systems are reducing CO_2 consumption, and whether we will eventually see 48V systems in full HEVs and EVs.

Of course, hybrid and electric motors are not solely the preserve of the commercial automobile, and many advances have been made in the aerospace and high-performance vehicles industries. As was the case in previous years, the conference will host a valuable knowledge-sharing forum, bringing together experts from the likes of NASA, Schaeffler and Boeing to cross-pollinate ideas between the industries.

The conference does an excellent job of bringing together the key players in the passenger vehicle, fleet, bus and off-road markets, all of whom are developing hybrid and electric vehicles. Once again co-located with The Battery Show and thus enabling you to hear all the latest on battery development, the Electric & Hybrid Vehicle Technology Conference attracts thought leaders and experienced professionals from across the EV/HEV supply chain in each market, so there is sure to be something relevant for everyone.

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Chief Business and Technology Officer,
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Mohamad Abdul-Hak,
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John Juriga,
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Matti Vint,
North America Engineering R&D Director – Powertrain Systems,
Valeo

Heraldo Stefanon,
Manager Advanced Powertrain – Gasoline Hybrid Group,
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Benoît Ferran,
E-FAN Battery Technical Stream Leader – Power & Propulsion Architectures (TX3P),
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UBM

Power gains

An innovative new power module for automotive inverters provides users with a faster switching speed for improved energy efficiency

Worldwide, the hybrid and electric vehicle market is currently booming and has seen the quickest growth in the automotive sector for decades. Oil consumption and the price of gasoline have been major factors over the past two years, but the EV market is now being driven by legislation on the reduction of pollution. For instance, upcoming standards will no longer penalize CO_2 emissions of individual vehicles, but entire fleets. This has had a significant impact on the development of electric and hybrid vehicles. As a result, a wider range of vehicles now need to be electrified, which requires scalable and cost-effective solutions.

To serve these requirements, Infineon continues to develop innovative frame-based modules. The company's latest product, the HybridPack Drive, provides an easy design concept and performance scalability. It helps Tier 1 suppliers and automotive OEMs to develop a platform approach.

The HybridPack Drive is an extension of Infineon's well-known HybridPack family. With the introduction of press fit and the latest Infineon IGBT technologies for automotive, EDT2, into the HybridPack Drive FS820R08A6P2, it is now 20% smaller in size than the HybridPack 2 FS800R07A2E3 but offers equivalent performance. In addition this new product line can be seen as a scalable platform through different power tab connections, IGBT and MOSFET technologies, and thermal stacks.

From the beginning stages of development, the HybridPack Drive concept has been designed to be modular. This concept begins with the connector tabs, which enable a fast welding process or bolt to connect cables, helping customers choose the method that best fits their needs. A long tab version is also in production to implement phase current sensors, such as LEM HAH3DR 800-S07, directly on the tabs.

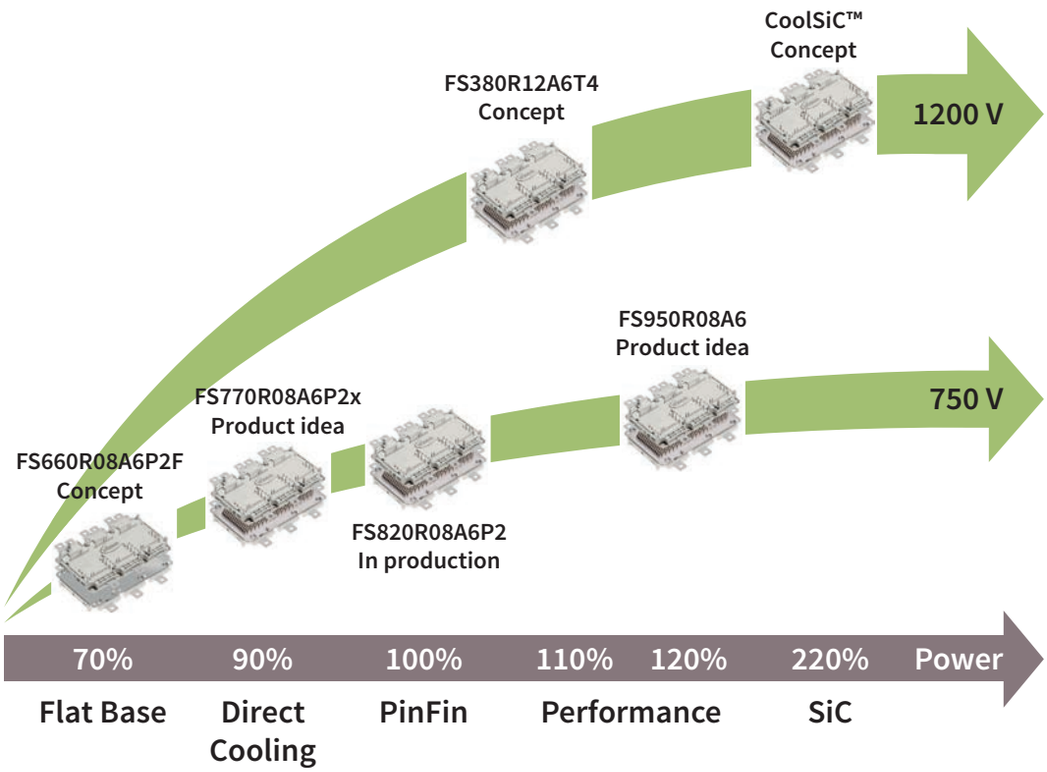

Figure 1: HybridPack performance can be easily scaled up or down depending on the requirements of the application

The performance scalability of the HybridPack Drive module has been designed to minimize the design effort and R&D investment of an inverter designer company, i.e. an automotive Tier 1 supplier or an OEM. The output power can be reduced or increased by changing the baseplate or the thermal stacks, while the silicon content remains the same. HybridPack Drive offers not only different base plates – flat, direct cooling and PinFin – but also different ceramic substrates. As a result, performance can be scaled up and down by keeping the same electronics (driver board and DC-link capacitor), the same inverter design, and adapting the cooling structure. With a 750V IGBT, performance ranges from 70% up to 120% (where the FS820R08A6P2 with PinFin structure and standard ceramic is the 100% reference point, Figure 1).

In addition, 1,200V technologies are also available in the HybridPack Drive – first with an IGBT, i.e. with advanced ceramic, and later on with silicon carbide (SiC) MOSFETs. SiC technology can help to double performance compared with a 1,200V IGBT.

SiC devices have existed for more than two decades, for example in solar inverters and power supplies. However, their use in automotive applications has been very limited, due to their low cost-effectiveness. Most of the major automotive semiconductor companies have either lacked SiC device experience or have chosen not to invest in SiC due to the unpromising market outlook. Due to low volumes, costs of SiC could not be reduced using the same economies of scale as are applied for silicon components. For example, the SiC wafer size has been considerably smaller than silicon wafers due to the difficulty in

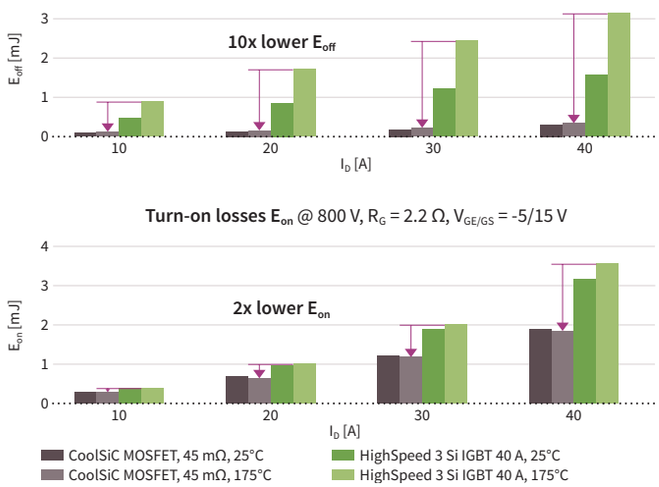

Figure 3: A SiC device offers a considerable reduction in turn-off losses

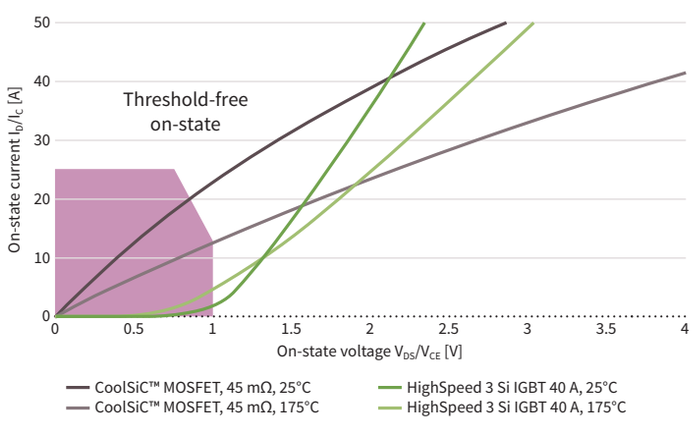

Figure 4: Conduction losses when the SiC device is used under partial load

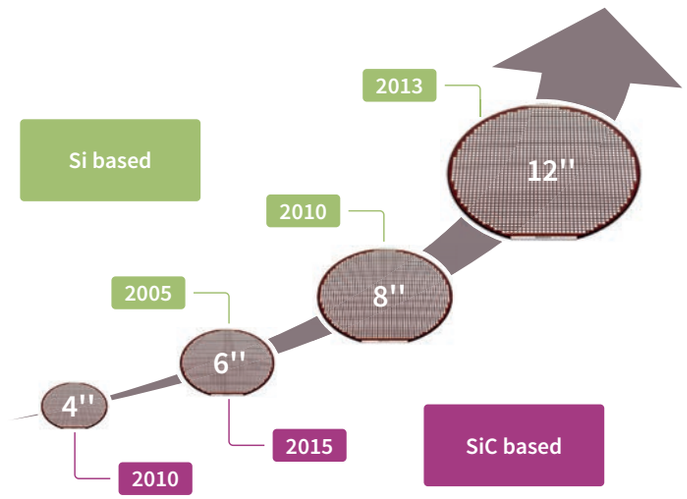

Figure 2: The SiC wafer size has been considerably smaller than silicon wafers

increasing the large-diameter wafer (Figure 2). The recent availability of high-quality 6in SiC wafers has improved the economic viability of this new technology. The number of qualified SiC wafer suppliers has increased considerably over the years to provide the quantities needed by the automotive industry.

Thanks to its semiconductor properties, a SiC device offers a considerable reduction in switching losses compared with Si devices. Typically, turn-on losses can be reduced by a factor of two. Due to the unipolar nature of the switch, the comparison is even more dramatic for turn-off losses, which can be 10 times smaller than for an IGBT at the same switching frequency (Figure 3).

The technological advantages of SiC MOSFET versus silicon-based switches are not only relevant for fast switching applications such as OBC or DC/DC converter, but can also be useful in inverter applications where switching frequencies below 20kHz are commonly used. SiC MOSFET has a resistance-like output characteristic in contrast to the IGBT's diode-like response. In partial load conditions, conduction losses can be greatly reduced (see Figure 4). In realistic driving scenarios, the inverter may typically operate for 80% of the time at light load. On average, inverter losses can be reduced by two-thirds.

This is especially relevant for EVs with a high battery power rating (>40kWh). For a given autonomy, the HV battery, which is the most expensive component in the car, can be reduced in size by 5-10%. This results in cost savings at the vehicle level. Furthermore, because they are much more efficient than IGBTs at higher voltages, SiC MOSFETs are most suited for inverters operating at a battery voltage in the region of 850V, which is a prerequisite to enable fast charging capability.

The next step of performance scalabilty with the HybridPack Drive is the introduction of SiC and CoolSiC. This combination does not only help to double the performance of the inverter compared with state-of-the-art IGBTs, but also enables system cost reductions through battery savings and downsizing of other system components.

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Industry challenges

The rise of electric vehicles is increasingly creating an industry culture clash, and putting new pressures on electrical systems design tools

Many experts in electrical systems design rely on Capital software tools developed by Mentor

Nobody buys a vehicle based on whether the software tools for designing and manufacturing the electrical distribution system (EDS) were operated using good, better or best practices. But maybe they should. Just how these tools are implemented matters deeply, since that may be the biggest determinant of the quality of engineers' work across the design cycle, from system prototyping through to harness manufacturing and assembly. And this development is increasingly challenging given the explosion of E/E complexity due to oft-reported industry megatrends, in particular the rise of both autonomous and electric vehicles.

Open questions include everything from where the next wave of EV growth will come from to whether the balance of power will finally shift from metal-bending mechatronic pros to those building robot cars who dream in code.

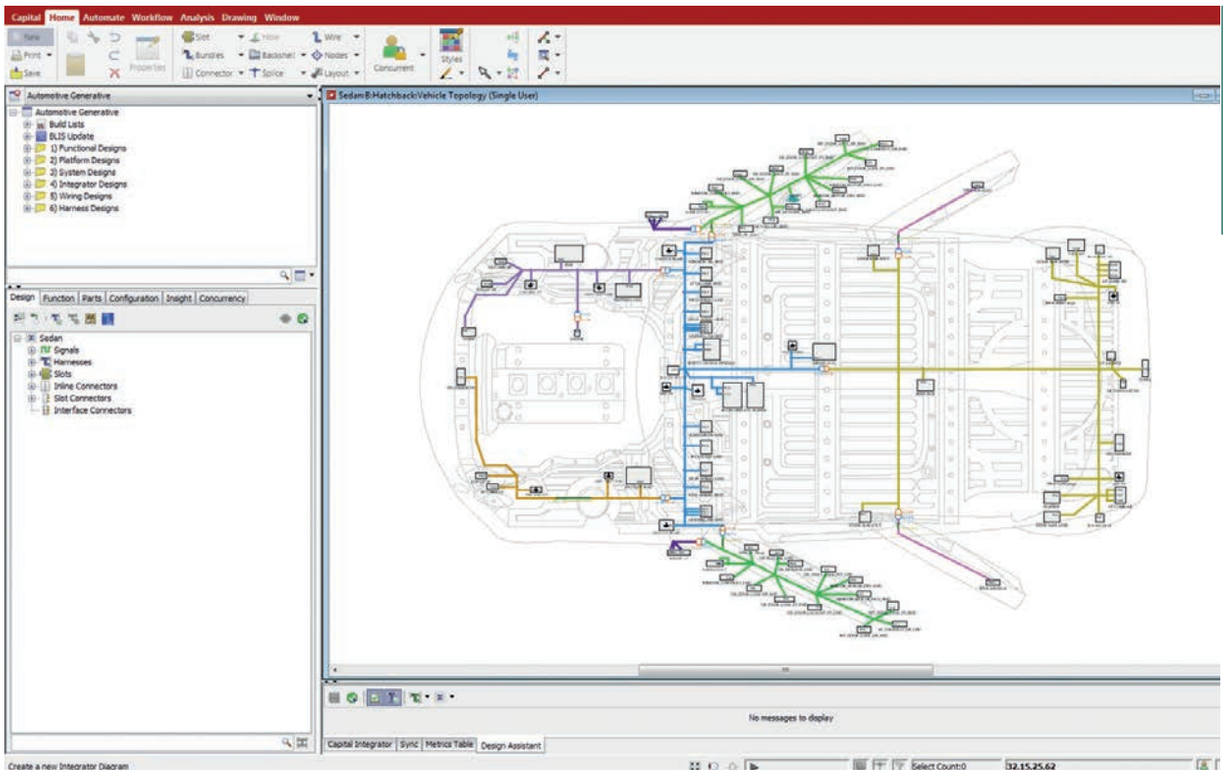
However, what's certain is the increasing degree of overlap between the autonomous and the electric domains, especially when it comes to E/E systems. A recurring theme in the recent literature on electric vehicles is how applying the 'X-by-wire' or 'drive-by-wire' labels really equates to 'drive-by-software', because the wires are carrying sensor and network information interpreted for actuation by software algorithms. Electrical interconnect design now often entails harnesses that include provision for messaging on networks – or rather, multiple networks, as between four and seven onboard networks isn't outlandish. That's true whether electric or plug-in hybrid electric (EV/PHEV), gas, diesel or LPG propulsion is used.

The most recent forecasts about the EV market prove the maxim that it's difficult to make predictions, especially about the future. Back in 2010, most expected a coming era of higher gasoline prices, which would help accelerate EV adoption. Instead, oil prices plunged, fueling the auto industry rebound, mostly through sales of internal combustion vehicles, especially crossovers and SUVs. However, despite cheap gas, as of last year, there are still 1.5 million hybrids and 500,000 EVs on the roads of the USA.

Still, a number of forecasts can be made with some confidence. First, there will surely be continued effects of the policy of the Chinese government in its particular form of command economy to promote the development of EVs. Many credible sources say that half the electric vehicles in the world will be made in China over the next few years (up to around 2022). So no matter where you are in the evolving automotive supply chain, if you're not focused in part on solving electrical engineering problems in this segment, for Chinese customers, you are at a severe disadvantage.

The Chinese government is enabling this market with financial incentives and a goal of two million domestic electric vehicle purchases per year by 2025.

Second, in the USA most of the buzz will remain about competition among affordable EVs, notably the



Mentor's goal is to multiply the effectiveness of automation with software, working with a 'system of systems' approach to projects where collaboration has not been attempted

Chevy Bolt and Tesla's Model C, boasting ranges that finally put American highway lovers at ease. Over the longer term, this step-up to the 200-mile range may be of only middling importance. After all, most global daily personal passenger vehicle use is well below current EV range averages.

It is generally the same EDS suppliers looking for business and winning it (with companies such as Faraday Future) as are competing to supply General Motors, Ford and Toyota's EV/PHEV vehicles. The new friends – the partner EDS suppliers chasing the hottest new EV vendors on the planet – are the old friends who have supplied Detroit for decades. To put it plainly: no one expects an emerging or new EDS supplier to compete at volume with the incumbents in the harness manufacturing market. Indeed, there may be real opportunity to disrupt the harness market since competition is not expected.

There's always been debate in the engineering community about how much electrical design work to outsource to the companies that specialize in this domain – experts such as Delphi, Yazaki, Leoni, Lear, Sumitomo and MSSL. Many of these suppliers use the Capital software tools from Mentor. The debate includes considerations of how critical the intellectual property surrounding the design of the electrical interconnects is. That is, just how proper is it for a company that designs finished goods to rely on critical component design that is beyond their control and their competence to validate?

The primary challenge facing the engineers working on electrics and hybrids is the cost and weight of the electrical distribution system – EVs and hybrids can contain as much as US$17,000 more E/E content than comparable gasoline cars, according to some estimates. This is why engineers spend countless hours scrutinizing their design for giveaways in the vehicle circuitry that will never be used. The most important design capability is modeling at a true systems level – abstracting the wired interconnects that will serve as the backbone for all vehicle functions, whether fulfilled by autonomous embedded software or human drivers – before working out the physical wiring.

Mentor is working in this 'system of systems' space to integrate the design information from different domains. The company's goal is to multiply the effectiveness of automation with software in cases where collaboration hasn't been attempted before.

The second challenge stems from the fact that those working on electric and hybrid vehicles are increasingly not traditional 'car people'. In the USA there are at least 200 software companies involved in this sector and within this group there is considerable heterogeneity – at least as far as can be determined by perusing job boards. Among the sought-after specializations are embedded software and Internet of Things, AutoSAR, GenIVI, Linux fast-boot engineers and many more.

The software world can be somewhat murky and ill-defined, and doesn't always meld with auto makers in terms of location, size, history, capability, demographic, market capitalization, inspiration, mission and corporate ethos.

An engineer at a well-known EV maker was once heard to say: "Why should we bother about process? We may be out of business in 10 months." Process is for people who were doing changes in a controlled, supervised, predictable environment, model year to model year, year on year, for a decade. Process is not as important for those trying to sprint to develop innovative vehicles before venture capital money runs out.

One of the management theorist Peter Drucker's more famous quotes is "culture eats strategy for breakfast". This is why, even as robot cars dominate the headlines, the biggest E/E design challenge of all may actually have little to do with mechatronics and software systems, and everything to do with people.

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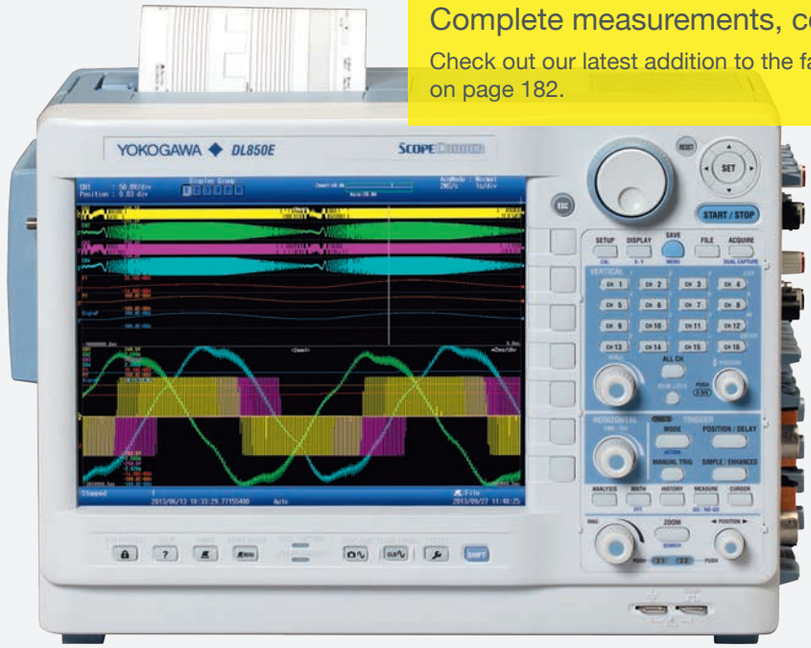

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Acoustics design

A sophisticated sound system that can produce an array of signals offers customized engine sounds for electric and hybrid vehicle acoustic refinement

The IPG5 actuator can be mounted directly onto the vehicle chassis

Kendrion's HAB128 sound actuator for external sound (front and back view)

A silent vehicle can represent a safety hazard. However, newly developed devices can now add sound to electric and hybrid vehicles to enhance the driving experience and conform to new safety standards.

Vehicle sound is a personal preference: every individual has a different idea of what sounds good and what is considered noise. An electric or hybrid vehicle, however, provides a completely different experience from the traditional ICE vehicle as there is virtually no acoustic feedback in electric mode to indicate speed, acceleration and deceleration. Most electric vehicle drivers appreciate the low noise level of their vehicles and quickly get used to the total absence of noise, especially from the engine.

Yet while drivers and passengers welcome the quiet comfort of an EV, the unexpected quietness of this new generation of vehicles can represent serious problems for pedestrians and others outside the vehicle. Since there is no sound from the engine, it is difficult for pedestrians to realize when a car is approaching from behind. That's why an acoustic vehicle alerting system (AVAS) has been legislated by several governments as a feature of future EV product lines.

A recent study of EV drivers, which was conducted by a large vehicle manufacturer, revealed mixed opinions on AVAS technology. While the vast majority of drivers consider it a very useful feature, many of them also like having the ability to switch it off in some situations as there are times when the sound can be unpleasant or even annoying.

This has led to the conclusion that while AVAS is definitely a vital technology, especially for EVs, the presence of such synthetically generated sound is not fully appreciated by all drivers. Another conclusion is that most, if not all, EV owners consider the low interior noise level to be a truly pleasant experience and do not really miss the typical acoustic feedback of driver vehicle interaction that drivers have become accustomed to.

EV manufacturers have developed different approaches to this. While some aim to simulate a certain acoustic response of the vehicle in line with changing driving situations, others have instead preferred not to employ any noise actuators at all to

influence the interior acoustics of their electric vehicles.

Another trend in the field of electric vehicle acoustic design is an increasing focus on controlled external sound emissions by an AVAS that is designed in such a way that it has certain effects on the interior perception of sound as well.

Automotive suppliers such as Kendrion are extremely familiar with the challenges of EV sound development. The company's experts can adapt to a wide range of manufacturing philosophies while keeping an eye on the reactions of the first adopters in a market still in the early stages of development.

"When used in conventional automobiles, sound systems provide an acoustic signature to improve the overall driving experience. This is a significant feature to increase driver and passenger comfort as well as develop and maintain brand identity. As an added benefit the actuators also mask a variety of noise sources that become more evident due to the absence of any dominant engine noise," says Michael Richter, head of electroacoustics development at Kendrion passenger cars.

Kendrion has developed a two-pronged product strategy to address the sound requirements for electric vehicles conforming to the upcoming standards.

The IPG5 is a sound actuator designed to induce structure-borne sound that is emitted to both the exterior and the interior of the vehicle. The highly compact unit has a diameter of only 55mm and can be mounted directly onto the chassis at any suitable location.

The HAB128 is an embedded actuator designed primarily to produce exterior sound. The actuator is equipped with a seismic transducer featuring a carbon sandwich membrane that provides a sound pressure of up to 85dB. The actuator generates bending waves that result in exactly the type of sound expected from an AVAS.

Both these models of sound actuator produce a warm and natural sound and are extremely compact. They offer an extended low frequency range, wide sound dispersion and a radiation pattern of up to 180°. Another benefit of the actuators is that the sound source cannot be localized acoustically. It seems to be omnipresent and appears to be part of the natural acoustic surroundings of the car, whether it is cruising through the city or traveling along a highway at high speed.

The Kendrion EV sound system solution consists of two hardware components: a sound actuator and an electronic control unit with CANbus interface and eight flashable sound profiles. All components offer IP6K/9K rating and are resistant against extreme temperatures as well as frequent exposure to dust and water.

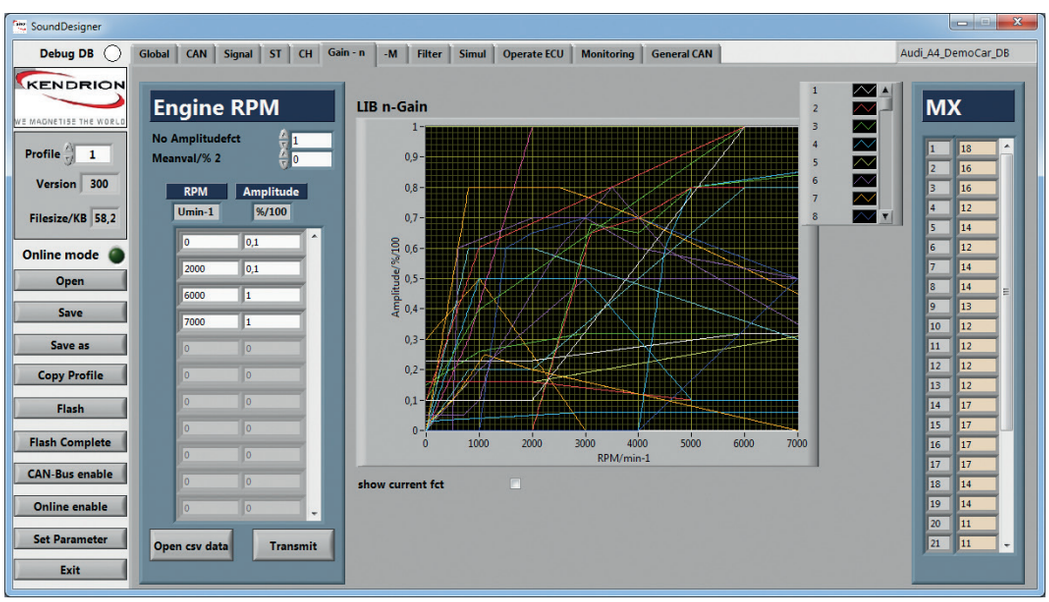
The intended interior and/or exterior sound can be developed with a special sound design software package. This system features a graphical user interface and creates soundtracks consisting of any combination of sampled and synthetically generated sound components. The sound system supports live editing, meaning that the sound pattern will change depending on parameters such as engine speed, torque, acceleration and deceleration. The required vehicle information, such as engine RPM and pedal positions, is derived via the CANbus from the vehicle's onboard controller and enables the generation of a situation-related ambient sound output that can be perceived both inside and outside of the vehicle.

There is one issue, however, that automotive sound designers are still unsure of. The majority of drivers have their idea of what a high-quality sports car or an elegant luxury limousine should sound like. But what kind of sound is expected from an electric vehicle? What will be considered a pleasant sound by the car buyers of tomorrow? Will they consider sound a necessary evil or welcome it as a contribution to an enhanced driving experience?

"It is hard to predict actual market expectations at the moment," says Richter, "but good automotive sound will always be sound that is only perceived subconsciously.

"Kendrion can deliver for the exact requirements for each vehicle – sound that will add to the overall driving experience without driver and passengers actually realizing why this is the case. That's why we work hard to make sound systems that are as inconspicuous and effective as possible."

Information on engine RPM can be used in the generation of situation-related ambient vehicle sound



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Cooling technology

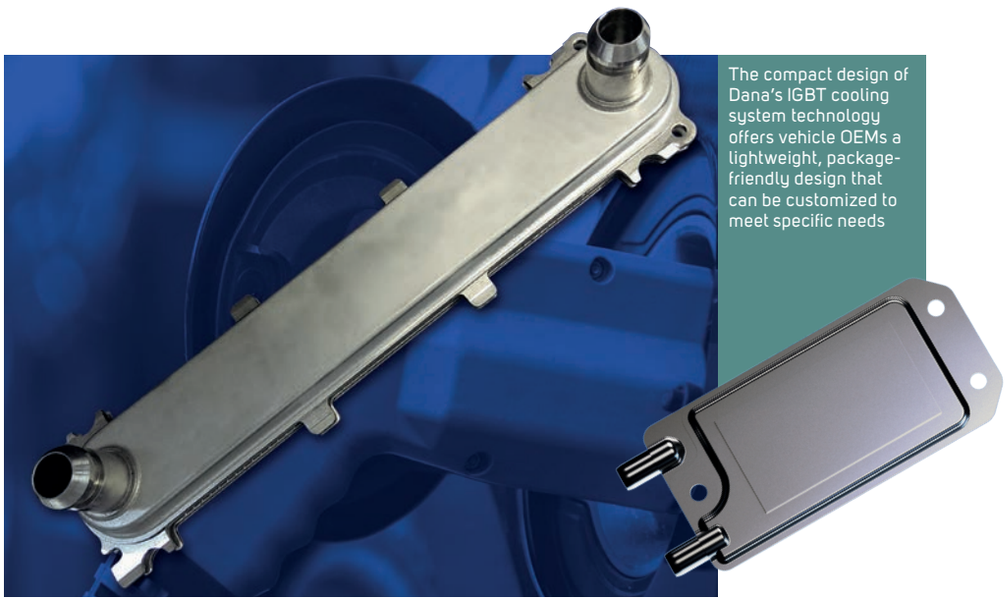
These Long, aluminum, double-sided chip cooling solutions are precision-engineered for high thermal performance, reduced vehicle weight and lower manufacturing costs

OEMs require cooling solutions that reduce costs and enhance vehicle efficiency. Long double-sided insulated gate bipolar transistor (IGBT) cooling systems produced by Dana enable electrified vehicles to operate smoothly and consistently with long-lasting performance.

As OEMs continue to design new electric vehicles that can compete with traditional passenger cars and achieve higher speeds, the need for innovative cooling solutions grows. The emerging generation of electrified vehicles requires both improved battery thermal management, as well as power electronics cooling for IGBT devices used in the DC/AC inverter power control units. Increasingly, the extreme operating conditions of vehicles result in high levels of electrical current and unwanted excess heat in IGBT inverter devices. The experts at Dana are focused on finding new ways to meet these thermal challenges, to ensure electric vehicles remain safe and efficient.

Traditionally, these types of cooling systems have been made with copper, which offers good conductivity. Although copper is still used when necessary, it is expensive and not the most lightweight solution. Now OEMs are looking for lighter, cost-effective alternatives, driving Dana's move toward aluminum.

Dana's know-how in this area has been honored at the highest levels of the automotive industry. The *Automotive News* Premier Automotive Suppliers' Contribution to Excellence (PACE) Awards named Dana's double-sided chip cooling technology a finalist in 2016. Among global automotive suppliers, the PACE Awards are recognized as the industry benchmark.



The compact design of Dana's IGBT cooling system technology offers vehicle OEMs a lightweight, package-friendly design that can be customized to meet specific needs

Leveraging Long's expertise in thermal management, Dana is the first manufacturer to introduce double-sided IGBT cooling with an all-aluminum fluxless brazed construction. As aluminum is about 70% lighter than copper, this technology helps OEMs reach their weight reduction targets.

Dana's reliable sealing technology and fluxless brazing construction also provide considerable benefits. With flux brazing, contaminants and debris are common. Dana's proprietary fluxless, continuous aluminum brazing process enables precision cooling products to be made with cleaner parts. This minimizes coolant contamination to maintain low conductivity in the power electronics cooling circuit.

Another key advantage of Dana's IGBT cooling technology is its flatness. Without this, the IGBT chip can overheat due to decreased thermal resistance. The flatness of the device and, in turn, full surface contact, improves the heat transfer rate, ensuring a reliable power electronics solution.

"Faster vehicles demand more advanced cooling solutions – and that's what Dana delivers," explains Nick Kalman, technical business development manager, Dana Power Technologies Group. "Dana develops cooling solutions that help the electric vehicle industry expand. With production-ready solutions such as double-sided IGBT cooling, our engineers are developing unique methods to improve these vehicles – reducing the number of components and boosting efficiency."

Dana continues to break new ground with its cooling technology. In an effort to reduce packaging size and improve lightweighting, its engineers are developing next-generation IGBT cooling technology with fewer layers within the IGBT cooling stack, enabling even higher power without compromising on safety and reliability.

The company's cooling expertise has been recognized by the China Decision Makers Consultancy several times with technologies that can be found in electrified vehicles globally. In 2016, Dana was named Outstanding Power Electronics Solution Provider of the Year, while the company earned Best Battery Solution Provider of the Year honors in both 2015 and 2016.

Providing corrosion resistance and recyclability, the company's aluminum IGBT cooling system is advancing thermal-management technology to meet even the most stringent OEM requirements. Dana is an established supplier with the ability to take battery cooling solutions to market quickly.

Today, leading inverter and drive control manufacturers rely upon Dana's IGBT technology. With full-scale production and manufacturing processes in place, systems can be custom-designed in a compact, lightweight package. Dana believes that its unique innovations have positioned it at the forefront of the EV segment for years to come.

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Dual-clutch transmission

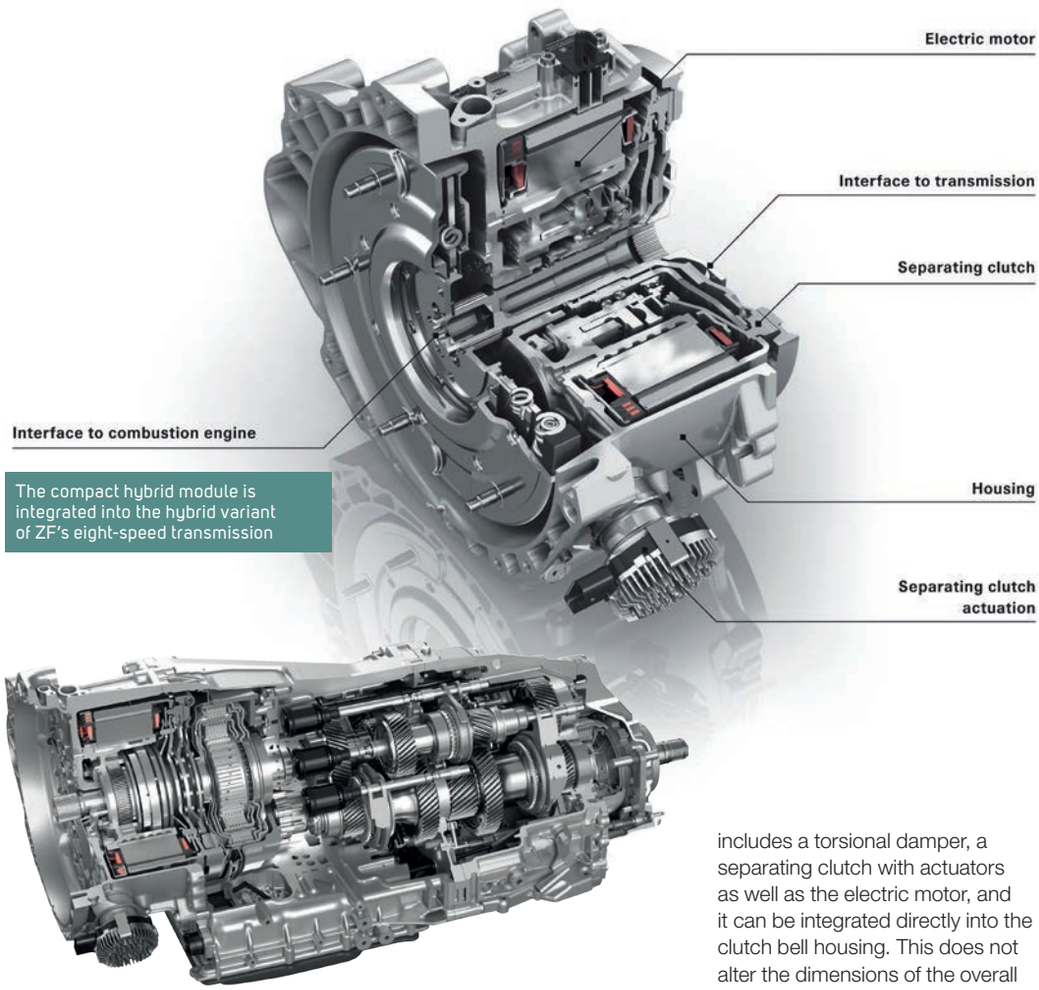
An all-new modular hybrid transmission combines swift shift times with extremely high levels of efficiency and comfort for sports cars

With an all-new eight-speed dual clutch transmission (8DT) as a basis, ZF and Porsche have worked in close collaboration to develop a modular hybrid transmission kit for sports vehicles, catering for current and future drive trends. The new sports transmission for rear-wheel and all-wheel drives is said to distinguish itself from the competition with its incredibly rapid shift times, high levels of efficiency and flexibility.

A major development goal was to make electric power an option for this transmission. Thanks to a new gearset design it was possible to integrate a 100kW hybrid module without increasing the length of the transmission, compared with the current 7DT sports transmission. Another goal was to integrate an all-wheel distribution option, driving the front axle in the most fuel-efficient manner possible using a hang-on clutch. Power loss in the basic transmission is reduced by up to 28% thanks to several factors: The gear spread, which at 11.17 is very high; an additional eighth gear; a demand-driven lubrication system; and the optimized electronic TCU, which was developed and produced independently by ZF.

Torque resistance, sporty performance, high levels of comfort and the efficiency of the new eight-speed dual clutch transmission surpass that of the current 7DT, while its size remains almost completely unchanged. Power loss can be reduced by up to 28% and the incredibly quick shift times have been improved even further.

The 8DT is available for front longitudinal configuration in four variants (standard, all-wheel drive, hybrid, all-wheel hybrid) in three torque classes, to a maximum of 1,000Nm. The torque classification is defined by the configuration variety of the dual clutch modules, with the basic transmission and gearset remaining the same. This is also true for the transmission hydraulics, shift system, parking lock and control unit, including software.



The compact hybrid module is integrated into the hybrid variant of ZF's eight-speed transmission

ZF's eight-speed dual clutch transmission forms the basis for a new flexible modular system

In order to make the 8DT basic transmission as small and compact as possible, a new gearset concept with two countershafts and one summation shaft was constructed. The fixed gears, which are all located on the transmission input shafts, can be used several times, resulting in fewer wheel levels and making the basic transmission much shorter in length. This was the only way to maintain the required length of the hybrid module and integrate it into the limited installation space.

This gearset architecture offers another advantage. As an optional variant, ZF has created a customized compact hybrid module. This includes a torsional damper, a separating clutch with actuators as well as the electric motor, and it can be integrated directly into the clutch bell housing. This does not alter the dimensions of the overall transmission but has considerable impact on its properties. With 100kW peak output, 55kW continuous power and 400Nm torque, a vehicle can accelerate up to 140km/h on pure electric power alone. With this technology, all other hybrid functions are also possible – from recuperation to boost mode.

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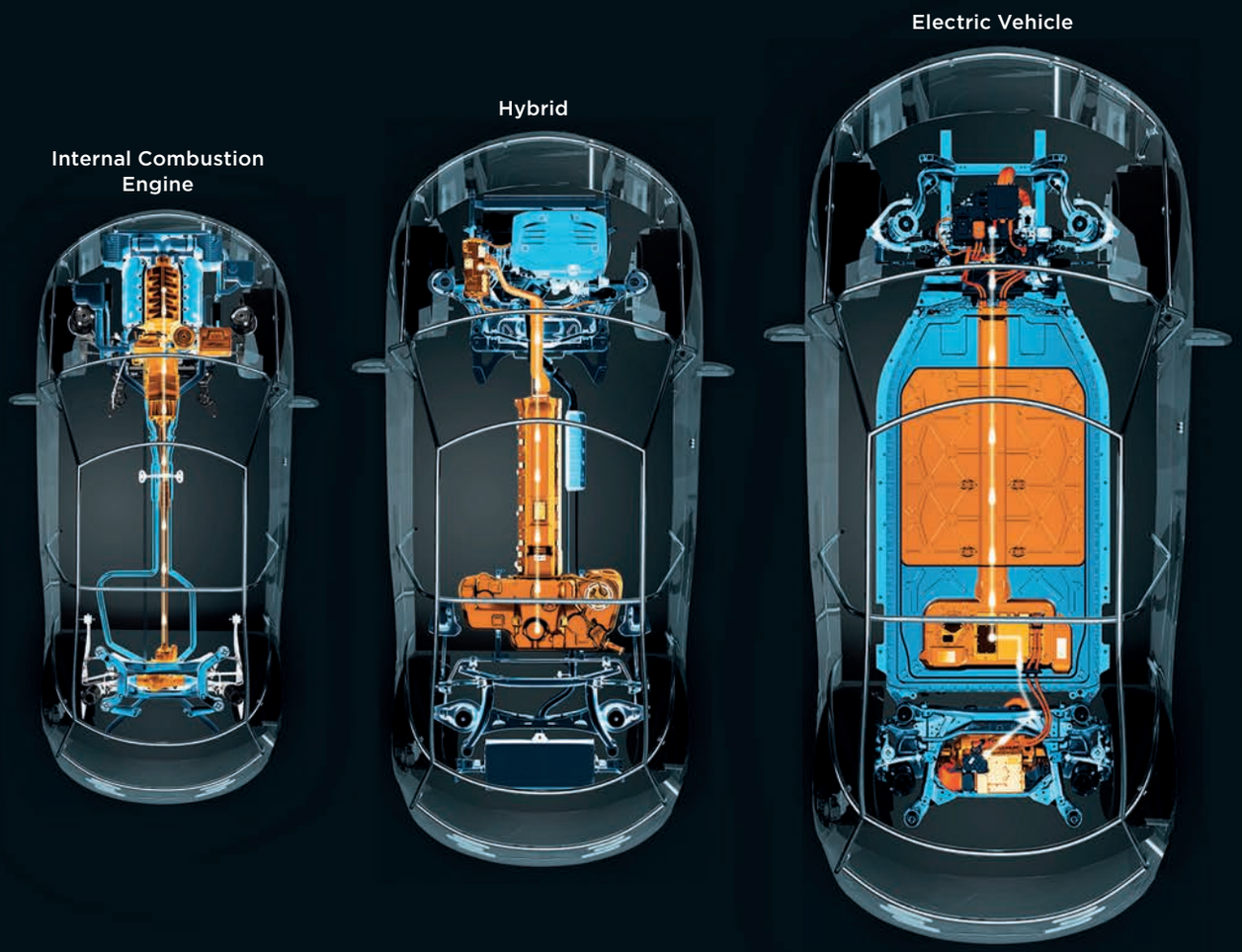

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Recognized as a pioneer in the modern battery testing industry, Maccor started operations in Tulsa, Oklahoma, in 1986, dedicated to the development of high-performance battery test systems. With a nucleus of engineers experienced in emerging battery technologies and computer control systems, the company has enjoyed continued and rapid growth.

In the past, the only commercial products available for the evaluation of battery performance had been designed and built specifically for lead acid vehicle battery applications. These were relatively high-power units without any high degree of accuracy, had limited test programming capabilities, and collected data relatively slowly. In the mid-1980s, when there was a resurgence in new battery technologies, it quickly became obvious that the available battery test systems were inadequate.

Maccor's founders conceived of an entirely different design for a battery test system. The result was a system that provided extremely accurate results, collected test data at high speed, would test large numbers of batteries at the same time, and that could be programmed to perform virtually any test sequence required.

Over the past 30 years, Maccor's innovative technology has enabled the company to become the industry standard for most companies that are involved in the research, development, quality control and evaluation of cells and batteries for a wide range of products and cell chemistries. This solid foundation provides Maccor with the knowledge, experience and resources for the future. Today, the company has earned a greater than 80% share of the US business in its product area, and has a major share of the European market, as well as an expanding market in Asia. With more than 2,000 systems in regular operation in over 50 countries, there is no doubt that Maccor is a true leader in the battery test industry.

Maccor is a USA-based developer of high-performance battery test systems that offer high levels of accuracy and customization

Maccor designs all its own hardware and software. Most systems are customized to meet a customer's specific requirements, and from time to time customers also request customized features in the software. Over the years, this has provided Maccor with a wealth of knowledge and experience in the design and performance of these systems. This experience is being used to develop systems for the future, with even higher levels of performance, additional advanced features and capabilities utilizing new computer technology.

Maccor is confident that it offers the widest range of features and capabilities of any manufacturer for this type of equipment. If the company's standard equipment doesn't meet a customer's exact needs, Maccor can customize equipment to specific requirements.

In early 2014, Maccor announced an exclusive agreement with the Scientific Instruments business unit of Ametek Advanced Measurement Technology. Scientific Instruments comprises the Princeton Applied Research, Solartron Analytical and Signal Recovery businesses of Ametek. This agreement enables Princeton Applied Research or Solartron Analytical impedance analyzers to be integrated with a Maccor test system to perform EIS experiments *in situ*. These integrated solutions result in: higher productivity by switching automatically between Maccor's test equipment and Ametek's electrical impedance instrument; greater data integrity with more reliable and reproducible test results; and reduced idle time and in-test waiting caused by operators having to move test devices from one instrument to the other.

Recently, Maccor and Voltaiq announced a marketing agreement. Voltaiq is a leading supplier of data analytics whose vision is to provide the leading informatics platform and expertise for optimizing energy device performance throughout the product lifetime. The Voltaiq Battery Intelligence software platform integrates seamlessly with Maccor's leading test equipment, providing a completed end-to-end solution for battery testing, analysis and optimization.

In 2009, Maccor moved to a newer and larger facility due to the increased demand in sales volumes. In 2015, the facility was expanded due to additional increases in demand and sales volumes.

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E-turbo performance

With an improved understanding of new materials and their application, substantial performance gains can be achieved in high-speed motors

The demand for continuous improvement drives engineers to push the capabilities of existing designs while adding innovations to augment and/or replace existing technology. New materials applied to these systems and novel applications of technologies can accomplish this goal at minimal risk.

An e-turbo (a high-speed machine added to a vehicle in the form of an electronic turbocharger) is an example of where improved materials can facilitate a new application of an existing technology. This relatively low-cost solution increases the drivetrain's power density. A drivetrain equipped with an e-turbo can therefore either generate more power or, thanks to the application of the e-turbo, the size of the internal combustion engine can be reduced while performance is maintained.

The development of high-speed machines comes with a number of challenges which, until recently, had prevented widespread adoption of this technology. Broadly speaking, these challenges can be split into two main categories: mechanical forces from the rotational inertia; and losses.

In addition, high-speed machines require a high-speed switching drive. Although incremental improvements have seen the technology evolve, current drives still inject high-frequency harmonics in the stator coil. The image displayed on the left of Figure 1 shows a typical current waveform in a high-speed machine. Drive harmonics couple with the spatial harmonics from the geometry and induce eddy currents in any conductive material exposed to these harmonic fields.

To deal with the mechanical forces, traditionally an inconel sleeve is placed around the rotor. This material is conductive, which means it will generate losses due to the harmonic fields. Arnold's Wraptite carbon-fiber sleeve is non-conductive and is therefore more thermally efficient. Carbon fiber is less dense than steel, providing better balance and rotor dynamic characteristics. The low density also provides higher containment capability as it reduces self-induced stresses at higher speeds. A Wraptite sleeve can address the mechanical forces with the added benefit of reducing losses. This technology can also facilitate faster rotor speeds with increased efficiency.

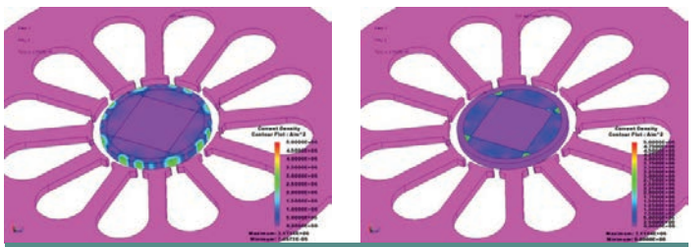

Figure 1: Typical current waveforms in a high-speed machine application. Represented here are an inconel sleeve (left) and carbon-fiber sleeve (right)

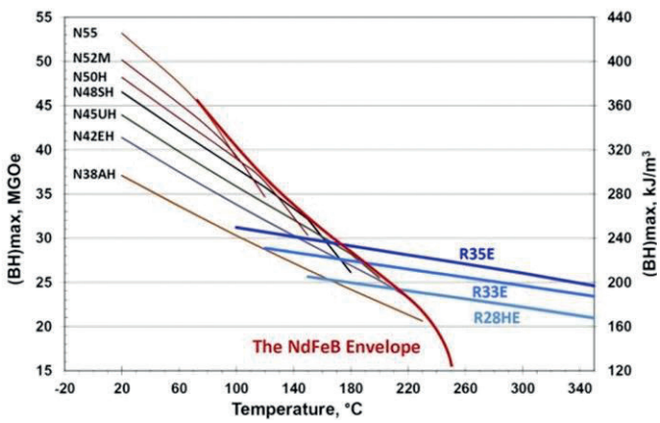

Figure 2: Remanent flux density vs temperature for different materials and grades

Efficiency of 100% in electric machines can never be achieved, therefore effective means to reduce power loss are critical to achieving high performance. These losses manifest themselves in the form of heat; high temperatures can be detrimental to material performance. Environmental factors and physical space constraints can cause high operating temperatures of an e-turbo, so these systems require magnets with high resistance to thermal demagnetization.

Neodymium-based magnets have a reversible temperature coefficient of 0.11%/C, which can lead to a huge reduction in performance in high-performance machines. Samarium Cobalt (SmCo) magnets on the other hand, have a reversible temperature coefficient of 0.035%/C. The graph in Figure 2 shows the remanent flux density (Br) versus temperature for different magnet materials and grades. Even though the neodymium magnet has a higher residual field strength at room temperature, it quickly crosses the SmCo line as the operating temperature increases. The lower demagnetization value of SmCo magnets compared with neodymium magnets means it achieves consistent performance across a wide temperature range.

A machine equipped with Recoma SmCo magnets in the rotor will have a more consistent output torque at different temperatures. This makes the machine's performance more predictable and results in higher efficiencies across the entire operating range.

Additional efficiency gains can be made by switching the stator material to a low-loss lamination steel. Typically, lamination steel thicknesses range between 0.3mm and 0.5mm. Arnold can provide much thinner lamination steels.

Arnold's precision thin metals division manufactures a line of thin gauge non-oriented silicon steel specifically for high-frequency motor applications – Arnon 5 (0.127mm thick) and Arnon 7 (0.178mm thick). The company's non-oriented silicon steel materials reduce losses and increase efficiency by limiting eddy currents. Typical machines would use a lamination steel similar to a 29 Gauge M19. A high-speed e-turbo with an Arnon 5 stator could reduce iron losses by up to 50% when compared with traditional lamination steel.

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Smart test technologies

A suite of innovative test solutions for ECU software for hybrid and electric vehicles provides the ultimate toolkit for development of the next generation of e-mobility

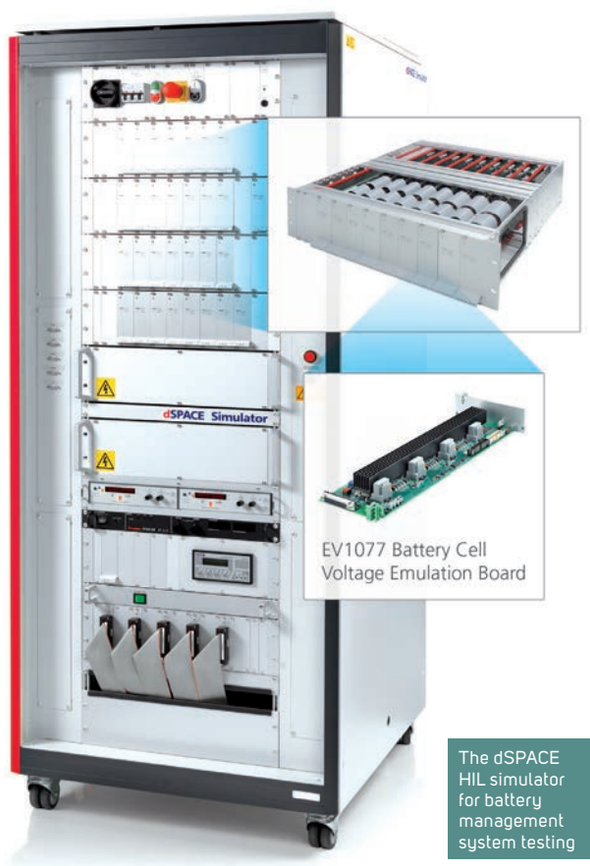
In the context of future vehicle concepts and environmentally friendly power supply systems, terms such as 'smart charging' and 'smart grid' are increasingly used. But what exactly do they mean? During the charging process, the electric vehicle and the charging station communicate with each other to optimize the energy exchange process and schedule charging times – smart charging. At the same time, smart energy systems are paving the way to a green energy supply. They generate power from infinite natural resources, while linking energy generation, energy consumption control, and energy storage to achieve optimal balance between energy supply and demand.

These fairly new concepts of vehicle powertrains and power generation are important trends in the automotive and electric power industries. The two areas are closely linked. For example, the charging behavior of electric vehicles has to be analyzed and controlled so that power grids are not overloaded. At the same time, the batteries of electric vehicles can be used as mobile storage systems for the grid.

The interconnectedness of electric vehicles and the electricity grid means that development in electromobility cannot focus solely on the vehicle. It is also vital to consider the charging technology and integration in the electricity grid.

For both existing and established power electronics topologies, dSPACE provides complete library elements for a B6 bridge circuit through to a three-phase induction motor. Special requests and customer demand for devices such as DC/DC converters are covered by engineering solutions. However, many applications are becoming more complex and individualized.

Developers of electromobility applications are facing a wide variety of challenges in three principal areas – the vehicle, the charging process and the power grid



The dSPACE HIL simulator for battery management system testing

Electric and hybrid vehicles have electrical systems with different voltage levels.

The need for HIL simulation of power electronics systems is also increasing in the smart grid sector. Especially for these systems, which have inherently different setups, simulation based on ready-to-use library elements is not always useful. Individual engineering models often involve a large amount of work. With the new Electrical Power Systems Simulation Package, users can create real-time simulation models directly from the circuit topology, for both processor- and FPGA-based simulation.

The batteries used in hybrid and electric vehicles, as well as stationary storage systems for grid stabilization, usually consist of lithium-ion cells with a nominal voltage of 3.6-4.2V. These are connected in series to achieve voltages of more than 800V. Just one faulty cell in the series affects the behavior of the entire battery. A battery management system (BMS) is required to control these high-performance batteries, and cell balancing is needed to keep all cells' state of charge at the same level at all times. In addition, the BMS has to estimate the battery's current capacity.

As a result of this, a rapid control prototyping (RCP) system has to meet the strictest real-time requirements for the development of control algorithms. There are also specific requirements for measuring the cell voltages and activating cell balancing. dSPACE RCP systems effortlessly achieve the required accuracy of 2mV for voltage measurement and 1ms for the update rate for up to 300 cells.

Such systems are classified as safety critical and comprehensive testing is indispensable. Closed-loop HIL testing requires a real-time capable battery simulation model and a cell voltage emulator that outputs the analog terminal voltage. Both of these are provided by the dSPACE Automotive Simulation Model Multicell Model and the EV1077 Battery Cell Voltage Emulation Board.

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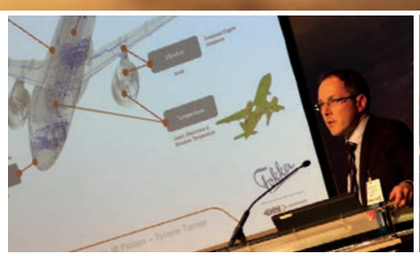

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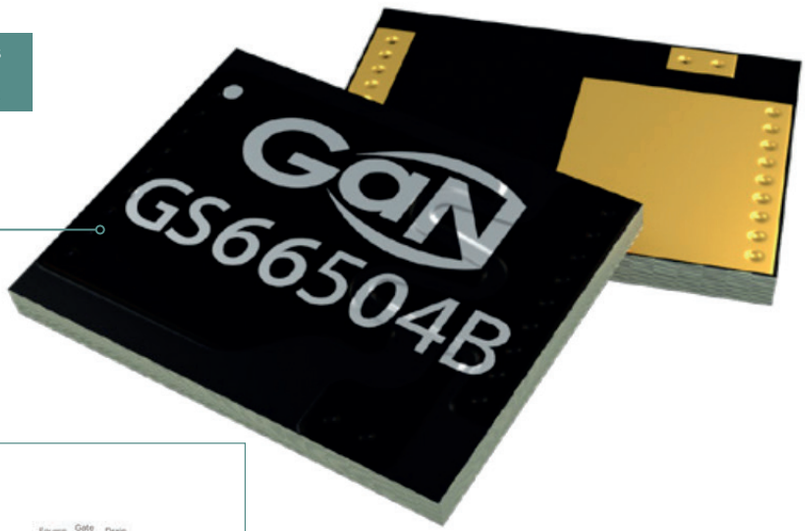
Wider EV proliferation

Due to their ability to handle high voltages and faster switching speeds, power discretes that use wide bandgap compounds may be the foundation upon which future powertrains depend

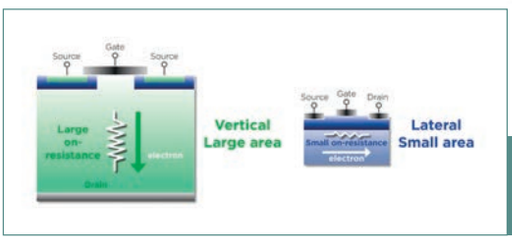
The European Union has set the ambitious objective of reducing its greenhouse gas emissions by at least 80% by 2050. The automotive industry's contribution to this will need to be extremely large. In the USA, though the Trump administration is likely to conduct a review, the Corporate Average Fuel Economy (CAFE) standards have been instrumental in improving the environmental credentials of vehicles. If these standards remain unchanged, OEMs will need to achieve drastic fuel economy improvements across their ranges, with a 49mpg average expected by 2022.

Much greater market uptake of electric and hybrid electric vehicles is essential if these targets are to be met. Analysis by Bloomberg New Energy Finance has predicted that EVs will constitute 35% of annual worldwide vehicle shipments by 2040 (which translates to 41 million units). However, there is still a huge gulf between this and what is seen today. With the exception of Norway (where over 20% of vehicle sales are now plug-in electric vehicles) and the Netherlands (close to the 10% mark), leading global economies, including Germany, the USA, China, France, the UK and Japan, all have figures below 1.5%.

The core challenge that must be overcome if the industry is to see a major switch from ICE vehicles to HEV/EV alternatives concerns the underlying power technology. The initial investment of buying the car has proved off-putting for buyers. These high prices are mainly down to the cost of the power inverter and energy storage elements. Other key challenges are the range between recharges and the length of time the charging process takes. Again, these stem from the power electronics employed.



GaN Systems' GS6650x series of GaN-based transistors for electric and hybrid deployment



Comparison of the form factors of a conventional MOS-based silicon transistor with Panasonic's X-GaN devices

Improving power efficiency levels will mean that inverters can be made smaller and, as a result, more cost-effective. It will also mean that they can be made lighter, enabling vehicles to cover longer ranges. Meanwhile, the advent of wide bandgap technologies, such as gallium-nitride (GaN) or silicon-carbide (SiC), offers a way of avoiding the power losses inherent in silicon. Both GaN and SiC exhibit far higher electron mobility and lower RDS[ON] parameters than silicon. They also support elevated switching speeds and have higher breakdown voltages and greater thermal conductivity (particularly SiC). Increasing power conversion efficiencies can deliver a range of benefits around thermal management. Heatsinking, as an example, becomes less of a concern, resulting in lower bill-of-materials expenditure and less space being taken up, while still maintaining extremely high levels of reliability.

Optimized for the elevated-voltage systems used in HEV/EV designs (up to 650V), the GS6650x series of GaN-based transistors from GaN Systems dispense with the need for bus bars (which take up space), thanks to the company's proprietary island technology. Instead, the transistors draw current off the chip vertically. This reduces inductance losses and enables greater figure of merit (FoM) values. This helps mitigate the trade-offs between saturation voltage and switching losses. Its GANPX packaging ensures inductance and thermal resistance are kept in check, despite the compact form factor.

Similarly, the devices that make up Panasonic's X-GaN enhancement-mode GaN power transistor offering each have heightened breakdown voltages (above 600V), while requiring minimal PCB real estate and only a limited number of additional passive components.

GeneSiC has combined advanced insulated gate bipolar transistors that exhibit low-loss operation with SiC diodes on its GA100SIC series. By replacing conventional silicon-based freewheeling diodes with SiC-based Schottky rectifiers, it is possible to boost switching performance substantially.

These are just a few examples of product innovations in SiC and GaN that automotive engineers should consider, as they look to implement next-generation power inverter technology. The potential of these emerging semiconductor materials is only just being recognized.

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In hybrid and electric vehicle applications, circuit protection is more important than ever, but finding the right solution can be challenging

Electric and hybrid vehicle battery packs include charge balancing/equalization circuits and a pack management circuit, which protects against overcharge, overdischarge, short circuits and thermal overloads (Figure 1). They incorporate a number of features.

A sense line fuse can be seen at (A). Up to 200 sense lines may be used to monitor the state of charge and health of each cell by measuring the voltage. Theoretically, shorting can happen between random sense lines, depending on failure modes.

Located at (C) is the cell monitor IC overvoltage protection. This protects the cell monitor's low-voltage input terminals from transients. Hot plug transients occur during battery pack assembly and maintenance; other transients can be induced from systems such as the charger, inverters and motor drives.

Overvoltage/ESD protection for daisy chain I/F communication is located at (D). The circuit protection device chosen should have a low capacitance, low clamp voltage, small form factor and a wide power capability range.

A high-voltage TVS across the battery string (E) provides transient protection – for example, hot plug.

Overvoltage/ESD protection for the microcontroller is situated at (F). CAN lines can be subject to overvoltage stress from ESDs or transients from other systems.

High-voltage/high-current fuse for power line protection (G) is the last line of defense against excessive current or short-circuit events in the high-power system.

In a typical onboard charger for electric and plug-in hybrid electric vehicles, a bridge rectifier at the input is followed by a power factor correction (PFC) circuit and a full-bridge DC/DC converter.

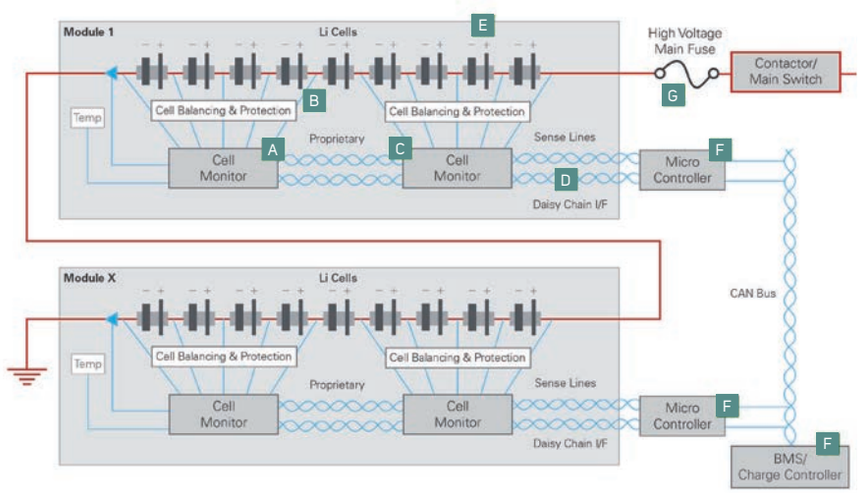


Figure 1: Circuit protection in an EV/ BEV battery management system

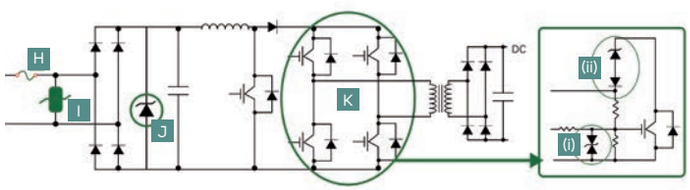


Figure 2: Bridge rectifier, PFC and full-bridge DC/DC converter and protection devices

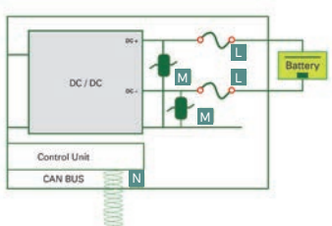


Figure 3: Protection from DC link overcurrent, overvoltage and CANbus transients

Figure 2 demonstrates a bridge rectifier, PFC and full-bridge DC/DC converter and protection devices. It also shows a number of features.

AC input line(s) fuses are situated at (H). These require automotive-grade fuses that can conduct high currents at up to 250V AC single phase, high interrupt rating, and the ability to withstand vibrations, surge transients and thermal cycles.

AC input line(s) transient protection can be seen at (I). The AEC-Q200-approved metal oxide varistors required must withstand elevated temperatures and offer AC line working voltages.

DC link capacitor protection can be seen at (J). Fast-acting automotive-grade TVS diodes can protect these costly parts.

Gate overvoltage protection is located at (K(i)). TVS diodes offer a fast response, high surge capability and a high level of reliability.

Active clamping protection at (K(ii)) provides direct feedback of the collector potential to the gate. If the collector-emitter voltage exceeds the clamping element's breakdown voltage, current flows to the gate, raising gate potential and reducing the collector current slope, resulting in a stable condition. The design of the clamping element determines the voltage across the IGBT.

Figure 3 shows a protection system from DC link overcurrent, overvoltage and CANbus transients.

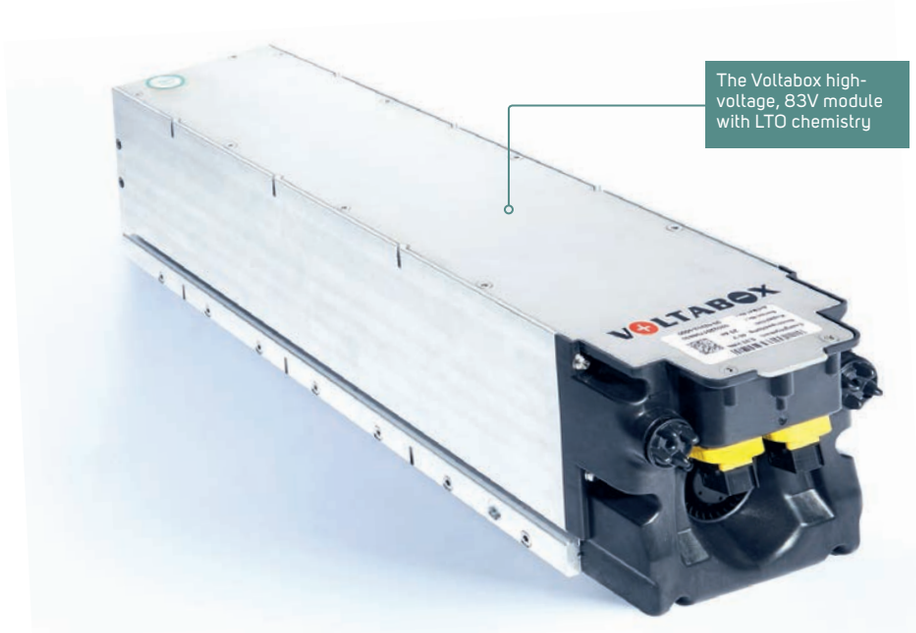
At (L), high voltage DC link overcurrent protection helps clear dangerous short-circuit conditions.

High-voltage DC link overvoltage protection at (M) clears overvoltage transients introduced by switching actions (hot plug) or other systems.

CANbus – ESD and transient protection is found at (N). The OBC communicates with other systems via CANbus. CAN lines are often subject to overvoltage stress from ESD or transients introduced from other systems.

Lithium titanate batteries

LTO technology looks set to be a game-changer for the public transport industry, offering new possibilities for energy storage at an attractive total cost of ownership



The Voltabox high-voltage, 83V module with LTO chemistry

Originally, Voltabox has chosen lithium iron phosphate (LFP) chemistry for application in its battery systems due to its intrinsic safety features (reduced possibility of thermal runaway) and high discharge capabilities. Many Voltabox battery systems are installed in vehicles in cities across Europe and the USA. Voltabox-equipped buses are able to tackle steep inclines with ease. The company develops its systems based on standardized, cutting-edge battery modules. A variety of configurations and customized battery systems can be created.

Now the company has introduced new, sophisticated lithium titanate (LTO) based batteries for buses and other applications.

Driven forward by a focus on electromobility, there has been a fundamental rethink by traffic authorities. In trolleybuses, integrated battery systems have mainly been used in situations where the electricity supply is not available, for example due to roadworks. However, coach operators are now looking to expand their networks by integrating a battery system into the normal operation of the bus. The additional range conferred by the battery boosts the customer service offer, and results in an increased number of discharge and charge cycles.

The company offers numerous modules with LTO chemistry including, for example, a high-voltage module at 83V nominal. This robust and powerful module has an extremely long service life and has been designed to accommodate the tough demands of electric bus applications. The 83V module can be scaled up for systems up to 830V.

Meanwhile, with the increasing requirements of legislation, Voltabox is in the process of developing an advanced new standardized system unit for application in electric buses. This standard container will be certified according to the most stringent regulations, such as ECE R100 rev. 2.

EoL test of a liquid-cooled LTO module


LTO-based trolleybus battery system

The development of Voltabox's reliable and proven modular concept into an independent standalone system marks another milestone for the company. With these units, more cost-effective solutions for a broader range of applications can be realized – with an even quicker time to market. This is because an integral number of those systems can be combined to form one battery system. At the same time, they also offer unique hot-swap capability.

The full range of Voltabox's cooling solutions, including active and passive air-cooled, as well as high-performance liquid-cooled systems, can be integrated. To complete the package, Voltabox provides its advanced proprietary battery management solutions for a safe, reliable and powerful battery system that can be seamlessly integrated into the vehicle. Voltabox has achieved compliance with the Buy America Act on several trolleybus projects – in 2014 and in 2016. From its locations in Delbrück, Germany, and in Austin, Texas, USA, the company provides solutions that are locally designed and manufactured in Germany as well as in the USA. The company is an expert developer of advanced, customized Li-ion battery system solutions.

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INQUIRY NO. 511

High BMS accuracy

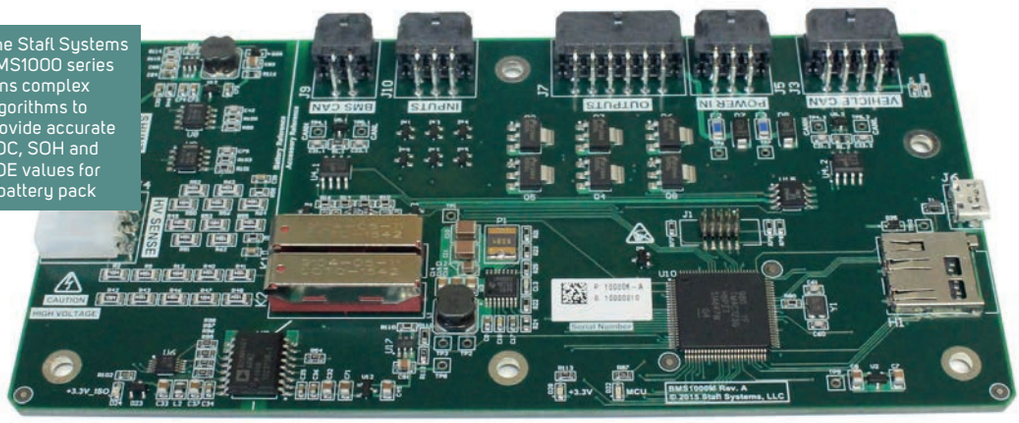
The accuracy of the SOC, SOH and SOE calculations provided by a battery management system are increasingly becoming a critical differentiating factor for many applications

The accuracy of the state of charge (SOC) calculation for a battery pack throughout its life is becoming a defining feature of a battery management system (BMS). Until now, a standard SOC accuracy error of 5-10% has been tolerated. However, as weight, volume and cost pressures reduce the capacity margin that is integrated in battery packs, achieving accuracy closer to 1% is critical.

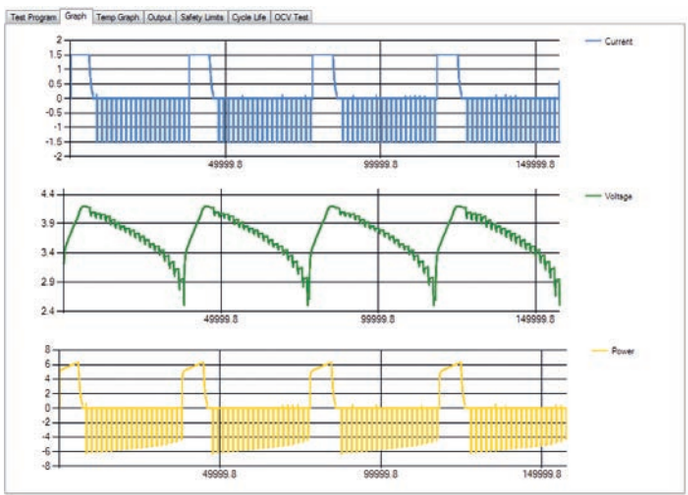
To achieve 1% accuracy of SOC, standard coulomb counting and open circuit voltage lookup table methods are insufficient. A more detailed, internal model of the cell that includes temperature dependence and impedance effects is required. The cell model itself is well known; indeed many academic papers describe complex lithium-ion cell models in great detail. The difficulty is generating the sheer volume of data required to ensure that the model matches reality.

Most battery management systems use data provided by the cell manufacturer in data sheets or technical specifications to drive their algorithms. This data often lacks the necessary detail and is occasionally optimistic about real-world cell performance, meaning that the performance experienced in the field may not meet the performance level expected in the design.

To address this issue, San Francisco-based Stafl Systems has developed an automatic cell characterization system that generates valuable cell test data across a number of temperature and discharge rate profiles. By independently testing a number of sample cells, this system can generate the data needed for a highly accurate SOC calculation for a new battery pack design. Using this system, Stafl Systems offers a cell characterization service to its BMS customers to enable packs using this system to approach 1% SOC accuracy.



The Stafl Systems BMS1000 series runs complex algorithms to provide accurate SOC, SOH and SOE values for a battery pack



An automatic battery cell tester generates the valuable multiparameter data that is necessary for successful application of highly accurate BMS algorithms

While generating enough initial data is important in achieving accuracy at the beginning of the life of a battery pack, the pack's performance will change with use and age. Therefore, an accurate SOC algorithm must continue to adapt to the real-world performance of the pack. In order to do this, Stafl Systems' BMS products use a built-in learning algorithm that measures and adjusts the predicted pack performance to match the actual measured pack behavior. This learning mechanism, coupled with a state of health (SOH) and a cell impedance growth algorithm, generates pack performance data that enables the user to confidently get the most out of the battery pack for their application.

Highly accurate SOC and SOH calculations are important, but there is another calculated value that can be very helpful for an application – the safe operating envelope (SOE). An SOE algorithm continuously broadcasts the maximum charge and discharge current that the pack can accept at any given time, due to the internal state of the cells. This varies with SOC, SOH and temperature. This calculated value allows the application system controller or vehicle control unit to ensure that it operates the pack within this envelope, avoiding potential safety faults leading to pack shutdown. This also avoids the need to include complex battery modeling code within the application controller, freeing up a program's development team to focus on other critical tasks.

To meet these requirements, Stafl Systems, through its BMS1000 series, offers a high performance, scalable BMS solution that can accurately generate the operational information needed to ensure the safe and reliable operation of a lithium-ion battery pack.

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INQUIRY NO. 512

A battery revolution

A new compact battery measuring just 80mm in height can be integrated into future battery electric vehicles that provide more comfort and improved driving performance

The global demand for battery electric vehicles in the sedan segment – which provide more comfort and performance while offering the same low-slung sporty seating position – is growing at a fast pace. These vehicles require batteries that not only meet the power and efficiency requirements, but can also be integrated into limited installation spaces. With its 80mm batteries, AVL offers a revolutionary solution.

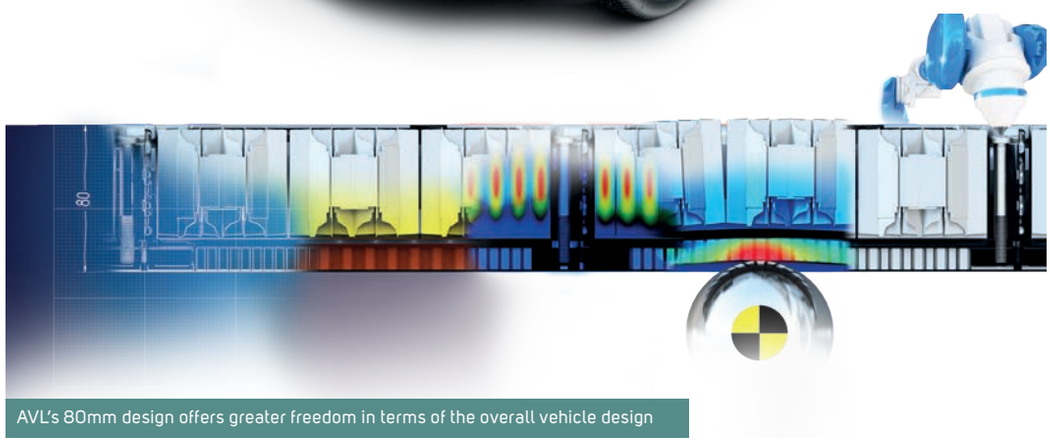
There is also an increasing demand for electric vehicles in the medium and upper sedan segment, with enhanced comfort, NVH characteristics and high driving performance as well as range. These are typically battery electric vehicles (BEVs), which call for batteries with a reduced height, and are able to offer the driving comfort of conventional sedans or coupes. Therefore many OEMs and cell manufacturers strive to achieve a battery size of around 100mm, through the adoption of advanced new technologies.

A smaller battery structure carefully integrated into the vehicle environment, enables a flat design but also presents a variety of new questions and challenges in several areas: this begins with cell selection and solutions for thermal management, E/E components and structural battery design, right through to final assembly.

Wenzel Prochazka, product manager for battery systems at AVL, explains, “Among other tasks we are able to deal with the selection of a suitable cell in close cooperation with numerous cell suppliers and in early development phases we can investigate ways to develop and implement new production processes.”

AVL’s 80mm design provides several advantages. The flat energy storage units offer much more freedom in overall vehicle design. “Extremely flat batteries can be tightly integrated into the vehicle structure,” says Paul Schiffbänker, product manager of electrification (batteries) at AVL. “As a result, they can be installed in the vehicle where they share functions with the chassis design. These might be partial aspects of vehicle safety or body stiffness. New design concepts and material selection enable a reduction in weight, a lower center of gravity with the highest stiffness and safety of the vehicle.”

Electric sedan vehicles are increasingly popular, but also have specific battery requirements



AVL’s 80mm design offers greater freedom in terms of the overall vehicle design

Drawing on its highly experienced international interdisciplinary team with wide-ranging capabilities, AVL can develop batteries as an integral part of the vehicle, rather than a single component.

AVL’s expertise covers the entire development process. That includes a battery benchmarking program in which experts examine 300 criteria and compare them with other BEV and PHEV batteries; concept development (a 25-point feasibility study ensures a solid concept addressing all risks until SOP), mechanical, electric and thermal design; simulation (frontloading for safety, thermal and mechanical aspects); virtual and prototype-based validation and verification; as well as production design.

To ensure high energy density, sufficient performance and improved charging time, AVL experts have also studied thermal issues closely. As Prochazka explains, “A battery should be kept in a specific temperature range during charging and utilization, therefore it requires an enhanced thermal system. AVL has developed and integrated a new innovative system which enables, despite the very low height, optimal cooling and heating performance.”

Revolutionary test tool

A new portable test instrument provides a complete solution for automotive engineers to take into the field, assisting in the detection of quality and performance issues

Today's automotive engineers face challenges in two key areas: the detection and remedy of design and manufacturing issues, and particularly the need for fast identification of faults so that remedies can be implemented; and the propulsion and energy storage system performance of electric vehicles must become more efficient and effective as EVs become increasingly accepted as alternatives to fossil fuel.

These industry challenges require laboratory-quality instruments that can be used in the field to record real-life operational situations. The Yokogawa DL350 ScopeCorder, a compact and lightweight portable instrument, lets engineers make more accurate and precise measurements and record them over long periods of time in the field.

The DL350 combines the features of a general-purpose oscilloscope and a high-performance data acquisition recorder in a single, portable instrument. Unlike alternative portable solutions (such as portable oscilloscopes and combined oscilloscope/multimeters), it adds high levels of precision and accuracy to field measurements, along with features such as isolated inputs for measurements at high voltage levels, and long-memory capabilities that enable long-term recording for hours or even days.

A further key feature of the DL350 ScopeCorder, which is not offered by other portable instruments, is its plug-in modularity, which enables it to be configured to suit a variety of user applications. This flexible input capability is achieved by incorporating two slots that can be populated with any of 18 different types of user-swappable input modules. For example, four isolated 16-bit voltage inputs can be measured at speeds of 1MS/s alongside 16 temperatures or two separate CAN or LIN buses, each containing 60 signals. Changing a single module enables measurement at 100MS/s with 12-bit and 1kV of isolation. Meanwhile, there are 16 logic inputs always on offer, with even more available by swapping a further module. Up to 5 GPoint of data per channel can be recorded directly to an SD card. This means that the DL350 can be used for continuous recording for up to 50 days, depending on the number of data points being captured.

The Yokogawa DL350 ScopeCorder is a portable instrument, ideal for field testing

When the DL350 is combined with the high-speed isolation and CANbus modules, it provides engineers with a powerful tool to measure drivetrain efficiency and performance of electric or hybrid vehicles. An optional GPS unit will be available to add coordinate information to correlate test track location and measurement data.

The DL350 is based on an A4-sized chassis and weighs 2.6kg (excluding battery) and less than 4kg including a battery and two four-channel modules. The built-in rechargeable battery provides three hours of continuous operation which, when combined with either mains or 10-30V DC power, provides the DL350 with a highly reliable power supply and worry-free recording for tests that are difficult or expensive to repeat.

The DL350 provides operating compatibility with other models in the ScopeCorder family and can share many modules and functions.

The DL350 offers recording capabilities for high-speed data capture, which is saved to internal memory or low-speed capture, saved directly to an SD card (for up to 50 days). Internally stored data can be transferred to an SD card after the acquisition. Engineers have the choice of a simple level trigger or enhanced triggers on such things as pulse width and waveform period across multiple channels. For example, the wave window trigger is ideal for AC power-line monitoring, and enables voltage sags, surges, spikes, phase shifts or drop-outs to be easily captured (available for 40 to 1,000Hz waveforms).

Plug-in modules enable automotive engineers to configure the DL350 to suit a variety of user applications

A CAN monitor function enables monitoring of CAN frame data as a trend. By displaying the trend as a waveform it can be compared with other data or analog waveforms. Waveforms obtained from the signals in the CAN or LINbus data can also be used as the physical value trigger source.

The DL350 can be used like a recorder or oscilloscope and the touchscreen makes it simple to access the advanced measurement and analysis functions. Engineers now have a laboratory standard multi-channel digital oscilloscope with data recording capability in a truly compact and portable package for field use.

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INQUIRY NO. 514

Vehicle sound design

This revolutionary tool brings life to a soundscape with customized sound for advanced NVH evaluation in test vehicles and application in the sound profile of the final vehicle

VSound is a sound-generation system for vehicles. It is both an integral part of Brüel & Kjær's NVH simulator suite, enabling interior and exterior sounds to be evaluated while driving on actual roads, and part of the final vehicle in the sound profile created. Typically, on-road and desktop simulators have been used at the concept stage to deliver an exciting sound to enhance and complement a new vehicle. But with the ever-increasing market for electric and hybrid vehicles, those sounds may not just complement an existing sound, they could make up the entirety of the sound, both for customer acceptance and legislated standards compliance.

Utilizing an NVH simulator in conjunction with this type of sound enhancement greatly simplifies the process. Sound can be auditioned, developed and refined in an NVH simulator, transferred to an in-car sound-generation unit for verification and final refinement, and then transferred to the on-board entertainment system for sound production enhancement.

Brüel & Kjær technology in a Tesla vehicle

A huge challenge in the NVH development process is ensuring that customers and stakeholders in the vehicle team are involved in sound-quality decision making. Interactive NVH simulators have enabled a cost-effective, customer-focused method for capturing the opinions and decision-making processes of non-NVH experts. VSound enables custom sounds to be composed on a desktop simulator and can in turn be evaluated while driving on the road. The sounds are created and presented to the vehicle driver in such a way that they appear totally natural and the assessor is not aware that they are synthesized. Because the subjective evaluations are performed on normal roads, key decision makers can understand and appreciate the value of the proposed sounds.

With VSound, the various vehicle parameters such as engine or motor speed, vehicle speed, gear selection, pedal position and other parameters from the CANbus, Flexray or transducers are used to generate sound in real time, responding instantly to any changes in the vehicle inputs. Interior and exterior vehicle sounds developed in the desktop NVH simulator or exterior sound simulator are generated by VSound hardware using the same methods as on the desktop simulator, recreating exactly the same sound in the actual vehicle as that designed on the desktop. The sounds are replayed through the existing vehicle speakers, additional interior or exterior speakers or other transducers.

'Sound quality' is generally used to describe those features of a sound that generate a positive emotional response from the vehicle's driver or passenger. In fact, the car's overall character can be reinforced by its sound quality. By studying independent vehicle quality survey data, the customer's perception of sound quality can be correlated with other aspects of the vehicle's performance.

In a sample case, customers were asked to rate the performance of a car during rapid acceleration from stationary and to rate the sound of the engine/exhaust on a scale from 1-10, with 1 being 'unacceptable' and 10 being 'outstanding'. The results showed a clear correlation between the customers' opinion of the engine sound and their perception of both acceleration performance and, more surprisingly, overall dynamic performance. Furthermore, by looking at the way customers describe their vehicles, there is a clear link between the performance of the vehicle and its sound.

Complex motor design

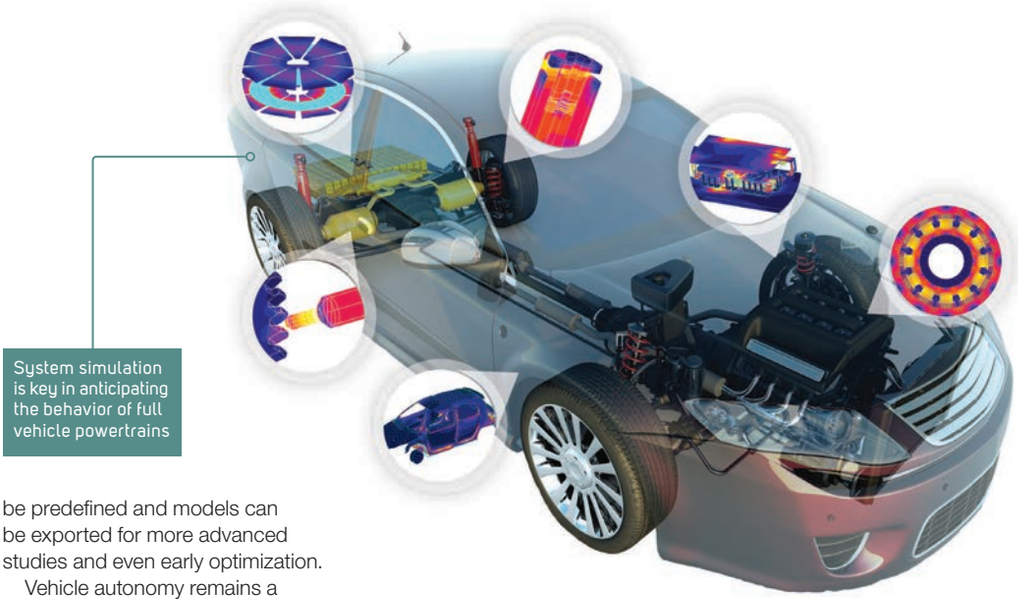
For a streamlined development process across R&D departments and facilities, 2D and 3D finite element modeling tools can be carefully combined to ensure accurate, reliable results

Driven by the requirement for innovation and environmental regulations, vehicle manufacturers must revolutionize their approach in developing the next generation of more efficient and convenient-to-use vehicles. The combustion engine has evolved over time, and today, every OEM is looking to develop an electric vehicle range.

Careful design of these electrical machines is vital to minimizing power consumption, maximizing performance and limiting temperature increases. Meanwhile vehicles must be compact and quiet inside the cabin. As the subsystems within a vehicle influence one another, it is necessary to optimize the entire system and test the dynamic interactions. System simulation is key to ensuring wise technical choices early in the design process and for anticipating the behavior of the full hybrid powertrain.

Maths and systems tools such as SolidThinking Compose and Activate offer an approach that can help engineers to make early choices in global design when selecting the best motor topology. Selection will depend on the powertrain architecture (fully electric, hybrid, motor wheels, with all imaginable variants) and the usage, including specifications for weight and volume, expected speed, torque, power supply and so on.

The next step is to use a motor predesign tool such as FluxMotor, which enables quick design, estimates and comparisons of machine performance in a single platform and provides the functionality to edit reports with accuracy within minutes. What used to be done by many different engineers, often using individual tools, can now be automated, easily shared and documented. At this stage, various specifications should be predefined and models can be exported for more advanced studies and even early optimization.



System simulation is key in anticipating the behavior of full vehicle powertrains

Vehicle autonomy remains a major purchasing criteria, with drivers looking for the same level of performance as traditional cars. Automatically generated 2D or 3D models studied in Flux will ensure an accurate view of the machine performance, including its efficiency, focusing on advanced modeling of losses; for example, checking local behavior between laminations or hysteresis phenomenon, while considering cost impact. As most of the losses are heat dissipated, transient thermal analysis can be run in the Flux environment, or even in CFD software such as AcuSolve. Simulation iterations can consider component temperature, improvements to the cooling and overall performance during the operation cycle.

The other consideration once the vehicle's range and acceleration has been optimized is linked to acoustic comfort. Coupling Flux with OptiStruct structural analysis software enables the evaluation of the vibroacoustic performance of the machine. Electromagnetic parasitic forces are the source of vibrations and noise, which remain challenging to reduce. Adapting the control strategy, adjusting the shapes of the rotor and stator, and optimizing the mechanical structure of the machine requires a specific approach to remain efficient.

Improving performance using a cutting-edge multidisciplinary optimization process managed in HyperStudy, while coupling Flux electromagnetic models with OptiStruct structural analysis, will change the design approach. Models are easy to set up and use – making design exploration and optimization efficient.

Finally, powertrain performance will depend on a combination of the power electronics driving the machine, and secondary functions such as current flow with energy storage, transmission, injectors, and the powertrain configuration in general. Driving scenarios are considered in co-simulation, coupling Flux to SolidThinking Activate, and the electromagnetic model is switched for an advanced electric one to test according to appropriate regulations. This enables evaluation of energy consumption on different homologation cycles. SolidThinking Activate will later automatically edit optimized and compact code in the controller.

The Altair HPC capabilities using PBS Works distribution for dedicated computation resources, together with a flexible licensing system, now enables designers to implement new simulation-driven processes and obtain accurate results in hours, while weeks – and often months – were the former reference units.

Furthermore, simple model and data exchange between software packages across R&D departments is fundamental to fostering multidisciplinary teamwork and improving project performance.

High-voltage distribution

A range of reliable, customizable and modular units ensure safe power distribution between all high-voltage components in any electric vehicle

Special and commercial vehicles, including trucks, buses and construction vehicles, are moving into the forefront of electric mobility. Local environmental regulations, as well as the need for greater efficiency and profitability, have driven development of these vehicles. However, a number of key challenges are apparent, including high board power and charging currents, stringent materials requirements, safety concerns and harsh operating environments.

Huber+Suhner, a leading global manufacturer of components and systems for electrical and optical connectivity, has developed highly reliable high-voltage distribution units (HVDU) to tackle these challenges. The HVDUs are designed and manufactured to meet the demands of the customer to ensure an easy assembly process. As standard, HVDUs are EMC protected, have low electrical resistance, meet the IP6K9K and IP67 ingress protection standards and contain an interlock protection system, which turns off the high-voltage battery when the lid is opened. Additional safety features can also be incorporated, such as an isolation monitor, which detects any drop in resistance and shuts down the high-voltage system accordingly, or actively discharges the threat to protect service staff.

Depending on the requirements of the customer, the units can be equipped with capacitors, fuses, an insulation monitor, inertia switch, active discharging unit and contactors. Furthermore, the dimensions of the lightweight aluminum housing are variable according to customer needs. The HVDU is supplied with a voltage rating of 850V (DC) and an operating voltage of 400-1,000V (DC). It processes a power range of 50-800kW and fits cable sizes from 2.5-95mm^2. With an ambient temperature range from -40°C to 85°C, the unit meets all current automotive standards.

Above: Huber+Suhner offers a range of reliable, modular and customizable high-voltage distribution units

Left: Systems are suitable for any EV where high-voltage distribution is required within the onboard systems

A modular HVDU (MHVDU) is also available. This variant enables the customer to assemble an HVDU by selecting from a wide portfolio of standardized components. This results in a simplified and harmonized solution designed for individual requirements. The final dimension of the housing is dependent on the selected elements. Thanks to its modular combination of standardized components, the Huber+Suhner, MHVDU can be developed at short notice and reasonable pricing.

For those who require an even higher level of customization of components and functionality, the company offers the customized HVDU (CHVDU). This version is completely custom-made to meet the specifications of the customer, whether that is in terms of the components required or the final shape of the unit.

Huber+Suhner's solutions are in use today in cars, trucks, buses and specialized vehicles such as snow groomers, providing safe interconnections between all high-voltage components in the vehicle, including motors, inverters, batteries, chargers, DC/DC converters and compressors.

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INQUIRY NO. 517

Advanced power modules

Motor controllers with silicon carbide-based power semiconductors increase the efficiency and power density of new energy commercial vehicle drivetrains

The electromobility market has taken off worldwide: total electric vehicle sales – comprising battery electric and plug-in hybrid vehicles – exceeded two million units in 2016. Particularly in China this market development is heavily supported by public funding programs. Consequently the country took the global lead in the electric vehicle share with more than one million registered vehicles on its roads. Even more impressive are the market volumes of new energy commercial vehicles (NEV) in Chinese mega cities: the commercial NEV market share was 34% in 2016 (171,000 vehicles). Thereof, 133,000 city buses have been put on city roads – this is more than 90% of the global market share. In 2016, the Chinese government established its final funding program, which cuts the incentives year by year and will be fully withdrawn in 2021. As a result, the pressure to continuously improve the cost-effectiveness of vehicle programs will continue and catalyze ongoing market penetration.

Batteries and electric motor power electronics equipment are key technologies in electric vehicles. The ongoing challenge is to further reduce use, weight and cost of the materials of these building blocks. Efficiency and power density are key indicators for these challenges.

Semikron, a leading supplier of power electronics equipment, has been providing systems for vehicle electrification for more than 25 years. Its work initially involved material handling applications such as forklifts in the 1990s. Semikron equipped more than 800,000 forklifts, 50,000 city buses and 60,000 passenger cars with power electronics devices. Since 2013, Semikron has offered the SKAI2HV motor controller platform, designed for electric and hybrid commercial vehicle powertrains between 50kW and 300kW (Figure 1).

Figure 1: The SKAI2HV system

Total switching losses @ I_{ph} = 180A_{RMS}, f_s = 20 kHz, V_{DC} = 600V

P_{SW}	1	2	3	4	5
(W)	3066	1490	920	460	368
	100%	-48%	-70%	-85%	-88%

Figure 2: A demonstration of the potential loss reductions resulting from the introduction of silicon carbide-based power semiconductors instead of silicon devices

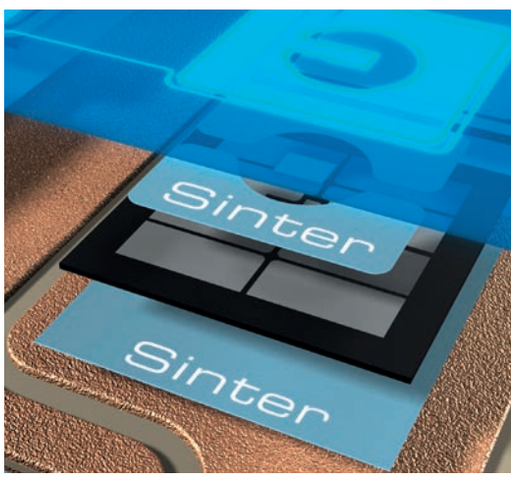

Figure 3: The next-generation SKAI HV with DPD technology replaces the wire bond connection with a sintered joint, increasing power cycling capability by more than 300%

The introduction of SiC power semiconductors provides the opportunity for considerable efficiency increases. Figure 2 highlights the potential gains that can be realized through use of SiC power semiconductors instead of silicon devices: 1 represents the standard 1,200V SKAI2HV as the reference with all built-in power semiconductors based on silicon; 2 shows a 50% reduction in losses with built-in SiC freewheeling diodes; 3 shows the improvement achieved with SiC MOSFETs; 4 uses SiC MOSFETs assembled in an optimal low inductance assembly, which will be available with the next SKAI HV generation – here reduction of losses will be in the range of 85%; 5 uses SiC MOSFETs and, in addition, SiC freewheeling shottky diodes.

The notable reduction of losses enables a reduction in the size of the motor controller and the required cooling features. The overall powertrain efficiency can be increased in the range of several percent, which enables higher vehicle mileage with the same battery size. Power semiconductors based on SiC will never be cheaper than silicon-based devices. However, thanks to the potential efficiency gains, a complete powertrain with SiC devices could be a more cost-effective option in the future.

Furthermore, SiC-based power semiconductors enable a large increase of the junction temperature compared with silicon devices. Today this capability is limited by the power semiconductor assembly technology. SKAI2HV comprises single side sintered silicon-based power semiconductors with aluminum-copper bonds on the top sides, which today represents the top end of power semiconductor assembly technology for high volume production.

The next-generation SKAI HV (seen in Figure 3) will comprise Semikron's recently introduced direct pressed die technology (DPD), which increases the power cycling capability by more than 300% toward SKAI2HV. With DPD, the wire bond connection will be replaced by a sintered joint.

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INQUIRY NO. 518

Intelligent test systems

A test lab equipped with unique test command optimization technology enables flexible, accurate evaluation of power components according to worldwide standards

As one of the industry's leading manufacturers of precision test and measurement instrumentation, automated test systems, intelligent manufacturing systems, and turnkey test and automation solutions, Chroma aims to improve the efficiency, accuracy and cost of electric vehicle testing through the development of flexible automated power conversion test platforms and regenerative battery test systems.

The company's automated test systems for hybrid and electric vehicles consist of standard test platforms that are combined into one expandable test system, which can be used to evaluate most power components. When compared with specialized test equipment developed for a single EV model or application, Chroma's systems are said to provide greater flexibility.

The Chroma 8000 automated test system meets the requirements of SAE J1772 and GB/T 18487.1 for full function testing of AC level 1 and level 2 electric vehicle supply equipment (EVSE) and is built to address the testing requirements of electric and plug-in hybrid vehicles in research and development through to quality assurance, production and field service.

Chroma has developed a range of flexible and accurate products to improve electric vehicle testing

In addition to testing hardware, Chroma has developed configurable automated test system software

The system has been built incorporating Chroma's extensive expertise in power electronics and enables seamless testing of EVSE, onboard chargers, DC to DC converters, motor drivers, and other power electronics. The Chroma 8000 test system can be configured with AC and DC power supplies, electronic loads, power analyzers, oscilloscopes, DMMs, as well as digital and analog I/O cards to address the requirements of multiple power electronic systems.

In addition to hardware flexibility, Chroma's automated test system software includes a range of pre-written tests and the ability to create custom tests, providing users with unlimited freedom in testing. The system also provides automatic data recording and statistical report creation, giving insight into opportunities for product improvement. This combination of configurable hardware and software enables manufacturers to reduce costs and ensure consistency in all phases of the product lifetime.

Chroma's lithium battery automated test solutions have been successfully adopted by a number of well-known automotive manufacturers, providing safe, real-time monitoring of the test process and reducing inspection time, considerably reducing production cost.

The company's battery testers are regenerative, high-precision systems specifically designed for cell, module and pack level battery testing. From charge/discharge to drive cycle simulation, the accurate measurement ensures reliable testing for battery incoming or outgoing inspections, as well as capacity, performance, production and qualification testing. A cost-effective regenerative feature recycles energy sourced by the battery module either back to the channels in the system or back to the grid. Systems are flexible, making field upgrades possible.

Electric vehicle safety is of the utmost importance; vehicles must comply with a number of regulatory standards. Chroma has developed several benchtop and automated test units to analyze AC and DC dielectric withstand, isolation resistance, leakage current and ground bond, as well as wound component analyzers. Safety test applications include the power system, motors, batteries, charging system, wiring, charging lines and connectors, as well as the charging station itself.

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INQUIRY NO. 519

Remote battery monitor

Remote BMS access is a cost-effective, preventive means of ensuring failsafe operation of traction batteries in electric vehicles

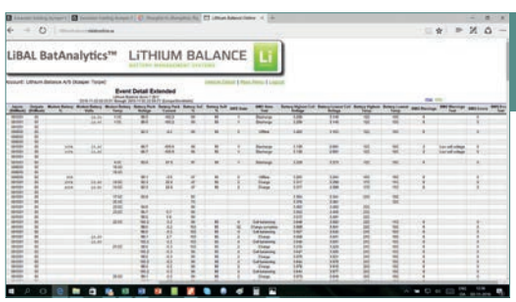
While lithium batteries are essentially maintenance-free, it is often highly beneficial to monitor the operational patterns of the battery in use, remotely and in real time. BatAnalytics was developed by Lithium Balance to provide manufacturers of electric vehicles access to live battery data, and to facilitate efficient support and optimization of batteries in the field.

The BatAnalytics system consists of a small modem with built-in antenna for GSM/3G connection, datalogger, GPS and impact accelerometer. The modem is easily installed in the vehicle, and, via the CANbus, battery data is collected from the battery management system. The data is transmitted to a secure server whenever there is something new to report such as operational status and error messages.

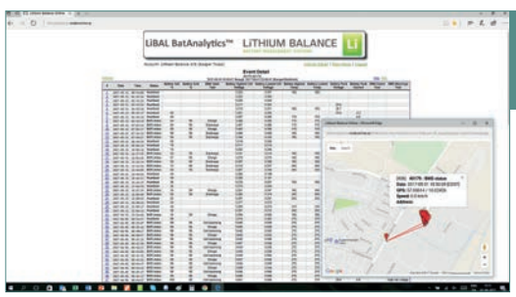
The data is displayed in the Lithium Balance BatAnalytics portal, which organizes data from all the connected vehicles. The OEM has an overview of the entire fleet, and can provide individual access to each of their customers for their vehicles also. The status of the vehicles is displayed with a simple green, yellow or red status marker, and for individual vehicle troubleshooting, detailed reports can be made with the relevant subset of battery information, including the position of the vehicle at the time of an event.

N.C. Nielsen, a Danish distributor of Linde forklifts and supplier of lithium batteries, has implemented the BatAnalytics system in customer vehicles. This enables the company to monitor vehicle status and provides the end customers with the confidence that their vehicles are being taken care of.

"When customers move from lead-acid to lithium batteries we encounter all sorts of questions. Is it safe? Will the battery be destroyed if we charge at high current? Will the battery survive the harsh conditions in a coldstore?" explains technical director and owner Per T Nielsen.



The BatAnalytics portal organizes data from all the connected vehicles



Lithium Balance's system displays vehicle status using simple markers

N.C. Nielsen has implemented the system to monitor customer vehicles. Image: N.C. Nielsen

"We can remove all of those concerns by providing this online overview, and the customer can look for himself, which further enhances their confidence."

N.C. Nielsen introduced lithium batteries to its customers in 2016, and the launch was facilitated by BatAnalytics deployed in customer demo vehicles.

Nielsen continues, "The real benefit can be seen when we extend the service to predict and prevent downtime, schedule maintenance visits and provide consultancy on how the customer and his operators can optimize the use of the batteries." This provides a complete service package, which can be regarded as a valuable add-on to the core product.

An additional advantage of the BatAnalytics system is the possibility for battery manufacturers to gain a valuable insight into the cell and battery behavior over a long period of time. The vast amount of battery data collected provides a source for better understanding the behavior of lithium cells and how a BMS can be optimized to manage the cell more efficiently.

Lithium Balance CTO Claus Friis Pedersen explains, "By having a constant stream of battery data flowing into our R&D team, we can see how BMS algorithms perform over time. We constantly develop new models for SOC, SOH and balancing, but these new models are often based on theoretical ideas. With BatAnalytics we can easily see how the models work in real life. Most of the data we collect in BatAnalytics would require huge investments in laboratory testing and it would take too long to get the data. With this tool we basically have historical data readily available."

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INQUIRY NO. 520

Advanced range extender

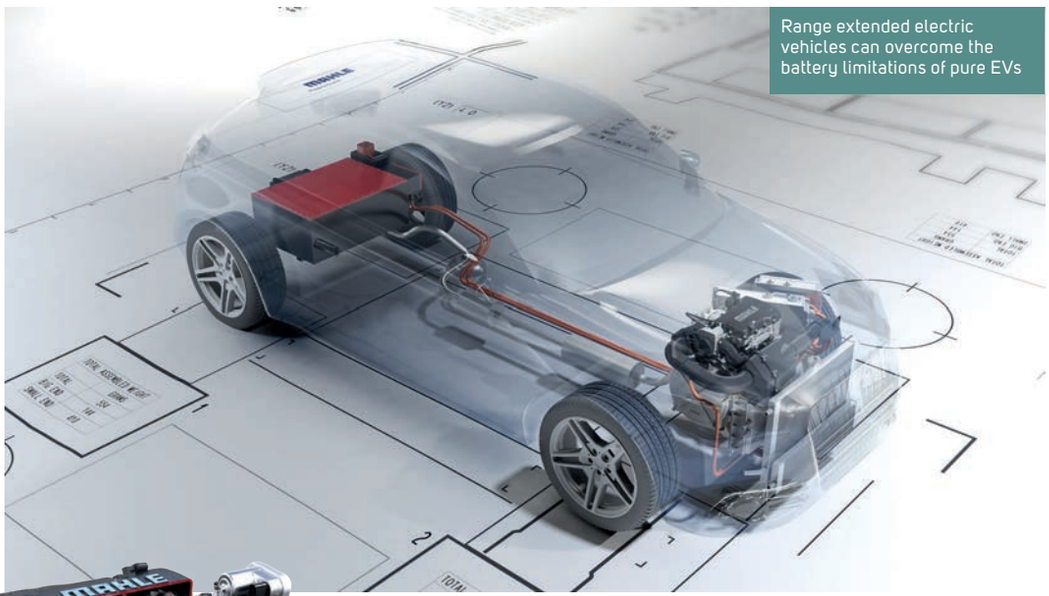
A family of high-output range-extender engine units provides the benefits of a pure EV with added flexibility and convenience, plus reduced range anxiety

The current focus on carbon dioxide emissions reduction technologies for road vehicles has increased the interest in hybrid and electric vehicle applications. Pure electric vehicles still require bulky, heavy and expensive battery packs to enable an acceptable driving range. Range-extended electric vehicles (REEVs) partly overcome these battery limitations by using a range extender (REx) unit that enables a reduction of the traction battery storage capacity while still maintaining an acceptable vehicle driving range.

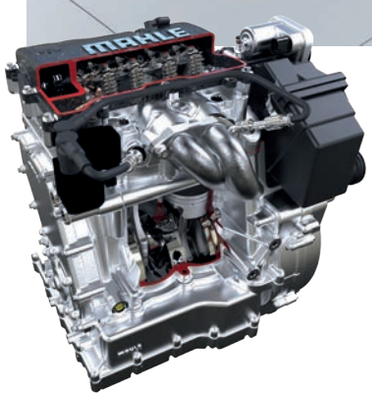
In response to this trend, Mahle initially developed a 30kW REx unit specifically for passenger car applications. Key design attributes for this engine included minimum package volume, low weight, low cost and good NVH characteristics. In order to showcase the resulting REx unit, a current production compact-class car was converted into a REEV.

Having proved the initial concept in a demonstrator vehicle, further work was then conducted to develop high-output variants of the REx unit while retaining high component commonality. This approach was considered critical to broadening the range of potential applications while also achieving the economies of scale necessary to allow cost-effective volume production.

The Mahle REx family has been designed to provide a range of power outputs while sharing major components with the original 30kW engine. The maximum power speed of this engine was set at 4,000rpm to ensure low NVH levels, enabling the REx operation to be completely unobtrusive to vehicle occupants. However, experience with the Mahle REx demonstrator vehicle indicated that higher engine speeds could be achieved without unduly compromising the NVH of the vehicle. Increasing the maximum engine speed to 5,500rpm has enabled 40kW power output to be achieved without any additional manufacturing cost, package size or engine weight.



Range extended electric vehicles can overcome the battery limitations of pure EVs



To achieve the 50kW power target with the 900cc two-cylinder variant, it was necessary to pressure charge the engine. The resulting design features a close-coupled supercharger layout, which crucially does not use a charge-air cooler – to minimize production costs and package size.

The latest development in the REx family is a three-cylinder version to produce 40-45kW without the need for pressure charging and only running up to 4,000rpm. This engine has been designed in response to customer demand for increased efficiency, reduced fuel consumption and enhanced durability. It is better suited for applications where the engine is expected to be running for extended periods during longer journeys. The three-cylinder version shares its architecture with the original two-cylinder engine and therefore has a swept volume of 1,350cc. At higher operating speeds, or with pressure charging, this three-cylinder engine variant could deliver up to 60kW of mechanical power.

Alongside the REx integration, a GPS-based operating strategy was developed to achieve further fuel-efficiency benefits. The REEV demonstrator was originally developed with a purely reactionary control strategy. Once the battery charge was depleted, the REx was activated to provide the energy required to propel the vehicle. As part of the continuing development of this vehicle, Mahle Powertrain has developed control software that can intelligently manage the use of the battery energy through the combined use of GPS and road topographical data. Advanced knowledge of the route prior to the start of a journey enables the control software to calculate the state of charge throughout the journey and predetermine the optimum operating strategy for the range extender to enable maximum charging efficiency and minimize NVH.

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INQUIRY NO. 521

Safe and efficient batteries

Computational flow dynamics simulation has evolved as an effective and accurate method to evaluate thermal management properties in Li-ion batteries

Lithium-ion batteries have made the electric vehicle a reality and electromobility is soon to be a 'not so distant' future. However, there have been several serious incidents of Li-ion batteries catching fire due to either faulty thermal management systems or abuse. This underscores the importance of finding new methods for effective, accurate design of the thermal management systems (TMS) that control temperature as well as optimizing the performance of Li-ion batteries.

Samsung R&D Institute, in collaboration with Samsung Advanced Institute of Technology, Korea, recently presented a novel liquid-coolant-based TMS for large lithium-ion battery packs to address these challenges. The team constructed a coupled 3D electrochemical/thermal model of the proposed battery pack. The simulation revealed that contact resistance had the greatest impact on the pack's thermal performance.

Considering the three-dimensional nature of the flow around the cells in a battery pack and the spatial variance involved in heat generation, simulation of battery packs using computational flow dynamics (CFD) methodology has evolved as an effective design and optimization tool to address thermal management problems.

For the large battery packs operating at high discharge rates typically utilized in EVs and HEVs, CFD studies have shown that liquid cooling is more effective than air cooling, enabling the design of more compact and efficient batteries.

The Li-ion battery pack that was developed used a commercially available 18650-cell Li-NCA/C battery. Conduction elements made of highly conductive metal transferred heat from the cylindrical cells to the coolant channel and finally to the coolant liquid (in this case water). A test pack of 30 cells was fabricated, with six cells in series and five cells in parallel (Figure 1).

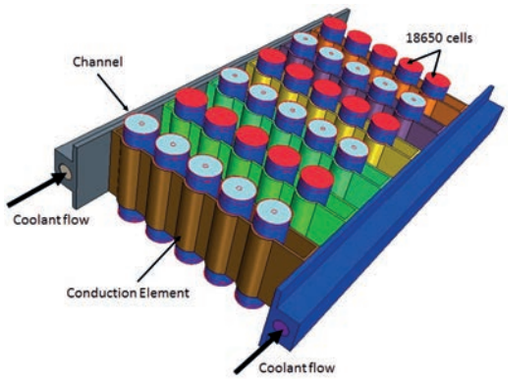


Figure 1: The geometry of the lithium-ion battery pack, which used six cells in series and five cells in parallel. Also shown is the pack's thermal management system

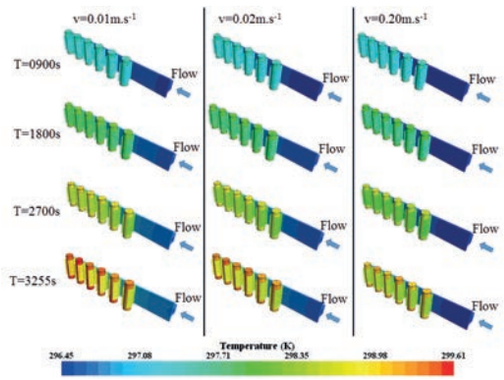


Figure 2: The temperature rise in the first set of series cells in the pack as a function of flow rate and time at 0.9 C discharge rate and contact resistance 0.0025m²KW⁻¹

A complete characterization of heat generation was obtained only by constructing a 3D CFD-based electrochemical model of the battery, which could be validated against experimental results then used to simulate and evaluate performance of the TMS under various operating conditions.

This project used STAR-CCM+ software from Siemens PLM software to simulate flow and conjugate heat transfer, while electrochemical input data was obtained from Battery Design Studio software. This combination was used to simulate performance of the battery pack.

The 3D TMS model successfully computed the performance of the representative battery pack. It was found that the average temperature difference between the hottest and coldest cells was only 0.5K. Observing a clear pattern in the temperature rise, the team realized that a properly defined temperature coefficient could predict the temperature of other cells based on the temperature of just one cell.

In electric vehicles, power for operating the TMS comes from energy extracted from the battery. Reducing the energy requirement of the TMS reduces its drain on the battery, therefore optimization of the coolant flow rate is essential. The STAR-CCM+ model revealed that more heat is stored in the battery pack in lower coolant flow velocity conditions, indicating that at lower flow velocities, less heat is transferred into the coolant.

In most battery packs, maximum temperature variation is limited to 3K along the direction of the flow stream. The experimental model easily met the 3K limit and could effectively cool the pack even at very low flow velocities. As seen in Figure 2, it was found that temperature rise in the battery pack using the experimental TMS is of the same order of magnitude as graphene-augmented, phase change material (PCM)-based thermal management systems reported in research literature. Although such PCM-based TMSs are also compact, this new TMS does not require novel materials such as graphene and can therefore be produced at lower cost.

Using the CFD-based TMS functional model created with STAR-CCM+ and Battery Design Studio, a close correlation between simulations and experimental measurements was achieved, validating the model against experiment with greater than 90% accuracy. Representative battery packs constructed using the symmetry of the total pack were successfully simulated, together with the TMS, to lower the computational cost.

The ability of this novel compact TMS to work effectively and safely under stringent conditions makes it a suitable candidate for large lithium-ion battery packs used in electric vehicles.

Battery monitoring

Development of a flexible and intelligent, future-proofed battery management system is vital to worldwide HEV and BEV adoption

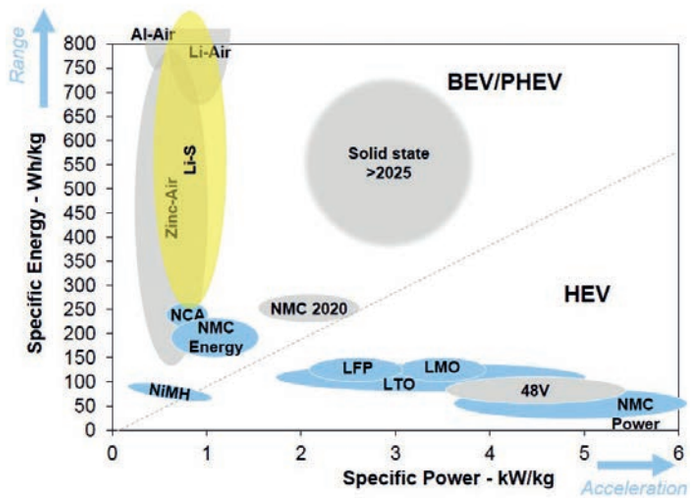
One of the keys to the success of the battery electric vehicle is the development of the vehicle high-voltage battery pack. Currently, battery electric vehicles (BEV) are more expensive than their internal combustion counterparts and to address this imbalance battery packs must become more power dense and lighter to enable BEVs to provide comparable range at a reduced cost to drivers. This is vital for making the technology more compelling to vehicle purchasers and advancing the adoption of BEVs across any geographic region.

The battery pack is made up of key components: the battery cells, which provide the power required by the electric vehicle; and the battery management system, which is responsible for handling the health and charge of the battery pack, and optimizing power usage to enable a more reliable battery pack over the lifespan of the vehicle. The battery management system is also responsible for communicating with all components within the electric/hybrid vehicle traction system.

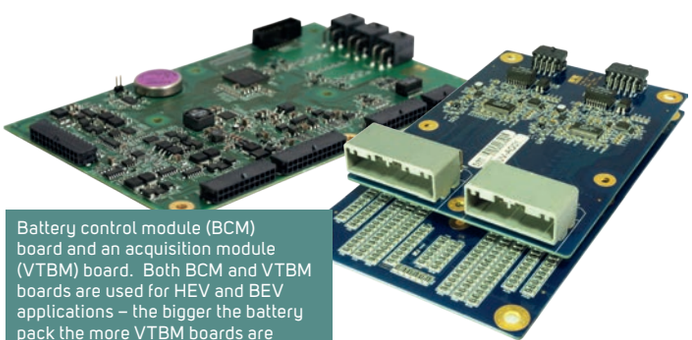
As the development of batteries improves toward making BEVs more affordable, in the short term several hybrid powertrain options are available to reduce CO_2 emissions in combination with the existing internal combustion engine.

Each of these architectures and powertrain types has different requirements from the battery pack, resulting in each architecture potentially requiring custom battery management systems.

One method for removing costs associated with battery packs is the development of a flexible battery management system that enables use in different battery packs, sizes, shapes, densities and split packs (two separate battery packs linked within the vehicle). This scalable approach is also key for developing a robust design that enables minor adaptations without wholesale changes to the circuitry. In order to enable this, the battery management system is divided into modules: the battery control module (BCM) and acquisition modules (VTBM). The BCM controls the overall operation of the battery pack, while the VTBM boards monitor the voltages, temperature and balance the charge across a subset of battery cells.



Different architectures have varying requirements of battery pack specification



Battery control module (BCM) board and an acquisition module (VTBM) board. Both BCM and VTBM boards are used for HEV and BEV applications – the bigger the battery pack the more VTBM boards are required, but still only one BCM

One principal reason for the requirement for flexibility is the need to accommodate different cell chemistries and types (prismatic, cylindrical and pouch), each of which have differing electrical properties requiring the BMS to be tailored for each specific application with minimal customization.

The development of the battery management system has a number of challenges, notably the ability to meet high ASIL levels within the ISO 26262 framework. The latest automotive compliant ranges of microprocessors (MCU) enable a high level of flexibility in design as they provide a scalable family of products that are footprint compatible. This compatibility across the family of processors enables scaled-down versions to be implemented on depopulated printed circuit boards for lower cost and smaller applications.

Microprocessor technology has advanced to enable multicore processing in the automotive domain, which is key for separating safety functions within the MCU itself, enabling more cost-effective delivery of high ASIL level (C/D) developments through hardware design. The majority of the major silicon providers are now able to offer highly capable, multicore processors for automotive applications, including Infineon, NXP, Renesas and Texas Instruments.

Ricardo engineers are currently engaged in a number of programs for both research and production implementation of a next-generation battery management system, using a standard base platform to provide options across multiple pack varieties – including novel and new cell chemistries – in a more cost-effective manner.

While all the attention in the industry is on the development of better battery technologies and cell chemistries, Ricardo understands that the optimization of these solutions through intelligent battery management systems is vital to the advancement of BEV and HEV adoption, and provides a more reliable and efficient battery pack to customers.

Hybrid powertrain

A new motor/generator offers a cost-effective solution for the hybridization of class 7-8 commercial vehicles

Although the production volume of electric vehicles has increased tremendously over the past five years, it can be argued that the market is still in its infancy and that a few challenges will need to be overcome before the market volumes of pure electric vehicles can be expected to overtake those of petrol-fueled ones.

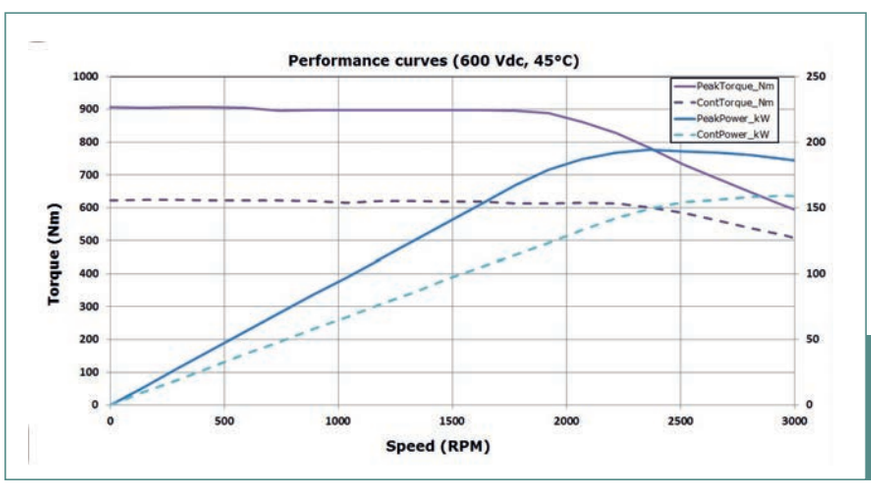
Before all-electric vehicles become suitable for the range of applications and markets, hybrid solutions will remain a stepping stone to reduce CO_2 emissions and ramp-up the production of electric vehicle components such as batteries, electric motors and power electronics. Several applications that rely on long range and low downtime are not yet suitable for complete battery-based operation without considerable infrastructure or technological breakthrough. As a result of this, a compact and efficient genset package for a range-extender system is a valuable asset to encourage electrification of the drivetrain.

TM4 introduced its Sumo line of powertrains five years ago to enable its customers to achieve cost-effective vehicle electrification. The company has continued to innovate to meet market needs: TM4 has recently launched as part of its Sumo family of products, a new motor/generator for the commercial heavy-duty class 7-8 market. The LSG130 was purposely developed for series and parallel-hybrid configurations; it can be coupled to diesel engines, multispeed gearboxes, or integrated into axles for ultra-low-floor buses. TM4 offers this new motor/generator with its proven three-phase CO150 inverter, which is installed in thousands of vehicles worldwide.

The system (which features a combined generator and inverter) can achieve 95% efficiency and has been developed to match the efficiency of a diesel engine, which is instrumental to optimize fuel savings. In fact, in a series hybrid, the combined use of the electric traction system, the optimized genset and electrified accessories can result in a 50% improvement in fuel economy compared with a conventional vehicle.

TM4 currently supplies its powertrains to several OEMs and technical centers in North America, Europe and Asia and equipped an astonishing 5,000 buses in China last year with its Sumo direct-drive powertrain systems. This new motor/generator is complementary to TM4's Sumo and Motive electric powertrains and enables the company to supply an even more complete range of solutions for any type of hybrid or electric application.

Production takes place at TM4's facilities in Canada, Boucherville and at its Chinese joint venture – Prestolite E-Propulsion Systems in Beijing. Both are equipped with high-volume, flexible and automated production lines, and a large range of dynamometers and test cells, which enable it to conduct full validation and certification of electric and hybrid powertrains.



The graph on the left shows the performance curves of TM4's LSG130 motor/generator

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INQUIRY NO. 524

CCS charging connector

A newly designed vehicle connector provides both consumer and operator benefits with its user-friendly design for more convenience and its aesthetically pleasing appearance

The Combined Charging System (CCS) is a method for the charging of electric vehicles in Europe and the USA and promises to put an end to consumer confusion between charging interfaces. The standardized CCS enables AC charging as well as DC charging with the same vehicle inlet, at charging currents up to 200A.

The CCS was established by car manufacturers and developed mainly by Phoenix Contact. All specific requirements have been finalized in collaboration with Phoenix Contact in the IEC 62196-3 and the SAE J1772.

Consumers will always compare the charging process with refueling of a combustion engine vehicle. DC charging according to CCS with power levels up to 200kW enables charging times of less than half an hour, which is a suitable duration for a coffee break. Fast charging solutions are especially necessary for motorists traveling on journeys that exceed the maximum range of the electric vehicle.

The high currents present during the charging process pose a safety risk – whether it is a technician or a non-expert handling the vehicle connector. By way of comparison, a single family house has a power consumption of approximately 0.5kW, which means EV connectors are not comparable to any other charging plug found in the home.

To satisfy the increasing market demands for both convenience and affordability, Phoenix Contact – a leading manufacturer of DC charging components – has now introduced an optimized CCS type 2 vehicle connector. Its innovative new design improves the current charging infrastructure, ready for the next generation of electric vehicles. Its design is both dynamic and striking, putting CCS vehicle connectors at the forefront of the industry.

The system is extremely high quality with its user-friendly plastic casing that has soft components – ensuring it is easy to grip and doesn't slide in the user's hand – and the handle bar, which is also available in metal. It is also an extremely rugged connector.

Usually CCS vehicle connectors are installed at public charging stations – there is frequent plug-in and plug-out, which could lead to damage to the connector. Service calls to replace the connector are costly for the station operator. To ensure it is more user-friendly, the new line has an exchangeable mating face. Even a non-electrician is able to change the mating face by simply loosening a few screws. Replacing it is easy and cost-effective for the charging station operator, and afterward it works as well as a new connector.

Charging connectors should be lightweight and easy to handle; however, the increasing cross-section caused by the higher current of DC charging systems adds weight onto the charging cable. This poses a challenge for developers of electric vehicle charging solutions. Engineers at Phoenix Connectors have been able to reduce cable weight by 25% in comparison with the previous generation system. This increases the flexibility of the cable and limits the copper costs.

These new, easy to use, reliable, second-generation CCS vehicle connectors support the expansion of the EV network worldwide.

The new CCS type 2 vehicle connector

Fast charging solutions are an absolute necessity for motorists undertaking long-distance journeys

Advanced energy storage

Using a combination of ultracapacitors and batteries in vehicle energy storage architectures can help reduce emissions and increase cost savings

Auto makers' attempts to comply with stricter CO_2 emission standards have sparked increasing demand for vehicle electrification. While 48V system architectures are slowly emerging to meet these standards, 12V architectures should not be overlooked. There is an opportunity to expand on 12V systems' existing applications, and to add new features that will help auto makers achieve these goals, without nearing the cost required for a 48V system.

Auto makers are testing system architectures to their limits by adding new power-hungry features to achieve vehicle electrification. As a result, 12V architectures are increasingly being designed to enable high-power boardnet loads such as electro-turbocharging, electric anti-roll control and electric power steering. Because these features require such high power, the demands on a vehicle's energy storage system are considerable. Traditionally, auto makers have relied on lead-acid batteries as the main energy storage device; however, batteries have their own limitations. It's not feasible to expect a purely battery-based energy storage system to handle all of these capabilities without experiencing performance limitations. While batteries can store large amounts of energy over long periods of time, they must be discharged at low discharge rates to avoid premature aging and are not ideal for the quick bursts of power required by these features. Plus, batteries do not perform well in extreme temperatures because they produce and store energy by means of a chemical reaction, which is slowed in cold temperatures.

Car manufacturers are looking into hybrid energy storage systems that can rely on alternative energy storage to complement batteries and lead to an improvement in their overall performance. Because a system needs to provide both reliable electrical performance across a wide temperature range and boast cost-efficiency benefits, auto makers need to choose a durable and cost-saving energy storage technology. Auto makers should consider pairing a standard 12V lead-acid battery with an ultracapacitor module as they continue to optimize electrical performance. Ultracapacitors are energy storage devices that offer nearly instantaneous power bursts during periods of peak power demand and, compared with batteries, can store and discharge energy with high power quickly and effectively. A hybrid ultracapacitor-battery system can enable ideal cranking performance in temperatures as low as -40°C and as high as 65°C. This combination enables the addition of high-power features such as stop/start, active suspension, electric power steering and electro-turbocharging, even in lower temperatures.

Pairing ultracapacitors with batteries can yield reliable performance and cost-efficiency benefits

A hybrid ultracapacitor-battery system can enable the use of high-power vehicle features such as stop/start functionality

Car manufacturers can create a hybrid energy storage system by developing a standard battery-sized box, using a smaller-sized lead-acid battery and filling the empty space with ultracapacitors. This reduces the size of the battery and also enables up to a 40% overall weight reduction, resulting in cost savings. Additionally, auto makers receive credits for vehicles that achieve specific fuel-efficiency standards based on grams of CO_2 emitted per kilometer. The addition of ultracapacitors also helps improve battery life, by taking stress off the battery, and improves overall charge acceptance. This means batteries need not be replaced as frequently, and require less maintenance.

It's possible to increase electrification at the 12V level with a hybrid energy storage system and auto makers are evaluating this solution for future vehicle platforms. Enhanced 12V systems that use a combination of ultracapacitors and batteries can help auto makers achieve reduced emissions and increased cost-savings, without the level of investment needed in a 48V system.

Precision battery tests

A higher degree of measurement precision will lead to new discoveries and characterization metrics in the energy storage industry, and will have a major impact on the EV market

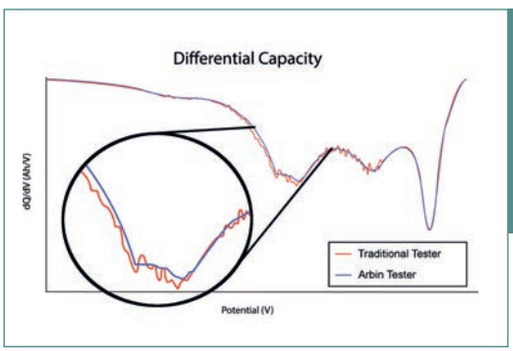
Arbin Instruments, the Ford Motor Company and Sandia National Lab recently completed an ARPA-E project to develop a high-precision battery test station. The goal of the project was to develop a testing system capable of 50ppm coulombic efficiency precision that will enable users to see degradation mechanisms more clearly on a full-scale cell under real-world conditions.

The need for this type of equipment was highlighted in a recently published paper entitled *The Importance of Coulombic Efficiency Measurements in R&D Efforts to Obtain Long-Lived Li-ion Batteries*, published by Dr Jeff Dahn et al, describing how the results obtained from ultra-high precision test equipment uncover key battery life trends that can be missed or overlooked using conventional test equipment. The need for high-precision test equipment drove Arbin to develop testing systems capable of 50ppm coulombic efficiency precision for systems ranging from 100mA to 5A for cell development, up to 200A for full-scale testing.

The technological breakthroughs that were developed during the project earned Arbin the R&D100 Award for Green Technology. Arbin's laboratory battery testing (LBT) series commercializes technology developed from this project and provides customers with an economical testing solution for applications requiring high-precision measurement and fast data sampling. Most other battery testing systems do not correctly specify their precision and/or have relatively poor precision, which weakens the conclusions drawn from results. Important trends and electrochemical indicators may remain unnoticed, lost in the measurement noise.

Arbin's new technology provides users with 0.01% precision and 24bit measurement resolution. Along with the ability to collect 2,000 datapoints per second with a time resolution of 100µs, the new LBT series hardware provides accurate capacity calculations to monitor long-term battery life. Arbin's hope is that these higher degrees of measurement precision will lead to new discoveries and characterization metrics across the energy storage industry for all organizations, not only those looking at coulombic efficiency as their key indicator.

The graph below illustrates the difference between Arbin's differential capacity and that of another leading manufacturer. The two distinct dips in the plot may be missed using an inferior tester. While many companies try to sell the same antiquated equipment, Arbin has been hard at work improving its designs to meet future industry demands. Arbin learned a lot during the three-year ARPA-E project and has implemented this new technology in its LBT and HPT product series. The HPT systems represent a premium product, but LBT is claimed to be superior to all other standard testers on the market.



An illustration of the improved precision showing the differential capacity as measured from an Arbin LBT system (blue) compared to a traditional testing system (red)

Arbin's High Precision Test Station with built-in temperature chambers

Building on the success and feedback of the new LBT hardware, Arbin will now provide a standard two-year warranty on all new hardware purchases. Arbin's engineering team has always been confident in the reliability and longevity of its products, with some of the first manufactured test stations still in use. Since 1991 customers have received responsive support through a network of offices around the world, and the new two-year warranty will provide customers with continued access to the support team, paired with a lifetime of phone and email support for as long as an Arbin test station is owned.

These major hardware and software improvements can be paired with Arbin's new lifecycle chamber, which is designed to provide an accurate and stable temperature. Regulating cell temperature fluctuation is an important factor for accurately measuring coulombic efficiency. The lifecycle chamber provides an integrated solution to control the temperature of cells from 10-60°C.

Arbin understands the vital role energy storage plays in everyday life and its importance to the future.

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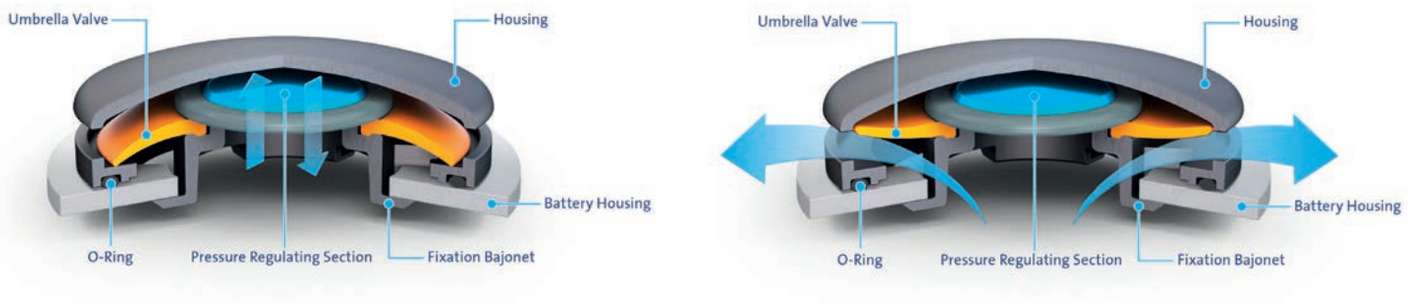
Pressure management

A pressure management system consisting of a multilayer nonwoven combined with an umbrella membrane provides several advantages over microporous film solutions



FST DIAvent with normal operation pressure-regulating function (left) and safety-relevant overpressure release on demand (right)

Large-scale batteries used in electric and hybrid vehicle applications require smart pressure management. Freudenberg Sealing Technologies has introduced DIAvent, an innovative solution made of a patented multilayer nonwoven fabric combined with an umbrella membrane. Together, these structures can handle pressure under any battery operating condition, intelligently and reliably.

DIAvent provides extremely high gas permeation in normal operation and a reversible emergency degassing function. At the same time, it meets the requirements for water tightness according to protection category IP67 and higher.

DIAvent offers a number of advantages over existing pressure compensation systems. These systems either achieve normal or emergency operation with two different components or they are irreversibly destroyed in the event of emergency operation. However, in the DIAvent, the functions are combined into just one component, while it is guaranteed that the emergency operation is reversible.

To develop this innovation, a critical challenge had to be overcome: on the one hand there was the need for high, surface-related air permeability, and on the other, a high degree of tightness when the system is in contact with water. Freudenberg has achieved this with its nonwoven combination, consisting of a highly permeable, filtering and hydrophobic external layer and a downstream water-blocking inner layer. The outer layer protects against penetration of water – in water columns of up to 100mm. It is only when higher pressures are present and the water passes through the outer layer that the inner layer activates and completely blocks the entry of water into the housing.

In comparison with microporous films, the nonwoven combination stands out for its ruggedness and high performance, which is not greatly affected by the unavoidable contamination seen over the part's operating life. In addition, the nonwoven can be processed in such a way that no residual water can collect on the nonwoven layer and reduce the air throughput.

Nonwovens are also a better choice than microporous foil due to their mechanical robustness (for example, creeping does not occur). It is only the substantial air throughput that enables the functional integration of emergency venting in the same installation space as is required by applications employing microporous films.

The DIAvent has a ring-shaped umbrella valve for the reduction in overpressure during an emergency degassing. Using its outer lip, it seals the outer area from the inner, but opens up reliably when there are slight housing overpressures. One important technical benefit is that the valve closes reversibly after a reduction in the overpressure. After an emergency degassing, interior operation is reliably protected – a damaged battery can be salvaged safely.

In addition, the umbrella valve can actively support the pressure compensation function during normal operation. This accelerates the exchange of gases from the interior to the exterior, making it possible to compensate for very fast overpressure fluctuations. This is beneficial for future developments for two reasons: on one hand, fast battery charging accelerates the heating processes; and on the other, large housings are much more sensitive to internal overpressure. As a result of this, compensation for overpressure represents a greater challenge than the reduction of under-pressures. In this respect, this combination of functions can contribute to, and positively support, future lightweight design trends.

The DIAvent developed by Freudenberg therefore represents a novel and innovative approach that meets the requirements of future battery systems. It can also be used in electronic systems without an emergency function – for example in transformers, electric motors, transmissions and headlights, which need a pressure compensation function with simultaneous water tightness.

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INQUIRY NO. 528

Laser welding tool

Laser bonding is suited for much larger connector cross-sections, where it offers the advantages of wire bonding, including high flexibility and ease of automation

Electric vehicles require much higher currents than those typical of traditional semiconductor applications – in the battery pack and in the drivetrain control system. This is where conventional ultrasonic wire bonding has its limitations, both on the technological and on the economic side. For a typical wire bond connection that uses aluminum wire of 500µm diameter, operating currents must stay well below the fuse current of about 35A. Using several wires in parallel, or even aluminum ribbons of 2,000 x 200µm size, is not a suitable solution either: the large amount of wires reduces productivity, and ribbons can be expensive. Not to mention the technical challenge of having to clamp the parts rigidly to sustain the high-energy mechanical friction needed for bonding.

Enter laser technology. Laser welding has long been a method of choice to connect much larger cross-sections, but for battery pack connections, automation is cumbersome because a connector bar or plate has to be placed across the cells with, ideally, zero gap between the spots that are to be welded. This is not easy to ensure and makes it all the more tricky to control the laser power precisely enough not to penetrate the thin metal can of a battery cell.

F&K Delvotec, which is based in Germany, has been manufacturing wire bonders for many years and took on the challenge to marry the two technologies. The company's new Laserbonder combines the flexibility and easy automation of a wire bonder with the high-quality welding performance of the laser. There are two major advantages of the laser: low clamping forces on the parts are sufficient, and the surfaces to be welded do not need to be very clean or even very smooth. True to its heritage from the wire bonder, the laser bonder simply reels off connections from cell to cell, or from cell to busbar, at the desired length and in the desired positioning, and cuts off the connecting ribbon after the second bond. Then it repeats the process for the next pair of contacts. If the heights of the battery cells are not precisely identical, the laser bonder will compensate for this by searching for the right height for each contact position. The same is true for shifting cell positions: an image processing unit locates the correct positioning and the machine automatically adjusts the connector length and direction, just like a conventional wire bonder.

For the welding itself, an infrared fiber laser of 1kW can handle copper ribbon connections up to around 10mm in width and 1mm thickness. A particularly powerful feature of the machine is deep penetration or keyhole welding, which, in combination with an oscillating beam, enables control of the width and depth of the weld seam independently of each other. This is ideal for battery cell connections where a large interconnection area – hence a wide weld seam – is desirable while the welding penetration should be in the range of 30µm or less, to ensure that damage does not occur to the thin sheet metal forming the battery cell container. These advantages, coupled with the cost-effectiveness of equipment, are generating a lot of interest in the industry.

The Laserbonder contains a wirebonder base with large working area (right) and a standard fiber laser with a control unit (left). Parts handling can be automated in a variety of ways, from manual loading and unloading to full in-line capability

A 18650 battery cell with a laser-bonded ribbon connection. Photo: Fraunhofer ILT

Super-fast charging

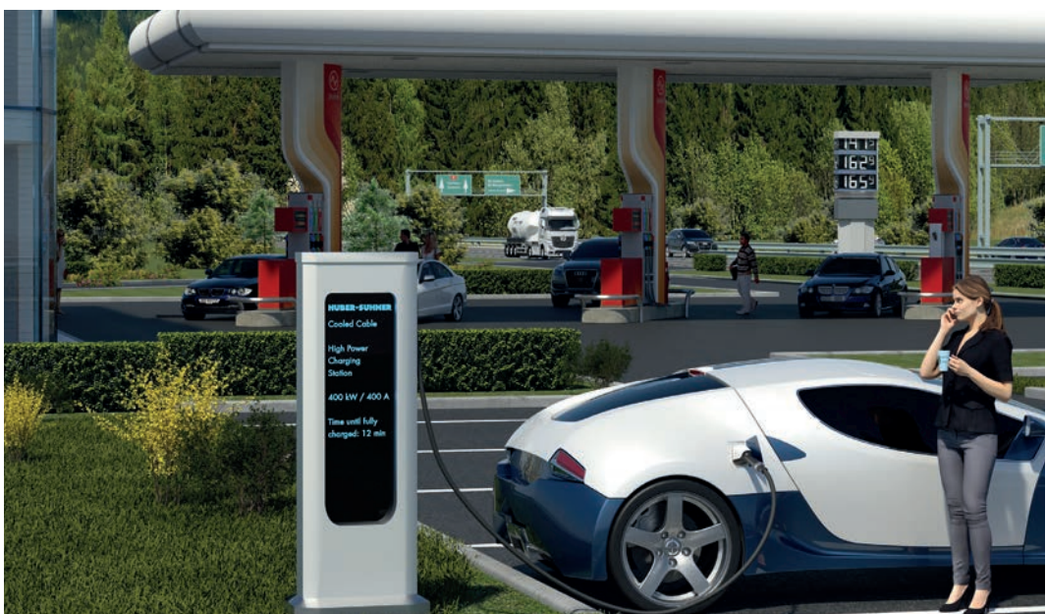
An innovative new cabling system is revolutionizing the charge process, ensuring quick and efficient top-up as well as improved levels of safety

Governments in countries across the world have continuously upped their game in the fight against global warming. Many have introduced regulations and/or established smart city initiatives to reduce emissions.

One of the main focuses is to reduce emissions in the automotive industry. With CO_2 levels currently at their highest in 650,000 years according to NASA, even more pressure is being applied to the automotive industry to speed up the implementation of environmentally friendly cars.

Electric vehicles are becoming the new standard, with more than 90,000 drivers switching to plug-in vehicles in the UK, according to Go Ultra Low. It is expected that these EVs will eventually replace internal combustion engine cars.

At present, electric vehicles are still the new kid on the block. Consumers must be savvy to find the best and easiest option for them. Currently, fast-charging stations work with an output of 50kW and charging currents of 120A, providing charging times of up to one hour for the latest generation of electric vehicles. This is quick compared with the previous eight-hour wait; however, if a driver needs to stop at a roadside charging point to charge their electric vehicle, an hour can often drag and become tiresome. Huber+Suhner, a Swiss-based manufacturer of components and systems for electrical and optical connectivity, has developed an innovative cable system to power electrical charging stations. Thanks to an integrated cooling system, it enables the charging of electric cars within 10-15 minutes, while ensuring it is safe and easy to operate for the vehicle driver.



Fast charging infrastructure is a key aspect of increasing electric vehicle uptake, making journeys more efficient and relaxing

The Huber+Suhner Radox High-Power Charging System guarantees safe performance for power delivery up to 400A and 1,000V. Meanwhile, with the advent of the Internet of Things, demands continue to change – therefore the design of the Radox HPC system has been developed to enable even higher ratings to cope with future charging requirements. The upward compatible and customizable system helps the utility provider to be prepared for future needs and, as a result, secure vital investments.

To bring the next generation of electrical 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 parking lots, a new generation of high-power charging points along pivotal travel routes are being implemented to ensure drivers are not restricted, with 96% of highway service stations in the UK installing a charging system.

With the ability to charge an electric vehicle in less than 20 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 transport. This game-changing infrastructure will not only make lives easier and safer, it will also make the idea of driving EVs much more appealing to consumers worldwide.

Huber+Suhner has developed a cable system that features integrated cooling

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INQUIRY NO. 530

Rapid pack development

The ability to leverage configurable battery modules built with standard cylindrical cells enables rapid deployment of high-performance custom battery packs

Sourcing or developing a battery system that is well-suited for a specific vehicle platform is a primary challenge for many prototype vehicle projects. Unlike a motor, drive inverter or other EV/HEV powertrain components, it is not possible for a handful of off-the-shelf products to serve the full spectrum of vehicle types. To address this problem, California-based Lithos Energy has developed a number of configurable battery modules based on standard 18650 and 2170 form-factor cells to enable rapid development and deployment of custom battery packs.

Lithos Energy battery packs are designed to meet energy storage capacity requirements, expressed in kWh, which can be quickly developed and implemented for initial prototyping and final vehicle production. Selecting an appropriate number and combination of modules to meet this energy requirement is the first step in a battery pack design.

The next primary design consideration is the expected charge and discharge rate for the application. This determines the type of cell (high-energy, high-power or balanced) that should be used in the battery modules. A pure hybrid will tend to require power-optimized cells, while pure-electric vehicles typically require energy-optimized cells.

The application's expected duty-cycle and charge/discharge profile also guides the selection of the cooling of the battery modules and pack. Lithos Energy modules are available in liquid-cooled, air-cooled or passively-cooled (uncooled) configurations, allowing for maximum application flexibility. Although most vehicle programs will use the liquid-cooling configuration for optimal thermal management of the battery pack, many stationary applications will use air-cooled or passively-cooled module variants for simplicity and cost savings.

A total of eight configurable Lithos Energy battery modules have been assembled into this 26kWh automotive-grade battery pack

An equally important design requirement for a battery pack is its nominal DC voltage, with 350V and 700V being common nominal voltages in automotive and heavy-duty applications. Since these voltage ranges are typically fixed, regardless of the pack size, it is important that the battery modules are configurable to different series and parallel (S and P) configurations. For example, the Lithos Energy 288-cell module is configurable to 6, 8, 12, 16, 24 and 48 cells in series. This way, a pack as small as 10kWh or as large as 100kWh can be configured to have a 700V nominal voltage.

Lithos Energy packs featuring this modular configuration can be built in as quickly as 12 to 16 weeks, providing considerably faster time to prototype and time-to-market speeds. A traditional battery development process that would yield the same results would typically require 12 to 18 months.

Lithos Energy's 288-cell module is an example of the primary building block for large-format battery packs, which can be developed extremely quickly

This rapid battery development and delivery can make a prototype vehicle program or race team's aggressive timeline possible.

When it comes to production, Lithos Energy battery packs using this modular design are designed for medium- to high-volume manufacturing, meaning that a completely new battery development effort is not required to move a vehicle design from prototype to production. By using standard 18650 and 2170 cylindrical cell form factors, battery designs can be upgraded to utilize the latest cell technology without having to redesign the mechanical structure of the pack.

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INQUIRY NO. 531

Sodium-ion batteries

British companies are helping to power the green energy revolution, collaborating to bring commercially viable sodium-ion batteries to the automotive market

Over the past two decades, lithium-ion technology has dominated the secondary battery market and is widely used in consumer electronics and the automotive sector. However, with advancements in the next generation of new low-cost battery materials, there are now attractive alternatives in the marketplace.

Sodium-ion (Na-ion) technology is one example, offering commercial advantages over current lithium technology, including lower costs and in-built safety characteristics.

The technology is being pioneered by Faradion, a Sheffield-based R&D company, partnered with AGM Batteries, to bring the technology to market. Having secured government funding through Innovate UK's US$36.4m initiative to make the UK a global leader in emissions-cutting technology, sodium-ion batteries could be powering production cars as early as 2025. There are a number of factors that make Na-ion technology an attractive alternative.

Na-ion cell formats can be identical to Li-ion. Their production uses almost identical process equipment, enabling manufacturers to convert existing production lines without new plant build and cost.

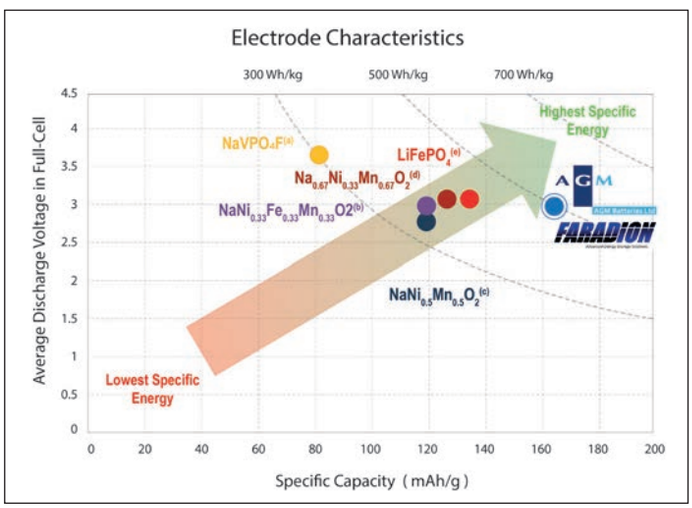
Furthermore, by using highly abundant sodium salts rather than lithium, it is forecast that volume production sodium-ion cells could be up to 30% lower in cost than conventional lithium-ion cells, an important step for cost reduction of electric vehicles in particular.

In addition, Na-ion cells have energy densities similar to those of conventional Li-ion materials.

Na-ion cells also offer comparable power. Electrochemical tests have shown that the rate capabilities can be as good as Li-ion materials.

Sodium-ion batteries possess in-built safety features, with safer materials improving thermal stability. The technology can be discharged and stored at zero volts (without affecting performance), making it much safer to transport.

AGM is working with its partners to bring battery technologies to market



The electrode characteristics of different battery chemistries. Image: Faradion

Cell testing has also shown evidence of excellent cycle life in many of Faradion's novel materials.

Finally, analysis indicates that sodium-ion has a similar shelf life to currently available Li-ion materials.

In terms of current timescales, Faradion and AGM, supported by WMG, are currently working to optimize the sodium-ion technology to meet OEM vehicle manufacturer EV specifications. This includes adapting the active materials at the cathode and anode. The ambition is to deliver a working prototype for EVs by 2018, which will then be tested by vehicle OEMs, some of which are also involved in Innovate UK projects developing electric vehicle powertrains.

"The pace and scale of the energy market is changing as a result of society's increasing requirements," says Faradion's lead engineer, Noel Roche. "It is exciting to be at the forefront of developing technology that will help transform the way we use energy. Faradion's technology proves that cost is no longer a barrier to take-up of more renewable energy and we are committed to delivering our emissions-cutting technology to the marketplace."

AGM Batteries is a UK-based cell developer and manufacturer, operating a large-scale cell pilot/small-scale manufacturing plant, focused on the scale-up of emerging new electrochemistries and cell types. The new project is growing thanks to collaborative work already underway between the various companies involved, with the aim to commercialize sodium-ion technology for volume manufacture at AGM's 4,000m^2 production facility in Caithness, Scotland.

"AGM is delighted to be working with Faradion on Na-ion technology," explains Colin Arnold, plant manager at AGM Batteries. "Using our expanding scale-up facilities, AGM is uniquely and ideally positioned to take innovative new technologies to market. We see excellent potential for low-cost and safe Na-ion in automotive applications and we're excited about the opportunities it brings to the rapidly growing energy storage sector, as well as opening new sectors such as oil and gas, which have been less inclined to adopt lithium solutions."

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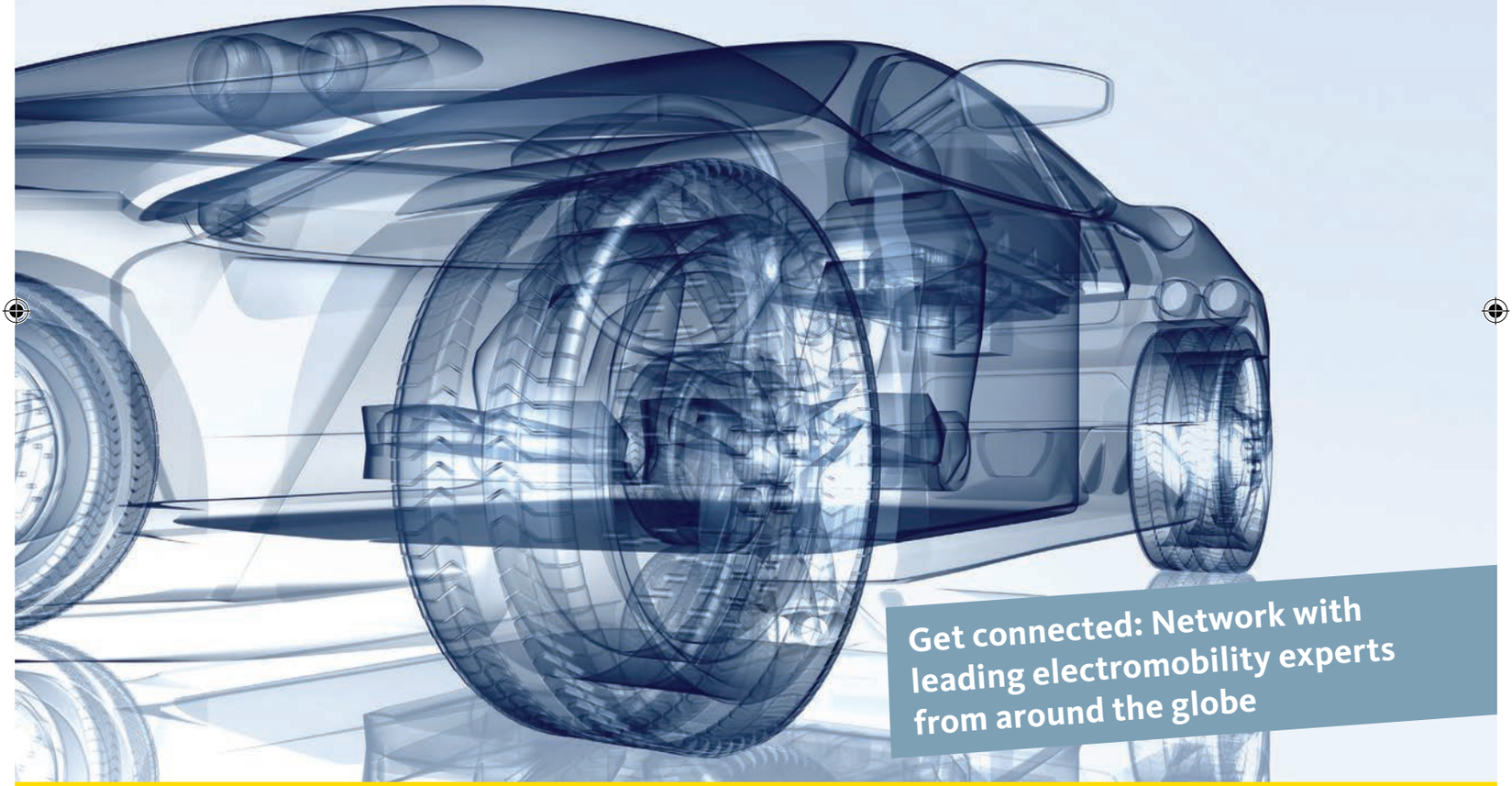

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Total accessory electrification for buses

Total electrification of bus accessory components is now achievable through Vanner's Increased Accessory Power II (IAP II) system. IAP II is a customizable distribution platform that provides power to operate electrical accessories such as air conditioning, air compressors and power steering systems for hybrid, EV and fuel cell buses.

IAP II can completely decouple accessories from the engine, significantly reducing parasitic loads and maintenance costs. A high-voltage distribution module (HVDM) provides intelligent high-voltage power control. A single HBA or dual HBAs can be used to convert high-voltage DC for the 24V DC system. Vanner's proprietary state-of-charge (SOC) modeling offers dynamic 24V DC system charging, and an inverter converts high-voltage DC to high-voltage AC for powering electric accessory systems while eliminating the need for a costly A/C system integral inverter.

Transit authorities realize that full bus electrification improves fuel economy, reduces emissions and lowers maintenance costs. IAP II further improves efficiency by removing parasitic loads from the engine and distributing electrical power through the entire bus.

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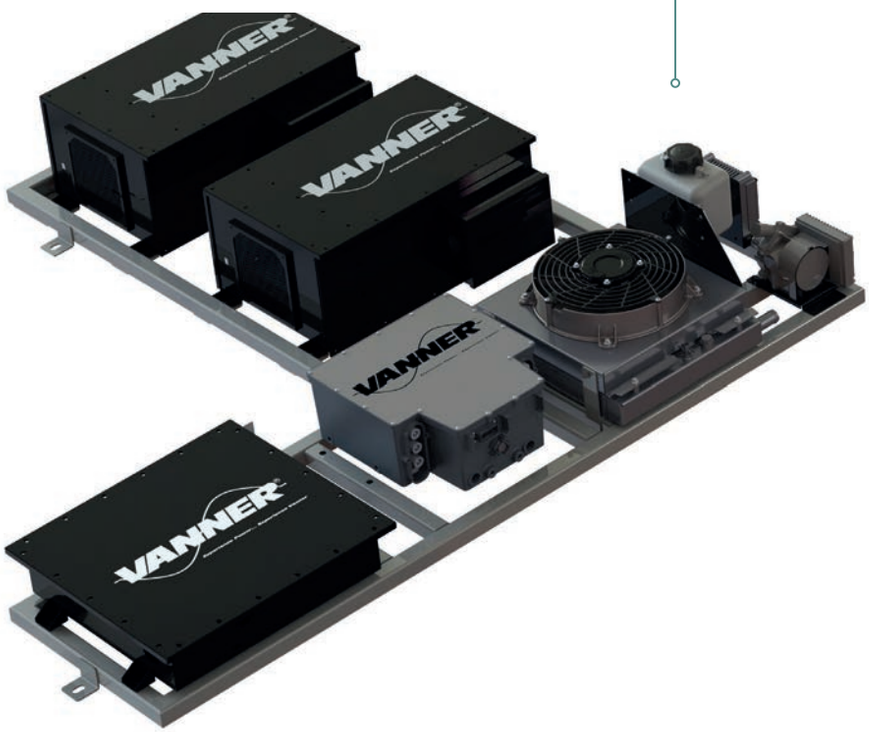

Furthering fuel cell vehicle development

Despite a strong and growing public commitment to development of pure-EV and battery technologies, behind the scenes many automotive OEMs have been quietly developing and industrializing fuel cell vehicles. BMW recently committed to commercializing fuel cell vehicles from 2020 while Toyota, Hyundai, Honda and a number of other OEMs already have shelf-engineered fuel cell vehicles. It is increasingly likely that fuel cell powertrains will soon become mainstream, part of the inevitable mix of electric and hybridized powertrains that will gradually help decarbonize our road transport from now until 2050. With hydrogen vehicles becoming mainstream, the hydrogen distribution network will also develop globally to meet growing demand, leading many other companies to start investing in hydrogen fuel-cell-powered vehicles.

The ground-up development of high-power automotive fuel cells is an expensive undertaking and remains the preserve of the major OEMs and large fuel cell R&D companies. However, the integration of a fuel cell power module into an automotive application is not dissimilar from other HV electrical components. Companies such as Hypermotive, with many of its team having previously worked for large fuel cell research companies, combine a deep understanding of fuel cell systems with years of automotive engineering experience. They are well placed to support niche vehicle manufacturers, technology developers and Tier 1 companies working to understand, apply or combine fuel cell technologies into their applications.

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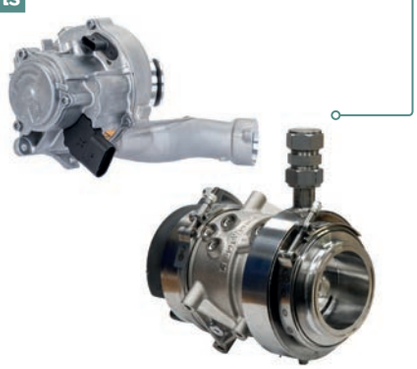
INQUIRY NO. 534

Advanced 48V solutions



Rising environmental awareness is currently driving a growing demand for clean and fuel-efficient products. BorgWarner's leading technology solutions help auto makers build advanced vehicles that meet this demand.

A key approach to meeting customer requirements and increasingly stringent regulations is the development of 48V technologies for improved efficiency and reduced emissions. To this end, BorgWarner is already producing the eBooster electrically driven compressor, which complements conventional turbocharging systems and improves transient behavior at low engine speeds while enhancing fuel efficiency and reducing emissions. In addition, the company has developed the 48V eFan series, an innovative airflow solution that enables precise and reliable thermal management.

Furthermore, BorgWarner is in the process of developing a broad range of additional technologies that take full advantage of a 48V power supply, including key components for an organic Rankine cycle (ORC) waste heat recovery system that recovers approximately 50% of the energy wasted in heat rejection, a compact disconnect system for electrified drivetrains, the electric all-wheel drive (eAWD) system and electric rear drive module (eRDM), as well as the integrated Belt Alternator Starter (iBAS).

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INQUIRY NO. 535

Enhanced measurement system

With its newly developed shunt-based IVT-S measurement technology, Isabellenhütte is responding to a market that now favors specified functions in current measurement systems. The main focus is on achieving dielectric strength that is as far as possible in line with the intended application. High dielectric strength must be guaranteed in battery-powered vehicles, for example.

To this end, Isabellenhütte is now introducing the IVT-S. The measurement system has a maximum dielectric strength of 1,000V. Its functional range includes the measurement of current and voltage. Isabellenhütte thus meets today's market requirements of traction battery systems or stationary, electrical energy storage devices. These lithium-ion batteries generate high energy density, at which higher voltages can be applied with smaller currents. Therefore the sensor's dielectric strength also has to be correspondingly high – a key quality feature that distinguishes the IVT-S from competing products. For fast-charging battery systems, this performance feature is extremely important.

A variety of components are used in the IVT-S. A 16bit A/D converter guarantees the precise transformation of the voltage drop into digital signals. Data is transmitted through a CAN 2.0 interface. Through this module, the internally developed current-counting firmware is provided with information on charge and discharge volumes. In addition, Isabellenhütte provides a CAN description file in DBC format that helps IVT-S users to swiftly integrate the application.

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INQUIRY NO. 536

Vehicle monitoring and control solutions

Curtiss-Wright Industrial division has extensive experience in the design and manufacture of solutions for the monitoring and control of vehicles, including applications throughout the on-highway commercial vehicle sector.

The dynamic state of global emissions regulations has driven on-highway vehicle OEMs to seek flexible, cost-effective technologies to meet changing regulatory demands. At the same time, fleet operators are seeking technologies that improve fuel efficiency and ensure safe and easy operation in complex environments.

Additionally, new vehicle controls are expected to simplify operation, automate daily tasks and reduce human error, therefore playing a vital role in transportation's economic success. Curtiss-Wright is also addressing new energy solutions for a greener environment by providing advanced motor controllers and power electronics for hybrid and electric vehicles.

The new WTI traction inverter product line – from the corporation's brand family of Arens Controls – offers state-of-the-art technology for use in hybrid and pure-electric applications. These inverters operate with multiple motor technologies, including AC induction, permanent-magnet synchronous (PMS) and internal permanent-magnet (IPM) types. The major components – insulated-gate bipolar transistors (IGBT), capacitors, filters and circuit boards – are all automotive grade and certified to AEC-Q100, Q101 and Q200. This ensures electrical reliability and an impressive power-cycle rating in excess of seven million cycles.

WTI traction inverters offer a versatile connection to the master control system using either standard J1939 or customer-specific CANbus protocols, as well as a customizable discrete interface that can support digital, analog and solenoid-drive control options. A range of four models cover supply outputs from 360-600V DC and peak power from 160-530kVA in either single or dual variants.

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Electric and hybrid vehicle cooling solutions

The engineering and manufacturing company that transformed the bus transit market a decade ago with its electric multi-fan cooling solution – Mini-Hybrid – has now set its sight on doing the same for electric and hybrid vehicle electronics cooling, including traction motors. Northern Michigan's EMP has launched a new electric oil pump (eOP) product lineup designed to provide the lubrication and oil cooling demanded by today's electric traction and generator motors.

Jason Cousineau, EMP's lead engineer for this revolutionary product, notes that the electric pumps represent a breakthrough in performance, durability and efficiency compared with other pump technologies. All EMP oil pump models feature high efficiency, long-life brushless DC motor and drive technology and are available in both 12V DC and 24V DC. The pumps are positive displacement types using gerotor pumping element technology

for quieter, more efficient operation. With discharge pressures up to 100psi, the pumps will handle a variety of fluid-transfer applications including lubrication, cooling, scavenging and general fluid management.

The eOP product lineup recently expanded to include a new higher flow capacity model that doubles the flow capacity of the existing OP40 pump up to 8 gal/min. A two-stage pump model has also been introduced for dry sump lube and cooling applications.

EMP is a worldwide leader in complex precision machining and advanced thermal and oil management technologies and has been manufacturing electric oil pumps since 2010. Based in Escanaba, Michigan, EMP's advanced products are used globally by major diesel engine manufacturers and hydraulics manufacturers.

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INQUIRY NO. 538

Precision mixed-signal power analyzer for polyphase measurements

Dewetron is pleased to announce the launch of the DEWE2-PA7 Mixed Signal Power Analyzer, capable of analyzing polyphase electric vehicles and engine behavior with only one system and a guaranteed basic accuracy of 0.01%.

A Dewetron DEWE2-PA7 is the solution for the simultaneous analysis of several motors, converters or complete drivetrains – up to 12 power channels. The DEWE2-PA7 is the only power analyzer capable of calculating power parameters, even for polyphase motors, with up to seven phases per power group.

Multiphase systems have several advantages over conventional three-phase systems: reduction of amplitude and increased frequency of torque pulsation; reduction of rotor harmonic currents; reduction of the current phase without increasing the phase-voltage level; lowered DC-link current harmonics; and increased reliability, as the analyzer continues to run even if one of the phases is open or short circuited.

A DEWE2-PA7 can combine waveform data, and mixed signal and power analysis, providing reliable, gapless recording of any analog or digital signal and high-performance power calculation of several power groups simultaneously. Up to 2MS/s/ch and high dynamic range guarantees data integrity.

Smart interface technology makes it easy to integrate a DEWE2-PA7 Mixed Signal Power Analyzer into automation systems and testbed environments, while guaranteeing reliable data transmission, easy-to-use remote control and remote configuration through TCP/IP-based protocols in compliance with standardized protocols such as ASAM and file formats.

Dewetron's Oxygen with Power software seamlessly integrates data being transmitted through multiple, totally synchronized signals into calculations for power analysis.

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INQUIRY NO. 539

High-voltage automotive battery stack monitoring

Analog Devices, which recently acquired Linear Technology Corporation, features the LTC6811 high-voltage battery stack monitor, a drop-in replacement for the LTC6804 with higher performance and a 25% lower price. The LTC6811 is a complete battery measuring IC for hybrid/electric vehicles that incorporates a deep-buried Zener voltage reference, high-voltage multiplexers, 16-bit delta-sigma ADCs and a 1Mbps isolated serial interface. An LTC6811 can measure up to 12 series-connected battery cell voltages with better than 0.04% accuracy. With eight programmable third-order low pass filter settings, the LTC6811 provides outstanding noise reduction. In the fastest ADC mode, all cells can be measured within 290µs.

For large battery packs, multiple LTC6811s can be interconnected and operated simultaneously, using Linear Technology's two-wire isoSPI interface. This built-in interface provides electrically isolated, high-RF noise immune communication for data rates up to 1Mbps. Using twisted-pair cabling, many LTC6811s can be connected in a chain to one host processor, enabling measurement of hundreds of cells in HV battery stacks.

The LTC6811 is offered in a small (8 x 12mm) surface mount SSOP package. Priced at US$8.19 each in 1,000-piece quantities, samples and demonstration boards are now available at Linear Technology Corporation's website.

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INQUIRY NO. 540

Bidirectional high dynamic test-bench energy systems

In the range of low currents or low voltages, buck-boost-converters with classic control mode have the handicap of discontinuous current mode. This leads to an irregular inductor current flow and decreases to zero value. It has the effect of the control mode of the power amplifiers changing significantly and is difficult to control, especially in the transition area between discontinuous and non-continuous current mode. This problem is reflected in the quality of the output signal and restricts the operating range downward.

With the development of an innovative switching operation for buck-boost-converters, Heinzinger accomplished the elimination of the discontinuous current mode completely. The maximum current and full dynamic is available now even at very small voltages.

For 48V low-power applications up to 20kW, Heinzinger will soon present a new ERS-System, which uses the latest FPGA and SiC technology and offers users the highest dynamic and smart test functions. Typical applications are characterization and verification of LV and HV batteries, as well as validation for electric drivetrains and their components. The power supplies are able to reproduce the real conditions during a test cycle by using high-speed control and communication to reach an undelayed and continuous transition between source and sink mode.

Heinzinger now offers not only a system suitable for all applications – from the low-voltage range starting at 48V to the high-voltage range up to 1,200V with 1,200A maximum current – but also further power supply solutions for test applications.

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INQUIRY NO. 541

Advanced MOSFETs

From powertrains to safety systems, and from comfort features to vehicle lights, MOSFETs play an important role in reducing system losses and delivering longer travel times between charges. At the same time, they must deliver the power densities and thermal performance that help designers save board space and reduce component count.

As more functions become intelligently automated, the MOSFET performs a vital role in switching power to carry out the commands of the growing number of processors to be found in modern electric and hybrid electric vehicles.

Based on the latest UMOS-6, UMOS-8 and UMOS-9 processes, Toshiba's automotive range includes both N-channel and P-channel devices with VDSS values from 40V to 100V. Currents up to 250A can be handled, yet the range includes smaller devices with ID ratings as low as 7A for smaller automotive applications. $R_{DS(on)}$ values down to just 0.79mΩ ensure minimal heat dissipation, enabling the power densities and reliability demanded by the challenging automotive environment.

A wide variety of packages are available, including DPAK+, D2PAK+ and TO-220SM(W), enabling designers to select the best form factor for the application – and the available space.

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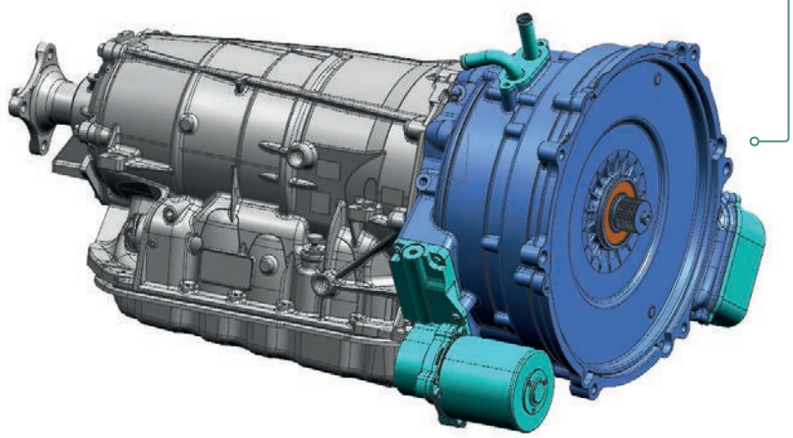
INQUIRY NO. 542

Scalable hybrid driveline solution

Today the automotive market is looking for transmission concepts that can meet and anticipate the trends for rising automation and electrification of the powertrain. The demand for automatic transmissions and their hybrid versions is gaining ground as fuel consumption targets are becoming more stringent. Punch Powerglide is providing a simple and efficient alternative to current parallel and power-split hybrid concepts by enhancing its proven 6-speed conventional RWD/4WD transmission (6L50) through a step-by-step approach for further electrification.

The first step has been achieved this year with the implementation of a hydraulic accumulator on the 6L50 transmission that supports the engine stop/start function. The next step will take place next year with the launch of a mild-hybrid version for vehicles equipped with a belt starter generator on a 12V or 48V basis. The final step will take place in 2019 with implementation of an actual hybridization with an integrated electrical motor in a P2 configuration.

Thanks to all these added options – such as stop/start, mild hybridization and a full hybrid solution – Punch Powerglide's customers will benefit greatly from a scalable driveline solution based on proven technologies and minimized investment, which is capable of responding to upcoming and future environmental requirements.



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INQUIRY NO. 543

Electric and hybrid vehicle supervisory control module

Pi Innovo, a company dedicated to delivering innovative prototype and production custom ECU solutions, has added the M560 targeting EV/HEV supervisory control applications to its family of OpenECU off-the-shelf controllers.

Through selected hardware redundancy as well as diverse software implementations on the main and secondary microprocessors, the M560 can meet ISO26262 ASIL D functional safety requirements. The M560 also includes internal signal monitors providing comprehensive fault diagnosis to support functional safety as well as OBD requirements.

The M560 comes with a safety manual to assist integration into new applications. This ensures all safety element out-of-context assumptions are communicated and the intended ASIL can be met with an off-the-shelf ECU.

The M560 OpenECU features 112 pins of flexible I/O designed to support development of complex hybrid and EV applications. Four CANbuses also help to align the M560 with the high bandwidth of communications that complex hybrid and electric vehicle architectures require. The integrated EVSE interface control, covering all global charging standards (J1772, GB/T, and Chademo) gives vehicle developers the flexibility to use this module for various markets, while providing the opportunity to eliminate a separate interface module on the vehicle.

Pi Innovo plans to offer future OpenECU models that incorporate higher bandwidth Ethernet connectivity and readiness for integration with vehicle ADAS and full autonomy functionality.

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www.ukimediaevents.com/info/ev
INQUIRY NO. 544

Electric and hybrid charging solutions

Delphi continues to demonstrate its commitment to the EV/HEV sector with an extensive portfolio of charging solutions that meet the demands of a comprehensive array of regions, markets and customers. Available via Delphi's global distribution partner TTI, highlights of the current portfolio include a comprehensive choice of Mode 2 portable charging cordsets. Developed in close collaboration with OEMs, these products have demonstrated their durability in the field over an extended period, offering safe, reliable operation in countless 240V AC grid applications. Options are available for all European markets, including Switzerland, Denmark, Norway and the UK.

With the market continuing to evolve, Delphi and TTI are now supporting the introduction of a second generation of Mode 2 charge plugs that offer full compliance with the new IEC 62752 standard. Significantly, end-user safety is further enhanced in domestic applications with residual DC protection and thermal sensing capability enabling automatic shut-off in the event of potentially dangerous operating conditions. Once again, OEMs and infrastructure manufacturers can rely on solutions for all European markets.

Other key members of the Delphi EV/HEV family, again proved in high volumes, include a full line-up of Mode 3 cable assemblies and connector pigtail options that enable infrastructure manufacturers to match the requirements of a diverse range of customers. Furthermore, across both well-established and new technologies, TTI's investment in local inventories and customer support ensures a highly responsive supply chain, optimizing production efficiency and cutting time to market.

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INQUIRY NO. 545

Next-generation electrification expertise

Experts in the development, integration and application of electric, hybrid and fuel cell systems for the automotive sector, Revolve Technologies is highly active in the evolution and integration of range-extended electric hybrid commercial vehicles and hybrid genset modules. Revolve is a leader in the development of implementation of hydrogen, in gaseous form, in both gasoline- and diesel-engine vehicles. Working with Innovate UK and the Advanced Propulsion Centre (APC), Revolve, as an SME, has been successful (as both partner and supplier) in the completion of a wide range of low-carbon projects.

Revolve is also helping some of the world's leading automotive OEMs to deliver their next-generation PHEV products. Revolve's expertise, developed through research and development over the past 15 years, has seen the deployment of hybrid and EV applications as diverse as double-decker buses, trucks, vans and passenger cars, as well as application of the company's hydrogen technology to marine projects. Revolve's unique skills and knowledge base can help customers develop their electrification project from the early concept and prototype stage through to vehicle-level systems' calibration and into full production.

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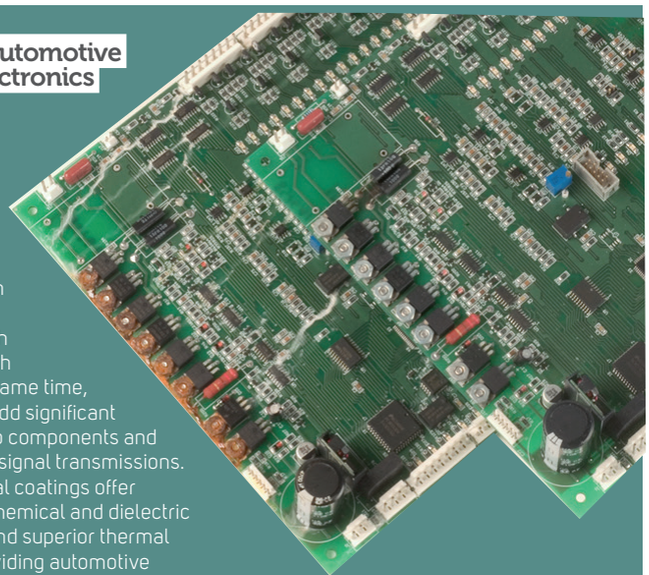
INQUIRY NO. 546

Protection for automotive sensors and electronics



Integral to electric motors and their associated systems, sensors and other electronic components in vehicles require specialized protection in order to be able to withstand the harsh environments in which they operate. At the same time, protection must not add significant weight or thickness to components and cannot interfere with signal transmissions.

Parylene conformal coatings offer excellent moisture, chemical and dielectric barrier capabilities, and superior thermal and UV stability, providing automotive electronics with a level of protection that is unmatched by many of today's coating materials. Parylenes are applied in micron-range thicknesses and are extremely lightweight. Applied as a vapor, there is no liquid phase in the Parylene deposition process, thus there are no subsequent meniscus, pooling or bridging effects. The molecular 'growth' of Parylene ensures not only an even, conformal coating at the thickness specified, but because Parylene is formed from a gas, it also penetrates into every crevice, ensuring complete encapsulation of the substrate without blocking small openings.

Parylene coatings are RoHS and REACH compliant and have proved to provide metallic whisker mitigation in lead-free solder applications. Parylenes are ideal for protecting circuit boards, sensors, MEMS, LEDs, elastomers and other surfaces and components that need reliable, long-life performance.

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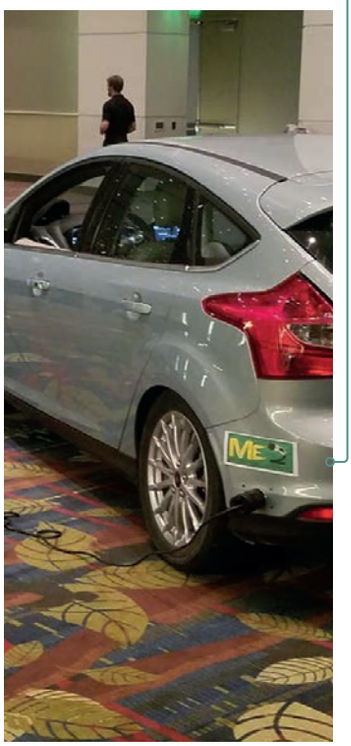
INQUIRY NO. 547

Aftermarket range extender

The team at Me2EV is currently developing its K-Loop Kinetic aftermarket EV range extender. The product has the same features as the company's L-Loop lead-acid battery bank, which loops the power into a 240V AC inverter and a 30-50A level-2 charger built into the electric vehicle with Me2's kit. Now electric vehicles can charge anywhere as long as there is lead-acid power remaining.

The aftermarket K-Loop has wheels that come out like an aircraft's landing gear, and the wheel generator feeds this captured kinetic energy back into the lead-acid battery using a bank of alternators. This patented process was created and patented by the company's founder, James Dierickx. The wheel generator refills the lead-acid batteries until full. Once home, users plug both battery chemistries into separate chargers, so they can always start off the day with full batteries.

Me2EV technology is currently designed for use with 2012-2017 Ford Focus Electric Hatchback models; later models (with the CCS DC fast charge module) will also be able to use the L-Loop and K-Loop kits. Me2EV will soon be making kits for the Nissan Leaf, Chevy Volt and Bolt, BMW i3 and Tesla. Me2EV believes that no other technology currently exists that offers mobile DC fast charge capability.



The company's biggest show stopper this year will be its 360-480V DC fast charge dynamic charging, which uses the K-Loop technology. Me2EV is hoping to demonstrate this at the Electric & Hybrid Vehicle Technology Expo in Novi, Michigan, in September. Me2EV will be at booth 632.

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INQUIRY NO. 548

High-performance contacts and connections

The stamped ODU Stamptac contact has been developed systematically over the past two years and is now available in 3mm and 6mm versions, ready to be used for example, in an IEC charger coupler. Thanks to its molded seal, tightness is compliant with protection class IP67. It delivers optimal results thanks to three surface varieties – for the crimp and contact areas as well as for the contact body – and offers a significant cost reduction compared with current turned contacts.

The latest development of the stamped and formed contact has a tripartite surface coating. The slotted contact fingers of the copper hollow body are silver-plated for better transmission. The crimping part, in contrast, is tin coated – an ideal solution for crimping. The middle part is nickel-plated and corrosion-proof. These optimized surfaces enable the economical stamped ODU Stamptac contact to display nearly the same properties as a turned contact system made of solid material.

E-mobility is a key market of the future, with enormous development potential. This applies both to numerous applications and almost all industries. The contact technologies and transmission systems used are an important foundation for the successful implementation of sustainable e-mobility applications.

As an established specialist in high-performing contact technology and connections in many industries, development work at ODU has been focusing on innovative approaches and optimizations in e-mobility for several years. This makes ODU a strong and experienced development partner for its customers – including for application-specific and customized solutions in current and future e-mobility technology.

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INQUIRY NO. 549

Advanced inverter technology

Rinehart Motion continues to grow. The company still provides advanced, specialty propulsion inverters for performance cars and professional motorsports – from three teams in every Formula 1 event to a plethora of road-legal EV and HEV hypercars. Major upgrades to facilities and validation test capability have enabled many more leading-edge propulsion system component and power electronics projects. SiC and GaN inverter technology, super-high-speed sensor-less controls to 200,000rpm for waste heat energy recovery, and now advanced electric aircraft applications, demand the ultimate in quality, efficiency, size, weight and cost.

But the big news is that Rinehart Motion has expanded to a larger facility and is setting up automotive-quality production of inverters in medium-volume production. By Q1 2018 a capacity of 20,000 units/year on a single shift will be realized for the new RM100 – the first of a family of low-cost production tooled automotive inverters. The RM family incorporates the technology and seven years' experience of supplying the PM100, PM150, and PM250 specialty inverter products for thousands of vehicles, working through the system integration and programming roadblocks with actual customers, making it one of the easiest-to-use propulsion system inverters available on the market, not just the lightest and smallest.

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INQUIRY NO. 550

Test systems fit for climate chambers

Kübrich has more than 15 years of experience with door slam systems for fatigue and durability testing in climate chambers (-40°C up to 85°C), end-of-line test solutions, and test solutions for the complete e-mobility vehicle generation.

With its Actere software, Kübrich has developed a turnkey test system individually designed for laboratories and test facilities. Kübrich has developed its complete actuator and robot program for endurance and durability tests focused on climate chamber use. All Kübrich systems are designed to simulate lifetime testing with up to a million cycles.

Testing of e-mobility components such as starter generators, e-drive motors and complete e-drive units has become a major focus at Kübrich, as well as component testing for development of autonomous drive system – such as electronic steering, self-parking and electrically driven aerodynamic components. All components interfaced with the Actere testing software enable users to create their own test sequences, displays and reports.

Kübrich's DuT (Device under Test) Modular offers a wide range of measurement possibilities and

simulations via CANbus or LINbus. Furthermore with its latest development – a new starter-generator test stand for 48V systems – Kübrich has set a new benchmark.

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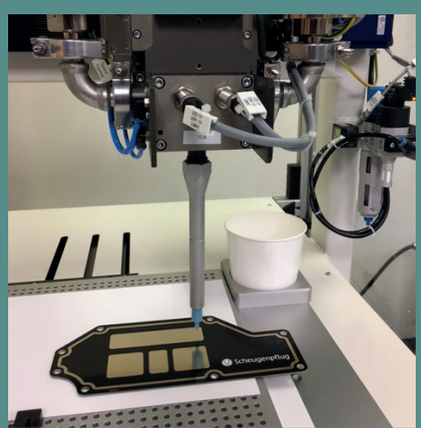
INQUIRY NO. 551

Advanced materials handling

The increase in inclusion of thermal interface materials (TIM) by the electronics assembly industry has led the way for lithium-ion batteries to become the reigning industry standard. While these heavily filled, viscous, two-component items have great characteristics engineered to dissipate heat from electronic components, newer material formulations with varying characteristics are used to bind battery cells into customized packs. These often abrasive and harshly engineered materials, which offer great performance characteristics, come at a cost to production processes and equipment. Often overlooked is the dispensing equipment's wear and tear on the production floor (due to the difficulty in dispensing these thick materials and pastes), where finding ways to minimize downtime is at a premium.

Many material dispensing equipment manufacturers have focused on dispensing viscous materials, but often lack the ability to process abrasive materials without severe damage to that material thanks to current industry processing methods.

Material evolution demands equipment manufacturers master the ability to process filled, highly viscous – and now abrasive – materials. Scheugenpflug has uniquely coupled the ability to handle highly viscous and highly abrasive materials thanks to its



advanced volumetric piston dosing system and proprietary methods of handling TIMs for true homogeneous dispensing. Scheugenpflug US offers its full laboratory testing and design services to material manufacturers to finalize custom formulations driven by market demands. This novel approach offers proven packages to both the electronics and battery pack assembly industries.

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INQUIRY NO. 552

High-performance connectors

Major trends in connector development over the past few years include miniaturization and increased contact density. System integrators in various markets are looking to increase the number of sensors and data acquisition means. Naturally this requires more connectors and cables in reduced space.

While LEMO connectors will probably not make their way onto final consumer vehicles, the company's Push-Pull connectors are being used for various testing equipment, such as battery monitoring systems, communications systems, sensors and ECU feedback. Today the M series can also be considered for high-speed data transmission. Special contact arrangements have been designed and tested for use with CAT5 and CAT6 cables. M series connectors can operate over a temperature range of -55°C to 200°C and are environmentally sealed to IP68. Because LEMO connectors are perfectly screened and designed to guarantee very low resistance to shell electrical continuity, these connectors are particularly adapted to applications where electromagnetic compatibility is important.

Since its conception in 2012, Formula E has gained significant popularity with motorsport fans and is also very much an R&D hub for the development of electric vehicle technology. The Formula E championship is currently contested by 10 teams with two drivers each.

Formula E serves as an ideal framework for research and development around the electric vehicle, accelerating general interest in these vehicles and promoting sustainability. It is a vision for the future of the motor industry. And it is a vision that LEMO's partnership with e.dams Renault will fuel.

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INQUIRY NO. 553

Semiconductor architecture

Silicon Mobility has introduced a new semiconductor architecture called the Field Programmable Control Unit (FPCU). The OLEA T222 is the first production release of this unique semiconductor solution. The FPCU marks a departure from conventional semiconductor architecture for hybrid and electric vehicle control. It combines flexible and parallel hardware for the real-time processing and control of sensors and actuators, coupled to a standard CPU. All this is complemented with an integrated ASIL-D functional safety architecture to form a single semiconductor. The FPCU is far more powerful and flexible than a conventional safety MCU and much more adequate than a generic FPGA or any other kind of mixed CPU + FPGA architecture.

The benefits of OLEA are numerous in electrification applications – such as inverter, DC/DC converter and AC/DC charger control – where its ability to execute complex control loops quickly and in real time with switching capability up to 500KHz (20 times greater than offered by conventional solutions) enables the use of power technologies such as GaN and SiC. The quality of conversion is improved and maximizes the energy transferred, increasing battery autonomy, charging time and e-motor size, weight and cost.

The OLEA T222 is available with development framework and software library from Silicon Mobility.

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INQUIRY NO. 554

Axial flux traction motor development

UK-based automotive cleantech firm Avid Technology has signed a deal with GKN to develop and manufacture the EVO axial flux traction motors. Avid has taken over the development, manufacture and sale of EVO motors and this will see Avid develop the technology to deliver new variants and additional market applications.

The EVO motor's high power and torque density, from its patented axial flux configuration, enable smaller, lighter and more efficient traction motors and generators for a wide range of EV and HEV applications. The EVO can also be cooled by conventional 50/50 WEG and its design is intrinsically resilient to vibrations and resonance, further easing its vehicle integration.

Avid is an award-winning leader in the design and manufacture of electrified powertrain systems. The company was founded by engineer Ryan Maughan, who is passionate about improving the efficiency and environmental impact of vehicles through electrification.

"As one of the highest power and torque density motors on the market, the EVO technology complements our existing range of high-performance products," says Maughan, Avid's managing director. "We see huge potential for this technology in our key markets of heavy-duty and high-performance vehicles, and some exciting new market applications we already have in development."

Avid's core business is the efficient electrification and intelligent control of powertrain ancillaries, such as thermal management systems, pumps, fans, motor drives and generators. Many OEMs of heavy-duty and high-performance EVs and HEVs use the company's expertise and pioneering technology.

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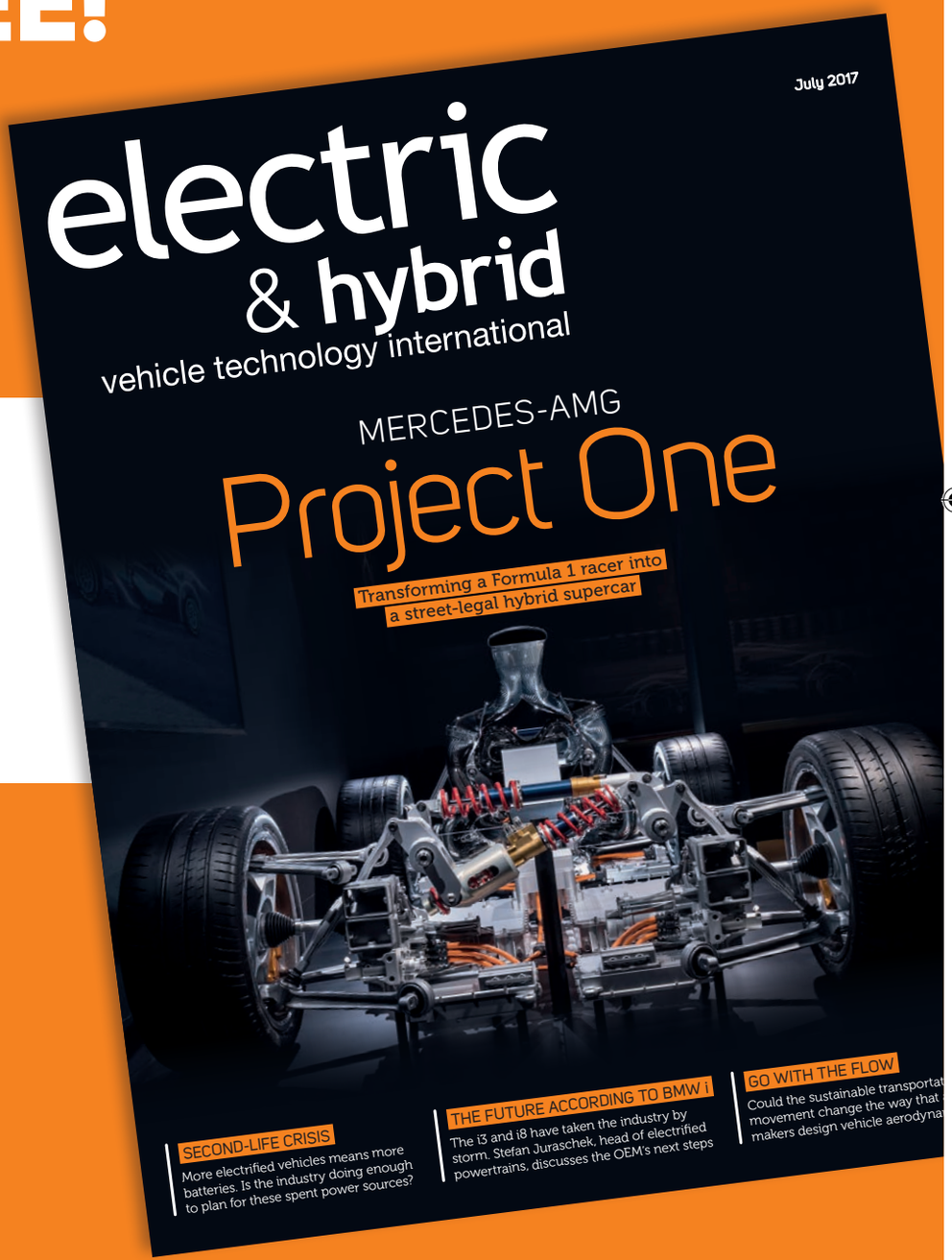

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With four high-performance inboard motors and four individual gearboxes, the NIO EP9 delivers 1MW of power, equivalent to 1,360ps

Power **trip**

Speed matters. One of the (many!) things that get people so excited about cars is speed. There's no denying that and I hope it will never change, especially for you engineers who work so hard on creating cars and powertrains that get our hearts thumping. In fact, for some cars, the 0-100km/h (0-62mph) Holy Grail and/or the Nürburgring lap time is all that matters. Car makers might be getting a little overly obsessed with the latter, but in general, I get all of that.

What I don't get – and what's really beginning to grate – is all these new EV startups essentially willy-waving with their 0-100km/h claims. Okay, we get that with your instant torque and stupidly huge e-power outputs your prototype is fast, but 2.39 seconds fast?! Really – is that even relevant?

WORDS: **DEAN SLAVNICH**

That latter reference is of course what Faraday Future claims its FF 91 family car – yes, family car! – can do. That's utterly crazy – and that's crazy not in a cool, wow-look-at-that kinda way. I mean, 2.39! Perhaps the good engineers at FF would have been wiser to focus on delivering a truly outstanding range, way beyond the claimed 700km (435 miles). But then it's probably not the engineers behind this, but rather FF's secret top-tier management. I'd gladly swap, say, 3.5 seconds of sprint time for an extra 90km (56 miles) on range!

Before you start thinking about my motives here, I'm not an EV hater. My daily drive is a BMW i3 range-extender and I absolutely love it. It's one of the finest moments of the e-powertrain movement to date, a tech revolution I fully support.

But back to that silly willy-waving contest. Of course what started all this was Tesla, and in the Model S it had to show that electric didn't mean slow, boring, sedate. Again, I get that, especially from a brand-building perspective. But we now know electric cars can be quick, super-quick, so 2.39 is really unnecessary.

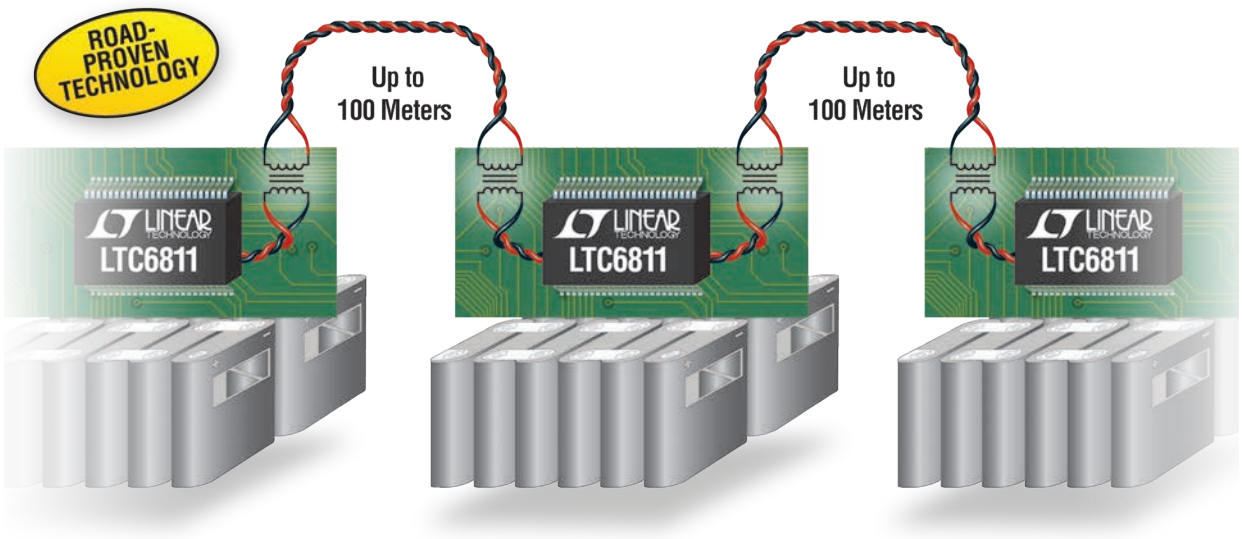
Prior to FF's build-up to CES 2017 earlier this year, where the 91 was showcased – glitches and all – came the rather better-looking (to my eyes) Lucid Motors Air. With 1,013ps, this sedan takes a whole 2.5 seconds to reach 96km/h (60mph) from rest. I mean – yawn!

From a BEV startup perspective, what NextEV is doing makes more sense: its NIO EP9 supercar is hypercar-like crazy, and this time I do mean crazy in a wow-look-at-that kinda way. A few things to ponder: 1,360ps, 0-200km/h (124mph) in 7.1 seconds, 313km/h (195mph) top speed and one of the fastest Nürburgring EV lap times. But the most important thing about NIO? This is a supercar, something that's been designed to mix it with, say, Ferrari and McLaren. This is not an exec sedan or crossover MPV!

And anyway, here's probably the most controversial thing I'll write on this subject: somehow, achieving a quick snap acceleration with an IC-engined car is so much more satisfying than with an EV. Foot down and off you go in the latter. The former? It makes you work for it, going through the rev range, especially if a good 5/6-speed manual is involved.

So, electric vehicle startups, let's back away from this arms race, and focus instead on range, more range, yet more range, faster charging, and then driving dynamics, interior tech and amazing styling. Because it's on these grounds that you'll beat the established names, not on crazy speed or unrealistic and unusable acceleration.

1.2mV Accurate, Noise Immune Battery Stack Monitor



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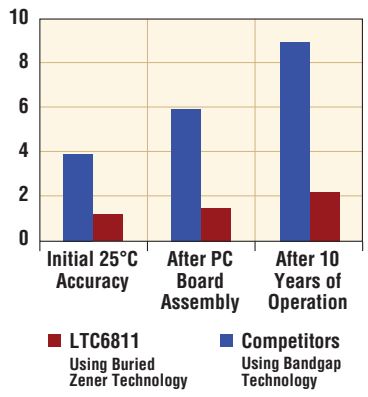
- Passive Cell Balancing
- 4µA Sleep Mode Supply Current
- AEC-Q100
- Engineered for ISO 26262 Compliance

Measurement Error (mV) when Measuring a 3.3V Cell



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