electric & hybrid vehicle technology international

July 2015

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20 ANNIVERSARY ISSUE

20

HURDLES THAT WILL DECIDE THE EV'S FATE

July 2015

TALKING HEADS

Leading industry experts predict what will be powering cars in 20 years' time

STOCKHOLM SYNDROME

Supercar maker Koenigsegg has created its first hybrid – and it's very, very powerful

CALIFORNIA DREAMIN'

Elon Musk's chief engineer, Chris Porritt, on swapping Aston Martin for Tesla Motors

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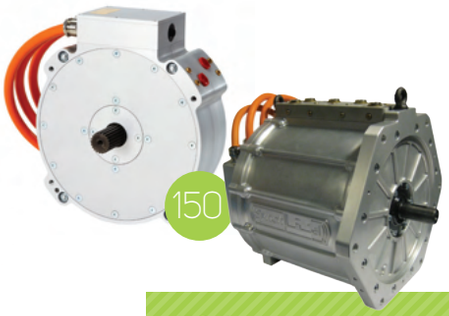

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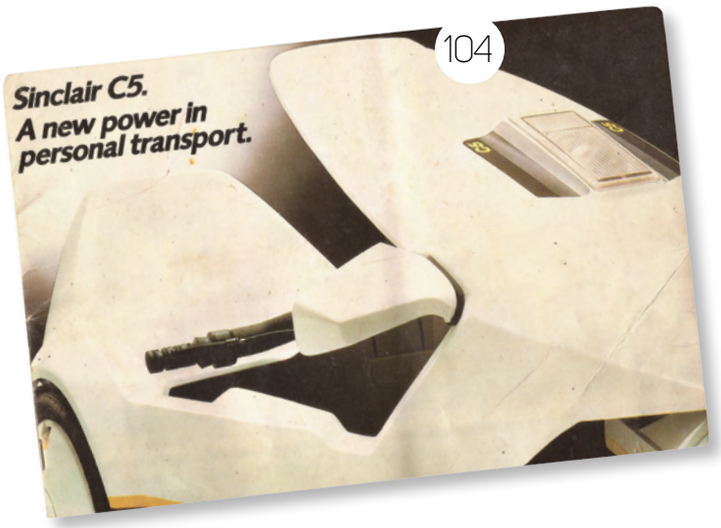

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EDITOR'S NOTE

So this fine magazine of ours has made it to its 20th year. What an absolutely wonderful achievement. And for one of those two decades I've been the lucky guy at the wheel.

A lot has happened since 1995 and for those supporting the e-powertrain movement, it's been quite the ride. So far. And I say so far because there's still much to do before we get to a point where most vehicles are not powered by our good ol' friend, the IC engine.

Since the launch of this magazine we've witnessed hybrids increasingly come to the fore, mainly thanks to the courage of Toyota with its Hybrid Synergy Drive as well as Honda with IMA, championing the technology even when there was so much doubt. Now, every major car maker in the world offers some sort of hybrid, be that a parallel, series or plug-in, and some are even serving up range-extender powertrains too, like BMW and Chevrolet.

Around the same time GM tried its best to kill the battery electric car with the EV1, but some 12 years later full electrics are thriving, albeit in a niche kind of way, with some mass market car makers actually repositioning themselves so that consumers think this is their 'thing'. The Nissan Leaf was, for me, a major moment and now look, we have the Renault Zoe, the VW e-Golf and e-Up, Ford Focus Electric, hell, even GM's back on the scene with the Spark EV and Bolt (which is for next year).

And then we have Tesla. Tesla, Tesla, Tesla. Here's a company that's not trying to be different from the rest. No, it's actually ripping up the 'here's how to be a car maker' rulebook, rewriting those rules, and winning. Okay, the Roadster didn't exactly spark the revolution, but the Model S? That's not a game changer, it's an industry changer. No wonder other car makers are so worried about the almighty rise of Elon Musk's company. Do you want to know what I love the most about all this? Tesla's indifference to those conventional OEMs. Why launch a car at Geneva, Paris or Detroit when you can drop it on Twitter instead.

Talking of social media, e-powertrains are also facilitating another, non-Tesla based revolution: autonomous vehicles and specifically the brave new world of Google and Apple cars, although the latter has not yet officially confirmed its automotive intentions. That's the next major battle. Why does Google want a slice of the auto pie? Simply because it wants us plugged in to the net all the time, and when we're driving we're not virtually networking. Yet. It is the power of the network that will win in the battle for autonomy.

Fuel cells have had a tough time during our 20 years of existence. They were the great green sustainable hope for so long, the product of huge investment from car makers – billions and billions of dollars – to only then subsequently drop off the radar as the 2008 credit crunch kicked in, and governments in the developed world championed BEVs. But they're back. And I truly believe they'll make the big time by the time this magazine celebrates its 40th. Why? Because cars that emit just water vapor are the end game. A dirty grid equals a dirty battery electric; all that FCEVs need is a robust infrastructure. Oh, and products, but those are coming (and confirmed) in the next three years from the likes of Toyota, Honda, Hyundai, Mercedes, Renault-Nissan, BMW and VW Group – and that's just the start.

I honestly believe the hydrogen fuel cell is where it's at, long term. Here are truly sustainable vehicles that have the same range as IC-engined products and can be completely refilled in a mere few minutes, just like the cars that have moved masses for the last 100 years. They are the future, of that I'm certain.

Finally, if you'll allow me to be self-indulgent for one moment, the timing of all this is particularly pertinent. As this astonishing title turns 20 years old, and I've edited it for 10 years now, this, actually, is my last foreword as editor. I am moving into the role of editor-in-chief. I'll still be around, and I'll still be part of this brilliant industry of ours (I'm taking the back page of this title – perfect for all my soapbox needs!), but it's time for somebody else to take this magazine forward. Thank you for letting me edit the most wonderful magazine in the world. Keep up the good work, because I know I will. Here's to 2035!

Dean Slavnich

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In 1995, when I wrote the foreword to the very first issue of *Electric & Hybrid Vehicle Technology International*, I had every expectation that it would be hybrids that would be the short-term winners of what was a race between battery electric cars, hybrid technology and would you believe, at the time, fuel cells. Exactly 20 years later and as the founder of the International Engine of the Year Awards that I started in 1999 – four years after the launch issue of this magazine – I have just presented BMW with the most coveted of the Awards; the International Engine of the Year 2015, given to the outright and overall winning engine; was awarded to the BMW i8. There are 65 judges from 31 countries on the International Engine of the Year panel and they were totally won over by the extraordinary combination of speed and real sports car performance, combined with zero range anxiety and of course where and when required, zero emissions courtesy of the electric-only propulsion mode. This powertrain is a technical *tour de force* and goes beyond my wildest expectations of 20 years ago for one very straightforward reason: it's Fun!

When I penned the words for the foreword in that first edition, I probably had visions of Prius-like models gliding mostly quietly past but lacking any of the pizzazz that makes cars things that drivers aspire to own. With all due respect to Toyota, which was fast into the hybrid world with groundbreaking developments like the Prius – a car that is a very good package overall – the word 'fun' is something you wouldn't really apply to Toyota hybrids. But that is the very marvel of the BMW i8.

So, what's for the next 20 years? I think fuel cells will be in the R&D domain for a long time yet, as to my mind the complexity remains far too big a hurdle for mass production in such a timeframe. As for battery electric vehicles, Tesla appears to be the one company so far that has really cracked battery car technology. Indeed the California company also picked up an International Engine of the Year Award this year – the prestigious Green Engine Award for the powertrain in the Model S.

So, my money is on two possibilities. One that I have written about from time to time is the potential to install wind and solar farms alongside inter-urban highways, with induction charging delivering energy into passing vehicles. This offers the potential to create self-sustaining zero-emissions long-distance highway driving. The second interesting possibility is very high-speed recharging that will give rise to next-generation refueling stations that will deliver conventional gasoline as well as electrical energy. These will contribute to a viable solution for those car owners who don't have ready access to recharging at home. For the short term, though, hybrids will be the dominant technology.

Whatever the case – for both short and long term – your partner going forward in terms of reportage of this fascinating technology sector will remain *Electric & Hybrid Vehicle Technology International*. We look forward to charting progress and from time to time offering our crystal ball view on where we think things are heading.

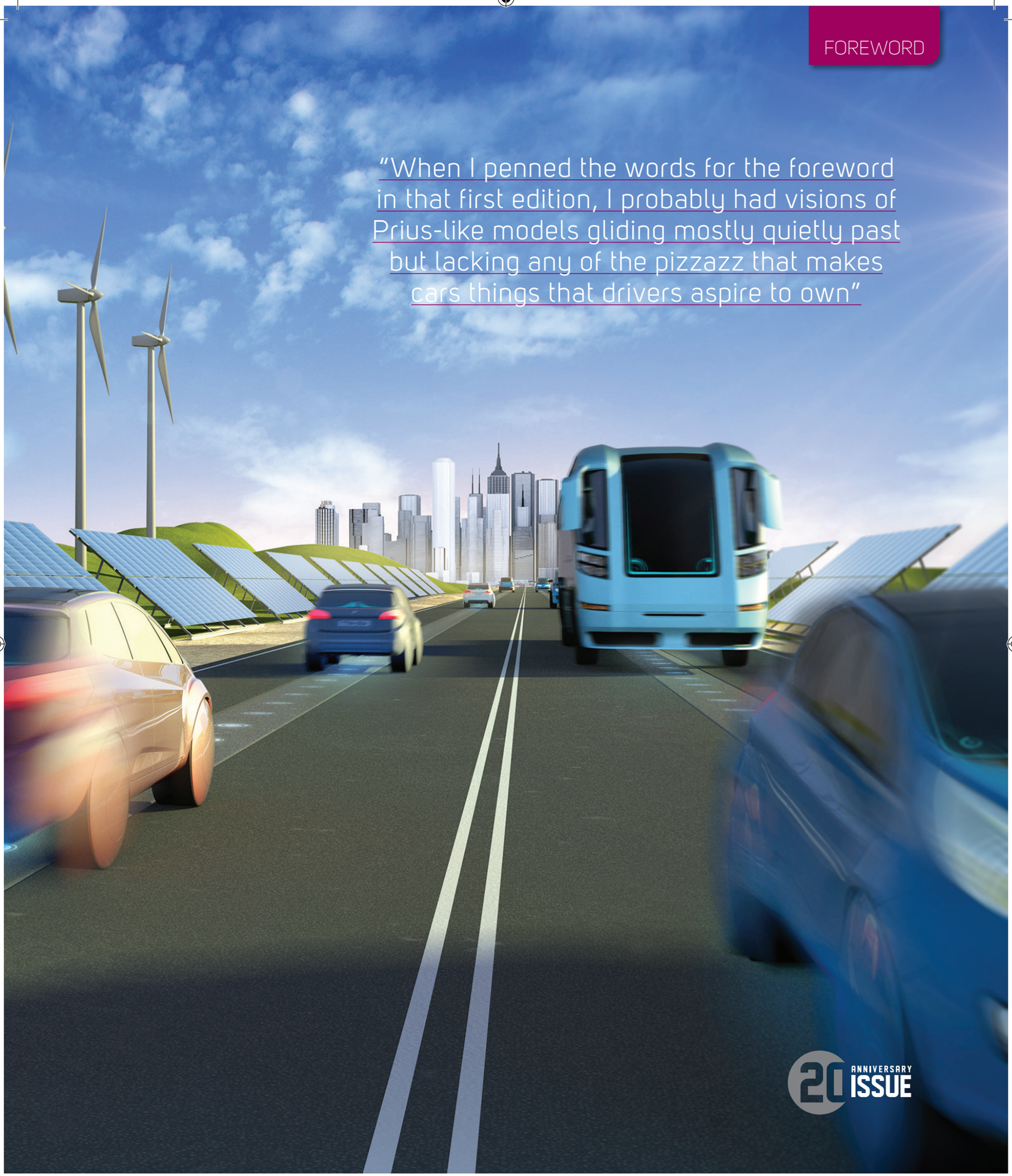
FOREWORD

ELECTRIC & HYBRID VEHICLE TECHNOLOGY '95

● Tony Robinson

Read the full 1995 foreword on the next page

TONY ROBINSON, CEO
UKIP Media & Events



"When I penned the words for the foreword in that first edition, I probably had visions of Prius-like models gliding mostly quietly past but lacking any of the pizzazz that makes cars things that drivers aspire to own"

To mark the 20th anniversary of *Electric & Hybrid Vehicle Technology International*, here is the magazine's first ever foreword, written in 1995 by UKIP Media & Events CEO Tony Robinson

FOREWORD

ELECTRIC & HYBRID VEHICLE TECHNOLOGY '95

● **Tony Robinson**

On the eve of going to press with this launch issue of *Electric and Hybrid Vehicle Technology '95*; I was confronted by two of the classic contradictions of opinion which highlight the disparity of views surrounding EVs. On the one hand, the view of the owner of a small GM four-seater; "Why wouldn't people want an electric car? – if it's cheap to run, reliable, quiet, comfortable and doesn't pollute the place – well I think I'd be more than happy to own one." The same day, a hard-nosed marketing man in Illinois told me, "We're not continuing to develop products for what we see to be a high risk, slow return and uncertain market. I don't think electric cars will ever succeed – at least not in the United States." I asked his view of hybrids. The silence was stony. Perhaps our man from Illinois had never heard of hybrids – perhaps he, like 99 per cent or more of today's car owners had never even contemplated that such a thing might or could even exist. And that view looks set to remain, at least, I think, for the short time being.

You see, until the men in Detroit, Stuttgart, Tokyo and elsewhere in the auto-motive industry are actually ready to press the 'go' buttons, the silence will prevail. One doesn't have to read too much between the lines of our extensive interview pieces with John Wallace and Bernard Robertson, to recognise the intent of their respective corporations. Ken Baker's statement – "GM has already invested over half a billion dollars in EVs in the 1990s" – should leave no doubt as to how seriously GM views the growth prospects in this sector.

But where then is all the normal ballyhoo associated with the launch of new cars? Ever so quietly, here and there, a prototype pops up at one of the Shows – at London this October KEV4 was on show, at Tokyo, Nissan's FEV II, apparently with a lithium-ion battery pack made a quiet debut. Yet ask for the details and there's silence, paper shuffling and some amount of fidgeting. Which all leaves me entirely convinced.

Never before, at least perhaps since the earliest days of the horseless carriage, has the world's auto industry had such a clear-cut signal as to the way the market will go. The unpopular US mandates have been fought, not unreasonably, for imposing requirements on automakers to put vehicles into production too soon, yet they have left them in no doubt as to the intent of the regulators to deal with the mobile emissions issue. At the same time, field trials in many parts of Europe and the United States have confirmed the unexpected – people actually like EVs and despite their limited range, for a surprisingly large number of people, EVs impose absolutely no constraints.

Take our man from Illinois, who may reluctantly accept that EVs could be suitable for city use, at least in compact cities in Europe, but denies their role in the United States where commuter distances are invariably far greater and where freeways require vehicles to achieve brisk acceleration – at least that is, up to 55mph. The question is, where are the world's hybrid developers to offer an answer?

On the subject of silence, Ford's John Wallace (Section One), told me; "We never talk about a new model before it's been launched." Such silence is deafening. So I have no doubt that in a short time from now the wraps will come off, the fanfare will begin, the loudspeakers will be popping and the media will be buzzing.

"Roll-up, roll-up! The 80mpg, 400-mile range ULEV is here, featuring near-silent 100mph performance, brisk acceleration and programmable characteristics to suit a range of drivers. Alternatively for short range commuting, choose from any one of our new range of battery electric cars that never need to go to the fuel station; they offer unprecedented levels of quietness and smoothness and absolutely minimal maintenance. Other cars in our range include an 18mpg fuel guzzler but it comes with a mandatory health warning and can only be used in a limited number of states or there's our 7-liter version of the same car but that's a phase-out model; it's heavily discounted, but then you've got the gas-guzzlers' levy to pay, a state pollution tax; Oh! do you have neighbours as well?"

The question for hybrid electric vehicles and EVs is not if, but when and by whom? KEV4, the outcome of Kia's Environmental Committee set up just two years ago, may be just one of many clues. Powered by a 50kW ac electric motor, this Korean company's hybrid has an 800cc auxiliary petrol engine mounted behind the passenger compartment. The vehicle seats four, has regenerative braking, programmable power steering and a solar-powered fan to ventilate or air condition the interior when the motor is stopped. The body, reinforced fibre composite, gives way to a total weight inclusive of lead-acid batteries of 1,478kg. Kia claims a top speed of 100mph and driving range of 250 miles. The same company also sells an electric version of its Pride model, which was the first electric car in Korea to gain road certification. Where's that man from Illinois?

There can be no doubt that the electric car is a reality, nor that hybrids will follow hot on their heels – whether gas turbine or petrol, diesel or subsequently fuel cell, their logic is impeccable.

Our participants in this 1995 issue of Electric and Hybrid Vehicle Technology are also entirely real. Our authors are not theorists or philosophers, but real world business people from commercial organisations with technology for sale and under development. They are not politicians or academics, but technical directors, commercial directors, project leaders and managers whose objective is to make electric and hybrid vehicles a truly commercial reality.

Indeed, *Electric and Hybrid Vehicle Technology '95* is not a text book on the subject of a possible subject. Like the technology it reviews it too has had to stand up in the harsh reality of a real world scenario. Its aim is not to lecture to the learned, but to demonstrate technologies which are both available and in the making; the wealth of material which it contains bears testimony to the considerable endeavours which are taking place at every level to both build and promote vehicles which offer a sustainable means of environmentally acceptable personal transport for the next century and beyond.

The path to bringing the electric and hybrid vehicle to market has been slow, even tortuous, and in applauding the endeavours of those who have so openly contributed to this publication, as well as the work of others not included in our pages, I hope that one man's frustration will at last be once and forever satisfied. To prelude this issue's technical articles I see nothing more appropriate than a review of 30 years of near misses by the man who calls himself the 'grandfather of the industry' – Victor Wouk....

20 ANNIVERSARY ISSUE

Number crunching

Mercedes-Benz's SLS Electric and Tesla's Model S were signs that it's time to stop thinking of EVs as just eco city cars. **Koenigsegg** thinks the same thing – but with a far bigger exclamation point!

WORDS: **MICHAEL TAYLOR**

There are car numbers and there are car numbers. And then there are the numbers related to Koenigsegg's Regera. Presented at the Geneva Motor Show earlier this year, this Swedish blockbuster of a supercar boasts comic-book-like figures that take the cynical some time to get to grips with. In fact, the acceleration proposed by Koenigsegg for Regera is actually bordering on the ridiculous, even by the standards of the outgoing Bugatti Veyron that sat alongside it at Geneva.

Koenigsegg claims Regera will reach beyond 410km/h (255mph) and will do it driving its 1,120kW of power – double what a Ferrari F12 can manage – and more than 2,000Nm of torque through just a direct final drive in a powertrain dubbed KDD.

That's probably fortunate for the reputation of transmission suppliers of the world, because the Regera has a 5-liter, dry-sumped biturbo V8, capable of 820kW of power at 7,800rpm and up to 1,280Nm of torque – although it has at least 1,000Nm on hand from 2,700rpm.

And then, for giggles, it has its three YASA-developed, axial-flux electric motors.

There is a 160kW, 300Nm e-motor attached (via a hydraulic coupling) to the crankshaft of the V8, then another two, each of which join the fun *after* the final drive to deliver 180kW of power and 260Nm of torque directly to each rear wheel. You were warned about the numbers!

The crankshaft-mounted motor acts as the car's generator on one hand and its reverse gear on the other. Even so, it does most of its work filling in below 30km/h (19mph) while the V8's turbochargers are gathering speed. The job of the wheel motors is to deliver instant, direct drive for added brutality, and then torque vectoring for fine nuance.

The Koenigsegg Regera, its manufacturers claim, will surpass 410km/h. It also boasts twice the power output of a Ferrari F12

Koenigsegg is claiming 520kW and 820Nm of continuous electric propulsion for a rear-wheel-drive car it says will not just reach out beyond that ludicrous 400km/h speed, but will do it in just 19 seconds! These claims make it the most powerful electric car on sale today – and then it sticks all of the V8's performance on top of that.

Officially, it will crash through the 0-100km/h (0-62mph) sprint in 2.7 seconds, but it will also thump from 150km/h (93mph) to 250km/h (155mph) in just 3.2 seconds. Both figures, boss Christian von Koenigsegg insists, are limited by the car's rear-drive status. From a standing start on a dry day, he says, the Regera S is capable of living beyond its longitudinal grip limit all the way up to 270km/h (168mph). Again, you were warned about these crazy, crazy numbers.

Boss Koenigsegg also claims a 410km/h top speed, although our calculations on the V8's 8,250rpm rev limit and the 2.85:1 final drive ratio should see it pegged out at 406km/h (252mph) – just 1km/h (0.6mph) shy of the Bugatti Veyron's official figure.

And what's more, Koenigsegg insists its new powertrain is just 88kg heavier than it would have been with a 7-speed transmission, but without the electric drive.

"At the beginning of last summer I came up with an idea to remove the traditional gearbox from the equation due to novel battery and electric motor technology," Koenigsegg explains.

"It has become so compact and light that in combination with our powerful combustion engine we have all the power and torque we need at any speed without a transmission.

"Suddenly, it made me enthusiastic about doing something I didn't want to do – a hybrid. Traditional hybrids I don't like, because they're either very compromised when it comes to weight and complexity with two drivetrains in one car, or you have a series hybrid which is quite compact but you have the negativity of converting energy too many times, from combustion to electric to mechanical, so you have a lot of losses with that.

"This way, we could remove the transmission and have as few components as a series hybrid, but with hybrid drive, so we don't convert the engine's motion into electricity and then to propulsion. Instead the energy goes straight to the wheels with the support of the electric motors."

Figure it out

There were still a lot of details to iron out on the way, though, things like the software to make the motors chime in and out, and figuring out the best combination of motors in every situation.

"We use the electric motors for reverse and we use it up to 30km/h (19mph) and then we close the hydraulic coupling," Koenigsegg adds.

"We get torque transfer then from the electric motor, because the combustion motor is only doing 700rpm, but quite quickly it's up to 1,000rpm, then 2,000rpm, and at 2,700rpm we already have more than 1,000Nm from the combustion motor.

"At 113-129km/h (70-80mph) you have 1,700rpm from the combustion motor with no electric support unless you ask for it."

1. The Regera sprints from a standing start to 100km/h in 2.7 seconds, and on from 150-250km/h in an impressive 3.2 seconds

2. The liquid-cooled battery pack, developed and built by Rimac Automobili, is situated within the Regera's transmission tunnel

At 4.56m in length, the Regera has genuine presence, sitting at 2.05m wide and just 1.11m tall. Astonishingly, even with a V8 biturbo petrol motor and three electric motors, the car claims a 1,420kg dry weight, or a 1,628kg curb weight.

That is, in part, because it runs a small capacity 9kWh liquid-cooled battery pack that is claimed to deliver 35km (21.8 miles) of pure electric running (although a quick calculation shows that it would give only a minute of full-throttle running, which isn't quite enough for the claimed 35km run).

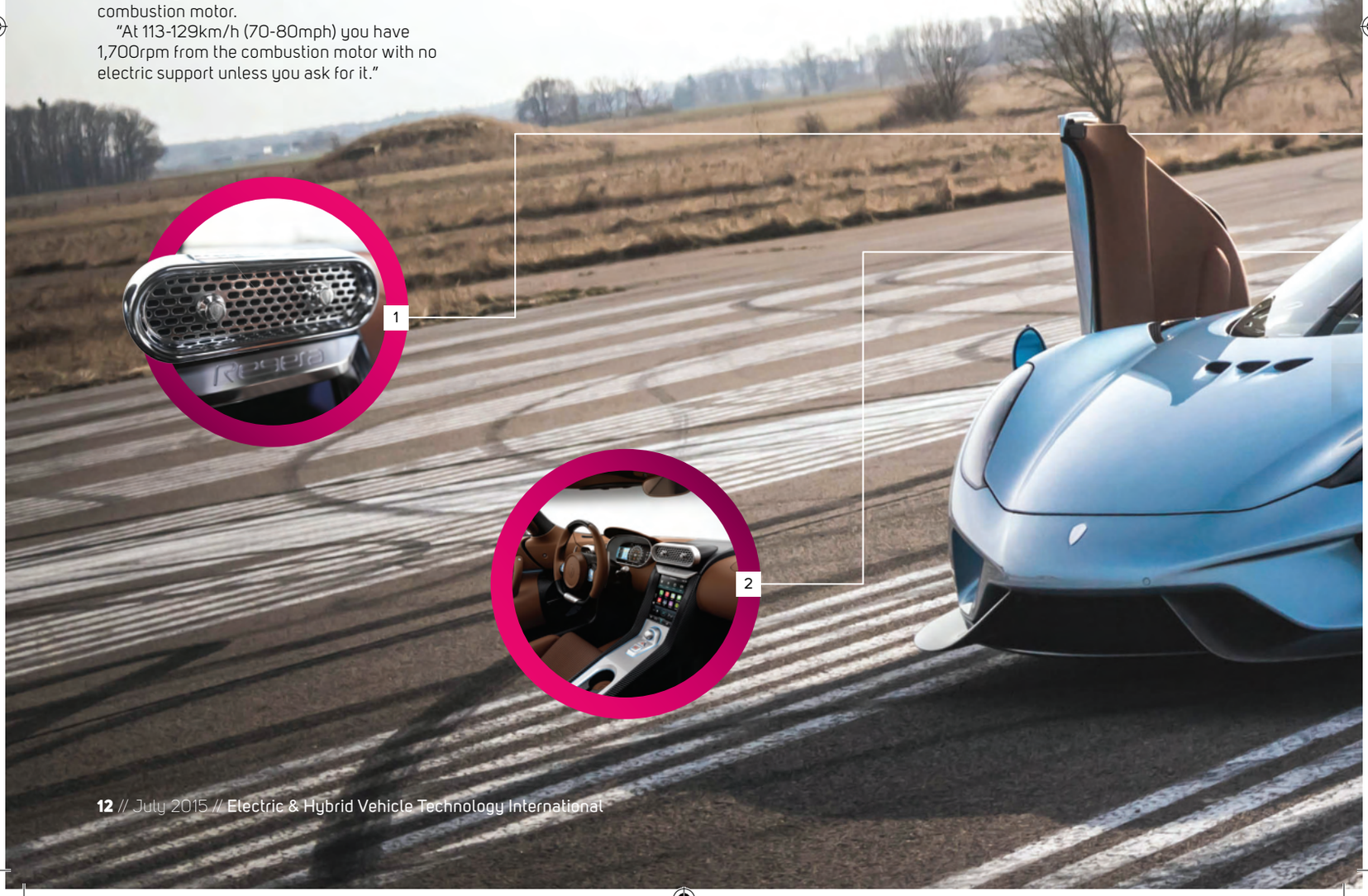
The battery itself, developed and built by Croatian supplier Rimac Automobili, weighs 115kg and eats 67 liters of space in the transmission tunnel. The 620V battery pack can punch out up to 500kW in short bursts and can recover energy at up to 150kW under hard braking.

"A standard battery pack would weigh more than half a ton to deliver those kind of performance figures," claims the CEO of Rimac, Mate Rimac.

"We developed a complex fully flooded thermal management system and a fully machined structural housing in order to fulfill Koenigsegg's radical requirements.

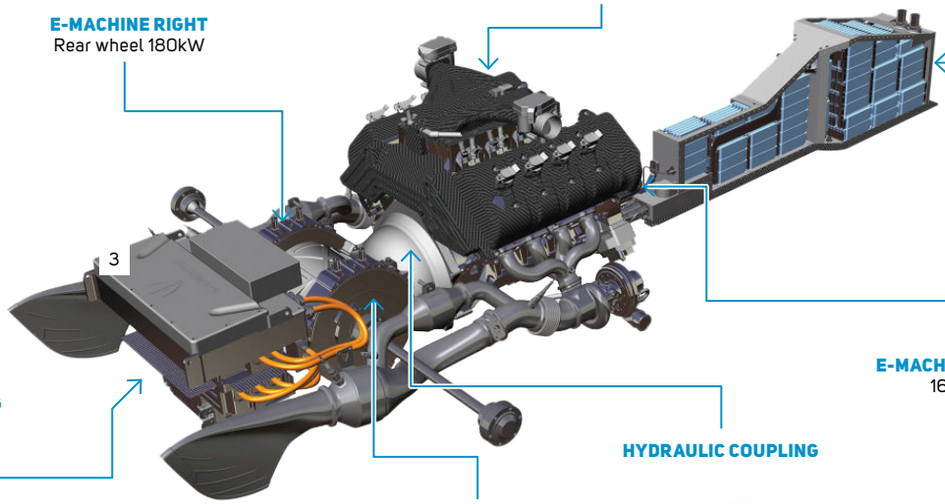
"This way, Rimac managed to develop a 9.27kWh battery pack consisting of more than 3,000 individual parts that is able to deliver 4.35kW per kilogram.

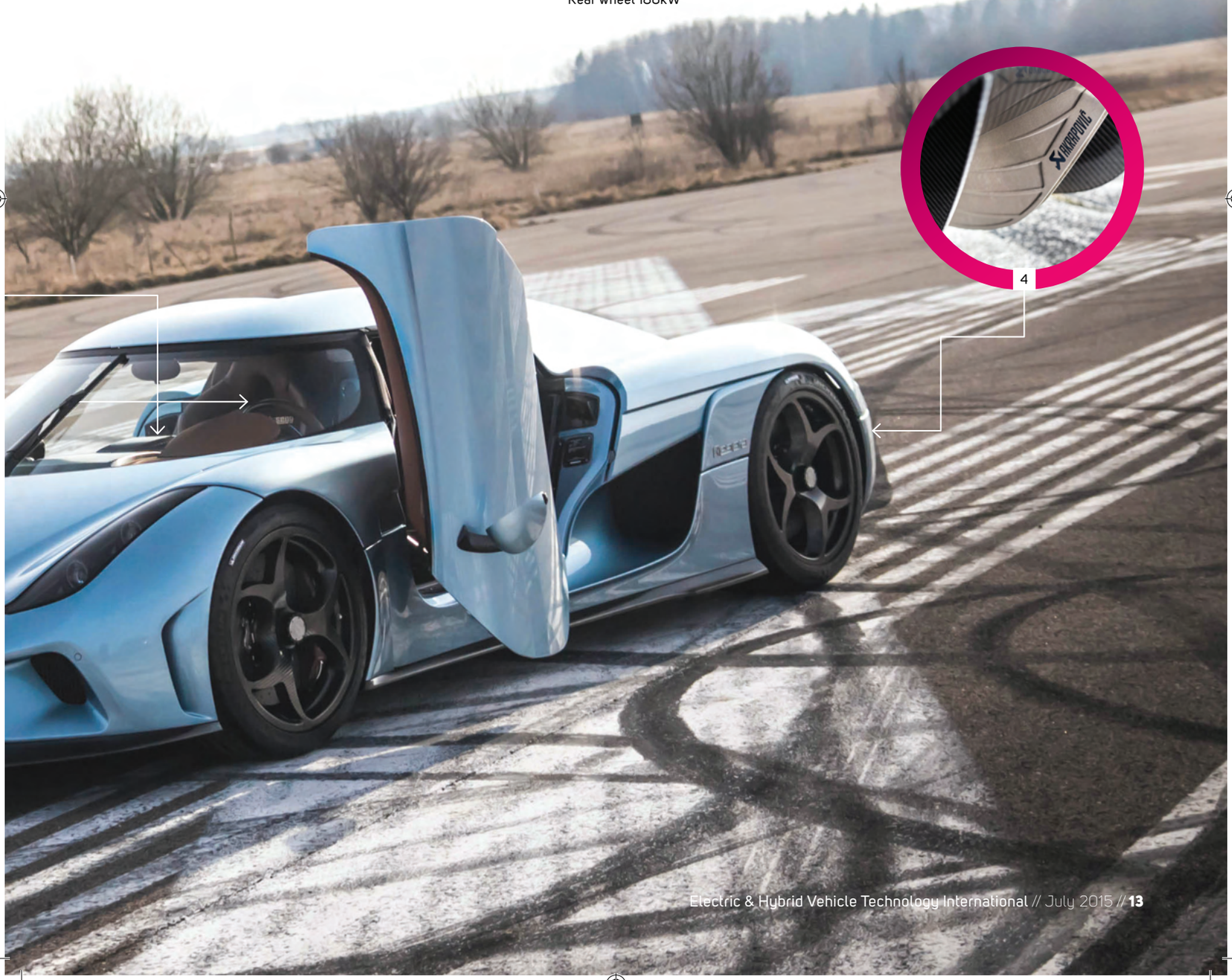
"The Regera is a perfect example of how technology can improve driving dynamics and enhance performance without compromises, while reducing emissions."



3. The Regera has a 5-liter biturbo V8 engine, capable of producing 1,280Nm, and a trio of axial-flux electric motors – one attached to the crankshaft and one connected to each of the vehicle's back wheels

4. The Regera's two wheel motors are responsible for delivering instant, direct drive, and torque vectoring





1. The Regera does not have a traditional gearbox. Shift paddles can be used to activate battery fast charging or put the motors into torque sleep mode

2. The Regera's single exhaust is actually a hot air outlet, expelling air from the electric motors and electric motor inverters

Creative thinking

Rimac, which has its own ultra-low-volume supercar on the books, essentially delivered a packaged system that enabled Koenigsegg to get rather creative.

"I've been dreaming for many years of getting rid of the traditional gearbox because you're only using one gear set at a time and if you're cruising on the highway, you've got six or seven gear sets just lying around waiting to be used and adding weight," Koenigsegg explains.

"It just feels so inefficient to have all this stuff hanging around if you don't use it all the time, so we got rid of it.

"The top speed is limited by the rev limiter, because it's direct drive, and RPM and speed follow each other all the time, so top speed is 410km/h when we hit the rev limiter."

That doesn't explain, though, why the car has shift paddles on the steering wheel when there's nowhere to shift.

"We can do several things with the paddles, but the one I like most is that you can hold the + paddle to tell the car to fast-charge the battery, for instance if you need a sudden boost for the lights.

"When you are cruising on the highway, you can put the electric motors into torque sleep, so you can have the first car in the world driving the combustion engine directly to the rear wheels with no support from any of the electric motors. Thereby you remove 5% transmission losses you'd otherwise have."

And there's more to it, too. The monocoque and even the wheels are made from carbon fiber and so is the rear wing, which helps it deliver 450kg of downforce at 250km/h (155mph).

It can do all that while being a convertible, with a removable hard top that can be tucked away under the tiny hood, because Koenigsegg claims that the Regera is a more street-focused machine than its traditional track-attack monsters.

All of its panels are a mix of carbon fiber and Kevlar, with sandwich reinforcements to save it from all that tortured air. It will ride on 19 x 9.75in front wheels and larger 20 x 12.5in rears. There are Michelin Supersport Unidirectional tires stuck to them, with 275/35 Y19 front and 345/30 Y20 rubber at the rear.

But don't be fooled, because not everything is quite as it appears.

"What looks like the single exhaust at the back is actually a hot air outlet for the electric motors and the electric-motor inverters," Koenigsegg reveals. "It's like a fan blowing hot air out.

"The titanium fishtail exhaust from Akrapovic is actually coming out of the sides in the venturi. It sounds like 8,000rpm when it's at 4,000rpm."

Koenigsegg has set up the globally homologated Regera to be built in batches of six or seven cars at a time, based around an in-house carbon-fiber tub, and it plans to build 80 of them in total, priced at more than US$1.89m each.

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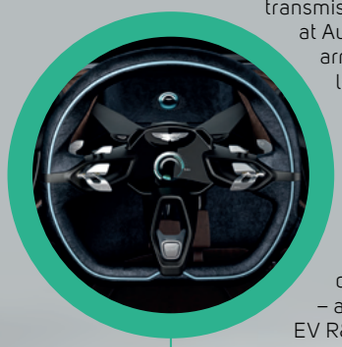
Fast track

With funding in place that will help accelerate new product development, Aston Martin recently showcased its first EV. And the concept now has the green light for production, too

It's no secret that Aston Martin has found itself in a rather challenging and somewhat tricky situation of late. After all, fending off serious competition from rivals that continue to churn out brilliantly engineered high-end products with a vehicle and powertrain architecture that's in desperate need of upgrading is no easy task, even for those clever engineers at Gaydon.

Which makes the last 12 months even more remarkable when compared with the previous five years. Put bluntly, Aston Martin has rediscovered its mojo, with new CEO Andy Palmer leading the charge. Palmer, a former transmissions engineer at Austin Rover, arrived at AM HQ last October, leaving his senior VP post at Nissan, where he influenced product development – and particularly EV R&D.



The all-electric DBX Concept was designed by Aston Martin's chief creative officer Marek Reichman and his team at the Gaydon HQ

"Being asked to lead Aston Martin, an iconic brand with tremendous global recognition and potential, was an opportunity impossible to refuse," says Palmer. "Together, we will create the next generation of Aston Martin products for the future."

And it hasn't taken long for that next-gen product assault to begin, with Palmer reinvigorating the engineering team and calling upon his e-powertrain expertise.

At the Geneva Motor Show earlier this year, Aston Martin genuinely surprised most of the industry when the covers were whipped off the DBX concept, the brand's first all-electric, all-wheel-drive creation.

"I asked my team to expand their thinking beyond conventions, to explore what the future of luxury GT motoring would look like in years ahead, and the DBX concept you see here is the result," says Palmer.

New territory

Despite being a two-door crossover, the most interesting part to the DBX is not its style, but rather what lies beneath the outer skin. Not much is known about its inner system workings, but traction is supplied to all four wheels by in-wheel motors powered by a battery pack made of lithium-sulfur cells. The progressive concept also features a kinetic energy recovery system and drive-by-wire electric steering.

"This is not a production-ready sports GT car, but it is a piece of fresh, bold thinking that symbolizes what GT customers around the world could request from us," hints Palmer.

And that's where most thought the DBX would remain in terms of potential for the immediate to medium term. But six weeks after Geneva, it became clear there's much more to the concept than being a 'thought starter'. Having secured more than US$300m of funding for product expansion from Investindustrial and Tejara Capital, the DBX has been given the green light, although nothing is being said on the type of powertrain that will ultimately end up driving it.

"This additional long-term funding will enable us to add extra model lines and broaden our presence in the luxury market segment by the end of the decade. The additional investment will allow us to realize the DBX and other new luxury vehicles," adds Palmer.

The creation of the DBX – and the additional funding for product expansion – is the latest piece of good news to come out of Gaydon recently. In February, it was announced that the Lagonda super sedan would be made available around the world, not just the Middle East; a month before that Aston Martin opened a new engineering facility at MIRA, which came six months after confirmation that a US$30m investment would go into upgrading existing manufacturing facilities at Gaydon, thus creating 250 new jobs.

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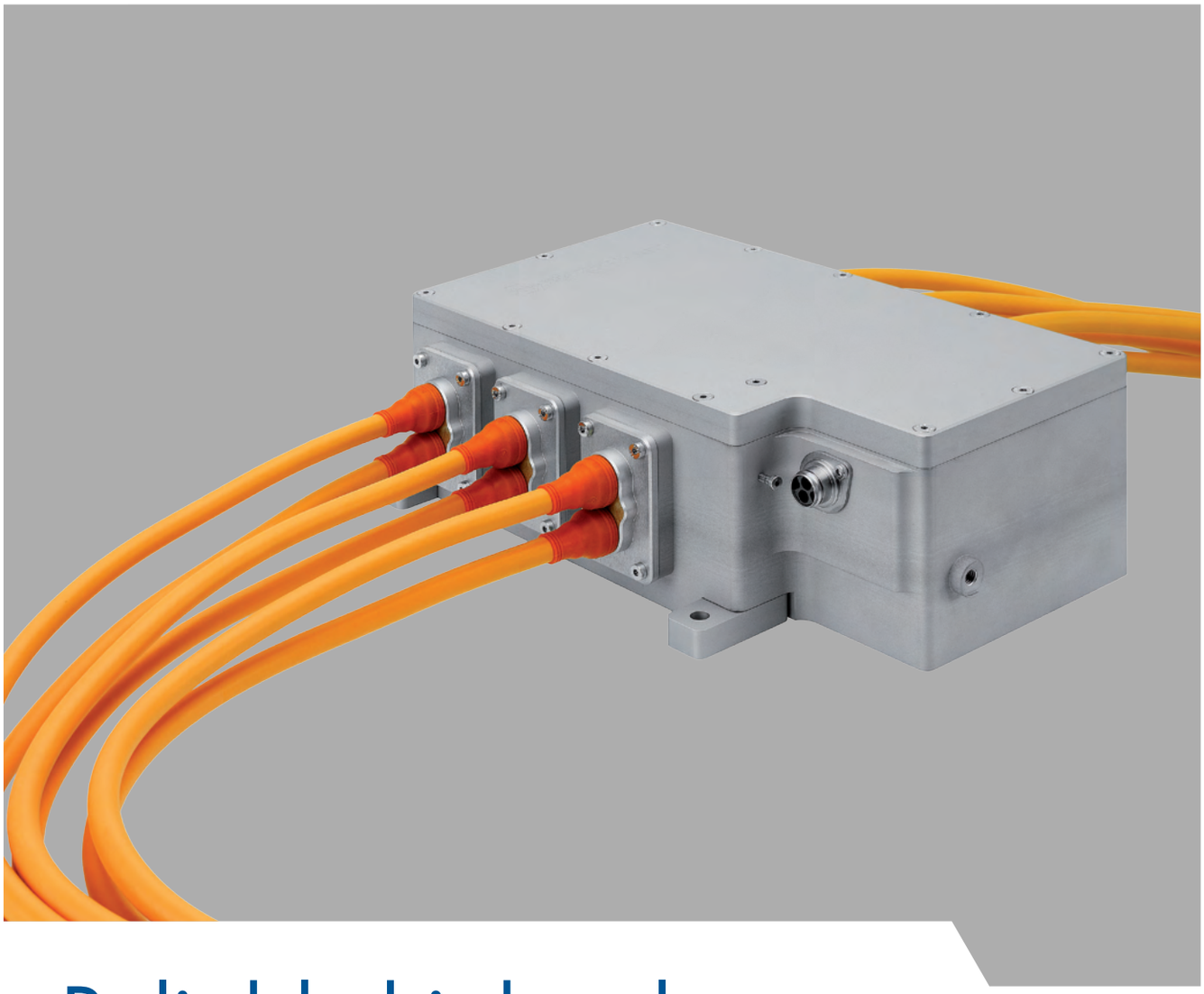

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Taxi driver

A new taxi is about to hit London's streets, and as well as featuring an advanced e-powertrain that will provide customers with a smoother, quieter ride, it's also going to save cabbies big money at the fuel pump

As those of you familiar with London probably already know, a taxi driver's favorite opening gambit in the UK capital city is said to be, "Guess who I had in the back of my cab..." However, that looks set to be replaced with, "Guess what's powering my cab!" in the coming months.

Why? Because following almost 10 years of development, and more than 1,000,000km of testing including, since last November, carrying fare-paying passengers on London streets, an all-new, range-extended electric Metrocab – complete with two battery-powered electric motors, recharged at intervals by a 1-liter petrol engine or from a domestic socket – is now just a couple of stops from production reality.

In fact, only in May of this year, Frazer-Nash Research and Ecotive, part of the same group of companies based in Surrey in the UK that are driving this development project, announced that its low-emission black cab will go into volume production as part of a new partnership with Multimatic Niche Vehicles, a manufacturing specialist based in Canada. The company has experience of building low-volume models such as the Aston Martin One-77 and Ford GT, while an offshoot, Multimatic Engineering, supplies organizations as diverse as Red Bull Formula One, Tesla and Mercedes AMG.

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Big spenders no more

The first electric Metrocabs will roll off a new Coventry production line toward the end of 2016. By 2018, annual production for the UK market is expected to be around 3,500, with each cab retailing at approximately £40,000 (US$62,360).

Those are big numbers, but Metrocab's project director, Sheban Siddiqi, is confident that, with its combination of low operating costs and good performance, the new taxi will win over London's notoriously skeptical cabbies.

"We're getting at least 90mpg in real-world testing, not far off the official figure of 98mpg," he says with pride. "It means that the typical cabbie will be spending around £8 to £10 (US$12 to US$16) on petrol each day, compared with the £30 to £50 (US$47 to US$78) they currently spend on diesel."

One thing that puzzled Siddiqi and his engineers during real-world testing was the occasional sharp variations in battery power consumption. Eventually, the drivers admitted they'd been racing – and beating – Porsches at traffic lights.

"The development cabs have a Sport mode for extra torque, and the drivers were selecting it to boost acceleration from a standing start," explains Siddiqi, who adds that he's considering keeping the mode for production models – extra torque can be useful in icy conditions or pulling away on inclines – but calling it something less racy, such as, simply, Torque mode.

Digital difference

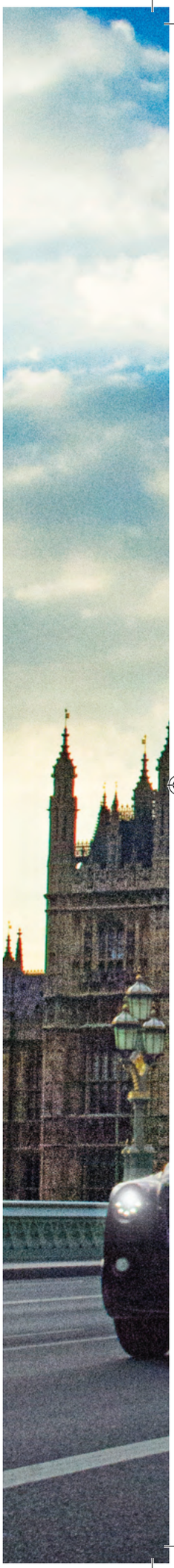
Yet while the next-gen taxis boast much advanced technology, the origins of the new Metrocab can be traced back to the late 1980s when Siddiqi's father, Kamal, built his first production go-kart. He'd foreseen that oil would become a scarce resource,

1. Metrocab will be built on a new production line in Coventry, with the first vehicles due in late 2016

2. The new Metrocab is the subject of close to 10 years of development and over 1,000,000km of testing

3. Annual production of Metrocabs is expected to be around 3,500 by 2018

4. In addition to charging from the petrol engine, the Metrocab can be charged at a domestic power socket



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so powered it by electricity – not by one electric motor, but by two, each driving a rear wheel.

To connect the two motors, and ensure traction was evenly distributed, he replaced the traditional mechanical differential with a computer-controlled electronic version he called a 'digital differential'. And it's this multimotor, digital differential arrangement that is at the heart of the new Metrocab's electric powertrain.

"The technology is unique to us," states Siddiqi. "A few powertrain developers have been to see us, liked the principle, but not followed it up.

"There are two reasons for this. First, it's very complex; it requires a series of complex algorithms to control its functionality. Second, it suits us because we have an electric powertrain to which we're adding a range extender, where other makers start with their powerplant and then add a secondary electric power unit. Basically, our configuration doesn't work with their big engines."

Of course, a third reason might also be that the technology doesn't work very well in practice, but Siddiqi claims otherwise.

"Most electric motors run at around 80% efficiency – ours run at 97%," he counters. But the project director won't explain how or why such an impressive number is attained – "It's a very sensitive project," he reasons – leaving *E&H* to guess it's due to reduced friction and some special materials, as well as a rather sophisticated design.

"The big difference between us and other makers and developers," he continues, "is that we source very little off the shelf. Much of the powertrain has been designed and developed in-house – the motors are unique to us, for example. This means we can create a very efficient system."

As proof, he points to the Metrocab's relatively modest 12.5kWh battery pack. It can be recharged by the range-extender petrol engine in 12 minutes, to give a range of around 80km (50 miles).

"The battery has excellent capacity for its size and, we think, the best battery management system in the world," he adds. "We developed it with EnerSys Advanced Systems. However, ultimately, production may go to someone else."

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1. The new vehicle can seat seven passengers, has a top speed of 129km/h, and will be capable of a combined range of 560km

2. After considering many engine options, Metrocab will most likely use Ford's award-winning 1-liter Ecoboost petrol unit

2

THE METROCAB

– Range extended electric vehicle

– Fully compliant with London Taxi Private Hire (LTPH) regulations

– Capable of zero-emissions operation

– Vehicle health diagnostics and status telemetry system

PERFORMANCE

Top speed: 129km/h (restricted)

Max gradient: 1:3

Emissions: <50g/km of CO_2

Turning circle: 7.62m (meets LTPH requirement)

Additional tech: regenerative braking

POWERTRAIN

Peak motor power: 2 x 50kW

Peak wheel torque: 2 x 1,400Nm

RANGE EXTENDER

– 1-liter petrol range-extender engine coupled to generator unit

– Fuel efficient urban and highway generating modes

– Meets Euro 5 emission standards

BATTERY SYSTEM

– Lithium-ion polymer large format cells

– Stored capacity: 12.2kWh

– 3kW onboard charging

Ecoboosting

Of course, one key system that Metrocab didn't design and build was the 1-liter petrol engine. It has tested many units, but it's likely that production models will use Ford's Ecoboost unit.

"We trialled many engines and the Ecoboost performed the best of all of them by miles in terms of power generation, fuel consumption and efficiency," admits Siddiqi.

But interestingly, Siddiqi is keen to emphasize that the new Metrocab is always an electric vehicle. The petrol motor is there only to drive a generator that charges the battery, which in turn drives the electric motors. The petrol three-cylinder (assuming it will be the Ford motor) only kicks in when charge capacity has fallen to 10%.

On production vehicles, cabbies will be able to choose between two operating modes: urban and highway (and possibly the aforementioned torque, too). In the former, used when operating demands are low, the relationship between petrol engine, generator, battery and electric motors is as just described. In the latter, the generator's electric current flows directly to the electric motors, therefore missing out the battery altogether.

"It gives the Metrocab the power to cruise at motorway speeds, which is particularly useful for the M4 highway to Heathrow Airport run that many of them do," adds Siddiqi.

Officially, the new cab (it can seat up to seven passengers) has a combined range of 560km [348 miles] and, with the range-extender running, emits 65g/km of CO_2. Its top speed is 129km/h (80mph). And besides its powertrain, another contributor to the new cab's impressive efficiency levels is its all-aluminum construction.

"Multimatic has designed and developed the body, chassis and mechanicals," explains Siddiqi. "Reducing the vehicle's weight has been crucial. We're targeting 2.7 tons, using aluminum for the body and chassis. We think we'll dip below it."

And with that US$62,360 price tag, "We'll be about on par with other cabs," concludes Siddiqi. "To break into the black cab market, we can't price ourselves at a premium level just because we're saving cabbies money." And that's one topic never far from cabbies' lips.

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Plugging the gap

GM took most of the industry by surprise when it revealed the second-generation Volt sporting an all-new range-extender Voltec powertrain

Since its launch in 2010, GM has sold more than 73,000 Chevrolet Volts and Opel/Vauxhall Amperas. And during that time, the General has collected a valuable bank of data from customers in the field; that experience has now been pooled with advances in powertrain technology – both IC engine and electric – to create a new generation of Volt, which is scheduled to go on sale in the second half of 2015.

All of the second-generation Voltec powertrain is new, according to Larry Nitz, executive director for hybrid and electric powertrain engineering at GM. The changes start with an all-aluminum, 1.5-liter DI gasoline IC engine replacing the old 1.4-liter motor. The new unit will be built in Toluca, Mexico, for the first year, and afterwards in Flint, Michigan.

"In the current car we have a full-size battery and a half-size engine," explains Nitz. "The battery is 110kW and the engine is 55kW. It works pretty well, but you can get into situations where the engine has to come on rather aggressively. Customers said that when the engine comes on, it's a little too noisy.

"For the second generation, we decided to give the engine more efficiency and more power," he expands. "We've brought in the all-new Ecotec, our 'small gas' engine, with 75kW (102ps). It's been tailored for the operating conditions of the Volt, so for efficiency it has a high compression ratio of 12.5:1, compared with around 9.5-10:1 normally. It has cooled EGR. It has wide-authority cam phasers so that it can act as an Atkinson-type cycle engine and move the cams back to a more conventional valvetrain arrangement to get more power. It also has a variable displacement oil pump and it runs on regular unleaded. Our customers said they didn't like buying premium unleaded."

VOLT
VOLT

Like the IC motor, the battery is also all-new, with modified chemistry and modified cell architecture. The original Volt has three cells in parallel and 96 in series; the new one gets two cells in parallel and 96 in series, but also more capacity.

"The pouch cells are larger but remain safe," assures Nitz. "They're in a simpler configuration and where the current Volt has 17.1kWh, the 2016 model has 18.4kWh. We worked closely with LG Chem on the cell chemistry to improve them over the current Volt. They have lower DC resistance so they also have higher power. Despite there only being two in parallel, we can deliver 120kW instead of 110kW. The pack is about 9.5kg lighter than the prior battery, too."

Keeping cool

As part of the extensive engineering changes between Volt gen-one and gen-two, the battery cooling system has been simplified and improved. The previous three cooling loops have been reduced to two. A cooling loop that also went to the atmosphere has been combined with the chiller.

"We can cool or heat the new battery to keep it at living temperatures. We found that this is a huge advantage because our batteries *are* living," Nitz stresses, before taking a swipe at rivals such as the Nissan Leaf. "Our customers are seeing range after three years in the field that is about the same as when the battery was new. That tells us that, compared with competitors who in our opinion didn't put adequate cooling in their battery pack, cooling is critical to battery life in the real world, not just in the laboratory. Putting this level of sophistication into the cooling is worth it."

Most of that high-level R&D takes place in GM's battery test labs, which Nitz describes as now running "like a well-oiled machine". And there's no getting away from the fact that the development of the second-generation Volt battery has benefited enormously from the usage data collected from Volt owners over the past four years, he says.

"Over many, many years we have created test cycles for engines and transmissions, cycles that we know have correlated back to customer use. We didn't have that for the [first] Volt so we originally created 22 different [usage] test cycles. We've narrowed it down to 11 customer cases that we test now. With the gen-one car we were able to use OnStar data to validate how customers really use the car.

"There has to be a correlation of what happens on the road in order for the lab to be meaningful," the GM engineering director explains. "The big thing we've learned is correlation – we know the test profiles that we now run in our battery lab will deliver a battery that will last the life of the car, not just for one customer in one condition, but many customers in many conditions. We

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BOLT FROM THE BLUE

The Volt wasn't the only surprise GM had up its sleeve at the Detroit Motor Show earlier this year. Shortly after unveiling the second-generation range extender, Chevrolet surprised showgoers and media alike further by revealing the Bolt Concept, a 321km (200 mile) range BEV concept with production intent. And for Larry Nitz, there are important similarities to be drawn between the powertrain in the Bolt Concept and the one in GM's current production EV, the Spark.

"That has a single motor that was designed by GM and built in our powertrain factory in Baltimore, Maryland, with a simple, fixed gear-ratio reduction to drive the wheels. It's a similar type of configuration in the Bolt Concept."

The Bolt has an advanced lithium-ion battery – supplier as yet unknown – but in a flatter pack arrangement than the Volt. It is located within a sandwich floor in the style of the original Mercedes A-Class; Nitz describes the car as a CUV and as such it requires a flat cabin floor.

"As a long-range battery-electric car, the Bolt Concept has its own circumstances around the utility of the battery," he adds. "Each cell is used a little less because it has a lot of energy, so the cooling is optimized for the utilization that we have."

RANGE FINDERS

Just how much is enough range? And when does range anxiety melt away? Both are crucial questions for OEMs in the EV arena, and is certainly one that GM has pondered long and hard.

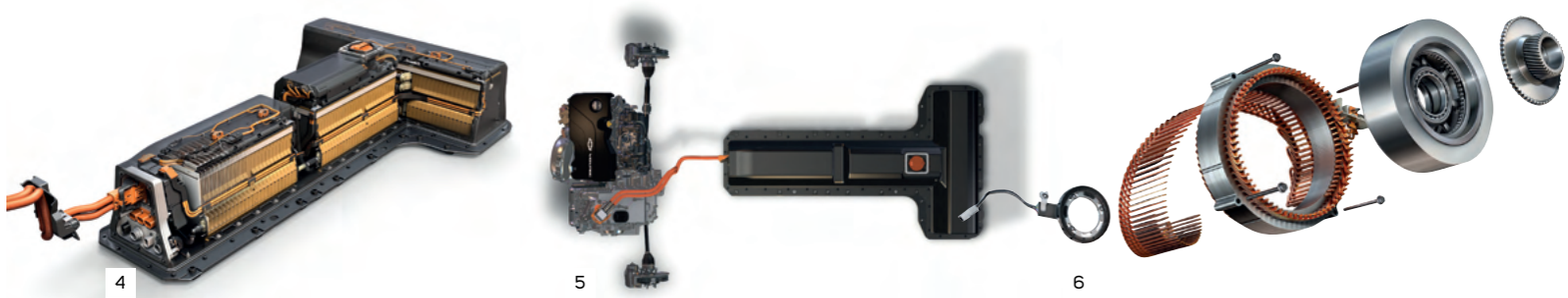
"A number of technical studies have been done around what number eliminates range anxiety in a daily commute," states Nitz. "It's larger than the rationally priced EVs on the market today: at 80-100 miles [128-160km] of range, you still have to think too hard. Most of the studies come out in the upper 100s of miles – short of 200 miles [321km] – for customers in every market to not have to worry about range. Because in a colder climate, like New England or Michigan, where you're going to use some battery power to make heat, you won't get the full range delivered in vehicle miles [kilometers] driven.

"Then there's a psychological factor too – 200 miles [as offered by the Bolt Concept] is a nice round number. It's a game-changing number to have for a long-range battery-electric car that's priced for the masses, not for the few. We think the appeal at US$30,000, net of tax credits, is really the place it has to be. It's a concept, but we think that's the kind of BEV that we would need to do to satisfy markets around the world."

However, for Andrew Farah, the Volt's vehicle chief engineer, range and range anxiety are two issues that are far more personal. "It's about your personal drive cycle so it's hard to make broad judgements. So, 80% of the trips our current Volt owners take are all-electric. That's a bigger number than people might expect. When we make the battery bigger [in the new car], we'll be up to 90% in some places. That tells us we're nearing the top for an EREV in terms of battery capacity, so perhaps the next step in EV-ness is something like the Bolt."

"We worked closely with LG Chem on the cell chemistry to improve them over the current Volt"

Larry Nitz, executive director, hybrid and electric powertrain engineering, General Motors



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think it covers all rational usages of the car. We're very excited about that and it's still something that very few OEMs have today."

Data is uploaded automatically from customers with active OnStar accounts. A second level of data is gathered from customers who agree to be part of an anonymous survey – essentially around two-thirds of current Volt users.

Nitz is also proud of what he describes as a "very bold change" to the 2016 Volt's all-new electric drive. "It still has two motors, but they are substantially smaller. The overall electric drive – motors, gearing, inverter, electronics and cables – is 45kg lighter. The motors have about 75-80% reduced rare earth content; one has no rare earth content – it's still a permanent magnet motor, but it's a ferrite magnet not a neodymium iron boron magnet. So the electric drive is up to 12% more efficient and it has more torque and power."

That is manifested in a 19% improvement in electric acceleration from 0-48km/h (0-30mph) in 2.6 seconds, and a 7% improvement from 0-96km/h (0-60mph), which translates to 8.4 seconds in the real world. Both motors operate together in more driving scenarios, in both EV and extended-range operation.

The changes have also had a positive effect on both the cost and sustainability of the components and subsystems. Nitz adds that the motors were designed in-house and are subject to a make-and-buy strategy, but won't disclose external suppliers used. The electric drive unit will be made in Warren, Michigan, and the local sourcing doesn't stop there – the new Volt has 20% higher North American content than its predecessor, at 70%, with reductions in the associated logistics costs. The inverter/electronics, for example, are now US-built, whereas parts were previously sourced from Japan and Mexico. The battery cells are made in Holland, Michigan, and the pack assembled in Brownstown, Detroit. The Volt itself will continue to be made elsewhere in the city at the Hamtramck plant.

The powertrain changes combine to extend the Volt's electric-only range from 61km (31 miles) to 80km (50 miles) – a direct response to current Volt owners' number one request. Total driving range is up to around 675km (420 miles).

1. The second-generation Chevrolet Volt showcases a sleeker and sportier design that offers 80km (50 miles) of e-range

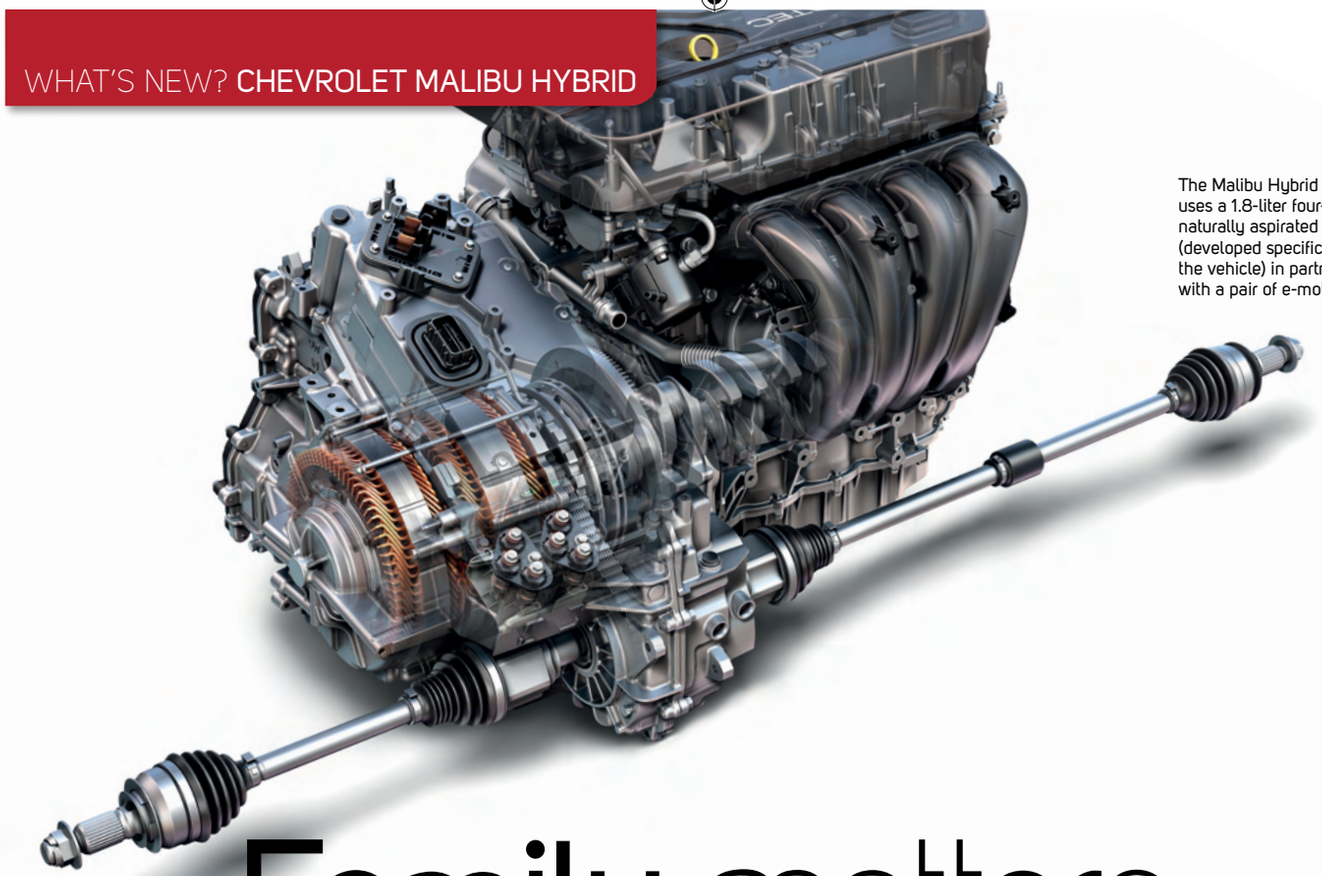
2. The all-new Voltec drive unit and 1.5-liter four-cylinder engine for extended range operation was designed to be more efficient and provide increased acceleration

3. The Voltec unit is 45kg lighter and 12% more efficient than the previous system

4. The new battery pack maintains its signature t-shape configuration but uses nearly 100 fewer cells than previously

5. The Volt's propulsion system is made up of the battery, drive unit, range extending engine and additional electronic controls

6. Engineers designed the electric motors to use less rare earth materials. One motor doesn't use any rare earth type magnets



The Malibu Hybrid (below) uses a 1.8-liter four-cylinder naturally aspirated engine (developed specifically for the vehicle) in partnership with a pair of e-motors

Family matters

The new Chevrolet Malibu Hybrid borrows heavily from the drive system in the 2016 Volt – but the differences between the two siblings are as important as the similarities

For the latest step in its alternative propulsion mission, GM has announced a hybrid version of the next-generation Chevrolet Malibu. And in selecting the new sedan's powertrain, GM's engineers didn't have to look too far for inspiration – the new Malibu shares much of its hybrid underpinnings with the 2016 Chevrolet Volt, and both applications were central to the propulsion system's development.

In order to create its total system power of 185ps, an all-new 1.8-liter naturally aspirated four-cylinder engine, developed specifically for the Malibu Hybrid, is paired with a two-motor drive unit, which is modified from the system found in the Volt. And, as Daryl Wilson, lead development engineer for the Malibu Hybrid, explains, the differences between the two powertrains might be small, but they're also pretty significant.

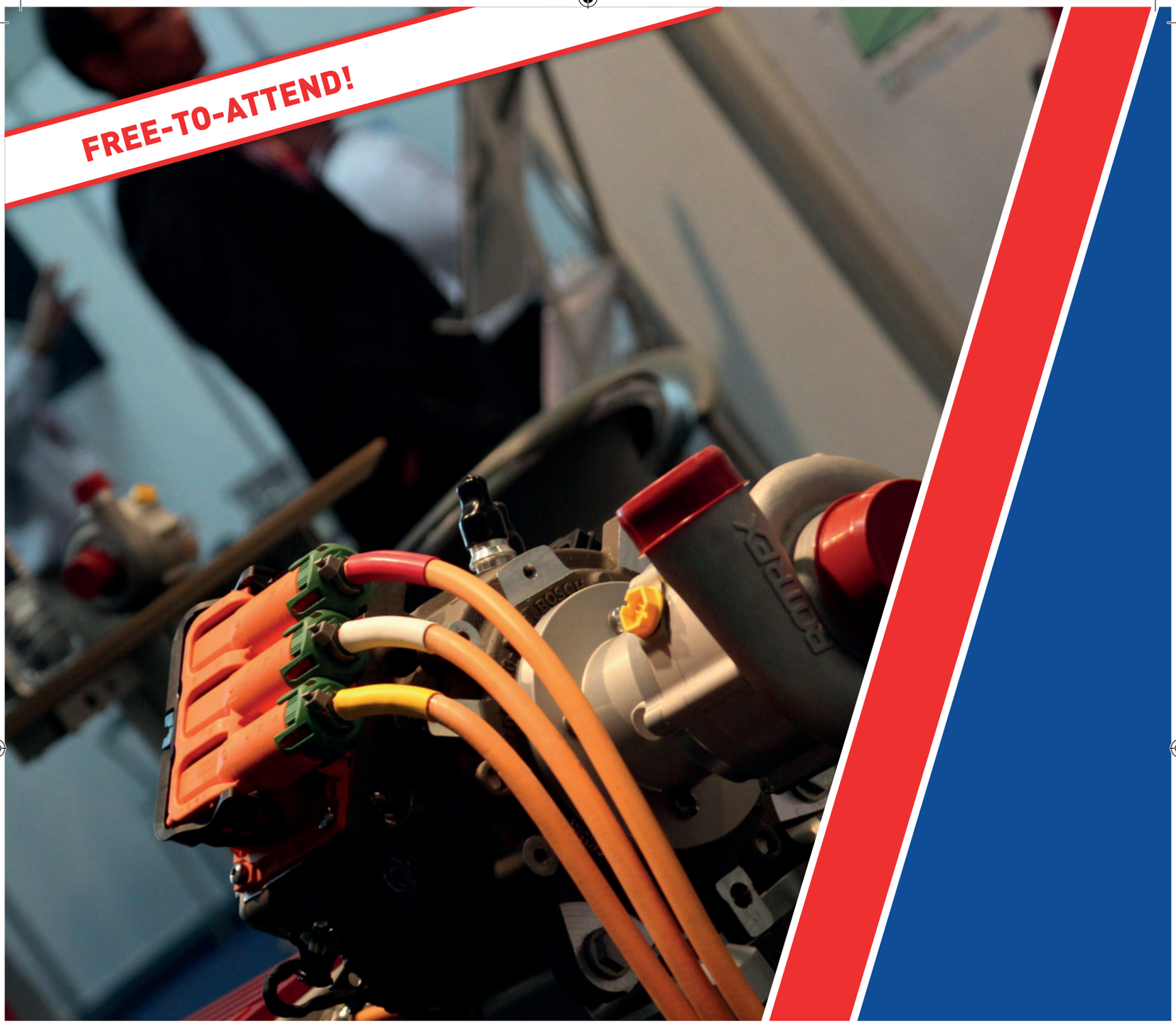
"There's an additional clutch inside the next-gen Volt drive unit that we do not have in the Malibu," he says. "The Volt has that clutch to allow it to use both of the electric motors inside the drive unit to provide forward propulsion. We don't need that in the Malibu because we're not motor-limited by our ability to provide electric power. We are battery-limited."

Similarly, the Malibu and Volt applications called for differences in their respective motor design. "We utilize neodymium magnet motors in both of the motors in the Malibu," Wilson explains. "The Volt does not; it has a neodymium Motor B, and a ferrite magnet motor A. This provides it some advantages from a cost standpoint, and also running at high speed electrically using a ferrite motor offers advantages from an efficiency standpoint. The Malibu does not run at high speeds electrically, so we don't see that same efficiency benefit that the Volt does with the ferrite magnet motor. So we use neodymium magnets – we saw some efficiency benefits there that made a better trade-off for the HEV than using a ferrite motor."

Doubling up

These two factors are the only main significant engineering alterations made to the hybrid system between the Malibu and the Volt, with the power electronics, internal electric pump, packaging, and even final drive shared between the two applications. But sharing development between two vehicles, in this case at least, hasn't caused either application to be forced to compromise – while the benefits are difficult to ignore. "I couldn't put a cost figure on [the advantages], but it is significant," Wilson admits. "Not just in terms of the tooling and the investment it cost to build that drive unit, but all the engineering and validation work that goes on with developing the drive unit is substantial. Developing this drive with these two applications in mind allowed us to combine those efforts. There are some specific things that need to get validated depending on the application, but the core validation and verification of the drive unit is done for all the applications at one time. That significantly saves cost and time."

What's more, the Malibu and Volt are suitably similar to make any compromise acceptable. "There was very little trade-off needed due to things like making components overly robust because of differing masses between the vehicles – we're fairly close with these two vehicles," Wilson adds. "And, as I said, we're able to tailor the system with this additional one clutch operation. That really is what enabled this drive unit to not be completely overdesigned for a HEV. A single motor (as in the Gen 1 Volt) to provide the electric propulsion would have been extremely overdesigned for our HEV – you would have had way more motor capability than you needed. Being able to split the power flow is what's allowed us to balance this well and not carry around extra capability that's not needed."



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Far East movement

A new zero-emissions performance scooter, complete with integrated electric powertrain, will hit the streets (and hills) of Taipei this year

The Smartscooter pioneers an interchangeable battery technology where drivers reserve replacement cells

One of the first things that strikes you about Gogoro's new zero-emissions two-wheeled EV, the Smartscooter, is the way it looks. And, explains Gogoro CTO and co-founder Matt Taylor, there's a very good reason for that. "The way that engineers build a motorcycle is quite different from the way that a designer would build a motorcycle. If it were just engineers working on this, it would probably look like any West Coast motorcycle that's out there today – very high performance, but the motor is just bolted on, you can see where the controller goes, and you've got this big battery between your legs."

Taylor and fellow founder Horace Luke started Gogoro – "a tech company that's focused mostly on energy" – in 2011. The pair have known each other for decades, and have worked together since 1999 at some of the largest consumer tech brands in the world, including Xbox and HTC. Frequent conversations during business trips inspired the pair to set up their own company, and assemble a team (blending those with extensive automotive experience with experts from consumer electronics and a number of other fields) to design the Smartscooter. The stylish, innovatively designed scooter is Gogoro's EV debut – and will make use of the company's impending modular battery-swapping infrastructure, the Gogoro Energy Network.

City living

The Smartscooter's liquid-cooled permanent magnet synchronous motor produces 6.4kW at 3,250rpm, and 25Nm of torque from 0-2,250rpm. That's good for a 0-50km/h (31mph) sprint of 4.2 seconds and a top end of 95km/h (59mph). Maximum riding range per battery swap is approximately 100km (62 miles). In-house development of the scooter's powertrain has been a major part of the project from the very beginning. "A lot of motorcycles at the time were being done with DC-type motors, but we'd been looking at brushless PM motors for some time," says Taylor. "Our initial performance targets back in 2011 weren't as ambitious as they ended up being, so the original motor was a fair bit smaller than what ended up on the scooter today, but we were convinced that PM was the way to go."

Power comes from a pair of Gogoro-designed interchangeable batteries – developed with Panasonic and utilizing 18650-size automotive-grade Li-ion energy cells – each providing, Taylor says, 1.4-1.5kWh. Drivers reserve replacement cells from kiosks situated throughout the city, swapping the spent cells for fresh ones.

The result, Taylor believes, is a vehicle that will not only outstrip anything else at an intersection, but one that pushes the boundaries of zero-emissions scooter performance. "It's really the edges of the envelope that you have to design for. The biggest challenge was to get from the nominal case – driving in the city on a hot summer's day – to climbing up a mountain with a friend on the back."

The Smartscooter will roll out in Taipei this summer, and Taylor admits that the powertrain is loaded with potential for future applications. "We've got core pieces of the platform – the motor controller, the motor, the battery – that could be scaled in one direction or the other. So if we wanted to dial up the torque of the motor by another 20-30%, that's pretty easy to do. The controller can be adjusted in much the same way. There are a lot of different directions that we could go with on the key pieces we've developed. A slight tweak or redesign to get into something like a city car? Not difficult at all. A higher or lower performance scooter? Not difficult at all. There's an engineering team in place right now, and we can go out and target the opportunities we think make most sense."

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Flow rider

Building on the success of last year's e-Sportlimousine concept, the Quantino and Quant F tech demonstrators represent the next step for NanoFlowcell's pioneering battery cell design

A year on from the debut of the e-Sportlimousine concept, as brought to you by *E&H* 12 months ago (*New Flow*, July 2014, p22), Liechtenstein-based NanoFlowcell has revealed further e-powertrain-based ambitions in the form of the Quantino tech demonstrator, a smaller and supposedly more affordable electric sports coupe showcasing the company's flow-cell battery technology.

This compact 2+2 promises a top speed of over 200km/h (125mph), but more impressive is its total driving range of more than 1,000km (621 miles) between top-ups of charged battery fluid into its two 175-liter tanks, one charged positively and the other negatively.

The Quantino creation differs from the Quant F super-coupe (both were unveiled at this year's Geneva Motor Show) primarily in its use of a low-voltage 48V all-electric drive system. The technology delivers around 138ps via four individual in-wheel three-phase induction motors, each producing 25kW and enabling torque-vectoring, as in the larger Quant F, and this output and performance has been facilitated by the higher energy density and efficiency of the flow-cell batteries. "NanoFlowcell believes in the combination of flow-cell and low-voltage systems," states CTO Nunzio La Vecchia. "And we consider this to be the perfect basis for successful and sustainable electric mobility of the future. Low-voltage systems in combination with flow-cell technology harbor great potential for large ranges and excellent performance figures."

According to La Vecchia, such low-voltage drive systems have previously been restricted to low-speed EVs – the likes of which include golf carts and some light-duty urban vehicles – mainly due to the high currents needed for greater performance levels and to propel larger, heavier and more luxury-based applications. "With the NanoFlowcell we have been able to solve this problem," he says enthusiastically. "Here we generate very high currents at a very low rated voltage. In combination with the buffer system we are achieving an enormous range and exceptional performance figures." The CTO also points out that in accordance with safety legislation on contact and flashover protection, low-voltage systems are much quicker and easier to homologate, and the company is aiming to put Quantino prototypes on the road later this year for real-world testing, followed by "rapid homologation in preparation for series production".

Technology progression

The luxury-level Quant F – which operates at a peak voltage of 735V – shows further technology progression for NanoFlowcell from last year's concept, now featuring a new 2-speed transmission and near-complete interior design in preparation for crash-testing. This 300km/h (186mph) four-seater has a range of up to 800km (497 miles) and is capable of a 0-100km/h (0-62mph) time of just 2.8 seconds, despite its 2,300kg mass. Total peak power output of 1,105ps comes from its four motors that each produce up to 200kW or 275ps on full boost from the supercapacitors, although operating power is a more modest 90kW each. Peak torque is a massive 2,900Nm per wheel!

Prototypes have been tested on road and track, the exterior design has been completed, and the

1 and 2. The luxury-level Quant-F develops peak torque of 2,900Nm per wheel and 1,105ps total peak power

interior is currently said to be "90% compliant" for US and European homologation, pending final work on airbags and the front display.

Quantino and Quant F share their flow-cell batteries, which consist of two cells through which charge – held in the ionic fluid, or electrolyte – passes via a membrane. These battery cells, developed in NanoFlowcell's Digilab simulation center in Zurich, are said to remain stable through 10,000 charging cycles with almost no capacity loss or self-discharging, and are also claimed to be thermally stable and less flammable than lithium-ion designs, producing negligible waste heat. In the Quant F, the energy generated from the parallel oxidization and reduction processes is stored in two supercapacitors, which further capture energy from regenerative braking.

The company is keen to point out that its patented technologies are developed from the redox flow cells similar to those used in other applications, such as static storage, and that its cells have a five-times greater energy density than the typical flow cells currently in production. "It has the same basis, but our NanoFlowcell is a new invention, with different hardware and software, higher energy intensity and different membranes," underlines NanoFlowcell technology specialist, Volker Pulskamp.

As such, not only is NanoFlowcell now extending its research and development work into other sectors including aerospace, railway, shipping, haulage and construction, it is also considering an initial public offering of shares and flotation on the stock exchange. The company has also established its R&D center in Weissach, Germany, plus a new production base in Waldshut in addition to a research lab in Lugano, Switzerland.

NanoFlowcell is also working on solutions for the supply and distribution of the necessary charged electrolyte fluid, but as Pulskamp points out, "It is not flammable, it is toxicologically friendly, it does not need high-pressure storage, and you can put it wherever you want. It could go to filling stations, you could have it at home, railway stations, market places – it offers many options." What's more, the supply chain for the fluid could piggy-back that in chemical production, mineral industries or other options, "and we are figuring out where to start and showcase," Pulskamp adds.

Main image: The AWD Quantino coupe features a low-voltage 48V drivetrain via four three-phase induction motors

3. An ionic liquid is stored in two 175-liter fuel tanks; one has a positive charge while the other has a negative charge

4 and 5. Exterior design has been completed while the interior is said to be around 90% compliant for US / European homologation

Not all hybrids are the same

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Supply and demand

In order to meet upcoming stringent emissions regulations and reduce upfront costs, car makers are increasingly relying more heavily on technology suppliers – and they don't come much bigger than Bosch

1

Although Bosch is loath to forecast too far into the future, its estimations for all-electric vehicle sales are relatively conservative. Five years from now, it anticipates over 90% of new cars will still have some sort of IC engine, although by 2025, some 15% worldwide – and over one-third in Europe – will have at least a hybrid powertrain, including three million plug-in hybrids and 2.5 million all-electric battery applications, with 48V-enabled technologies also having an impact.

"Electrification will take combustion engines to new heights," predicts board member and chairman of Bosch Mobility Solutions Dr Rolf Bulander. "Electrification means that IC engines will experience their best period of service life yet, giving an optimum range. They can be used more effectively and efficiently."

Bulander sees purchase prices and charging infrastructure as the main barriers to adoption of all-electric vehicles – "by 2020 we want to halve battery costs" – with crucial factors for the success of electromobility including driving enjoyment and also the use of wider sustainable-source electricity. "Electrification based on renewables makes real sense, it's a major precondition," he adds.

As such, it's no surprise that the industry's largest Tier 1 is working hard on a raft of high-tech e-powertrain solutions. Showcased at Boxberg at a special media event in June were several new cars that have benefited from Bosch engineering expertise of late,

2

1. Powertrain electrification is picking up pace says Bosch and current low oil prices will not change that trend. The Tier 1 expects around 15% of all new cars built worldwide to have a hybrid powertrain by 2025

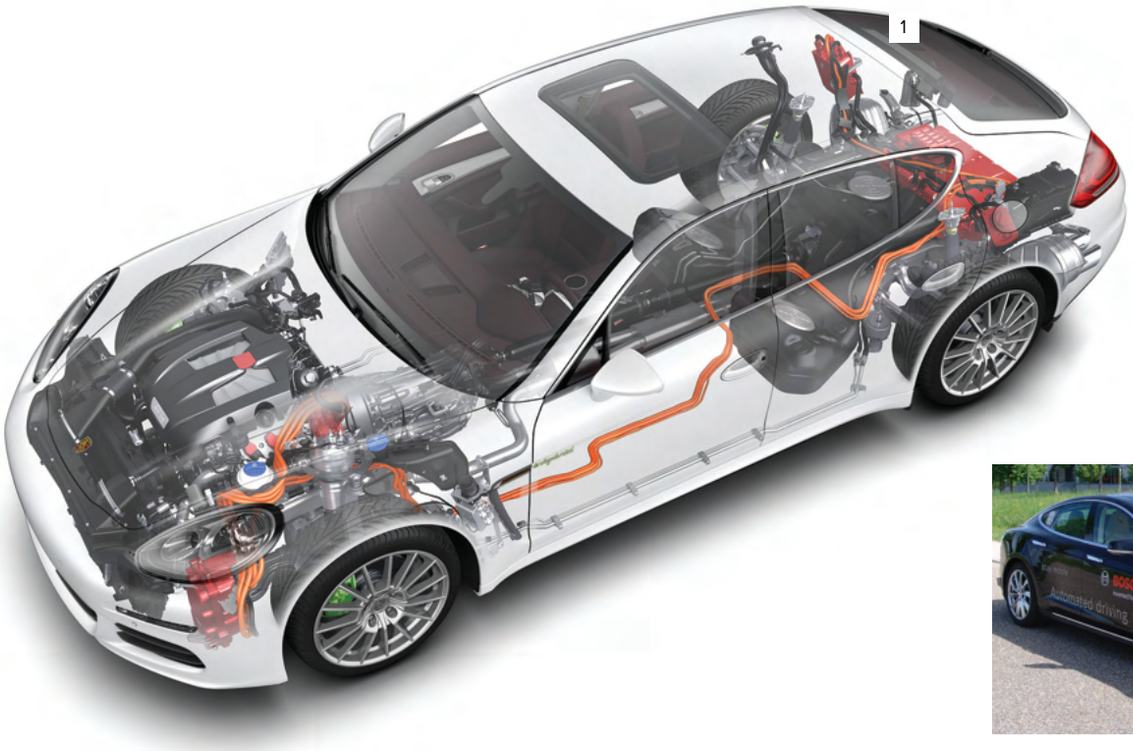
2. Bosch is stepping up its activities in the e-powertrain arena, bringing to market new products that will help EVs and HEVs to increase performance and improve driving range

including the Mercedes-Benz S500 Plug-In Hybrid, a fast-accelerating sedan featuring the IMG 290/110 motor built in the Bosch-Daimler EM-motive joint venture. This e-motor gives 245kW and 480Nm to supplement the twin-turbo V6. The similar 155kW/340Nm IMG 290/110 unit fitted in the Mercedes-Benz C350e Plug-In Hybrid makes this development capable of doing 130km/h (80mph) in electric-only mode, and both these Mercedes models perform to expected standards of speed, smoothness and refinement. Meanwhile, the 55kW EM-motive 180/20 motor, as used in the all-electric Smart Fortwo electric-drive, weighs just 35kg and is small enough to fit in a child's school backpack. The German engineering powerhouse also supplies the powertrain, including motor, power electronics, battery and regenerative braking system, to Fiat-Chrysler for the Fiat 500e on sale in the USA.

Ongoing electromobility R&D programs at Bosch further involve inductive charging and fuel cell powertrains, with prototypes up and running by the third quarter of this year.

Connecting the car

Yet according to Bulander, "Connected electric vehicles are the best electric vehicles, because added functions can be achieved," he explains, pointing out that by 2020, "Cars will be an active part of the internet – they will be able to collect and pass on information." Quite apart from general safety and convenience



1. Bosch has won some important technology supplier contracts of late, including the Porsche Panamera S E-Hybrid program

2. On an R&D level, two new test vehicles based on the Tesla Model S are helping Bosch engineers further refine automated driving

– warnings of icy conditions and congestion, or remote vehicle diagnostics – connected-car technologies enable the optimization of range and charge levels in electrified vehicles, as showcased in the Porsche Panamera S E-Hybrid, with its electronic horizon software that previews the road ahead to predict zero-emissions zones.

The next step is EV communication with charging infrastructure, smart-grids and home energy systems. Bosch Software Innovations has already developed a smartphone app for charging point reservations, billing across network providers and fleet management services, plus a system of web-enabled sensors in parking spaces to build a real-time parking map in order to reduce the time and energy consumption of looking for a space.

And "Connectivity is the key to electrified and automated driving," adds Bosch board member Dr Markus Heyn, introducing a third development path for the Tier 1 company. Electromobility, connectivity and automation are all ultimately interlinked – as showcased in the supplier's two automated Tesla Model S tech demonstrator vehicles. Each car is fitted with 50 new Bosch components, including a stereo video camera (SVC) that recognizes traffic signs, lane markings, clear spaces and obstructions, as well as featuring automatic, independently operating brake booster and ESP systems.

A ride in one of these prototype vehicles – the highlight of the day at Boxberg – showed that while there is still a long way to go before full automation is ready for mass-market application, the basic functions of the system are present and correct. The small size of the SVC means that no unsightly roof-mounted cameras are needed, and "After some 1,400 hours of work on each of them, the test vehicles are ready for highly automated driving," says board member Dr Dirk Hoheisel, noting that automation is particularly useful during the "boring parts of driving" such as stop/start traffic. Bulander adds that "Bosch technology will enable the cars of the future to not only autonomously accelerate and brake, but also steer."

3. The Bosch Boost Recuperation System brings four functions together in one package: recuperation, boost, stop/start and coasting. A fuel saving of as much as 15% can be realized, with a further 10% possible in real-world operation when coasting with the engine stopped

4. Bosch is pioneering technology that enables drivers to simply press and hold a button on the ignition key or smartphone to automatically maneuver the vehicle so that it parks itself in an available space

Beyond the car

For Bosch, electromobility encompasses two-wheelers too, and besides the eScooter drivetrain, comprising a wheel-hub motor plus electronic control unit, Bosch's eBike system gives battery-boost to pedal-cycles – one million of which have been sold in Germany, says Bulander with pride, making these Europe's most successful electric vehicles so far. Yet Bosch's renaming of its Automotive Technology business division, now Mobility Solutions, is perhaps the largest clue to its expected future direction. It's not just about cars and componentry any more, but services in the broader transport realm.

Besides the smartphone app, Bosch has provided software for a test project, Stuttgart Services, which allows city residents to access trains, buses, car- and bike-sharing services, and even swimming pools and libraries, via a single RFID card. Another trial, in Monaco, looks at inter-connecting smart city functions such as waste collection, bus networks, roadworks and even escalator maintenance. "We need to rethink personal mobility, at least in big cities, and move toward a multimodal concept encompassing bikes, trains, buses and walking," Bulander states boldly. "And we want to improve the efficiency not just of engines, but of traffic in general."

Official technology partner to the Porsche 918 Spyder

The targets for the 918 Spyder programme were simple: be the fastest road car ever around the Nürburgring and achieve fuel economy of 3 litres per 100km. To meet them, Porsche engineers chose GKN and its eAxle system.

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PROFILE: KENO KATO

Job title: Corporate vice president, global product strategy and EV product planning division
Company: Nissan

What career did you want when you were growing up, and what was your first job?
I decided to join Nissan when I was eight or nine years old, which I know is very strange. My father was a salesperson for Nissan, and when I was that age, it was struggling to fight against Toyota. It's a bit like being a football fan – you support Manchester United or Liverpool. It's very similar.

What was your career path to the position you currently hold?
I joined Nissan as a HVAC engineer. I spent five or six years in that position, and then I moved to product planning, where I have spent most of my career. However, I also spent two years in a Nissan dealership as a salesperson, two years with Nissan Europe and two years as a program director looking after several projects. Aside from those six years, I have always been in product planning.

What are the best and worst elements of your job?
Through the business I make a lot of friends in different countries due to the nature of my current role. This makes for unlimited learning about cars, people, cultures – as well as business management skills. That's the best part of my current job. As for the element I like the least? I like sleeping, and I wish I could get more sleep.

What would your dream engine specification be for today's eco-friendly world?
A pure EV with a very nice engine sound. In terms of the engine's characteristics, the torque delivery should be more or less similar to a diesel engine. And the top end of a Formula 1 car. But it must be an EV. With a range of hundreds of kilometers.

In your opinion, what is the greatest engine that has ever been produced?
I admit that my experience is very limited. If I had driven a lot of racing cars, or a lot of exotic cars from the 1950s, 1960s or 1970s, then I think it would be one of those. But I have a favorite engine. The RB 26 DTT, the GT-R engine, straight six. That was a sensational engine at that time. The sound and the character made it an amazing engine.

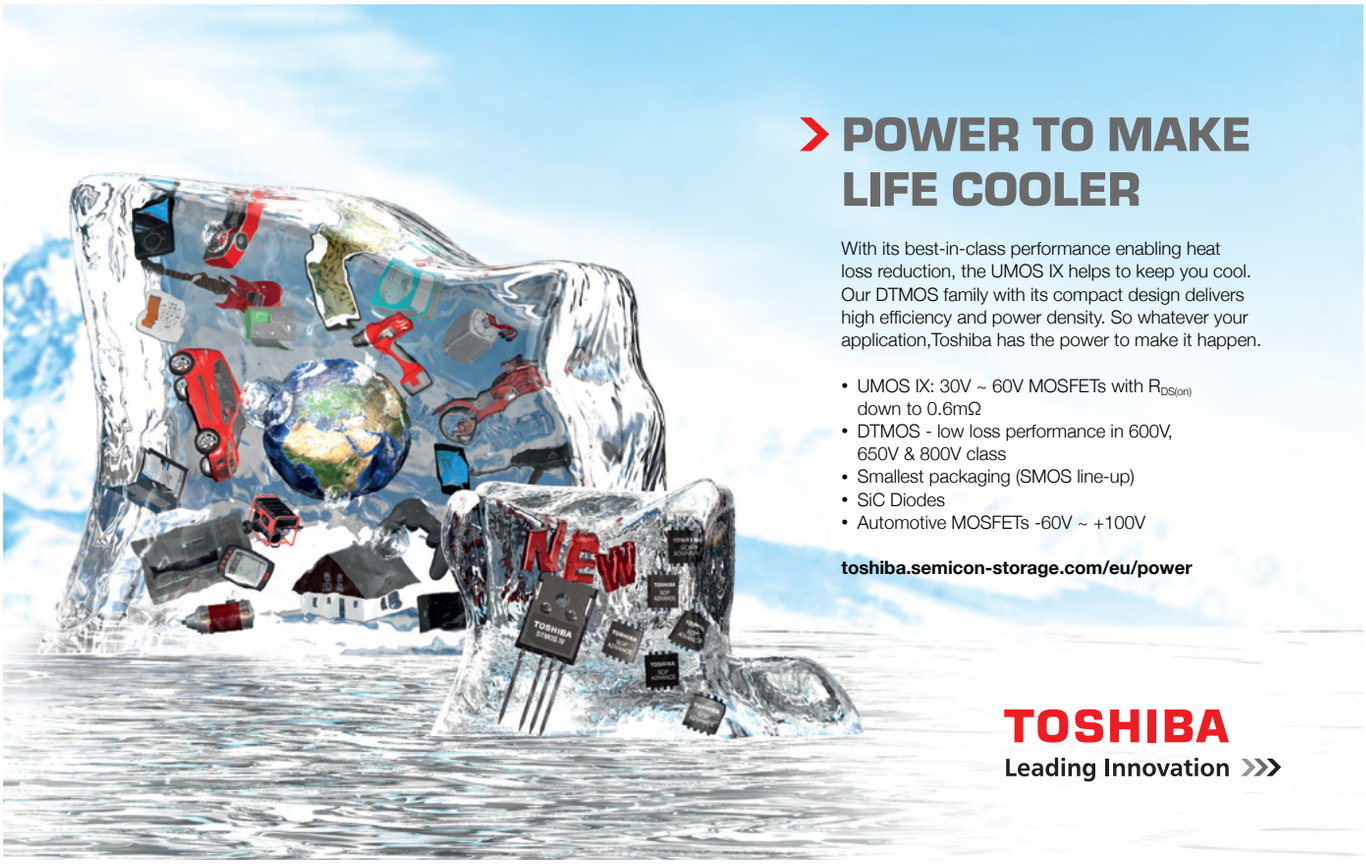
> Homologation can be painful, and CO_2 brings a lot of pressure. But without these, it's impossible for us to improve our performance significantly. These are the source of our technological improvements

What car do you currently drive?
A Nissan Cube. I would love to say the GT-R, the current model, but I drive a Cube. In Japan there is no company car scheme. Giving a car, rather than salary, is a good solution for the company and the employee in the UK and many other European countries. But it doesn't happen in Japan. So I bought myself a Cube – that might be slightly shocking to hear.

Which OEMs do you have an engineering respect for?
Volkswagen always cares about its customers, ensuring that it delivers value efficiently. This is not a recent development and has been at the heart of its activity for over 70 years. Ultimately the customer is the number one priority. Toyota shows a passion for quality at corporate level and strives to improve every single detail within its product range, which will result in quality improvement. I have a lot of respect for Mercedes-Benz – no description is required. Those working in the car industry respect them even more than Mercedes customers do. People tend to recognize BMW for its engineering expertise in terms of driving performance, but my view is different. To deliver the recognition, engineering plays a key role, as does dynamic styling. On top of actual driving performance, BMW has made some big gains in terms of dynamic styling. These days, I also have a lot of respect for Mazda. But of course, and perhaps unsurprisingly, I respect Nissan engineering the most.

What could legislators do to make your working life easier?
Homologation can be painful, and CO_2 brings a lot of pressure. But without these, it's impossible for us to improve our performance significantly. These really are the source of our technological improvements. So I'm not so negative about these restrictions – they're very tough, but necessary. The car industry is very much like a sports activity. To beat a great team, you need training, exercise, teamwork and improvements – every day.

In your opinion, what will be powering a typical family sedan in the year 2030?
Electrified powertrains will be really developed by then and we will see more and more of these on the roads in years to come. The IC engine will still have its place, but I think electrified powertrains will be sold in much, much bigger volume. Electrified powertrains undoubtedly offer greater comfort than IC-powered cars and are easy to use, offering drivers a unique experience. ®

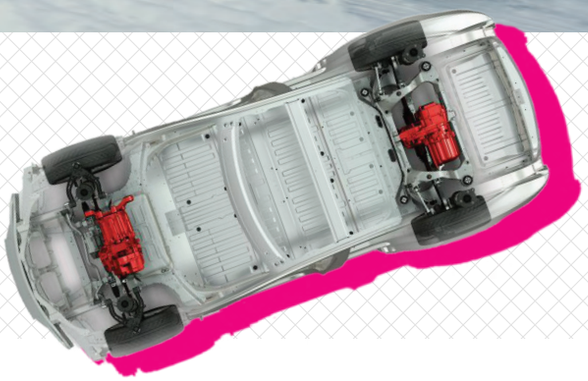


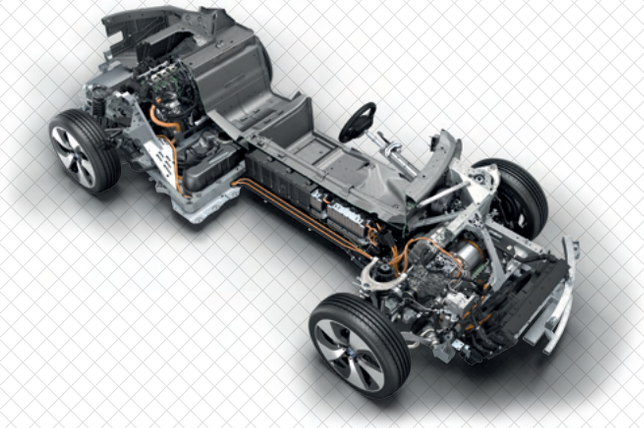
ELECTRIC POWERTRAINS **ON TEST**

Our thoughts on the next-generation cars we've tested recently that feature some sort of advanced powertrain electrification

TESLA MODEL S P85D

Is the P85D the most advanced, impressive, awe-inspiring battery EV yet? In a word, yes. Okay, that's just the opinion of editor-in-chief Slavnich, but, having spent a morning taking the range-topping Model S to task on local country roads and inner-city rat-runs in the UK, it's difficult to think of any other development that epitomizes the modern e-powertrain movement better. Launched a week after the Paris Motor Show last year – signalling the company's independence (or perhaps indifference) to the rest of the automotive world – the P85D always promised much on paper: a mind-blowing 700ps output to ensure a 0-100km/h blink-and-you'll-miss-it time of 3.4 seconds. That puts the P85D in the same room as some of the most scintillating petrolhead monsters, rubbing shoulders with the likes of Porsche, BMW M, Mercedes-AMG, hell even Ferrari and McLaren! Plant your right foot and the world whizzes by in a rush, and all this without spewing V6, V8, V10-shaped emissions. P85D combines the performance of the P85 rear motor – good for some 477ps – with an additional 50% torque that becomes available from a new high-efficiency front drive unit, generating the remaining 223ps. The motors on each axle digitally and independently control torque to the front and rear wheels, allowing for precise control of traction and response in all conditions. And you remember that old problem – range anxiety – that plagues so many other EVs? P85D's 85kWh battery pack helps ensure a driving range of 458km (285 miles), so much like any other high-performance IC-engined vehicle. In fact, the P85D is the best example yet that the IC engine isn't the only way for the automotive industry to keep our hearts beating and pulses racing.





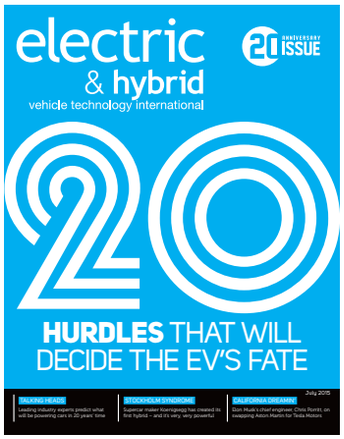
BMW i8

We started the Tesla P85D review with a bold answer to quite a tough, controversial question. So, how about this for a second time around: is the BMW i8 the most progressive sports car to date? In a word, yes! Just think about it before you go all hybrid hypercar on us. The i8 represents a momentous leap forward in terms of engineering and technology at a certain, 'you don't have to be a Saudi prince to own one', price point. It really is an automotive vision of the future that's essentially available today. While other car makers in this US$120,000 battlefield are putting out products with so-called downsized turbocharged motors that are inevitably six or eight-cylinders in design, the i8 is a three-cylinder marvel. The fact that a sports car of this caliber with just 1.5-liters of piston displacement and a seamlessely integrated e-motor works so well is living, breathing proof that hybrid technology that was once questioned – and even mocked – is here to stay. And it might even be the saviour of the IC engine and sports car as we know it. The 363ps powertrain consists of a 1.5 turbo triple to the rear axle and a front axle e-motor, meaning the i8 can outsprint a Porsche 911 while being good for 2.1 l/100km (134.5mpg) and emissions of only 49g/km. For the record, 231ps comes from the IC unit; the remaining 132ps from the e-motor, and the word on the Munich grapevine is that there's much more to come in terms of power, too. In the P85D and the i8, the automotive future has well and truly arrived.

KIA SOUL EV; AUDI A3 E-TRON; LEXUS NX HYBRID; RANGE ROVER HYBRID

Other electric and hybrid vehicles that we've had on test recently included the Kia Soul EV, Audi A3 e-tron, Lexus NX Hybrid and Range Rover Hybrid, and all were good examples of next-generation EV/HEV development. The Soul brilliantly showcases Kia's BEV intentions with a powertrain that easily competes with established products from the likes of Renault, Nissan and VW. The Range Rover is JLR's first attempt at a production hybrid model, and while it works well – it's not overly reliant on the diesel engine, so there's good mileage to be had in electric mode – expect more advanced e-powertrain designs from the UK OEM soon, including PHEVs. The Audi A3 e-tron is brilliant in every way, which is no real surprise as the powertrain is closely based on the wonderful VW Golf GTE. Finally, the Lexus NX demonstrates well the OEM's next-generation Hybrid Synergy Drive architecture.

FREE SERVICE!



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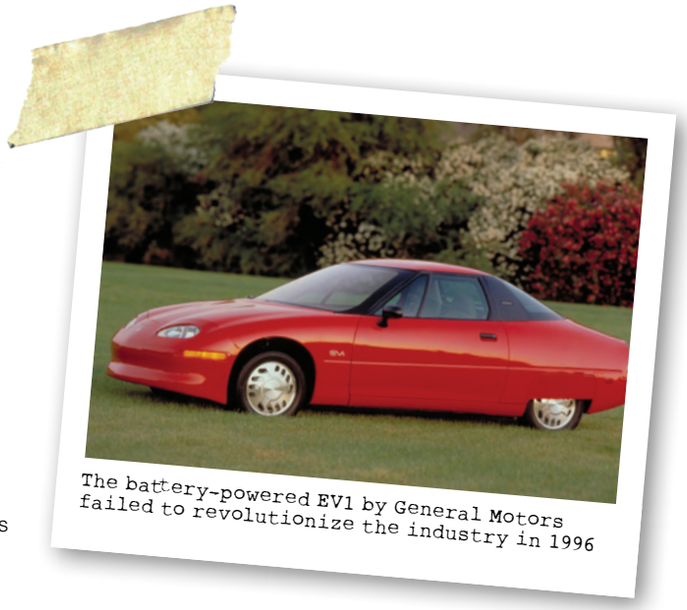
20 ANNIVERSARY ISSUE

Johnson

It isn't just this publication that's celebrating a 20th anniversary in 2015. I started working at UKIP Media & Events – publisher of this and 29 other magazine titles, as well as organizer of 17 exhibitions – in 1995, and *Electric & Hybrid Vehicle Technology International* was the first product I worked on.

I remember the amazing reception the publication received when that first issue landed. We were pioneers alongside Toyota, which had only just launched its first hybrid (the evergreen Prius), while GM had recently pledged to change the face of motoring with its 'mass-production' EV1. All other car manufacturers were constantly talking about developing electric-powered vehicles, with fuel cells being the next step. Indeed, Daimler was exciting the world with talk of its mass-production fuel cell car arriving in showrooms just five years after this magazine was launched. And *E&H* was the only publication in the world dedicated to revealing and discussing this so-called green revolution. It was predicted by all car makers that gasoline and diesel engines would be a thing of the past by 2015, so readers couldn't get enough of our exclusive features and industry opinions.

Twenty years on, and Toyota still insists on sticking with its parallel-gasoline-hybrid technologies (as opposed to range extenders, Toyota?). Meanwhile, GM's EV1 only changed the face of the US giant's bank balance for the worse, and it has subsequently had a go at another not very successful electric revolution with the Volt. And what of Daimler's fuel cell production car? I passengered in a prototype A-Class in 1998, and I drove a fuel-cell Jeep in 1999, but I have yet to have the chance to go to an actual showroom and buy one. So what looked like being an electric-powertrain takeover in 1995 hasn't quite happened as everyone might have expected back then.



The battery-powered EV1 by General Motors failed to revolutionize the industry in 1996

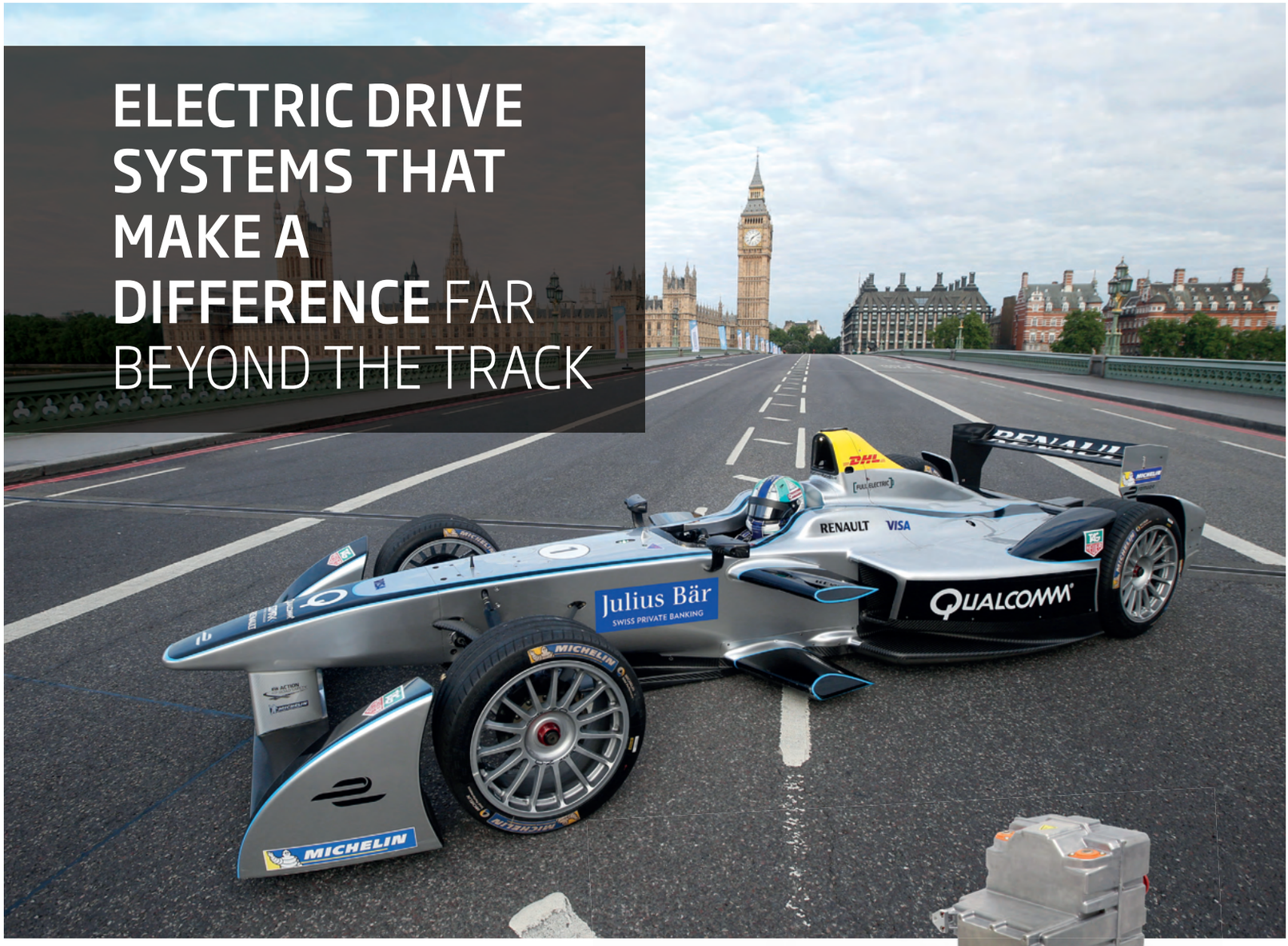
However, I do have an all-electric Renault Twizy in my garage at home. It lives next to a battery-powered, range-extending BMW i3. I can also purchase a range of Tesla battery-powered models, while a number of plug-in hybrids are available from numerous car makers, including sports car manufacturer Porsche. Why, even the fastest cars in the world – McLaren's P1, Ferrari's LaFerrari, and even Formula 1 race cars – now rely on electric propulsion in some way. The sales figures of electrically enhanced vehicles remain extremely low – I think it would be reasonable to say the numbers are insignificant, in fact – but what is significant is that car buyers are slowly switching on to the benefits of seamless power, home refueling, cheaper 'fuel' and quieter motoring. As soon as anyone samples electric power, they can't go back to fossil-fueled vehicles.

> "Car buyers are slowly switching on to the benefits of seamless power, home refueling, cheaper 'fuel'"

It's taken 20 years longer than anyone wanted, but it appears the electric and hybrid revolution could finally be coming. Just forgive me if I don't make any bold claims about what might be possible 20 years from now. Been there, done that!

McLaren
APPLIED TECHNOLOGIES

ELECTRIC DRIVE SYSTEMS THAT MAKE A DIFFERENCE FAR BEYOND THE TRACK



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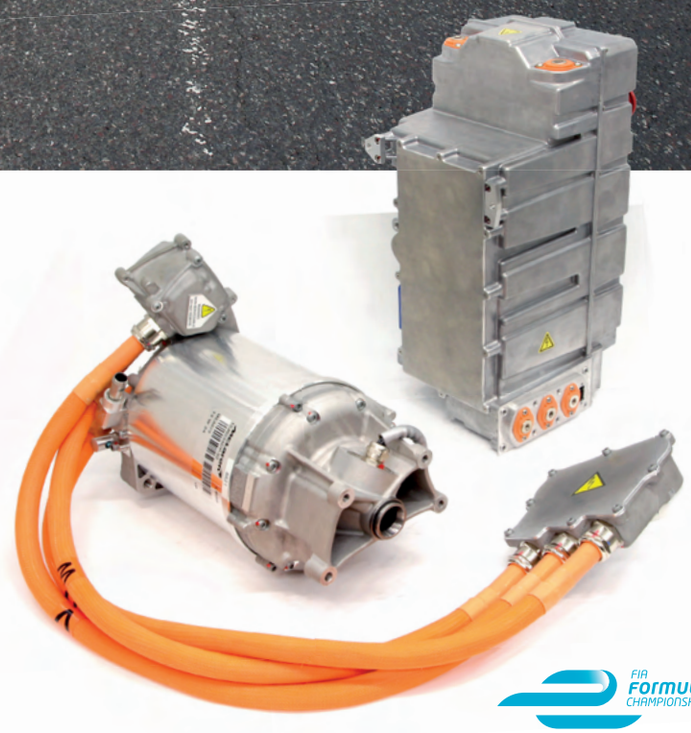

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FIA Formula·e CHAMPIONSHIP

Tesla's PowerWall demonstrates that better batteries have implications beyond the EV world

Llewellyn

It may be because I am currently reading Steve LeVine's incredibly well-researched and thought-provoking book, *The Powerhouse*, but I feel vindicated in my long-held opinion that batteries hold the key to the future of the electric and hybrid vehicle industry.

Many of us are used to outrageous claims about breakthrough technologies that eventually evaporate as the world rumbles on as normal. But, for once, predictions about battery cost from 10 years ago are holding up.

In 2005 it cost more than US$1,000/kWh to manufacture a lithium-ion battery. A few idealists were predicting that by 2020 the cost would have fallen way down to US$300/kWh, thereby making things such as electric cars more economically viable.

Now, in 2015, manufacturing costs are already below US$250/kWh, and the latest industry-wide predictions for 2020 are closer to US$100/kWh.

The billions of dollars invested in research, manufacturing techniques and advanced battery chemistry, it seems, are beginning to pay off.

I've always seen electric cars as a gateway drug, a door opener, and a symptom of something far greater. Once you can make cheaper batteries that last longer, the effects go beyond cheaper, lighter EVs with greater range, as we saw with Tesla CEO Elon Musk's fascinating recent announcement regarding the PowerWall home battery pack.

It was hard not to be reminded of Apple's iPhone launch – a charismatic corporate leader introducing beautifully packaged new technology. Except that, in both cases, the technology wasn't new and was developed by taxpayer-funded government research labs.

In the case of the iPhone, multi-touch screens had been developed elsewhere, but no one had done such a brilliant job of tying together all the technologies and packaging them so expertly.

The same is true of the home battery. There are plenty of companies selling systems similar to Tesla's – I saw one made by Bosch earlier this year at CES in Las Vegas. It was a combination inverter and battery: a slim, wall-mounted unit specifically designed for people with solar panels.

But Tesla's competitors have to face the fact that Musk got the press coverage with a vision that went way beyond the product – a vision of a world without fossil fuel. As a result, what would recently have been seen as another hair-brained prediction has far more credibility.

> "Once you can make cheaper batteries that last longer, the effects go beyond cheaper, lighter electric vehicles with greater range"

Tesla cars have thrown the rest of the industry into a panic, and the announcement of the Gigafactory has to be acknowledged as pivotal.

A combination of widely distributed, cleverly networked electricity storage systems makes all of the fluctuating input from renewables much easier to deal with. Breaking the old, centralized model of a massive power station with wires going out to towns and cities, the new model will consist of thousands of small power stations spread all over the place, with local storage to contain the excess. It changes the picture in ways that no one can predict.

It's a huge transition, and huge transitions are never 100% positive – they're disruptive and upsetting, and the vested interests that suffer will fight back hard. But history has shown us that eventually, when better technologies arrive on the scene, they are adopted regardless of the incumbents. Just look at landline phones and VHS tapes.

So I want to rest on my rather tatty laurels for a moment. In 2010, in a speech to industry leaders and politicians in Brussels, I said that the only thing we knew for certain was that fossil fuels would get more expensive and batteries would get cheaper. I am temporarily wrong with the first prediction, but bang on the money with the second.

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20 ANNIVERSARY ISSUE

Tipping point

RANGE FINDERS

Range extenders are not as bad an idea as some people believe they are. EREVs, as they're also known, have a bright future, if consumers can get their heads around the technology, and for that to happen, car makers' marketing departments need to get the message out there. These are not hybrids, people!

PUBLIC ORDER

Forgetting passenger cars – private ownership and business fleets alike for just one moment – surely it's in the public transportation sector that e-powertrains should first take the battle to the IC brigade. Think about it: we know the life and route of buses, garbage trucks, coaches, even some local government utility vehicles, so given this predefined data, surely this is the most obvious place where the e-powertrain can replace combustion motors. And just think, no more noisy, smelly diesel buses and refuse collection trucks – just calmer, cleaner and quieter vehicles. Urban bliss!

PLUG-IN PERFECTION

This one might be slightly controversial: make all hybrids of the plug-in variety. Time to ditch those conventional hybrid models that have got us this far but, really, in the real world, are still far too happy to trigger the IC motor for power.

To celebrate 20 years of *Electric & Hybrid Vehicle Technology International* magazine, we have come up with 20 all-important things, factors, points, lessons – call them what you will – that those championing the electric vehicle movement must take on board if the e-powertrain is to fully succeed the IC engine by 2035

WORDS: **DEAN SLAVNICH**

ON A CHARGE

Sorting out the charging issue is a priority. Quicker implementation of a standardized charging infrastructure is a must, as well as chargers that top up the battery pack far more quickly!

POWER TRIP

Come on now, let's start properly making the most of that instant torque. I mean, who doesn't like leaving a Porsche or Mercedes-AMG at the lights – especially if you're in a Nissan Leaf!

DIESEL DREAMING

Yes, we get that a diesel hybrid is essentially mating one expensive piece of kit with another, but it still makes perfect sense to us, especially in Europe, the heartland of TDI motors. It's time to accelerate the availability of this technology.

WHAT LIES BENEATH?

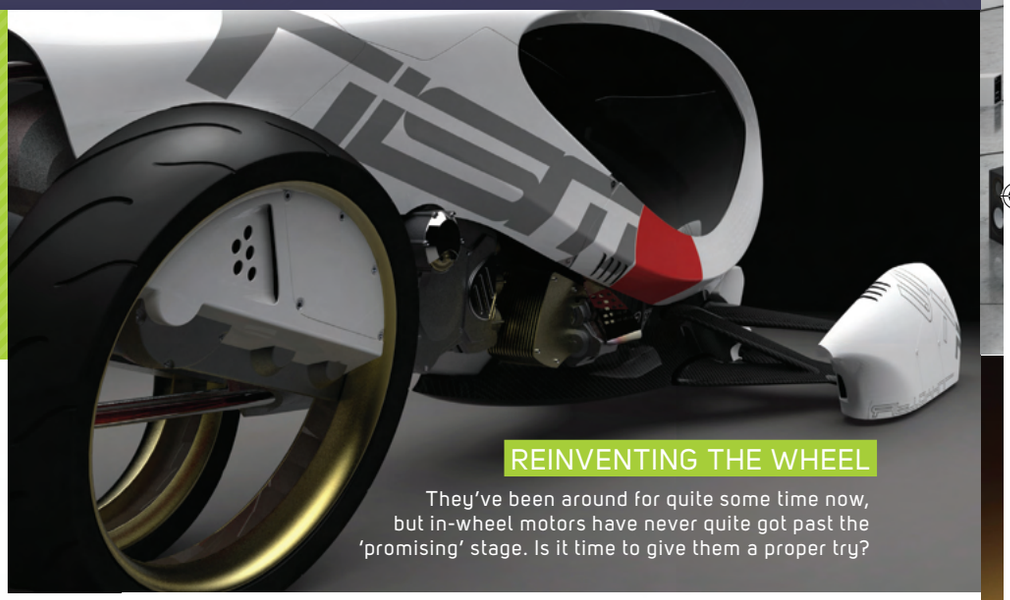
Time to really push ahead with the wireless charging dream, as in properly – not trials but real-world implementation of the technology. Imagine a world where your EV would be charging as it drove on the road... yeah, we don't think it'll happen either, or at least not by 2035.

HELLO WORLD

In life, you have to steal a march on your rivals, right? One place electric vehicles can start making serious inroads into the IC engine's dominance is tapping into the automotive industry's increasing obsession (and dependence) on connectivity. The Tesla Model S is at the forefront of this connectivity crusade, but other EV makers must take the battle up too. Why build an EV that has the same interior functionality as an IC product? The same can also be said for autonomous vehicles.

SUPER CAPACITY

If a big battery breakthrough doesn't happen sometime soon, it's probably time for super ultracapacitors to have a go. And that ultimately means one car maker sticking its toe in the water and giving this technology a proper try once and for all. If it works the rest will follow; and if you're the first, then you'll have an advantage for many years – just ask Toyota about hybrids.

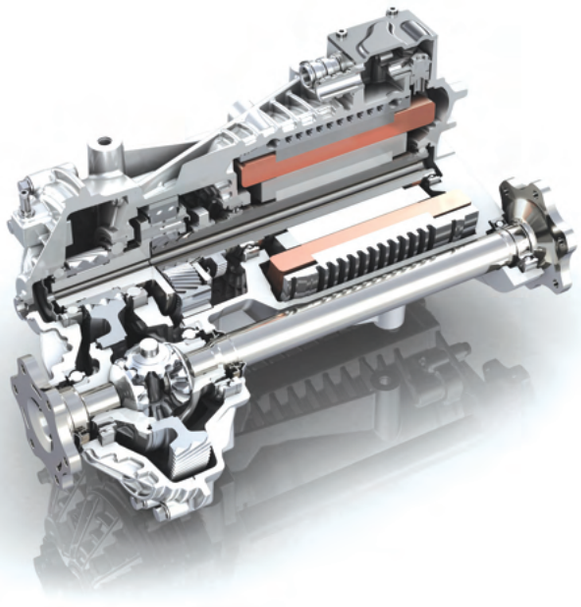


REINVENTING THE WHEEL

They've been around for quite some time now, but in-wheel motors have never quite got past the 'promising' stage. Is it time to give them a proper try?

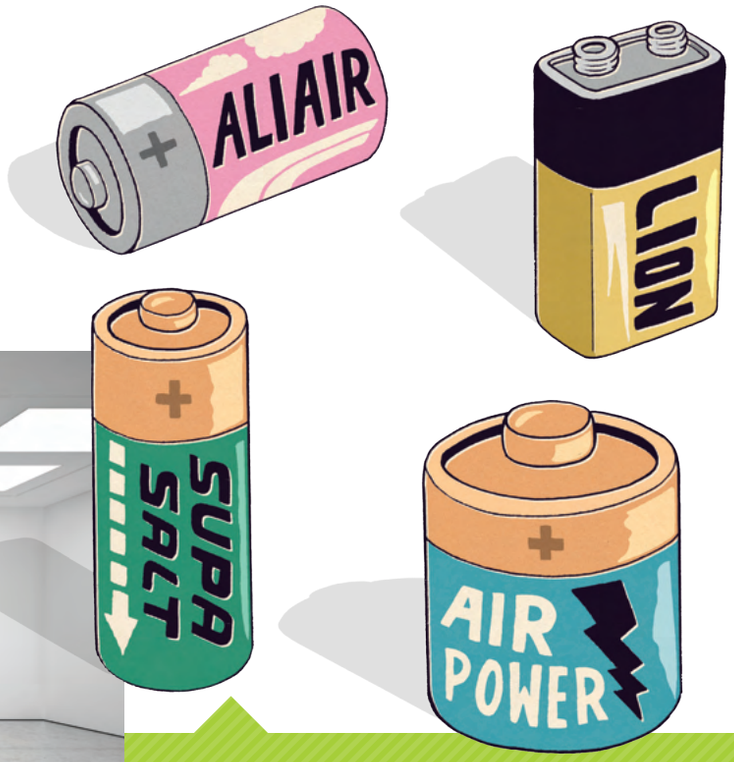
STUCK IN SECOND GEAR

It really is high time that all EVs ditched rudimentary 1- and 2-speed transmissions. Let's get more sophisticated shifters in next-gen developments, transforming these vehicles from eco-saviors that essentially move things (and people!) to cars that are still green, but also have a bit of sporty character and performance to them, too.



MAKE SOME NOISE!

For more than 100 years, the automotive world has continuously worked hard to create products that get hearts thumping and pulses racing, and along with powertrain performance, ride and handling, and beautiful design, nothing makes us stop what we're doing and look up at a passing car more than the sound that's coming out of the exhaust. Whether it's a burbling V12, a growling V8, a screeching V6, a spine-tingling five-cylinder, a screaming four, or those raspy two and threes, IC engines make noise we like. That's simply a fact.



BIG BATTERY BREAKTHROUGH

Whether it's lithium-ion, lithium-sulfur or even metal air or something entirely different, a momentous leap forward is needed in terms of battery technology, so that EVs can compete with their IC-engined cousins when it comes to range. In fact, we say that those driving the e-powertrain revolution should have a defined target: by 2020 BEVs should be able to travel on one charge the same distance (more or less) as a typical petrol/diesel powered vehicle that's just left the gas station.

FORMULA WON

Whether it's creating brand appeal that links the racetrack to the road, or pushing ahead with high-tech innovation, motorsport has always played an important role in the automotive industry and the continual evolution of the IC engine. In this same vein, EV makers need to support Formula E far more, or another motorsport that champions the e-powertrain's cause.

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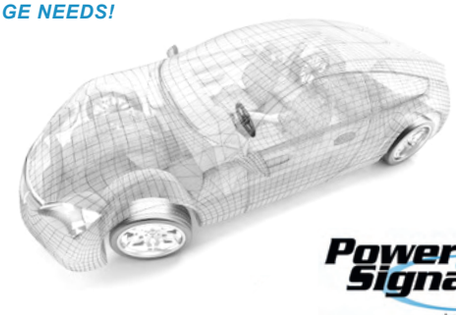

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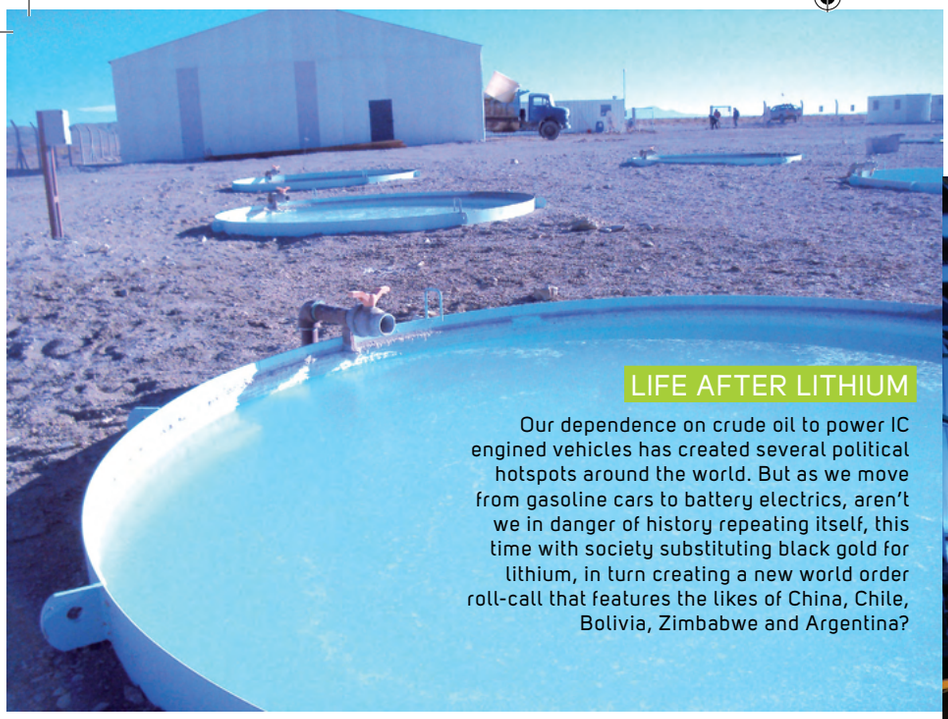
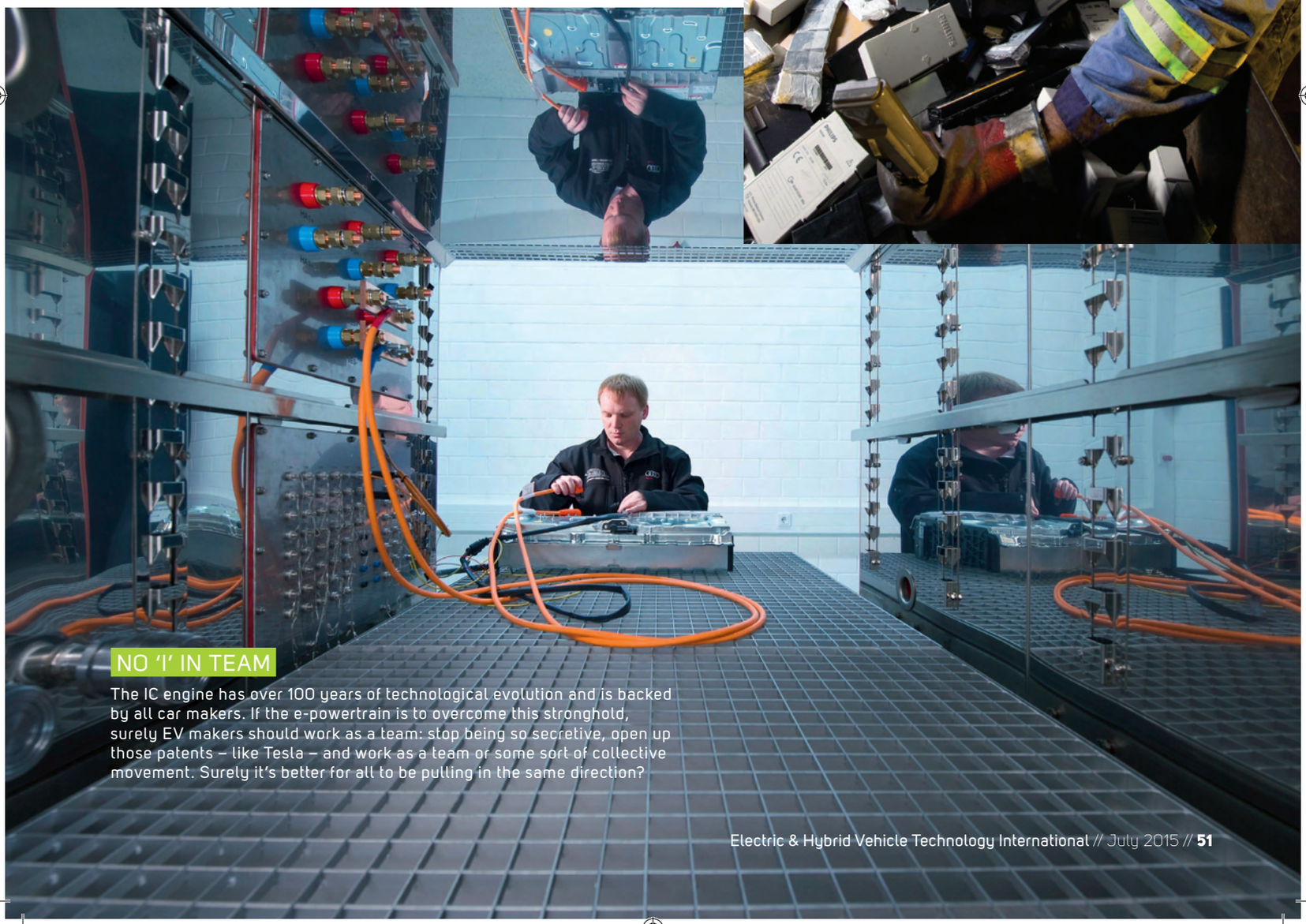


LIFE AFTER LITHIUM

Our dependence on crude oil to power IC engined vehicles has created several political hotspots around the world. But as we move from gasoline cars to battery electrics, aren't we in danger of history repeating itself, this time with society substituting black gold for lithium, in turn creating a new world order roll-call that features the likes of China, Chile, Bolivia, Zimbabwe and Argentina?

LIFE AFTER DEATH

As an industry, have we really thought about what we're going to do with all these batteries once they're dead? Landfill? Bottom of the ocean floor? Or is there a true sustainable recyclability strategy in place to deal with these packs, especially once EVs move from the niche and into the multimillion masses?



NO 'I' IN TEAM

The IC engine has over 100 years of technological evolution and is backed by all car makers. If the e-powertrain is to overcome this stronghold, surely EV makers should work as a team: stop being so secretive, open up those patents – like Tesla – and work as a team or some sort of collective movement. Surely it's better for all to be pulling in the same direction?

DIRTY GRIDS

There's no getting away from the fact that a dirty, coal-based grid equals a dirty EV. All that happens in this equation is that emissions (and pollution) are being moved from one stage to another (albeit less local and far later) stage – and don't those IC engine supporters know this. As such, an EV in, say, South Africa or Poland really doesn't do the job. So, for all your wonderful pioneering technology and R&D innovation in the labs, the automotive industry needs to lobby governments for them to clean up their acts too – an EV can only truly replace the IC engine as the dominant sustainable automotive propulsion technology if the entire picture is clean and green.

WATER THREAT

The IC engine has seen off many pretenders to the throne, so a word of warning for BEVs: not only does the e-powertrain have to overcome the IC motor somehow, it needs to do this while also keeping one eye on another technology that is growing in stature: hydrogen fuel cells.

LEARN FROM THE BEST

If the e-powertrain is to succeed the IC engine, then do it by learning from the best. The IC engine has continually reinvented itself, seeing off one technological challenge after another and overcoming catastrophe after catastrophe. Whether it's getting more power, downsizing, going further on less fuel, or emitting fewer emissions than ever before, the IC has not only seen and done it all, it has written the rule book. Those backing the e-powertrain will do well to acknowledge this and learn from it too. This is probably the single best way battery electric will smash through piston combustion.

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Back to the future

A trip through 20 years of electric and hybrid vehicle history

COMPILED: **MATT ROSS**

Over 20 years of *Electric & Hybrid Vehicle Technology International*, the magazine's writers and editors have spoken (and, on occasion, quarreled) with the industry's leading figures, gaining access to the most important people and projects in the world of vehicle electrification. As part of this special anniversary issue, we take a look back over some of *E&H*'s defining moments, revisiting a selection of the interviews, sneak peeks and predictions – some, with the benefit of hindsight, have proved to be less accurate than others – that have appeared in these pages since the first issue in 1995, providing a fascinating insight into how trends and attitudes have changed over the years, and following some of the landmark announcements to shape the industry.

1995

John Wallace, director of Ford USA's EV program, discussed the OEM's Ecostar testbed program, and how electric and hybrid vehicles fit into Ford's future plans.

"In general, the hybrid is a replacement for our current vehicle. It's not a new type of vehicle, really, in the sense that the customer perceives it as a new type of vehicle; it's just a different approach to the current vehicles that we drive... Ford certainly agrees that EVs are worthwhile. EVs have a role in the marketplace and Ford is putting a lot of energy and a lot of resources into developing these challenges. However, there are some pretty severe challenges."

1996

Chrysler's engineering head Bernard Robertson sat down with *E&H* to talk about the ESX concept car. Among several highlights of the fascinating interview was Robertson's thoughts on attitudes towards battery electric cars, and the OEM's priorities moving forward.

E&H: "Can I make a guess that Chrysler sees the battery electric car to be at best a very small niche? Maybe you're not really too worried about entering that race in a terribly serious way?"
Robertson: "Well the first part of that statement I agree with absolutely and I suppose maybe less enthusiastically with the second one! We're always going to be competitive and we're putting a lot of effort into battery cars, even though we don't think it necessarily makes a lot of sense. We're certainly not going to be dialed out of the market."

1996

Many years before the i8 had even been sketched out, BMW's head of drivetrain research, Siegfried Friedmann, gave his thoughts on the potential of parallel hybrids.

"We think that the parallel hybrid represents an interesting opportunity for improved fuel economy that we can achieve with the battery size reduced drastically; if we have a rather small surge power unit, which gives us access to transferring high power in and out of this storage device, then in combination with a high-efficiency combustion engine, there is the potential to reduce fuel economy and improve performance."

1997

During a 1997 article on the Audi Duo, project manager Marius Lehna was asked about what powertrains consumers would see in the future.

"I think we will have conventional vehicles, it doesn't matter whether they are diesel or gasoline. Some people don't like the diesel engine, they think it's still loud, ugly and has poor performance, but it's just not true. We will have diesel and gasoline ICEs for another 20-30 years, with reduced fuel consumption and better exhaust fumes. As well as these, two other systems will be developed: electric and hydrogen-powered vehicles."

1997

During an update on the release of the Ranger EV and development of the P2000 hybrid concept, John Wallace, Ford's director of alternative vehicles, gave a fascinatingly frank verdict on GM's EV1.

"Ford did not think it was advisable to launch a retail vehicle. We felt that the limited performance and high costs would be big issues for retail customers. GM took a different route. You've got a vehicle in the EV1 that has roughly a 65-mile cycle range – which is maybe 50 miles in customer usage – and is a fairly small two-seater with a price of US$33,000. I know they introduced it at a very low lease rate, but it was still an expensive vehicle. You have to ask yourself 'was that a good match for the customer?' and maybe the answer is 'no, it wasn't'."

"BMW intends to sell several thousand hydrogen-driven cars by 2010, with a possibility of half of its cars sold in 2020 having hydrogen engines. We are very happy with the hL's progress. The cars are mere prototypes and are not of a standard that a BMW customer would expect, but we are very happy. We plan to bring a product based on hydrogen technology to market within the next few years, even knowing that a complete infrastructure is not available. We took the first step despite the chicken and egg problem, as someone has to take the initiative. We are positive that many others will follow because hydrogen is the key technology for the coming decades."

2001

Ford's Tom Watson, manager, powertrain engineering, pondered what might be powering family sedans in 2010.

"Even though we're all pressing for hybrid electric vehicle technology to get into a lot of products, I'm a realist. I know that it will take at least 15-20 years for any new technology to become integrated into the market. The ICE has proven to be an extremely efficient way of converting energy into power, and of providing personal transportation in vehicles."

1999

Then editor Graham Johnson sat down with Bill Powers, vice president of research at Ford, who offered his thoughts on the longevity of some of the industry's early production hybrid vehicles.

"When you look at [the Honda Insight and Toyota Prius] hybrids, they are losing money. I don't think that either vehicle is the long-term, high-volume solution."

2000

A strong supporter of research into hydrogen power, BMW was vociferous in its support for developing the technology. In a 2000 article, Claus Pehr, head of hydrogen cars, had heady goals for the 750hL, the future of hydrogen, and the fuel's role in the OEM's future.

2003

E&H featured the Toyota CS&S – the brainchild of designer Roberto Falasca, a man who believed that hybrids should be desirable. It's a train of thought that has endured throughout issues of the magazine right up to today.

"'I just figured we should be doing an extreme hybrid car, a car that would make people see hybrids as something desirable rather than simply kind to the environment.' Here's a car that, in Falasca's words, 'dispels the belief that hybrids are boring'."

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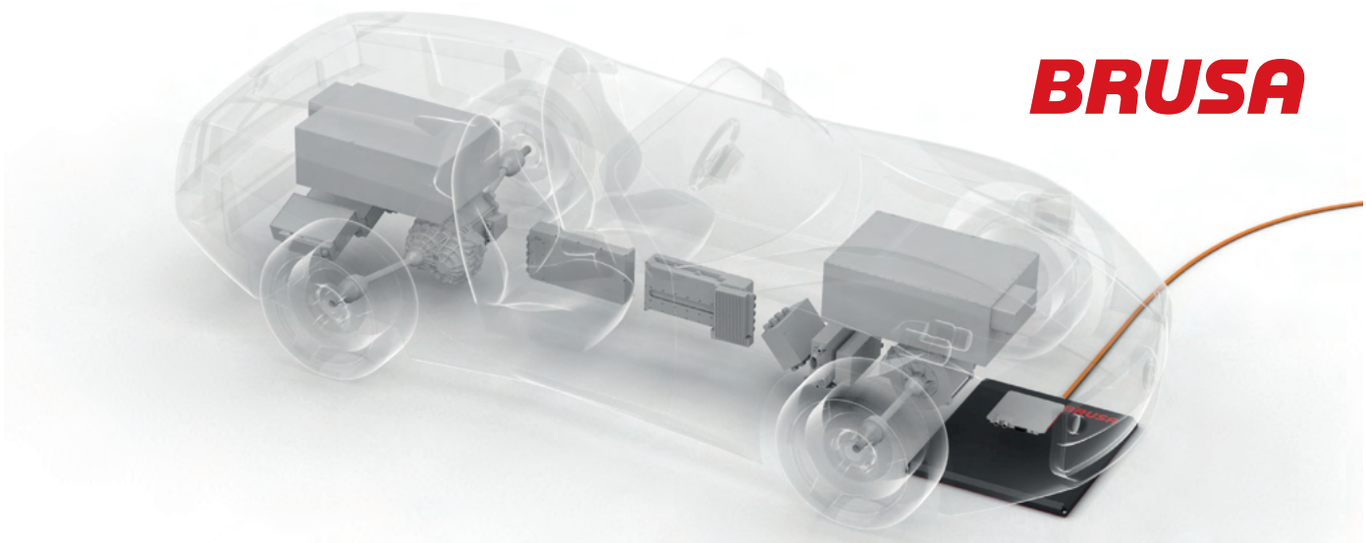

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2003

During an OEM interview with GM's Larry Burns, the vice president of research and development and planning opened with a rather staggering proclamation.

"We'll be selling one million fuel cell vehicles at a profit within the decade. As I sit here, knowing that we have technical and commercial proof of concept by 2010, I know we can deliver a fuel cell vehicle by 2010. The next question is, can you go from that validation to building and selling one million profitably? The answer is you can do that pretty quickly!"

2005

After a visit to the Frankfurt Motor Show, columnist Matt Davis surmised that the hydrogen bubble may have burst.

"Over the past six or seven years, we have hypothesized over hydrogen, and wondered just how much more money BMW was willing to pump into its CleanEnergy effort in order to finally beat the Japanese to a dominant marketing position. Great minds were giving 10- and 20-year pronouncements in response to the fossilized question about the timetable for a viable hydrogen infrastructure. Sorry BMW, but a world driven by hydrogen is on the back burner for the next long while."

2004

As part of a feature looking at aspiring young vehicle designers, *E&H* showcased a design for the London Routemaster Bus of 2015 – featuring a diesel hybrid powertrain and regenerative braking. More than a decade later and the latest Routemaster bears a striking resemblance – powered by a diesel hybrid powertrain and regenerative braking.

2004

In the year when Toyota's Prius was named the International Engine of the Year, editor-turned-columnist Graham Johnson had some advice for car makers.

"Wise up. If you want a hybrid success on your hands, there is only one option: create a bespoke car that doesn't match the refinement, practicality, and driveability of your standard fodder – it's got to better it in every way. And make sure it looks like a hybrid, i.e. different. In other words, make a Prius."

2005

An examination of clean technology in motorsport pondered an interesting question – would F1 ever play a role in green powertrains? Seems the developers of Formula E were paying close attention.

"Many see it as motorsport's highest technology echelon, but others would question the environmental credentials of an ultra-lightweight V10 that revs to 19,000rpm. Is there any possibility that F1 could take the central role on a clean motorsport agenda? 'I think that one day we will eventually come to clean motorsport,' believes Axel Plasse, engine project manager for Renault's double championship-winning RS25 V10. 'I clearly believe that only the FIA will ask for, and drive, this kind of change,' he continues. 'F1 fuel is now about the same as that in normal road cars – a big step forward from the early 1990s. As for a hybrid F1 car? Maybe – in 2015!'"

2007

E&H took a peek at Tesla's Roadster in 2007, getting to the bottom of why the emerging car maker thought it could take on the big boys.

"Martin Eberhard, CEO of Tesla Motors, knows why electric vehicles in the 1990s, such as General Motor's EV1 and the Toyota RAV4, failed: 'They weren't exciting vehicles,' says the former electrical engineer, who designed the Rocket eBook digital book reader. 'They were built to meet the zero-emissions mandate. From my perspective, there's a better place to enter the market.'"

2008

As many of the more optimistic timetables regarding widespread implementation of fuel cell vehicles continued to give way to more pragmatic expectations, *E&H* examined why the following few years could prove decisive.

"'When we look forward I believe we'll see a world where, absolutely, fuel cells will be successful,' states Noordin Nanji, chief customer officer, Ballard. 'But I don't see a world where it's only fuel cells. For the next few decades we'll see multiple solutions because it's going to depend on different geographies and different contexts as to what makes the most sense.'"

With a top speed of 130km/h, a zero to 100km/h time of four seconds and a price tag of over US$100,000, could this be the ultimate EV?

Tesla Roadster

Martin Eberhard, CEO of Tesla Motors, knows why electric vehicles in the 1990s, such as General Motor's EV1 and the Toyota RAV4, failed: 'They weren't exciting vehicles,' says the former electrical engineer who designed the Rocket eBook digital book reader. 'They were built to meet the zero-emissions mandate. From my perspective, there's a better place to enter the market.'

The major auto makers were forced to design, manufacture and market EVs at a time when full-size SUVs were profitable cash cows and consumers barely noticed gas prices. They were such a low priority that the standing joke at

2009

Before the idea of eco-supercars was in vogue, *E&H* contributor Keith Read looked at why high-performance car makers were going green.

"Green and environmentally friendly supercars, surely a contradiction in terms, an oxymoron of the first order? Well, don't you believe it: makers of some of the most awesome automotive products in the world are working hard to ensure that future supercars pay more than just lip service to the environment and to the world's ecology."

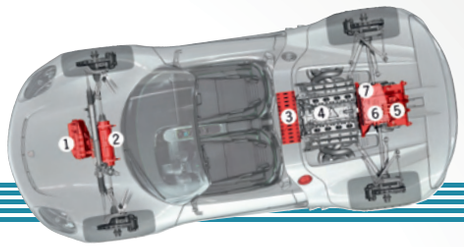
2010

As the magazine continued to hunt down the inside track on the industry's most exciting new projects and technologies, *E&H* shed some light on the details of Porsche's super-secret 918 Spyder.

"The concept was such a secret that nobody outside Porsche knew of the 918 Spyder until it was revealed, and only 100 people were in the loop within the Porsche's racing and production prototypes departments at the Weissach technical center."

2010

It may look familiar nowadays, but a rather striking BMW concept graced the pages of *E&H* back in 2010.



2013

It seems strange to look back on the early days of a brand now so firmly entrenched in the EV industry, but in 2013 *E&H* traveled to California to find out more about that issue's cover star – the Tesla Model S.

"The Tesla Model S all-electric sedan is the quickest sedan ever built in the USA, taking just 3.9 seconds to race from standstill to 100km/h. Blink, and you'll miss it. But that's not all: with the potential to cover 265 miles, this truly remarkable vehicle also takes the crown for being the clear leader in the EPA-rated driving range. But here's the thing: all this comes from a product that tips the scales at a hefty 2,180kg. How is this possible? Well, simply put, it's because this is the first electric sedan conceived in Silicon Valley, by a cadre of geniuses."

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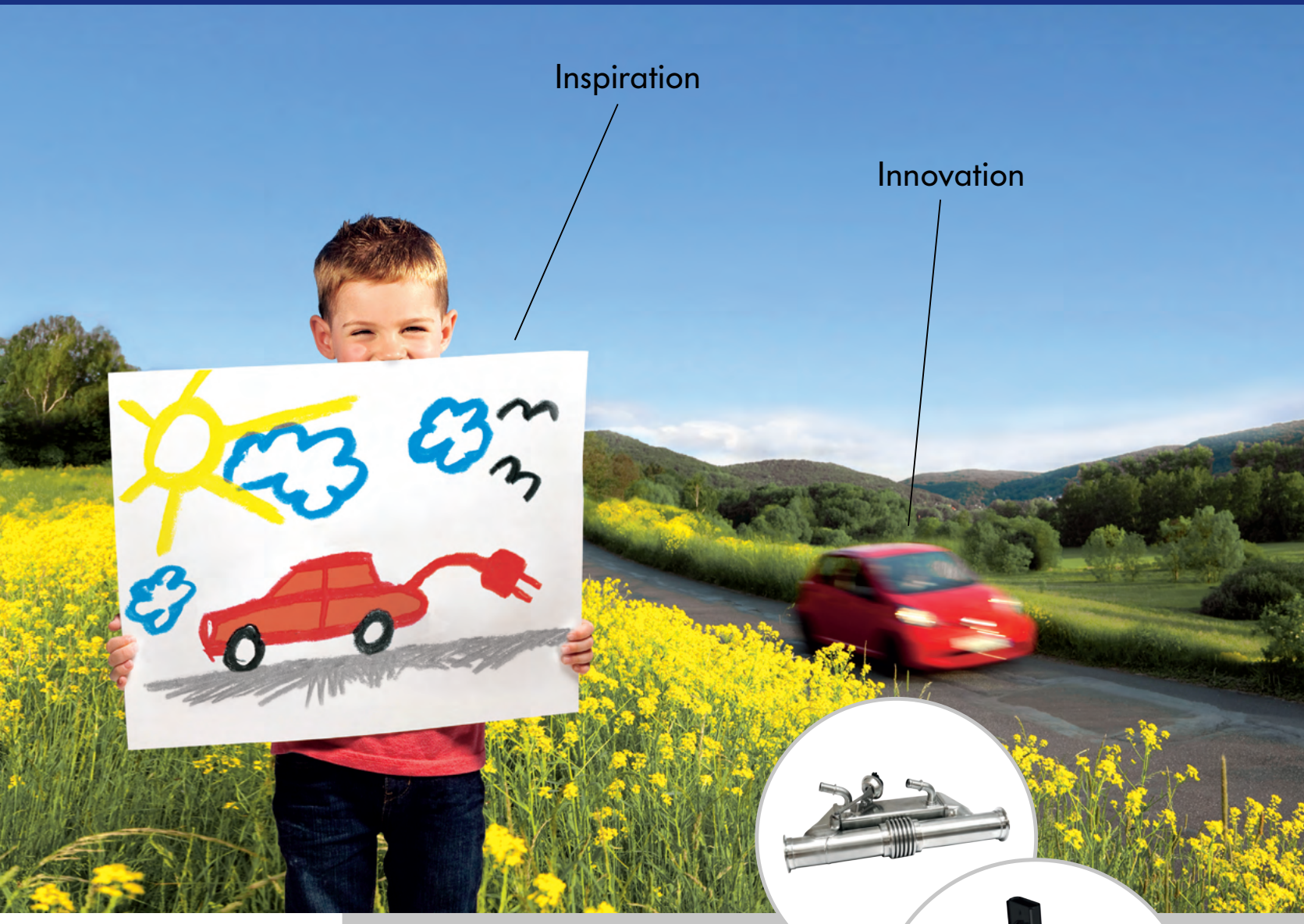

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Flash forward

"Forget 2035; within five years fully autonomous vehicles will be manufactured by OEMs and owned by ride-sharing services"

Paul Scott, founding board member, Plug In America

20 ANNIVERSARY ISSUE

WORDS: **FARAH ALKHALISI AND JOHN THORNTON**

To mark the 20th anniversary of *E&H*, we decided to look forward 20 years – and specifically, what will the electric vehicle scene look like in 2035? What kinds of technology will be in common usage, how will the infrastructure have developed, and what else will have changed? We asked 25 experts from a variety of sectors, businesses and backgrounds to comment, including leading OEMs and Tier 1 suppliers, service and technology providers, pressure groups, think-tanks and industry consultancies.

As you'll know from reading the past reflections feature on page 54, making accurate predictions in this rapidly changing world is not simple. In 2015, opinion is divided as to whether electrically propelled vehicles will predominate by 2035, or remain a niche-specific option. However, one clear theme has emerged: simply considering vehicles in isolation is shortsighted and the wider concept of electromobility must be embraced by all. This encompasses the associated powertrain technologies, related services, potential convergence with other sectors such as the energy supply chain and, most importantly, user behavior and what may be very different ways of accessing a car to travel in.

DIRK ABENDROTH

SYSTEM INTEGRATION MANAGER, POWERTRAIN, BMW I

My personal opinion is that, in the end, everything will end up being electric. I don't think hydrogen combustion engines will come true, so for me, it's a question of if they have a hybrid between hydrogen and electric in a fuel cell combination. But in this kind of timeframe, I think electric cars will take over for the majority of powertrains. I think hydrogen is a good storage for energy, but if it goes to power, you need something in-between and that something might be electricity that fills that gap. That combination is powerful. So, if you think about hydrogen in a fuel cell, which gives you continuous energy, you need some power storage in-between.

"In the end, everything will end up being electric. I don't think hydrogen combustion engines will come true"

GERALD KILLMANN

VICE PRESIDENT OF R&D, TOYOTA MOTOR EUROPE

Several technologies will coexist because they each excel in one particular area. EVs are perfect for last-mile mobility, or for relatively short preset routes. Used like that, the battery size, weight and cost can be kept limited, and the user doesn't need to worry about range. Hybrid and plug-in hybrids will continue to grow in importance as they reduce our dependence on oil, and in the case of plug-in hybrids not be limited in range, yet improve local air quality when driven electrically in city centers. Fuel cells will definitely have an important role to play, since they offer a normal range and quick refueling, yet don't pollute. Of course, for electric and fuel cell technology to take off, investments in infrastructure will be required – that is a step that society will need to take.

KOERT GROENEVELD

HEAD OF RESEARCH, DEVELOPMENT AND ENVIRONMENTAL STRATEGY, MERCEDES-BENZ

We don't see one single technology as a silver bullet for future sustainable mobility. Our approach is an intelligent, made to measure blend of drive concepts to suit all needs – from optimized combustion engines to various types of hybrids, plug-in hybrids and electric drives powered by batteries or fuel cells. And future mobility goes far beyond the automobile itself. Modern information and communication technologies play an important role; the areas of smart cars, smart grid and smart traffic, or even car sharing, are in focus. Also, more and more advanced autonomous driving will open up a whole host of new possibilities.

KARL-JOSEF KUHN

HEAD OF CORPORATE TECHNOLOGY, NEW TECHNOLOGY AND INNOVATION FIELDS, PROJEKT RACE, SIEMENS

In recent years, many countries have achieved some progress in reducing greenhouse gases, but in terms of different industry areas, the mobility sector – in which road traffic stands for the biggest subsector – contributed least. Electromobility is the best-suited instrument for implementing a path toward a remarkable CO_2 reduction in road traffic; and besides this, electromobility reduces respirable dust and noise, and will lead to improved quality of life in urban areas.

RICHARD FARQUHAR

HEAD OF POWERTRAIN, MCLAREN AUTOMOTIVE

You have to consider the context of where it's all going. If you look at the revolution that we're headed into of the connected car and hydridized to electrified powertrains, then by 2035 that world would have defined what the powertrain needs to be. So it won't be what we have today, it'll evolve from that and maybe even beyond fuel cells. Connectivity is a must and must be embraced as is electrified powertrains, which can also form part of connectivity.

"More and more advanced autonomous driving will open up a whole host of new possibilities"

MATT JOHNSTON

VICE PRESIDENT, BUSINESS DEVELOPMENT, DRS TECHNOLOGIES

I firmly expect HEVs to have been widely adopted in both consumer and commercial applications by 2035. I would also expect that energy storage and power electronics would have shown the most dramatic advancements in both performance and cost/value. I sincerely hope to see us making great strides toward power parity from a regeneration perspective; it just makes too much sense not to do so. The idea of multipurpose use of the vehicle related to energy storage and power potential would have come into its own both in V2G and exportable power.

ALLAN PATERSON

CHIEF ELECTROCHEMIST, JOHNSON MATTHEY BATTERY SYSTEMS

There continues to be a large investment globally in the development of next-generation, high-performance energy storage materials. In the longer term, the more attractive battery systems, although currently only in early development stages, may one day be based on lithium sulfur, or non-lithium systems based on sodium or multivalent magnesium, or in the even longer-term, based on rechargeable metal-air batteries.

MIKE BASSETT

HEAD OF HYBRID PRODUCT GROUP, MAHLE POWERTRAIN

The IC engine will still dominate as the prime propulsion source for the mass market – 0.6-0.8 liter, turbocharged, two-cylinder designs – but city cars and luxury vehicles will increasingly be plug-in hybrids or full electric vehicles. In this 20-year timeframe, I think 48V mild hybrid systems are likely to be dominant. I believe the biggest transformations will come about from the areas of autonomous driving and automated parking of vehicles. When you reach your destination, your car will drop you at the door and then drive itself to a parking slot, which it had pre-booked when you entered your destination.

DOUG CROSS

CTO, FLYBRID

By 2035, decarbonized fuels (using renewable energy to make synthetic liquid fuel at the source, rather than transporting electricity) will have made significant progress, keeping IC engines on the road, but this is not the only fix to CO_2 emissions. Auto makers will continue to be under pressure to improve fuel economy in order to meet legislative targets, while market pressures will simultaneously drive the technical solutions to be low-cost and fun to drive.

BART MANCINI

SENIOR PRINCIPAL ENGINEER FOR HYBRIDRIVE SOLUTIONS, BAE SYSTEMS

In 20 years' time, expect modest growth in HEV market share, with EVs perhaps attaining a 10-15% share. Mass EV implementation will likely be hindered by available electric infrastructure and costs thereof. Economics will still rule the day, so one could expect to see higher levels of conventional propulsion bus electrification with electrified accessories and/or microhybrid technology. Overall, though, HEV/EV technology will largely remain as it is today, with substantial but evolutionary improvements in system integration and component efficiency, energy density and the cost continuing to make EV/HEV increasingly more viable and mainstream.

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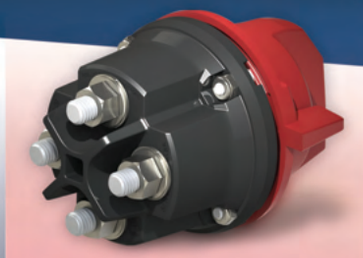

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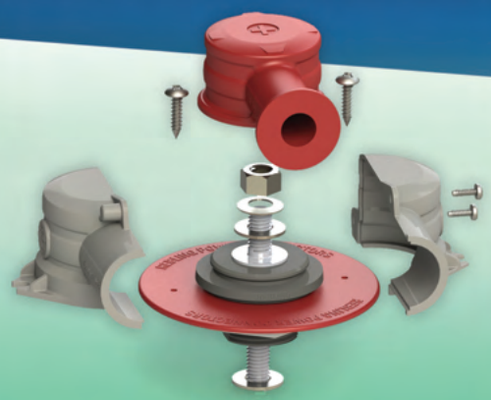

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GAETAN DAMBLANC

BATTERY APPLICATION TECHNOLOGY SPECIALIST, CD-ADAPCO

In 2035, EVs can be expected to dominate the market thanks to the development of long-life, low-cost batteries. With expected improvements in lithium-ion chemistry, the calendar life of batteries will be extended to decades. Battery production in giga-factories will serve to lower costs to the point where battery-powered vehicles will successfully compete against vehicles with IC engines. Fast-charging stations will be globally prevalent, and city centers will become much less noisy and polluted, with fast and smooth flowing traffic, thanks to the parallel development of autonomous driving. The availability of low-cost batteries will also make solar power stations more effective and widespread, to the point where most electricity generation in 2035 could originate from solar panels.

"Fast-charging stations will be globally prevalent, and city centers will become much less noisy and polluted"

PHILIP MARKS

DIRECTOR, GLOBAL PRODUCT ENGINEERING, FEDERAL-MOGUL POWERTRAIN

HEV powertrains will continue to lead the way, helped by the increasing efficiency of IC engines, toward a 15% share of the worldwide light vehicle market. There will also be an increase of EV/PEV, NGV and fuel cell/hydrogen powertrains, which could account for 2% of worldwide vehicle production. This will, to a large extent, be determined by the development of a viable recharging/refueling infrastructure to support users choosing these technologies. Whatever the outcome, there will be wider use of high-voltage cabling in vehicles, which will necessitate greater reliance on lightweight EMI shielding and crash protection.

CLAIRE CLEUZIOU

PROJECT MANAGER, BMW I

Although it's hard to anticipate what will be around in two decades' time, we can already identify two major development fields in e-mobility. In the first instance, electric driving will be about connectivity. This process has started with the search for a free charging spot, planning an intermodal route, or integrating an EV into a smart home. A lot of car functions will be automated, and vehicles will communicate with other cars and with the infrastructure, making trips much more efficient and safe. Secondly, we also expect battery density to multiply, which will make long ranges for lightweight EVs possible.

NEVILLE JACKSON

CHIEF TECHNOLOGY AND INNOVATION OFFICER, RICARDO

Existing OEMs are likely to converge toward becoming mobility providers, incorporating ICT systems that provide on-demand usage. In general, by 2035 electric propulsion should be making major inroads into the passenger car market. It will not displace the IC engine for longer-distance or high power requirements, but the ICT revolution will provide a solution to the range utility/range anxiety issues faced today. From a technology perspective, I'm sure we'll have better energy storage technologies than today's, but I don't see any revolutionary steps, just incremental ones. Maybe two or three times better than today, but insufficient to be used in long-distance or heavy-duty applications.

JÜRGEN POGGEL

HEAD OF ENGINE DEVELOPMENT, BMW M

In my opinion, we'll see the best of both worlds, so a combination of different engines and powertrains. We need to get a lot of speed in our cars so we need a lot of energy. That said, I don't think it'll be a 3-liter six-cylinder engine that we're using in this future timeframe. A smaller engine [like the 1.5-liter three-cylinder plug-in powertrain in i8] is the right direction.

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MARK-ALLMAN WARD

SENIOR APPLICATION SPECIALIST, BRÜEL & KJAER

In 2035, our ears will still inform us of approaching vehicles, but with more autonomous and quiet vehicles we will inhabit a different soundscape, complete with electronic warning sounds. Design of these will differentiate vehicles from one another, promoting their brand. Inside cars, as we gradually forget about engine sounds, we will become used to sound dominated by wind and road noise. These will be continually minimized through refined efforts, and as designs are optimized for efficiency and lower road and wind noise. Combined with selectable driving modes, vehicle sound styling could become commonplace, where people download a vehicle sound onto the entertainment system to go alongside the music or movies they experience while driving, or being driven.

ANJAN HEMANTH KUMAR

POWERTRAIN AND EV PROGRAM MANAGER, AUTOMOTIVE AND TRANSPORTATION, FROST & SULLIVAN

In 20 years' time, alternative powertrains are expected to account for 60% of new car sales, with battery electric and fuel cell vehicles penetrating roughly 40% of the market. Cars will be designed to navigate around and within the crowded metropolises, prompting the consumer to possibly use multimodal transportation. Cars will also be designed around personal tastes. Toyota has made a step in this direction with its three-wheeled i-Road, by custom 3D-printing body parts. By 2035, we should also witness self-driven autonomous vehicles in cities. Semi-automated cars can already be driven today, laying a strong foundation for a highly automated car in the near future.

PAUL SCOTT

FOUNDING BOARD MEMBER, PLUG IN AMERICA

The future of electromobility is autonomous door-to-door service at a price point per mile driven. Forget 2035; within five years fully autonomous vehicles will be manufactured by OEMs and owned by ride-sharing services such as Uber and Lyft. The savings to society will be enormous, since all of these cars will be powered by renewable electricity. The number of cars on the road will drop by at least 80%, since one autonomous car can replace 10-20 privately owned cars. Crashes will be virtually eliminated. Hundreds of billions in medical costs and repairs will be saved. Parking lots could be used for parks, gardens, or uses other than just storing cars.

> "The number of cars on the road will drop by at least 80%, since one autonomous car can replace 10-20 privately owned cars"

ROLF BULANDER

CHAIRMAN OF MOBILITY SOLUTIONS, BUSINESS SECTOR, BOSCH

While the IC engine will remain the basis for efficient mobility, anyone taking a look under the hood is likely to find much more than a conventional gasoline unit. By 2020, batteries will offer twice the energy density for half the present cost; by then, some three million charge spots will have been installed around the world – 10 times as many as in 2013. This gives the market ample room for growth in the next decade. In 2025, around 15% of all new vehicles built worldwide will have at least a hybrid powertrain, while in Europe more than one-third of all new cars will be at least partly electrically powered.

ANDERS KOLSTRUP

TECHNICAL DIRECTOR, ROTREX

When Tesla released its EV, it totally changed the industry. Now, a lot of conventional manufacturers, like BMW, are trying to do the same. I think it'll become increasingly expensive to produce cars that aren't fully electric – where everything is built around old technology. It'll be cheaper to start with a clean piece of paper, like Tesla did. But really, it comes down to the type of energy that will be supplied. With nuclear power, it'll be possible to have all the energy in the world, in a clean way. I can't understand the opposition to nuclear plants because a nuclear plant built today is more efficient and absolutely safe compared with a lot of other technologies. So, depending on people's attitudes, nuclear power could have a huge influence on the future direction of the automotive industry.

PHILIPP MATT

DEPUTY GENERAL MANAGER, BRUSA ELEKTRONIK

We are convinced that every vehicle will utilize some form of electric drive. One important condition for electrification is the exciting breakthroughs in battery technology, enabling long ranges and cost parity. As a direct result of the change in battery technology, the total cost of ownership of an electric car will be lower than a conventional vehicle. Wireless charging will replace cable charging and the source of energy will switch from fossil to regenerative fuel.

JAMES BATCHELOR

MANAGING DIRECTOR, MOTIVE DIVISION, INTELLIGENT ENERGY

The scale of change by 2035 will be huge. The powertrain spectrum will become more fragmented, with vehicle buyers choosing the technology that best suits their lives. The IC engine will still be with us, but with hydrogen refueling becoming more widely available, the argument for FCEVs – by then already well established in captive fleets and gaining market share as true personal transport – will be even more compelling. With a familiar ownership experience in respect of driving range and refueling times, they are/will be the intelligent choice – although whether users will be at the wheel or in the passenger seat is another discussion.

CARSTEN WEBER

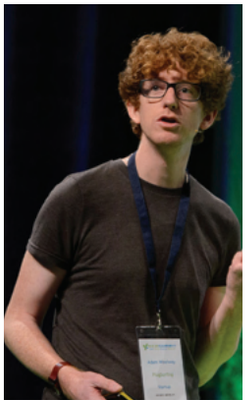
MANAGER, POWERTRAIN RESEARCH AND ADVANCED ENGINEERING EUROPE, FORD

Everyone is excited about alternatives, but they're not paying enough attention to what is closest to us. I think that, in the end, the combustion engine will be the main, dominant energy source for any kind of vehicle for the next 30 to 40 years. Potentially, this could be in combination with something else, but in the end, the predominant source of energy to move a vehicle will be a combustion engine – whatever we are burning. It's not necessarily true that we will still be using the fossilized stuff; there are other, very interesting things that are under consideration and these are working quite nicely.

"Just as consumers of music now stream rather than buy, consumers of mobility will share and subscribe to mobility concepts"

ADAM WOOLWAY

CEO AND CO-FOUNDER, PLUGSURFING



We will see a trend toward mobility providers being service providers, rather than simply manufacturers. Cars will have fewer moving parts, will become cleaner and more automated, and importantly the relationship between the OEM and the driver will need to be more involved and sustained. Just as consumers of music now stream rather than buy, consumers of mobility will share and subscribe to mobility concepts, as well as consume and produce energy, using flat-rate tariffs and cloud-based services.

JOS DINGS

DIRECTOR, TRANSPORT & ENVIRONMENT

Shared and electrified is our vision. Whether for an e-bike, train or car, green electricity is the energy of the future. The mobile IT revolution will make vehicle ownership an old-fashioned waste of resources. Electrification and shared vehicles are made for each other – electric vehicles are quite expensive to buy, but cheap to use, so the more they are shared, the more sense they make. But all this will not happen by itself: investment and change only comes with political dedication, for example further stretching EU-wide CO_2 standards for cars.

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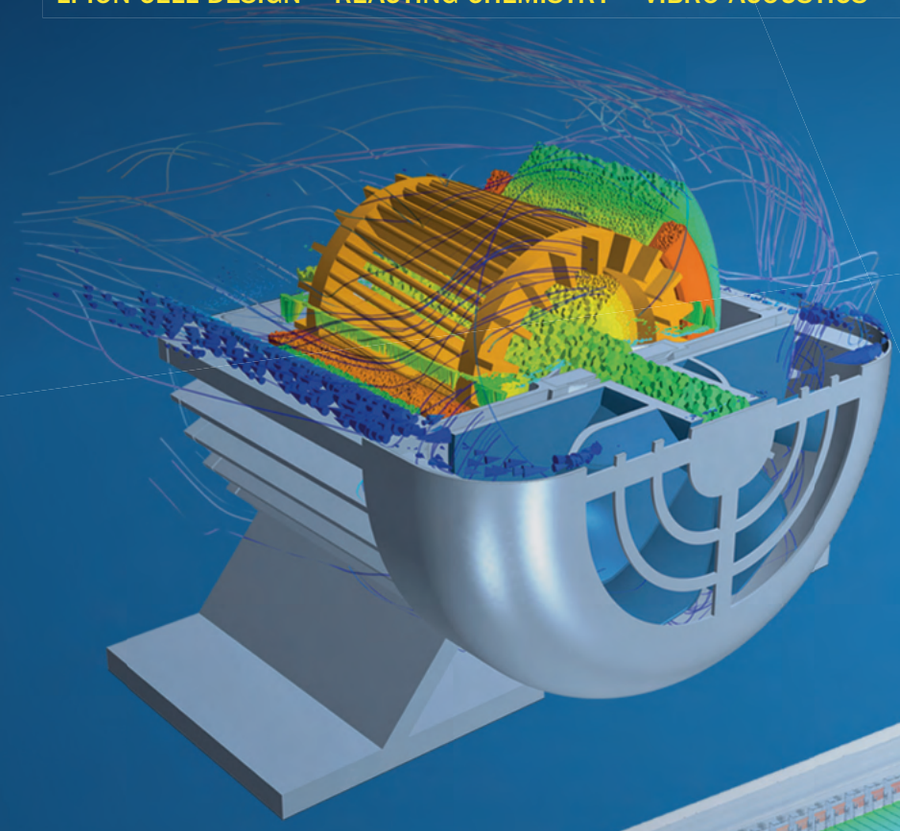

FLOW, THERMAL &
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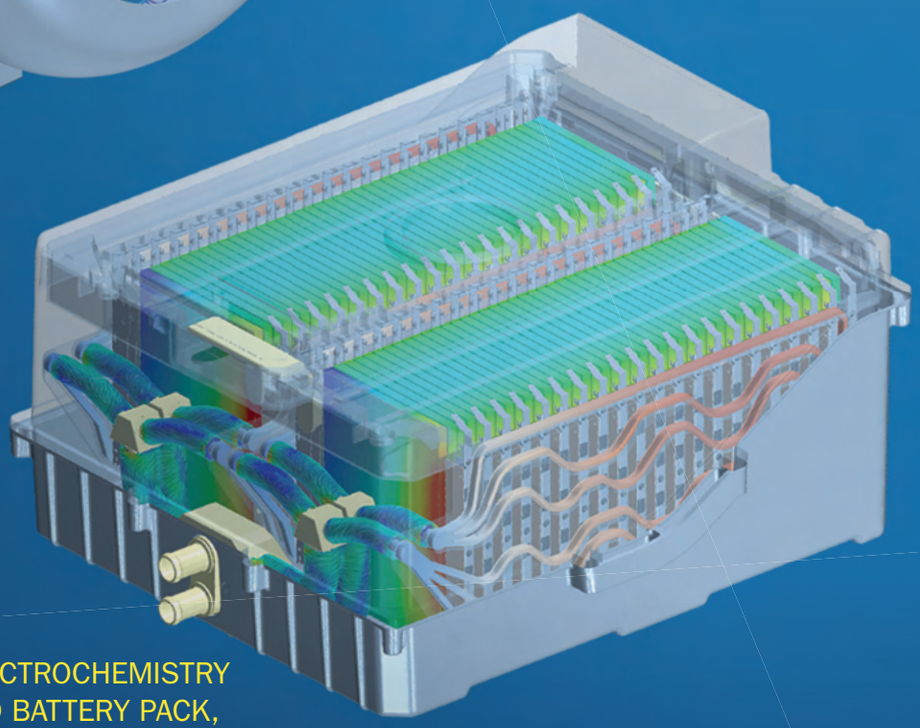

FLOW, THERMAL & ELECTROCHEMISTRY
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Water babies

WORDS: **PHILIP BORGE**

It's been a long and challenging road for hydrogen fuel cells, as the technology over the decades has attempted to transition away from the R&D labs of OEMs and their tech demonstrator prototype vehicles, and into production cars that can land safely and soundly in the hands of the public.

Concerns surrounding safety – mainly storing hydrogen onboard a vehicle – have for so long been a constant pain for the FCEV. So too has the technology's bulky, weighty dimensions, its inability to start in certain cold conditions, and the use of some expensive materials – not least platinum. And to top it all is the chicken-and-egg scenario of refueling infrastructure.

With all these hurdles in mind, it seems less surprising that even though the first automotive application of a hydrogen fuel cell can be traced back to 1966, half a century later cars that emit nothing but water vapor from their tailpipes still haven't made it to mass production and adoption.

But now the cavalry – the industry's great green hope – is finally on its way. Those struggles with safety, weight, cold-start design, materials and cost have all been (nearly) overcome, and thanks to a multi-governmental drive, even the infrastructure is developing, albeit slowly. In the next three years, mass-market FCEVs from no fewer than six car makers are scheduled for launch and that's just the start. So here's what we know so far about these all-important water babies.

TOYOTA MIRAI VITAL STATISTICS

Type: Polymer electrolyte fuel cell
Volume power density: 3.1kW/l
Maximum output: 114kW
Humidification system: Internal circulation (humidifier-less)
Tanks: Two high-pressure hydrogen tanks
Nominal working pressure: 700 bar
Tank storage density: 5.7wt%
Tank internal volume: 122.4 liters (front tank: 60 liters; rear tank: 62.4 liters)
Motor type: AC synchronous electric generator
Maximum torque: 335Nm
Battery type: Nickel-metal hydride

1. TOYOTA MIRAI

In a development that will surprise nobody, it's Toyota that will be one of the first – if not the first (although Hyundai might have something to say about that) – to launch a hydrogen fuel cell vehicle to the mass market.

Called Mirai, the Japanese FCEV went on sale in its home market at the end of 2014 and will be introduced in Europe by the third quarter of this year.

Having pioneered hybrid technology in the 1990s, Gerald Killman, Toyota Europe's powertrain head, says lessons learned during the company's Hybrid Synergy Drive program have shaped and influenced its fuel cell activities.

The Mirai uses a Toyota Fuel Cell System (TFCS) that features both fuel cell and hybrid technology, and includes the car maker's new proprietary FC stack, FC booster converter and high-pressure hydrogen tanks. The result, says Killman, is a driving range on a par with conventional IC engine vehicles and a refueling time of around three minutes, in one swoop overcoming two major issues that have so far plagued battery electric vehicles. Mirai's stack achieves a maximum output of 114kW; electricity generation efficiency has been enhanced through the use of 3D fine-mesh flow channels – a world first – that ensures uniform generation of electricity on cell surfaces, providing compact size and a high level of performance, as well as a power output density of 3.1kW/l, some 2.2 times higher than that of the previous Toyota FCHV-adv limited-lease model.

The compact, high-efficiency, high-capacity converter has been developed to boost power generated in the stack to 650V. Increasing the voltage has made it possible to reduce the size of the electric motor and the number of cells in the stack, leading to a smaller but higher-performance fuel cell system that's cheaper to produce.

Finally, the tanks employ a clever three-layer structure made of CFPR in addition to other materials to store the hydrogen at a high pressure of 700 bar. Compared with the high-pressure hydrogen tanks used in the Toyota FCHV-adv, tank storage has been increased by 20%, while both weight and size have been reduced.

The development program of the Toyota Mirai was shaped by lessons learned during the company's Hybrid Synergy Drive technology journey. The FCEV went on sale in Japan in 2014 and will be introduced in Europe and the USA later this year

DID YOU KNOW...

As part of efforts to further push fuel cell technology ahead on an industry level, Toyota is allowing royalty-free use of its 5,680 FCV-related patent licenses, including pending applications. Tesla, eat your heart out...

DID YOU KNOW...

In 2003 the Honda FCX became the first fuel cell vehicle to start and operate in sub-freezing temperatures

The FCV debuts a new Honda designed and developed fuel cell stack that's 33% smaller than its predecessor, but is capable of an output of more than 100kW. This means the FCV has some 60% better performance over previous Honda fuel cell vehicles

2. HONDA FCV

Although officially still a concept, the word on the street is that the production Honda FCV will not stray too far from this show car that made its first public appearance in Tokyo last year.

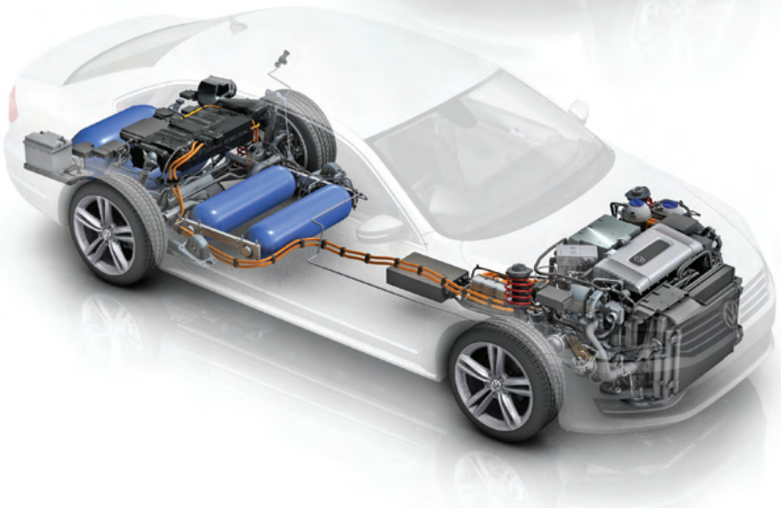
Building on Honda's experience with the FCX and FCX Clarity projects, the FCV is a preview to an all-new fuel cell road car due to go on sale in Japan in the first half of 2016, and then after in the USA and Europe within a 12-month timeframe.

What do we know about the technology underpinning the FCV? It will debut a newly developed fuel cell stack that's 33% smaller than its predecessor, but is capable of realizing an output of more than 100kW and an output density as high as 3.1kW/l. This, claims Honda, contributes to an overall performance improvement of 60% compared with the other two Honda FCEVs.

Some clever packaging from the Japanese OEM means that the fuel cell powertrain slots completely within the front engine compartment of the vehicle, allowing for efficiencies in cabin space as well as flexibility in the potential application of fuel cell technology to multiple vehicle models in the future.

This five-seater vehicle is equipped with a 700 bar high-pressure hydrogen storage tank that provides a cruising range of more than 700km (435 miles). Like the Toyota, the tank can be refilled in around three minutes.

The Golf HyMotion (right) and the Passat HyMotion (below) showcase VW's very serious intentions about developing and launching a fuel cell vehicle. Based on the company's acclaimed MQB architecture, the Golf and Passat's drive components are located at the front end with the lithium-ion battery situated directly over the rear axle



3. VOLKSWAGEN GOLF SPORTWAGEN HYMOTION

While it is yet another concept, this one showcases VW's expertise in the FCEV field, as Europe's largest OEM readies itself to launch its very own fuel cell creation.

Developed in-house and on VW's venerable MQB architecture, the design of the Golf SportWagen HyMotion sees all drive components housed at the front of the tech demonstrator, with the lithium-ion battery situated directly over the rear axle. The fuel cell drive system and battery unit combined allow for total system power of 100kW.

HyMotion's electric motor, which has been adapted from the e-Golf, and the coaxial two-stage 1-speed transmission are joined in the front engine compartment with a low temperature PEM fuel cell stack, cooling system, and a tri-port converter that regulates the voltage between the e-motor, fuel cell, battery and turbo-compressor. Power electronics, located in the area of the center tunnel, converts the direct current into three-phase alternating current, which is then used to drive the motor.

Hydrogen in the tanks is stored at 700 bar, with two of the four carbon-fiber composite tanks located under the rear bench seat and the other two in the luggage compartment floor.

What this all means is that the front wheel drive Golf SportWagen HyMotion accelerates to 100km/h (62mph) in 10 seconds, but perhaps more noteworthy is that a driving range of 498km (310 miles) is possible. Refilling, again, takes just three magic minutes.

DID YOU KNOW...

Thanks to the use of MQB architecture, the current Golf has become the world's first vehicle model series that can host all conceivable drive types, boasting gasoline engines, diesel motors, a natural gas drive, a battery electric offering and a plug-in hybrid powertrain. How long until the hydrogen fuel cell technology from HyMotion is added to that production list?

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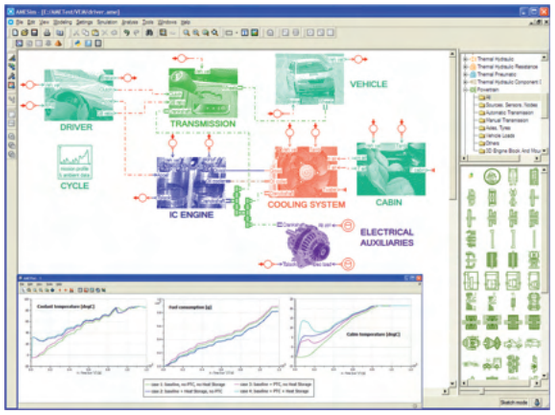

The Siemens VEM test center is the first facility in the industry to couple advanced, full-vehicle testing solutions with in-depth simulation to balance seemingly conflicting requirements for fuel economy, drivability, noise, vibration and handling (NVH) and comfort.

Realize innovation.

WHERE IT ALL STARTED: GM ELECTROVAN

While the Toyota, Honda, Volkswagen, Hyundai and Audi (see next page) FCEVs all promise to be truly revolutionary in their realization of the great green sustainable transportation dream, homage must also be paid to their forefather.

Widely credited as being the industry's first-ever fuel cell vehicle, the GM Electrovan, a converted GMC Handivan, was unveiled way back in 1966. It emerged with a drivetrain that had a continuous output of about 32kW, with peak output increasing as high as 160kW.

GM engineers placed motor and control systems under the two front seats of the Electrovan, while beneath the floor were 32 thin electrode modules connected in series by an astounding 167m of plastic piping. Behind the middle bench seat of the van were cryogenic hydrogen and oxygen tanks.

According to GM, the Electrovan's top speed was 112km/h (70mph) and it could muster 100km/h (60mph) from standstill in around 30 seconds, which is all rather impressive, especially since the entire application is said to have weighed over 3,200kg. And it's driving range was equally impressive – a respectable 240km (150 miles). But sadly, because of safety fears, the demonstrator never made it off GM property and onto public roads.

Despite it's rather rudimentary design, the Electrovan is seen as being truly ahead of its time, symbolizing an era when innovation and acclaimed R&D was ripe in the automotive industry. But in the end it was cost that ultimately killed the project; there was said to be enough platinum used in the fuel cell alone to buy a whole fleet of vans.

The IX35 fuel cell represents nearly 15 years of hard work for Hyundai on this FCEV program alone. The compact SUV benefits from a 100kW electric motor and a 24kW lithium-ion polymer battery that's been jointly developed with LG Chemical

4. HYUNDAI IX35 FUEL CELL

Having been available to selected trial partners since 2013 – and now on the road in some 15 countries around the world – Hyundai claims the ix35 is the industry's first mass-produced fuel cell EV.

The compact SUV is equipped with a 100kW electric motor, enabling it to reach a maximum speed of 160km/h (100mph). Two hydrogen storage tanks, with a capacity of 5.64kg, enable the vehicle to travel up to 594km (369 miles) on a single fill, and it can start in temperatures as low as -25°C. All energy is stored in a 24kW lithium-ion polymer battery that's been jointly developed with LG Chemical. Such impressive numbers deliver huge engineering inroads made on Hyundai's previous fuel cell prototype, including a driving range that has been extended by more than 50%.

DID YOU KNOW...

In preparation for the ix35 Fuel Cell launch, Hyundai has clocked up more than two million durability test miles on its fuel cell fleet since 2000

DID YOU KNOW...

The A7 Sportback h-tron represents the latest chapter in Audi's fuel cell development journey, following in the footsteps of the A2 H2 and Q5 HFC test cars

5. AUDI A7 SPORTBACK H-TRON

Developed to cover some 500km (310 miles) on just one tank of fuel, the Audi A7 Sportback h-tron is a plug-in hybrid fuel cell tech demonstrator with some seriously impressive real-world capabilities.

Total power from the fuel cell drivetrain – which is placed up-front, mirroring a conventional A7 with an IC engine, as well as a battery pack and electric motor at the rear – is 170kW, far more than the other FCEV developments mentioned in this feature, and enough to ensure a 0-100km/h (0-62mph) sprint time of 7.9 seconds before hitting a top speed of 180km/h (112mph). This power is transferred to the front and rear wheels of the Audi hydrogen sedan through an e-quattro arrangement – fully electric management of torque distribution – avoiding any mechanical connection between the front and rear axles.

The fuel cell itself comprises more than 300 individual cells that together form a stack. At the core of each of these individual cells is a polymer membrane, with a platinum-based catalyst on both sides of the membrane.

The entire fuel cell, says Audi's board member for technical development, Ulrich Hackenberg, operates in the range of 230-360V, with main auxiliary assemblies including a turbocharger that forces air into the cells; a recirculation fan that forces unused hydrogen to the anode; and a coolant pump.

The h-tron's four hydrogen tanks are located beneath the base of the trunk, in front of the rear axle and in the center tunnel. For the tanks themselves, an outer skin made from CFRP encases an inner aluminum shell. The tanks can store around 5kg of hydrogen at 700 bar.

Being a PHEV means that total driving range is boosted by 50km (31 miles) thanks to an 8.8kWh lithium-ion battery that's been largely based on the unit in the A3 e-tron. With the battery operating at a different voltage level to the fuel cell, the Audi tech demonstrator houses a DC converter (DC/AC) between the two subsystems. A tri-port converter is housed behind the stack.

The two electric motors, which are cooled by a low-temperature circuit together with the voltage converters, are permanently excited synchronous machines. Each motor has an output of 85kW – or 114kW if voltage is temporarily raised. Peak torque is 270Nm, and the e-motors' housings incorporate planetary geartrains with a single transmission ratio of 7.6:1.

The A7 h-tron's total system power is 170kW. Its drivetrain is located at the front of the vehicle, like a conventional IC-powered A7, with the battery pack and e-motor placed at the rear. The 8.8kWh lithium-ion unit has been based on the battery in the A3 e-tron

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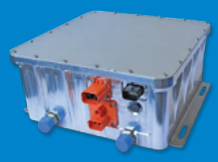

INV Series: The Bel Power Solutions 350 / 700INV60 product is a high-efficient DC/AC inverter that converts high-voltage DC power into split phase AC power 120/240 VAC required to drive AC accessory loads directly from the High Voltage DC Drive or Battery Bus. Liquid cooled DC/AC inverter operates at input voltages from 240 to 850 VDC and power range up to 6000W. The DC/AC inverter utilizes CAN communication to the vehicle controller which allows selection of operational modes and frequency selection. The DC/AC inverter is built in a sealed IP67 aluminium enclosure, ready to be mounted to the vehicle chassis and is a commercial-off the-shelf solution for electric vehicle manufacturers and developers. Features include full galvanic isolation between input and output, very high efficiency, high reliability, low output voltage noise, and excellent dynamic response to load/input changes.

INVCH Series: The Bel Power Solutions 350INVCH150 product is a 15 kW inverter charger that converts AC to DC voltages in charge Mode and converts DC voltages to pure sine wave AC to power AC accessories. The liquid cooled inverter charger operates at 250-435 VDC and 120 / 240VAC (50 / 60 Hz). The inverter charger powers up to 15 kW in either direction. Features include a full galvanic isolation between input and output, very high efficiency, high reliability, low total harmonic distortion (AC), low output voltage noise (DC) IP67 case, Serial CAN Bus interface, and excellent dynamic response to load/input changes.

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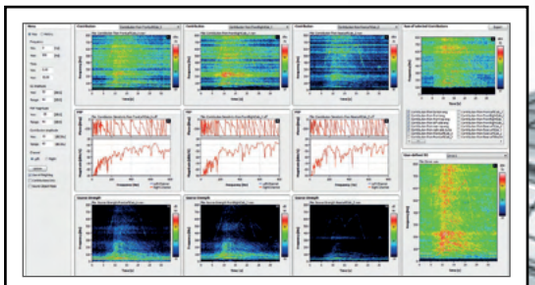
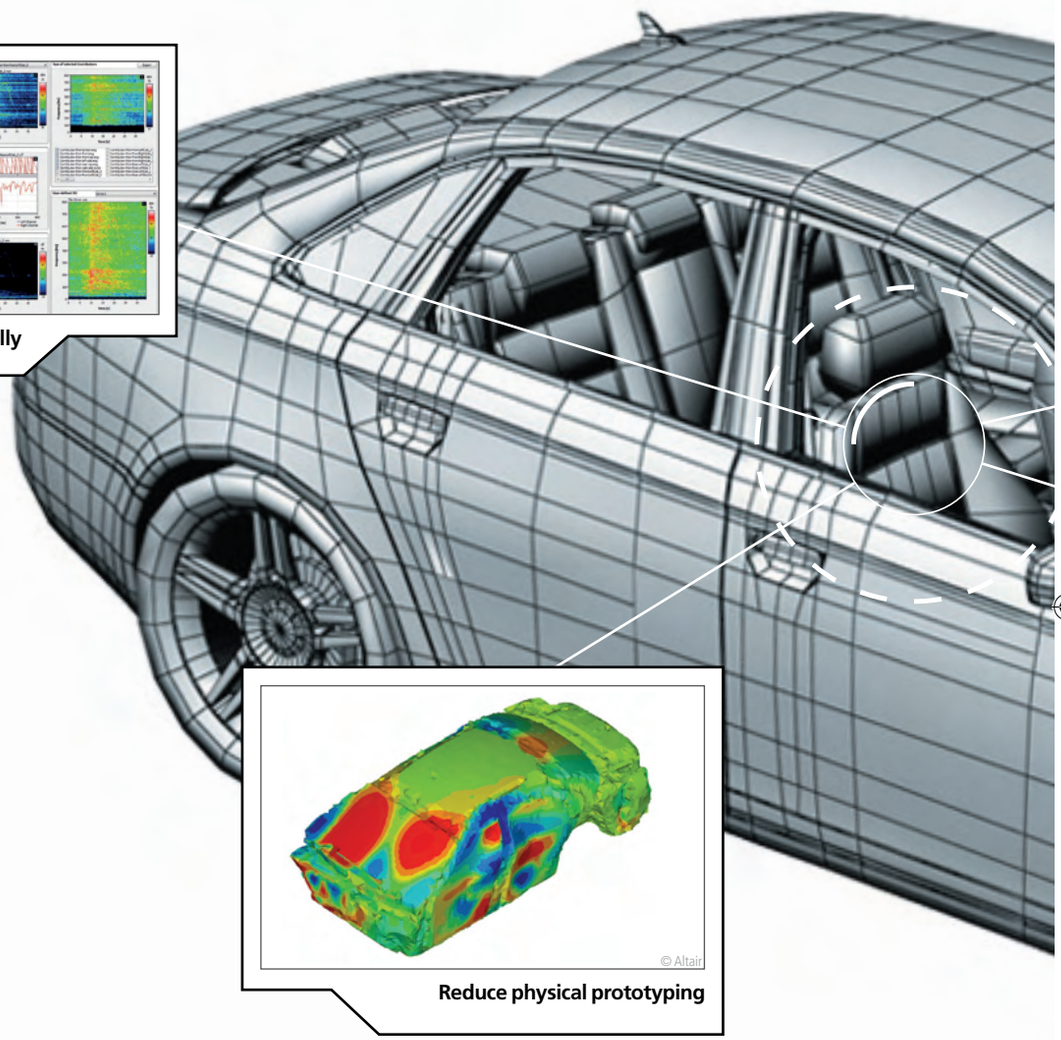


Compare design alternatives virtually



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Range finder

Just over two years ago, **Chris Porritt** swapped Gaydon and Aston Martin for California and **Tesla Motors**. And the British engineer is reveling in the can-do culture of "a place where everybody is so clever"

WORDS: **BRIAN LABAN**

Far beyond its cutting-edge pure-electric powertrain technology, Tesla Motors challenges many conventions on how a motor manufacturer operates: a controversial direct marketing strategy; a closer-than-usual relationship with customers; an impressively open approach to confronting technical issues and sharing technology, including patents; and an attitude to core development that reflects Tesla's intellectual affinity with Silicon Valley. Simply put, it's a company that does things differently.

Chris Porritt joined Tesla in May 2013 as vice president of vehicle engineering, based at Tesla Factory in Fremont, California, on the east side of San Francisco Bay. After 16 years at Aston Martin – latterly as vehicle engineering leader and chief architect of the One-77 – Porritt is reveling in a refreshingly open-minded working culture.

"Like anyone," he says, "our fundamental role is to make the car reliable, robust and safe. But how we do it may be slightly different. Trying to do things as quickly and efficiently as possible isn't unusual, but we try even harder to be even cleverer, integrating tasks in the most efficient way. For instance, if we're testing stability or traction control or whatever, we might try to run that together with, say, cold-environment testing. Without loads of products sitting around for us to test, we have to make the process as robust as possible."

But the real secret is the philosophy behind the process. "In the traditional automotive world," Porritt outlines, "there's the 'recipe book', and everybody follows the book. Different companies look at the recipes in different ways; but ultimately, they're essentially the same. If you bring in people from high-tech companies, on the other hand, they

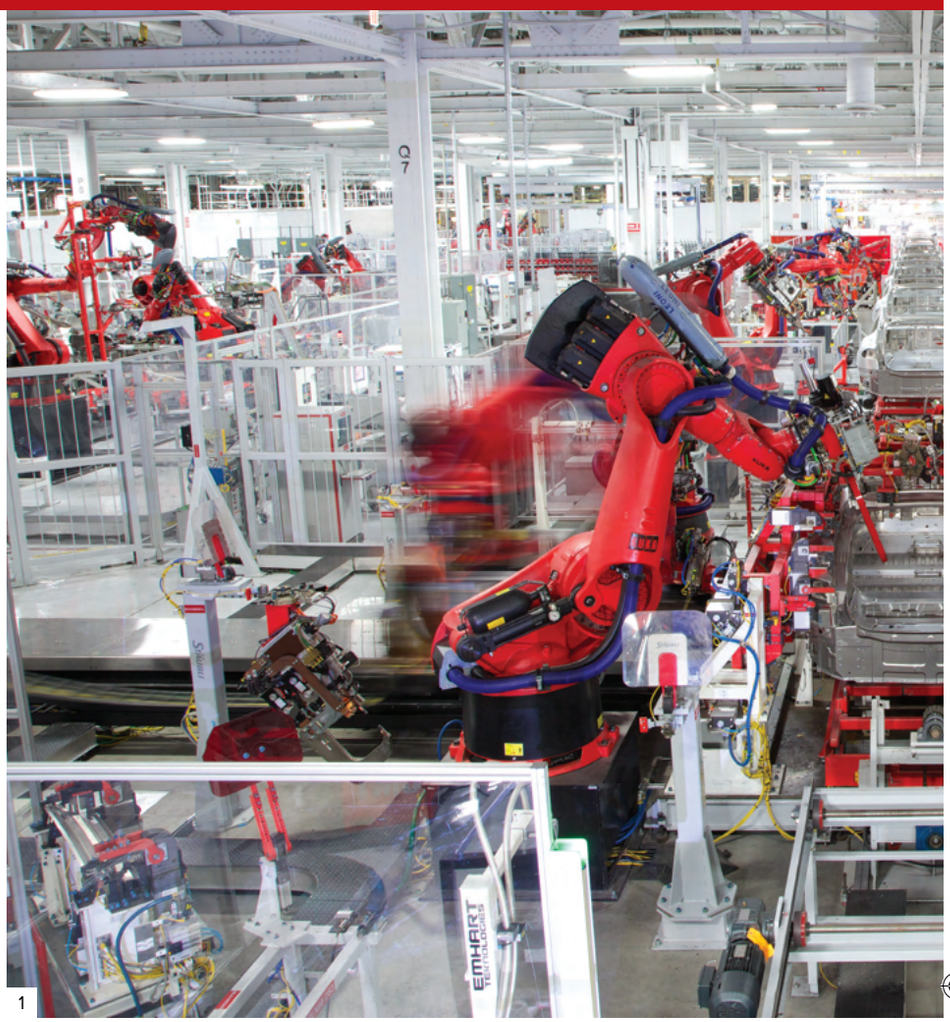
look at the book and say, 'Well that's ridiculous, why are you doing it like that?'. Many automotive companies reply, 'That's how we've always done it'. We can challenge that: it's not how we've always done it, because we haven't always done it.

"Because Tesla embraces people from such a variety of backgrounds, we do apply methods and techniques you'd see in traditional automotive companies – but also ones you'd see from a Silicon Valley culture, such as Apple, Microsoft and Google, whoever."

That team is multinational as well as multidisciplined. "My team probably has another 30 Brits from all walks of life – from JLR, Aston and the Big Three," Porritt continues. "We have Europeans, Chinese, Indians and obviously quite a few Americans. It's a brilliant, multicultural team. The common factor is talent. I've never been in a place where everybody is so clever."

And there's a healthy balance between car guys and tech guys, too. "The technology people tend toward powertrain and software, but my team has both. Probably 80% is automotive, but we can pick the cream of the crop: people with high motivation, high energy; clever people – not just those who are looking to work in a normal automotive environment, but in a technology company whose product happens to be automotive. Being cutting-edge appeals to car guys who want to do something genuinely new – myself included.

"Having people from all those areas brings a whole new approach," he expands, "to how to sign things off, to what reliability actually means, to what robustness is, to how to plan to test those things. Here, anybody can challenge anything – in ways you wouldn't necessarily imagine, but always good ways, and that's absolutely brilliant."



1

Engineering at its core

Tesla only started selling cars in 2006, so in the grand scheme of things it's still a low-volume manufacturer (it delivered about 22,300 vehicles in 2013). But its ambition and commitment are huge, with advanced technology and engineering underpinning everything.

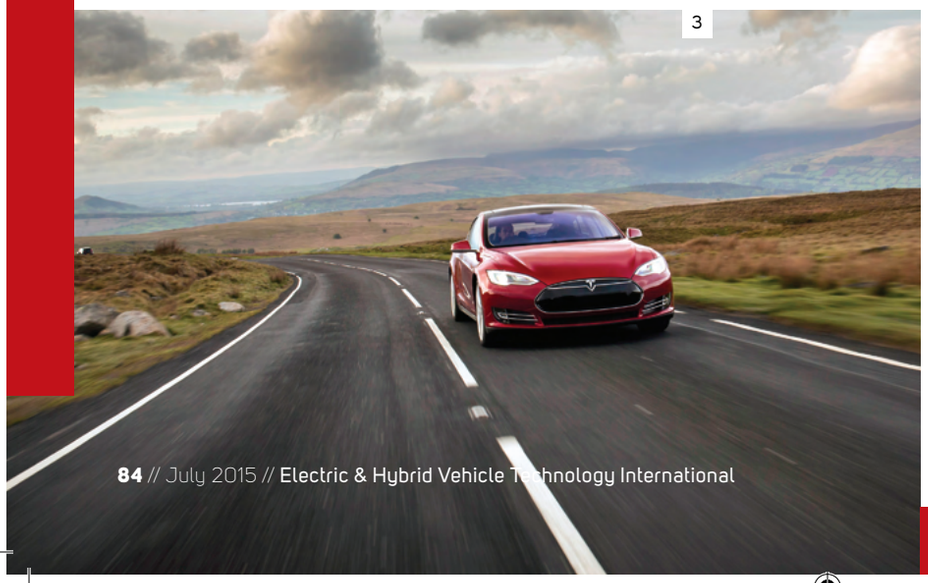
"My department has about 230 people (and is growing) to look after chassis, body and interior engineering," states Porritt. "I also have cross-functional groups, including a materials group that looks at plastics, metals and high-level battery enclosures – but not down to cell level, or battery chemistry. I have an NVH team, run by a long-time colleague. People might think that NVH with a pure-electric car is easy – but with no background noise, managing road noise, wind noise and motor noise is deceptively difficult.

"My vehicle dynamics team is clearly cross-functional as well," he adds. "I have a strong and fairly large CAE group that does all the analysis for crash, structural integrity and so on. Being focused is essential. As companies grow, you tend to end up with departments who do their bit in isolation, without looking over the fence at what their colleagues are doing, and so are not integrating properly. For us, that's a critical area."

For the size of the company – some 6,000 people in total – this is a big operation, particularly when only the

1 and 2. The Tesla Factory in Fremont, California, is where Porritt calls home now in a work capacity. The former GM/Toyota joint venture facility is ramping up production of the Model S, and will soon also start manufacture of the Model X crossover

3. The Model S has been a spectacular success for Tesla so far. Sales continue to grow worldwide and the all-electric powertrain has been critically acclaimed



3

2

"We do apply methods and techniques you'd see in traditional automotive companies – but also ones you'd see from a Silicon Valley culture, such as Apple, Microsoft and Google"

Porritt and his colleagues are also building a test and development organization from the ground up. "With no legacy, we're still building our database," he says. "Having physical prototypes enables us to build data sets others might have from years of production experience. [Other OEMs] can reduce the number of prototypes, but we're looking at it from a different viewpoint: we have to build experience. At certain stages in any program, you can't beat having products to test. However much you analyze, you'll still find things you haven't thought about."

Most of the design and testing for the right-hand-drive Model S program was done in less than eight months. "For Autopilot [Tesla's new ADAS], it was probably four or five months, which most OEMs would think was absolutely ridiculous," admits Porritt.

For physical testing, Tesla balances strong external links with robust internal capability. "We tend to do as much as we can ourselves, so we have strong groups for vehicle test, traction control, stability control and tuning. We tend to buy components – or subsystems – from suppliers, then do the integration ourselves – rather than buying systems that are often tailored toward more traditional applications, but don't necessarily work for us."

The level of internal capability is impressive – and growing. "The test group manages all our whole-vehicle testing, environmental, performance and coast-down testing, and dynamic sign-offs for the USA and now Europe," Porritt explains. "It also manages all our crash testing. We've built a low-speed barrier facility so that we can run tests up to 25mph [40km/h] in-house, which is brilliant for the early stages of a program. Before we get a car, we can build and test specific front-end sections on the trolley to correlate with our CAD predictions.

4

4. Tesla recruits from far and wide, and not just in terms of geographical difference from its California HQ. The company prides itself on managing to secure talented engineers and designers from other car makers, but also from the likes of Google, Microsoft Apple and Samsung

Model S is currently in production. A lot of the team is working on the forthcoming Model X SUV. And as Porritt notes, "there's plenty to do".

Musk time

Tesla's approach to development starts from both the top down and the ground up, as befits CEO Elon Musk's mission to champion sustainable transport and to create pure EVs from scratch, rather than adapting older, compromising technology. Porritt says he meets with Musk "three or four times a week and we're absolutely on the same page, there's no ambiguity".

"We're building other whole-car and component test facilities, too. We already have vibration rigs, hot and cold chambers and rolling-road dynos. But we haven't just splashed out money and said, 'We need this'; we've taken a step-by-step approach and said, 'We've been outsourcing this, if we did it in-house could we save money and iterate quicker?'. Generally we've picked off the relatively inexpensive stuff; now we're working through the more complex, more expensive [facilities]. Our whole approach is focused on improving efficiency.

"For example, it was costing us quite a lot just to transport cars to outside facilities to do a low-speed [barrier] test, then bring them home. We reasoned it would be better to build our own concrete slab; and because we can control the motor that pulls the car into the block with technology from the cars, we were able to build digitally controlled crash-testing!"

For the time being, Tesla's high-speed crash tests are performed at Karco in California, IDIADA in Europe, TRC in Ohio, and unspecified laboratories in China. "We benchmark everybody and work with whomever's appropriate; we don't have any particular allegiance," says Porritt. "But it won't be long before we can do, say, 30mph+ [48km/h+]. We don't have space to do side impacts, but we analyze every requirement, and if it looks as though it would be cost-effective to do it, we'll do it."

He's helped in these decisions by a can-do culture and the backing of the CEO. "We get absolutely what we need," stresses Porritt. "We're not so naïve as to think we can develop good cars for nothing, so we spend what's appropriate. We need to make sure we're doing the job properly. We can do all the physical modeling we need in-house, for example, with SLS (selective laser sintering), rapid prototyping, five-axis milling machines – we have amazing ability. Even before full production tooling was in place, we were milling complete gear casings.

"We also have a lot of robots in the factory, and robots are relatively cheap," he adds. "If we want to prototype something or lay out a prototype line, we'll take robots to do it. For Model X, we're building a prototype facility using the robots we'll eventually use in production. So we're learning all the time, learning appropriately, and making sure we're doing it sensibly and efficiently."

If you get the sense that Chris Porritt has become almost evangelical about his new employer, you'd be right, and he's excited about others converting to the cause. "New people bring new ideas," he enthuses. "Here, that's welcomed, not frowned upon, because in the big picture it's better for Tesla. If anybody in the automotive industry reads this, and they're high-caliber people who like the idea of working with Tesla, give us a shout. We're open for business."

FIRE FIGHTER

Tesla has a notable reputation for confronting problems head-on, and publicly. In 2013, two Model S owners suffered accidents causing underfloor damage and small battery fires. One ran over heavy debris at motorway speed; the other went over a roundabout at 177km/h (110mph), demolished two walls, lost both front wheels and finally hit a tree. In both cases, the onboard data system warned the drivers to stop and evacuate the car, before any fire occurred. The fires were contained by the standard steel/ceramic firewall, and there were no injuries.

Tesla's first response was an over-air software update, increasing the default high-speed ride-height setting. By March 2014, (beyond the ¼in, ballistic-grade alloy armor fitted as standard) it added a multi-element underfloor protection package as standard on new production cars and as a free-of-charge retrofit. Tesla performed more than 150 tests to develop the new package, impacting truck-size alternators, concrete blocks and the 'worst-case' three-ball tow hitch. None resulted in underfloor penetration, and the effect of weight and the modified aero performance on range was less than 0.1%. Tesla published a high-speed-capture video on its website showing the results. And typical of the avalanche of customer comments was one that said simply, "This company never ceases to amaze me."

"We're not so naïve as to think we can develop good cars for nothing, so we spend what's appropriate"

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3

1. The next important chapter in Tesla's evolution will be the Model X – a family-friendly crossover that shares the Model S's all-electric powertrain

2. On a longer-term projection, the Gigafactory in Nevada represents a landmark moment for Tesla. Set to be operational in 2017, the projected cost to build the facility is US$5bn. But Tesla expects to achieve a minimum of 30% reduction in production costs for its car batteries when the base opens

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Das e-auto

Volkswagen Group not only wants to triple its EV and HEV product offering by 2018, it also has ambitions to eventually become the most eco-friendly car company in the world. It's a tall engineering order. The man leading that charge is powertrain chief **Dr Heinz-Jakob Neusser**

WORDS: **MARC NOORDELOOS**

The Volkswagen Group has been rather busy of late proving its commitment to a rich e-powertrain future encompassing battery electric vehicles, plug-in hybrids and hydrogen fuel cell applications. The German engineering powerhouse is looking to have no fewer than 40 models with either EV or HEV technology at their core within five years – nearly tripling its current product offering. In fact, as far back as September of 2013, CEO Dr Martin Winterkorn went on record to announce, "We are electrifying all vehicle classes, and therefore have everything we need to make the Volkswagen Group the top auto maker in all respects, including electric mobility, by 2018." As such, a significant share of its US$7.7bn annual investment into research and development is spent on electric mobility – more than any other field. Since Winterkorn's statement, Volkswagen of America announced a US$10m outlay in EV infrastructure in the USA and part of this capital expenditure includes partnering with the world's largest EV charger network company, ChargePoint, to greatly expand the number of DC fast chargers. Volkswagen of America also invested in California solid-state battery company QuantumScape. Meanwhile, Volkswagen China plans to launch more than 20 EV/HEV models in the world's largest auto market in 2016, including the Audi Q7 e-tron 2.0 TFSI quattro and the China-only Audi A6 L e-tron.

Leading this ambitious EV and HEV product push on an engineering front is Dr Heinz-Jakob Neusser, head of powertrain development at the Volkswagen Group. "We believe in electric mobility and, therefore, Volkswagen Group already offers EVs, such as the VW e-Golf and e-Up; PHEVs including the VW Golf GTE and Audi A3 e-tron; and HEVs, like the VW Jetta Hybrid," the 55-year-old German told *E&H* during an exclusive interview.

"Our goal is to introduce the right technology, at the right time, in the right place. Part of this approach is a stepwise introduction of electrified vehicles. Therefore it is not by any means necessary to be the first on the market, but to offer the best product."

Full charge ahead

Neusser, who arrived in Wolfsburg from Porsche in 2011 to lead powertrain development for VW, and just one year later took charge of powertrain development for the entire Group, has a clear view of how new-gen EVs and HEVs will play out on a global scale: "The main markets for these kind of cars are the USA, China and Europe," he says. "VW initially is selling the e-Golf in select states in the USA, including California, Oregon and New York, whereas the Jetta Hybrid is available all over the country. We are differentiating ourselves from our competitors by performance and efficiency. The e-Golf offers a market-leading efficiency of 116MPGe. We believe that sustainable mobility is becoming increasingly important. We at the Volkswagen Group have committed to providing a full suite of alternative powertrains – including hybrids, plug-in hybrids and full electric vehicles – for sale around the world." Backing up Winterkorn's comments from 2013, Neusser adds, "The Volkswagen Group is committed to being the leader in e-mobility by 2018."

"Our goal is to introduce the right technology, at the right time, in the right place. Part of this approach is a stepwise introduction of electrified vehicles"

Heinz-Jakob Neusser, head of powertrain development, Volkswagen Group

1

1. Audi's A3 e-tron forms part of the VW Group's current e-mobility program

2. The Volkswagen Jetta Hybrid is available to customers across the USA

But as with any new technology, it takes time to gain acceptance with buyers and to define its level of success. "Our EVs and HEVS have been introduced successfully in many markets," states Neusser. "But it is too early to define a ranking because the global introduction phase is still ongoing and there are no predecessor models in the respective classes to compare with. We are aware that EVs will take time to resonate in the markets."

2

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A key to growing the take rate of EVs in the market is increasing battery capacity. Volkswagen Group has already stated that EV range will jump to 299km (186 miles) by 2017 and the company expects to eventually see well over 485km (300 miles) on a single charge. And Neusser's thoughts on the big technology struggles for EV and HEV development echo just that. "We place high value on careful development and intensive testing of our models and technologies," he notes. "The main challenge is the battery capacity. Currently we are developing batteries that offer higher capacity to increase the electric driving range, no matter if they are fitted to EVs or HEVs."

On a Group level, e-powertrain development at present seems to be most prominent for the mainstay brands of VW and Audi, but the technology is also growing in importance at Porsche, while increasingly influencing product thinking at Bentley and Lamborghini at one end of the spectrum, and SEAT and Škoda at the other. Then there's also Ducati motorcycles to take into consideration, as well as MAN and Scania commercial vehicles and even super supercar maker Bugatti. From an outsider's perspective, it seems like a complex setup, with different brands at different stages in their e-powertrain journey, but Neusser has a different take: "Corresponding to the specific customers, Audi and VW will focus on EVs and hybrids – both HEV and PHEV – while the other Group brands offer only hybrids at this time. Sports car brands like Porsche can obviously use the electric power to increase their peak performance, but also compact size cars like the Golf GTE and A3 e-tron are designed to compete in the hot hatch segment, offering great acceleration and eager handling. Because electric drivetrain components are capable of increasing the vehicle performance as well as the efficiency, it is conceivable that the Lamborghini, Bentley, Bugatti and Ducati brands will be equipped with EV or HEV drivetrains in the future."

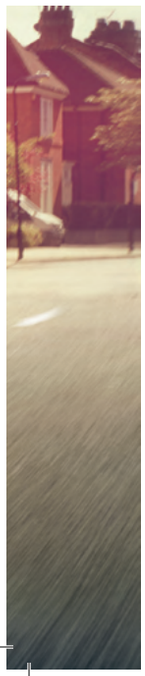
It's a rather telling point by Neusser; e-powertrains not only enhance efficiency, they also have the capacity to increase performance. So what then does the future hold for those iconic Group hot hatch racers, like the VW Golf GTI and R, as well as Audi S3 and RS 3? "Volkswagen Group was the first to offer so-called performance hybrids like the A3 e-tron or Golf GTE and the Porsche PHEVs [such as the Porsche 918 Spyder]," answers Neusser. "The performance and efficiency of the Porsche PHEVs impressively demonstrates that the term 'hybrid' is not a synonym for 'compromise'."

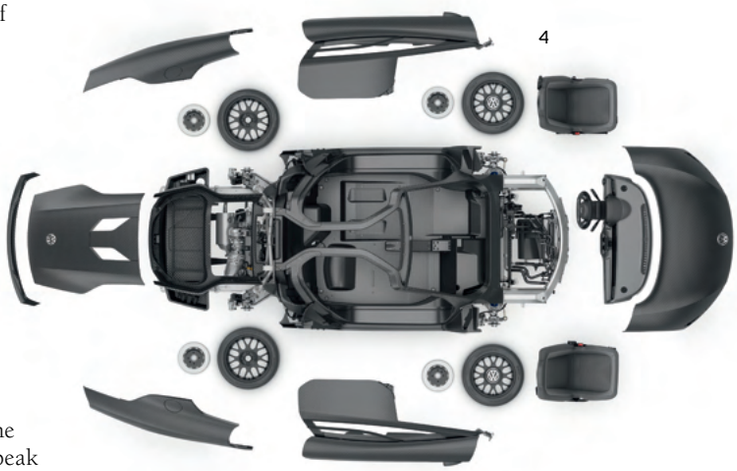
i competition

Over in Munich, BMW has been busy realizing its own philosophy on electric vehicles. Models falling under the company's 'i' sub-brand feature distinctive styling and lightweight carbon fiber technology, combined with innovative e-powertrains. Does a similar plan make sense at the Volkswagen Group? "The VW XL1 has already proven unmatched efficiency in the automotive sector," counters Neusser. "The XL1 is an outstanding example for innovative lightweight construction, a highly efficient drivetrain and advanced materials. But to implement a new technology successfully into the market, you have to consider many different facts. First of all, that means cost. The Volkswagen Group's MQB strategy is

3. The architecture of Volkswagen's e-Golf, which offers market-leading efficiency

4. VW's XL1 features advanced materials, an efficient drivetrain and lightweight construction





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a huge step regarding standardization, as well as weight and cost reduction. It allows us to produce our EVs and PHEVs on the same production line as conventionally powered vehicles. Additionally, we have to focus on various regulations and customers' needs in relevant markets. Our aim is to offer vehicles that are fulfilling the different requirements."

BMW's i3 range-extender offers a unique powertrain setup in the EV world. It's primarily an electric vehicle, but a small, 647cc gasoline motor is able to maintain the present battery level, helping increase the range and the usability of the vehicle. Does a similar powertrain make sense at the Volkswagen Group? "During the technical development process, we continuously compare the different approaches regarding efficiency, cost, profitability and marketability," says Neusser. "The concept that fits the requirements best has got good opportunities to become realized. From our point of view at the moment, our PHEVs are offering sustainable e-mobility without restrictions."

In addition to increasing overall driving range, lowering costs is another key component for EVs and HEVs if they are to cross into the mainstream. "The main driver to lower costs is the number of units sold," Neusser says, with a degree of simplicity. "Therefore, it is a probable way to spread electric drivetrains over the vehicle range. Within the Volkswagen Group, the development of technologies and components for e-mobility represents a very significant share of total research and development [budget]. To achieve customer acceptance, we have to lower cost and increase battery capacity. On the other hand, a comprehensive charging network is also fundamental to come to a breakthrough for EVs and HEVs."

1

1. Though Tesla has opted for a proprietary charging network, the Volkswagen Group is committed to DC fast charging, getting behind the CCS standard

2. Consolidation of charging standards, or compatibility between standards will, Neusser believes, be vital to the growth of EVs and HEVs

2

In this respect, Tesla is going down the route of a proprietary 'supercharger' charging network to increase mobility and the usability of its EVs. Meanwhile, Volkswagen Group is committed to DC fast charging. "Currently, the Volkswagen Group, with other global partners like Mercedes, BMW, Ford and GM, is promoting the CCS (Combined Charging System) standard. The goal is to implement this standard globally. We are supporting the implementation of a charging network, but it is not the task of the automotive industry. Therefore, we partnered with companies like ChargePoint in the USA to secure access to its more than 21,900 facilities nationwide. Today, there are several ways of charging the e-Golf's battery."

Neusser continues, "Overnight charging and at-work charging works well for many of our customers [via standard outlet or 7.2kW wallbox]. The growing number of DC chargers will allow for quick charging during breaks on road trips. The e-Golf has standard DC fast charging capability and can be recharged at levels up to 40kW, allowing the battery to reach 80% in around 30 minutes."

These charging connector standards need to be streamlined to help the growth of EVs and HEVs for all manufacturers. "To bring e-mobility successfully on the road, it is necessary to define a consolidated standard or at least a compatibility between different standards," adds Neusser. "We are convinced that other car manufacturers will recognize the advantages of the CCS standard."

Government subsidies and investment are also an integral part of the present EV/HEV business model, as Neusser notes: "We focus on vehicle development, not on incentives, because those are not granted for a long-term future. Nevertheless, infrastructure investment and promotion of regenerative energies are important factors in convincing more customers of the benefits of e-mobility."

It's an important point, especially as society is not helping lower emissions if it's exchanging the burning of fossil fuels in conventional cars with the burning of coal to generate electricity for EVs. "From an environmental standpoint, e-mobility makes the most sense when powered by energy from renewable sources," Neusser agrees. "So, in Germany, we promote offers where certified partners offer electricity coming from renewable sources. That's also growing in a number of other markets. With our 'Think Blue Factory' concept, we already use a certain share of renewable sources like wind, water and sun for the production of our cars. In addition, we have set ourselves the target to reduce the necessary energy and waste by 25% in the year 2018. Our goal is to be the most eco-friendly car company in the world."

MAN ON A MISSION

It comes as no surprise that Dr Heinz-Jakob Neusser is Volkswagen Group's chosen man to make true all of its e-powertrain ambitions and aspirations. Having graduated as a mechanical engineer with a doctoral thesis on multivalve petrol engines at Aachen University for Applied Science, Neusser's first step to becoming an engineering great began with FEV Motorentechnik in Aachen in 1986, where he was responsible for petrol engines alongside various R&D projects in the USA, China and South Korea. He stayed with the engineering consultancy for a decade, but when Porsche came calling, the WRC enthusiast couldn't resist, taking up the position of project manager and then, just two years later, heading up engine construction. During this time Neusser shaped development of Porsche's V-engine family and new-generation of flat engine designs. From 2001 to 2011, Neusser headed up drivetrain development at Porsche, devoting himself to the creation of new all-wheel drives, as well as dual-clutch gearboxes. Having taken Porsche forward with next-generation powertrain and transmission technologies, Neusser landed in Wolfsburg in 2011 to head up powertrain development for VW and one year later he assumed total powertrain development control for Volkswagen Group.

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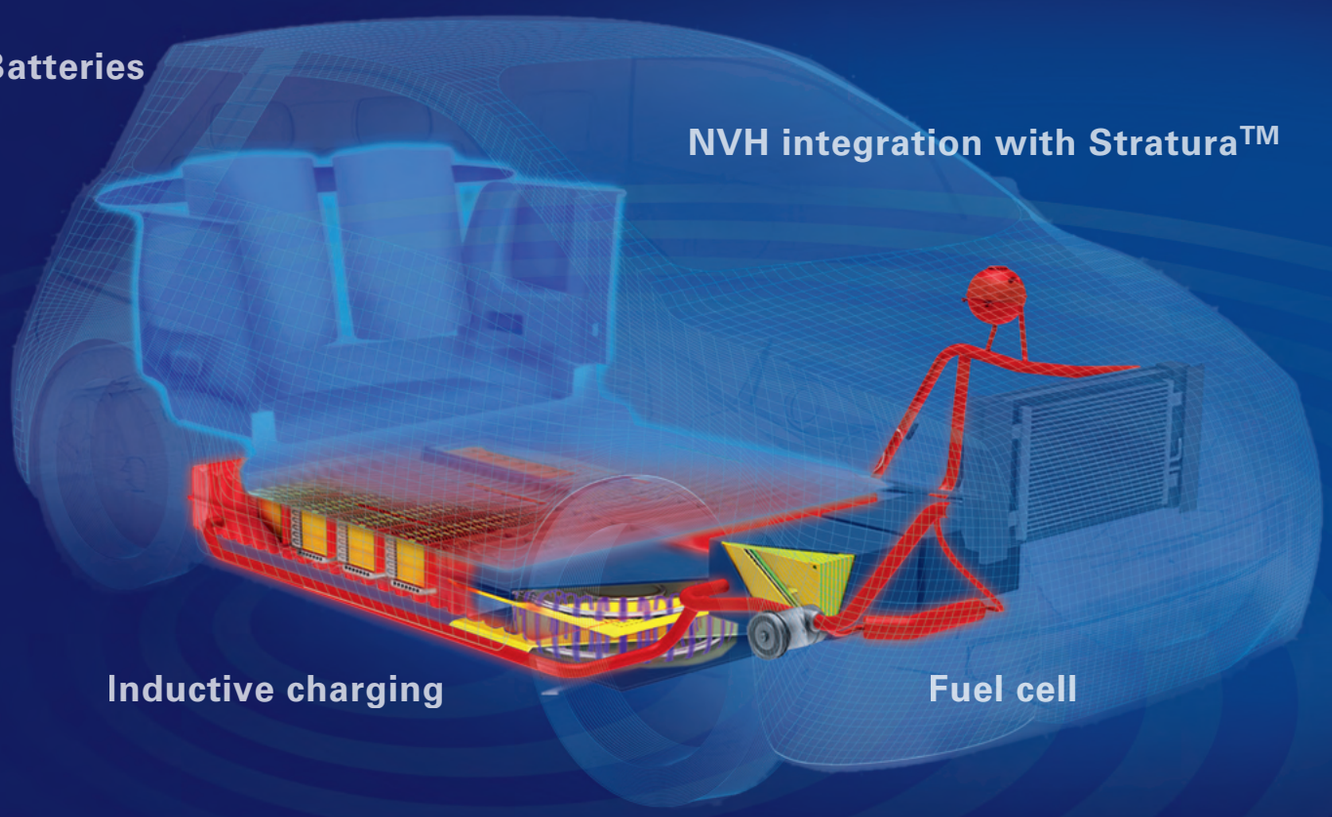

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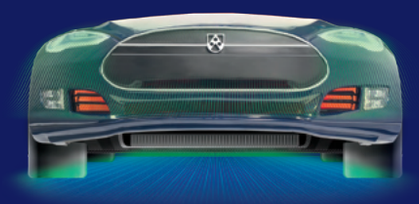

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Alternative choices

It's not just the established car makers that are fast-tracking e-powertrain plans – new innovators, tech pioneers and smaller OEMs also have eyes on the EV prize

WORDS: **FARAH ALKHALISI**

>> MAGNA STEYR MILA PLUS

This sporty concept is Magna Steyr's eighth prototype in the MILA series, showcasing the company's engineering and vehicle-building capabilities, and specifically demonstrating weight-saving construction techniques and technologies alongside an advanced plug-in hybrid powertrain.

The 4.4m-long two-seater weighs 1,520kg and is based around a mid-mounted three-cylinder gasoline engine and two in-house Magna-developed electric motors. Its flexible, modular, extruded aluminum spaceframe construction could theoretically accommodate other driveline configurations, components and subsystems.

The BMW i8-like powertrain configuration gives a total output of 200kW and 580Nm of torque, meaning a 0-100km/h sprint takes just 4.9 seconds. According to Magna, the CO_2 emissions equate to a mere 32g/km.

One of the MILA Plus motors is positioned between the engine and the transmission to drive the rear axle, and the other is mounted on the electric front axle, according to Manuel Erlacher, senior project manager for vehicle concepts and alternative production processes at Magna. Such a setup delivers all-wheel drive in performance hybrid mode.

Further modes of operation include a pure-electric setting in which a 75km (46 mile) range can be achieved, as well as recuperation and IC engine load-shifting, which allows the engine to run at the most efficient point of its map to conserve energy. Even when running on battery power alone, 0-80km/h (0-49mph) acceleration comes in at 3.6 seconds, indicating plenty of get-up-and-go before the IC unit needs to kick in.

Erlacher reveals that the MILA Plus has been designed to accommodate a number of options according to client request, but has also been conceived as a one-stop turnkey solution. Besides offering a choice of different OEM-supplied three-cylinder engines, it "can accommodate different batteries, packaged in a T-shape across the rear axle and central tunnel should the lithium-ion cells [that give an installed 13kWh output] not be to the desired specification".

Incorporating batteries into a lightweight spaceframe across that T-shape setup has the added benefit of reinforcing structural rigidity as well as allowing for the assembly of the body components in a cold mechanical joining and bonding process, rather than by welding.

This technique has already been applied to the Mercedes-Benz SLS-AMG and the Aston Martin Rapide, built by Magna, and is said to be cost-effective as well as extremely strong.

Further underlining the environmental promise of the plug-in hybrid setup, the modular aluminum body-in-white of the MILA Plus is fully recyclable; its lightweight body panels are plastic, providing styling flexibility and corrosion resistance; and its interior features bioplastics and natural fibers.

As with last year's stripped-down MILA Blue concept, a natural gas-fueled city car, a holistic approach has been applied to the engineering of this prototype, examining all of the aspects in which sustainability can be enhanced and optimizing vehicle architecture alongside the substitution of materials. As such, the MILA Plus is not short on typical concept-car touches and flourishes, including exterior mirrors being replaced by rearview cameras that project images onto display screens and aid aerodynamics.

The MILA Plus does, apparently, comply with all global safety standards and could therefore be easily accelerated through the homologation process should a company wish to adopt it. However, even if it does not reach series production as an entire vehicle, its technologies, packaging solutions and materials are expected to make their way into other models Magna Steyr develops or produces for its clients.

1. With an electrical range of 75km and vehicle weight of 1,520kg, the MILA Plus impresses with average CO_2 emissions of 32g/km

2. The performance of the three-cylinder gasoline engine is enhanced by two electric motors for AWD

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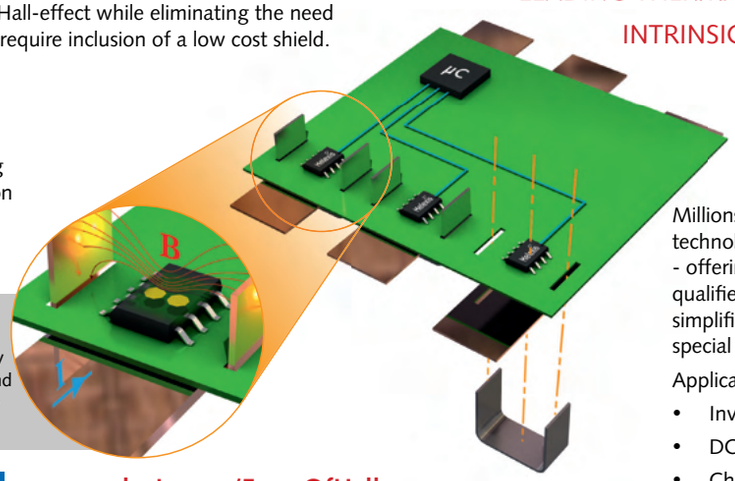

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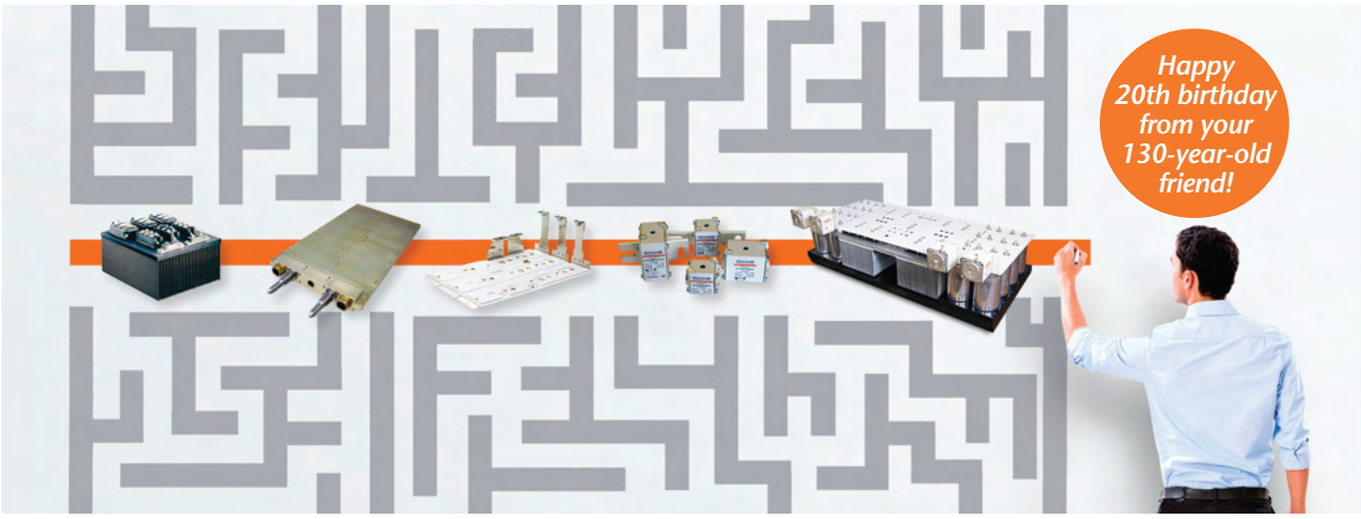

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>> ED DESIGN TORQ

Autonomous vehicles with e-powertrains are all the rage in the automotive world, with car makers scrambling ahead with R&D programs and real-world tech demonstrators. But it's not just the OEMs that are increasing their interest in vehicles that do away with the human driver. This year so far ItalDesign Giugiaro has showcased its luxurious limousine-like GEA concept and then there was Rinspeed, with its BMW i3-based Budii. But it is ED Design that has created arguably the most pioneering of all concepts so far.

Torq has been specially designed to showcase artificial intelligence, augmented reality, heuristics and connected-car technologies, all packaged into an arrow-like 250km/h (155mph) racing vehicle with a four-motor 320kW in-wheel electric powertrain delivering 1,800Nm of torque. Its batteries – which can be swapped in a four-minute pit stop – are placed in the central tunnel, allowing for the super-aerodynamic V-shaped tail.

The concept is based on a skateboard-type structure, with a floating passenger compartment, optimized for ground-effects and maximized downforce.

"Why autonomous driving for race cars?" asks ED Design CEO and design director Michael Robinson. "Because we always test innovation, the next big thing in the extreme context of the track, to see what's happening."

Robinson envisages a race series of such vehicles – the winner being, it seems, the result of the most intuitive human-machine interaction and learning, the most sophisticated collaboration between man and machine.

The notable absence of windows – which are replaced by lightweight, curved 360° screens with images projected from the outside world – illustrates the extent to which the occupant relies on the car's own sensor technologies, including a virtual personal assistant that ED Design calls Ambrogio, an Italian nickname for a chauffeur/concierge-type figure. Robinson says that Ambrogio can learn from a professional driver in test laps, then work alongside drivers during the race: "The machine learns during laps, but the goal is to use a human expert to win. We're not interested in robots, the goal is to create the HMI together, working with an intelligent and emotional machine. The idea is to create the feeling between Ambrogio and the driver."

1. Featuring four electric in-wheel motors, the Torq car produces 1,800Nm of torque and its lithium-ion battery pack stores 88kWh

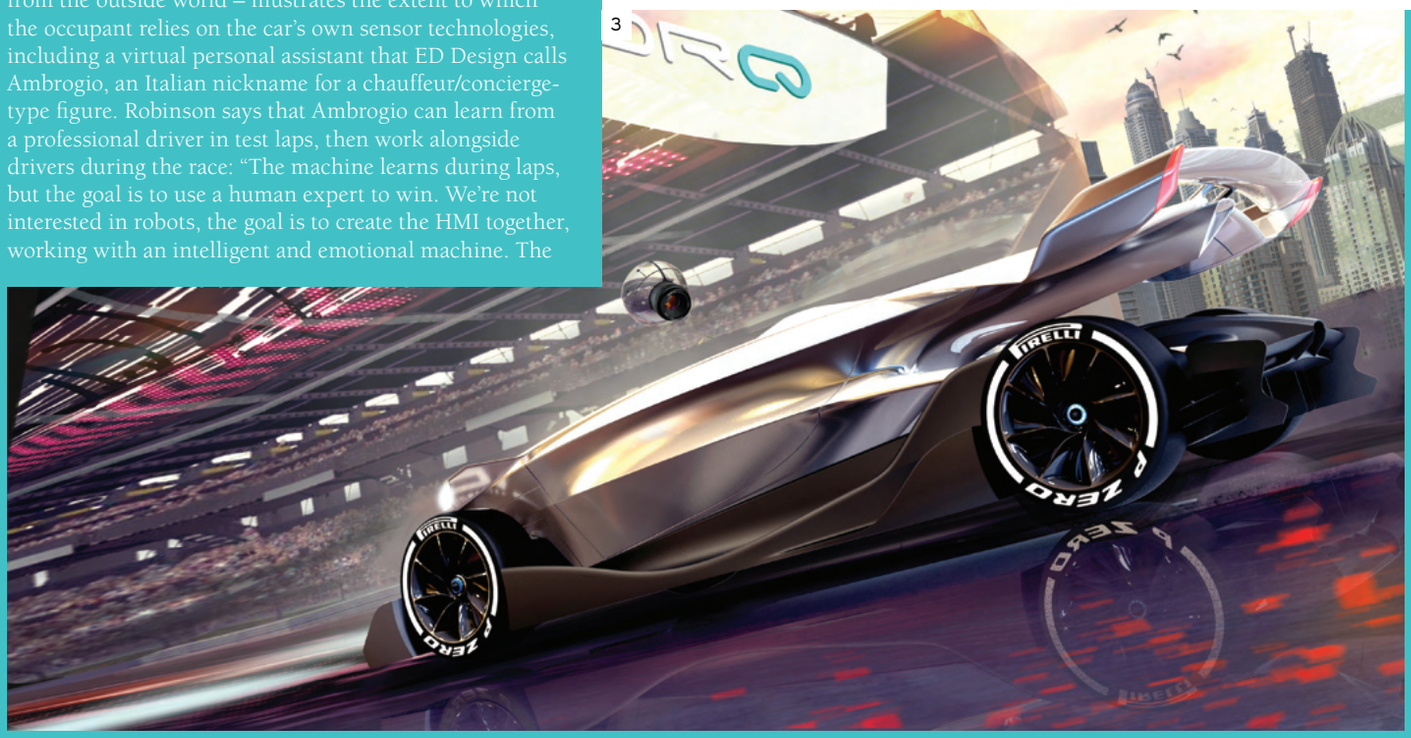
2. Despite the 550kg battery pack, the total weight of the Torq race car is only 1,000kg

3. With a top speed of 250km/h, ED Design aims for Torq to complete 12 4-minute laps at Le Mans on a full battery charge

On a more real-world note, an extensive program of non-competitive and consumer testing is also planned as part of a project called the Mobile Autonomous Automobile Laboratory (MAAL). The intention is to supply vehicles to researchers worldwide as open-architecture technology testbeds, with a view to introducing driverless technologies in order to reduce or even completely eliminate road traffic accidents and casualties.

"Electromobility is the perfect mix with autonomy," Robinson says. "We want to put the tech into city cars and MPVs. We want to be game changers and technology suppliers."

Robinson says ED Group, which is based near Turin but has further facilities including an office in Detroit, will have a functional model in 12 months, with vehicles ready for delivery in 2016/17 to universities and think-tanks, OEMs and the likes of Google and Apple. He sees the project as a way to find a future for the automobile: "Our goal is to save the car," he declares. "The autonomous world will not kill enthusiasm for the car."



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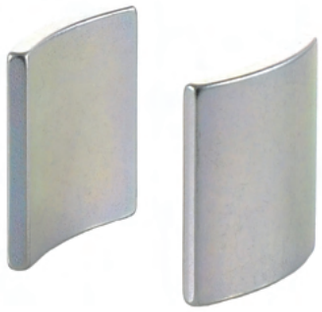

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<< RINSPEED BUDII

Based on the BMW i3, the Budii, another autonomous EV, has also made headlines this year. Here's what we know about the concept:

E-motor: Hybrid-Synchron-Motor
Power output: 170kW
Torque: 250Nm
Battery: 21.6kWh
Powertrain: Rear axle
Top speed: 150km/h (93mph)
0-100km/h (0-62mph): 7.2 seconds
Range: 200km (125 miles)
Suspension: Pneumatic height adjustment
Body: CFK with aluminum base structure

>> AVTOVAZ PHEV DEMONSTRATORS

In the past 18 months Russian car maker AvtoVAZ has built several plug-in parallel hybrid demonstrators funded by the Russian government.

The high-voltage powertrain components used have been developed by Russian suppliers, including Itelma for the engine control unit and research institute NAMI for the e-motor, lithium-ion battery and motor-controller. These were integrated with an automated manual transmission incorporating electronic shift actuators and control software from ZF, onto which the e-motor was mounted in place of the fifth gear. The project was supported by a British-based engineering team from Ricardo, which also designed and integrated the control system software.

A CO_2 benchmark of 115g/km was reached by each of the four variants. These Lada Granta-based vehicles, built and tested in Togliatti, feature AvtoVAZ's 1.6-liter unit in gasoline- and natural gas-fueled forms (97g/km and 90g/km respectively), a naturally aspirated 1.4 (84g/km), and a new prototype turbo 1.4 being developed for AvtoVAZ by Ricardo in an ongoing program (90g/km).

Although the control strategy algorithm across the four engines was essentially the same, "one area where we did have to manage the variants carefully was on the emissions control to meet Euro 5," says Ricardo engineer Daniel Chambers. "The challenge was making sure the catalyst was hot for as much of the time as possible and different engines heat the catalyst at different rates, so we had to calibrate differently."

Electric-only range is said to be around 25km (15.5 miles), potentially supplemented by regenerative braking.

>> EV-LITE BATTERY

Now for more of a focus on EV components rather than the bigger tech demonstrator picture, and specifically a new lightweight prototype battery that challenges the costs of assembly, ongoing maintenance and future applications or upgrading.

So far five patent applications have been made as a result of a two-year project, called EV-Lite, which is funded by Innovate UK (formerly the Technology Strategy Board) and based at the Manufacturing Technology Centre in Coventry. Aiming to develop a low-cost battery for EVs that is lightweight, easy to maintain, and simple and quick to manufacture, the project also considered problems OEMs may face in scaling-up battery production as the EV market expands, as well as second- and even third-life applications and ongoing upgrades in situ.

Partners in this collaboration included Loughborough University, researching to inform the battery's specification and operational parameters and later repurposing; Unipart, assessing manufacturing demands and costs including factory space, equipment and energy use; Cenex, supplying sample data on EV drive cycles; and the UK government-funded Centre for Remanufacturing and Reuse (CRR). Canadian battery maker Electrovaya supplied its lithium-ion SuperPolymer cells, plus a Maya 300 EV microcar for teardown analysis and benchmarking, though the final prototype was designed for the British Bluebird EVX sports car concept.

"Bluebird asked if we could start looking at how to integrate that battery into the body tub," says program manager Mark Ireland. "They did a lot of work looking at the space requirements and the packaging, and gave us the data for the specification as a starting point." The Bluebird Innovation Group further looked into integration of the battery into its prototype delivery van and a battery-swapping system.

1

1. The EV-Lite project saw the weight of a 26.5kWh-sized battery system reduced from 295kg to 215kg, and the weight of non-cell components reduced from 144kg to 72kg

2

2. The new battery design has no wire or screws, which has translated into significant improvements in battery pack assembly

3. When compared to a benchmarked battery, the EV-Lite design has a parts count of 196 versus 807 for a 4kWh-sized module

3

The EV-Lite battery performs a structural function as part of the EVX's floor, contained safely within the floorpan or components such as chassis crossmembers. The modules of the cells do not need a hard, solid casing – thus giving weight savings – and are easily replaced or upgraded. The cells can be swapped just one or two at a time, so a vehicle's future owner need not face a large outlay for a replacement pack.

Though the project has looked at lithium polymer and lithium iron phosphate, it has taken other chemistries into account. "Part of the reason I wanted to be able to take cells off is that I wanted the Bluebird EVX owner to be able to upgrade their battery with the latest tech as it becomes available," reasons Ireland. As such, the battery design is completely scalable: "You just keep plugging on the cells," he adds. This also makes the battery just as suited to static energy storage or domestic applications and "quite often something that's easy to assemble is easy to disassemble, so what we've ended up with is going to be really easy to recycle."

The real saving in assembly time, however, is the embedding of the BMS inside the battery itself, between the bus bars and the cells. "By sandwiching it in the middle we can take all our instrument measurements without the need for any wires, screws or soldered fittings," says the program manager. "It is now error-proofed as well, so anyone can assemble it – it'll only go together one way." That too is subject to a filed patent, as is the Intelligent Battery Interface System. In the Bluebird concept this innovation monitors a string of eight battery modules, each with 36 cells, and is contained in a single unit plugged onto the battery. A fifth pending development patent is the integration of a heat-synch into the bus bars, cooling them to avoid potential overheating and to aid efficiency.

Overall battery weight (including structure, BMS and charging systems) has been reduced by over a quarter, compared with an equivalent current design, and the weight of the non-cell elements of the battery decreased by 41%. The cost of non-cell components has been cut by 63% to less than US$5,200 and a fully automated build of the battery takes just 18 minutes. ■

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Sinclair C5. A new power in personal transport.

It was supposed to kickstart a wave of new electric vehicles, but the **Sinclair C5**, which turns 30 this year, ended up being a high-profile failure WORDS: **JOHN SIMISTER**

Was it really 30 years ago? That was before the internet, when the Amstrad PCW was the mass-market word processor of choice and Sir Clive Sinclair, Alan Sugar's chief rival in domestic computing, was famous for his LED Black Watch as well as his ZX computer kits and pocket calculators. But Sir Clive was about to overreach.

He'd been planning a revolution in clean, green, electric transport, to culminate with a four-seater car but starting with a tiny one-person tricycle. Today we see the C5 badge attached to a Citroën family car, but in 1985 it identified with a 1,744mm-long three-wheeler whose one-piece, matt-white polypropylene body was the single biggest injection molding ever attempted by the plastics industry at that time.

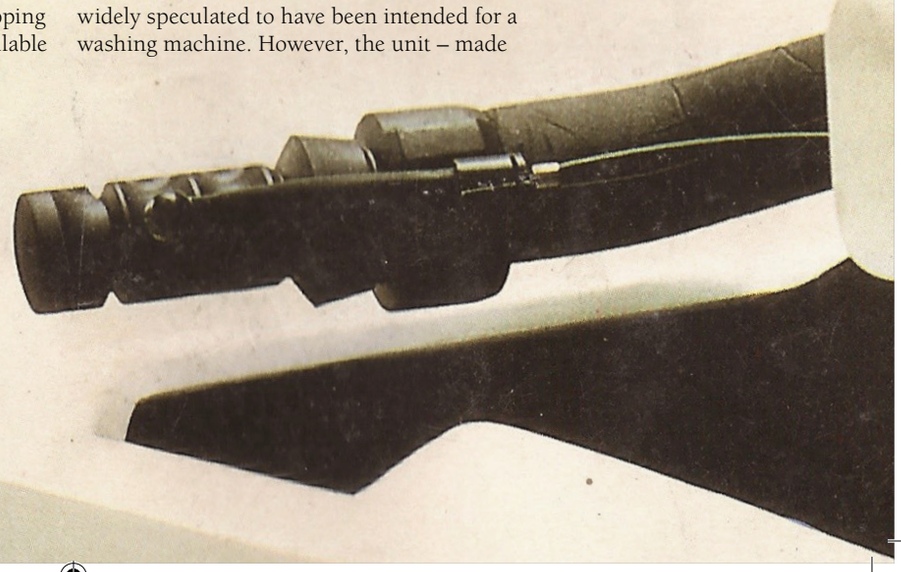
Sinclair envisaged whole squadrons of happy families taking to the roads in their C5s, be it for the station commute, a shopping trip (for which you would need an unavailable trailer), a sports event, or a picnic. UK law allowed anyone over the age of 14 to drive/ride a C5 without a license, crash helmet, road tax, insurance or even a registration plate, as it was legally an electrically assisted pedal cycle. How could it fail?

In many ways, as it turned out, and only Sinclair's blind optimism prevented him from asking several obvious 'what if?' questions.

Pioneering promise

Yet despite this, the C5's pedigree was promising. The body was styled by Ogle Design with refinements by Sinclair's in-house graduate, Gus Desbarats from the Royal College of Art. The chassis and running gear were developed by Lotus – the backbone design of the structural element resembled that of a miniaturized Lotus Elan and its flexibility provided some suspension effect. The slender, but pneumatic, tires did the rest.

Power came from a 250W electric motor widely speculated to have been intended for a washing machine. However, the unit – made



The C5's running gear was developed by Lotus. It also featured a 250W electric motor made by Polymotor that got its power from a 12V, 36Ah lead-acid battery developed by Oldham

"Pressing a button on the left handgrip activated the motor – it was either off or on, with no power gradation possible – and off the C5 zoomed, provided the road was flat or downhill"

It needs no petrol, just an overnight charge from a mains socket.
Press a button to start, squeeze a lever to stop – there's no gearchange, no clutch.
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You don't need a licence. You pay no road tax.
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The C5 solves it all. You can park five C5s – comfortably – in the space normally occupied by an average family saloon. And the C5 turning circle is less than two-thirds that of a Mini.
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C5 and your family.

The C5 is such fun to drive that you may find yourself forgetting that it's also very practical indeed.

The C5 is really a resource for the whole family and it doesn't take long to discover even more uses for it. Paper rounds... visiting

New questions...

How is the C5 constructed?
For the technically-minded, the C5 consists of a high separate body. It's a proven automobile design, deve

by Polymotor in Italy – was actually designed for a truck's cooling fan, according to knowledge gained since the C5's early demise. It sucked its energy from a 12V, 36Ah lead-acid battery made by Oldham – this capacity, it was claimed, offered a range of up to 32km (20 miles), while the motor promised a speed of up to 24km/h (15mph). The 'up to' is crucial here, and certainly there was no prospect of both performance limits being reached simultaneously.

The idea was that you ordered your new C5 by post, at a cost of £399 (US$630) plus £29 (US$45) for packing and delivery. It would then be dispatched in a large cardboard box from its contract manufacturer, the Hoover washing-machine factory in Merthyr Tydfil, Wales. Sinclair had charmed Hoover into taking on not only the assembly of his project but also the service back-up, provided by Hoover's nationwide fleet of traveling service vans.

That £428 (US$675) total would buy you only the basic C5, however. If you had any remotely serious intention of driving it on the road, you might also consider the optional indicators, mirrors, horn, wet-weather apron and high-visibility reflector mast, without

which the C5 might lurk dangerously unseen between taller vehicles (essentially any other vehicles, in fact). Thus equipped, your road-usable C5 would have cost you nearly £600 (US$945).

Cold reception

I was on the staff of *Motor* magazine when the C5 was launched to the world in early 1985. Snow lay on the ground, slush and spray spewed from trucks. A worse time to launch a tiny, slow, open-top transport module is hard to imagine, but Sinclair needed a return on his investment and needed it very quickly. A large cardboard box duly arrived at the magazine's office, and shortly afterwards the C5 achieved the accolade of being the first road-test car to be driven out of the lift, along the office corridor, and parked next to the technical editor's desk.

We were all keen to have a go, but to do this properly meant taking it outside again and braving the winter. First impressions were promising. You sat more on the C5 than in it, but the curious position of the handlebars – under your legs, which were raised high to power the pedals – worked surprisingly well. Pressing a button on the left handgrip activated the motor – it was either off or on, with no power gradation possible – and off the C5 zoomed, provided the road was flat or downhill.

Uphill there was much less zoom and you had to work those legs to maintain pace. Here was the C5 concept's first key snag: far from being a small electric car with all that implies, it actually relied heavily on human muscle power. And when the battery neared the end of its charge, it became clear that pedaling the C5 was hard, heavy work.

Our tests at the MIRA proving ground showed that on level ground, using the motor continuously and the pedals not at all, the C5 expired after 12km (7.5 miles). It achieved that distance at an average speed – motor at full power, remember – of 19km/h (11mph). Any greater speeds would have been down to your thigh and buttock muscles. It's true that the cold weather reduced the battery's performance, but the mass gathering of press reporters at the C5's lavish Alexandra Palace launch a month earlier, on January 10, 1985, didn't cut the C5 much slack in that regard. Our tests did show the C5 to be capable of covering the 0-10km/h sprint in just 2.1 seconds, though.

Then there were the brakes, all two of them. The front used a bicycle-style caliper and rubber blocks, and did very little. The left rear wheel performed the C5's propulsion, leaving the right rear wheel to do the rest of the braking. This meant that powerslides in the snow were possible only when turning to the right. Such antics were fun, but driving the C5 on the road was not.

There were two problems: self-preservation and self-image. You're very vulnerable in a C5 as you create a mobile chicane at 19km/h, all but invisible to truck drivers – although you have a fine view of their wheels and axles ready to crush you, and great, direct access to their exhaust fumes. And the brakes are hopeless on a wet road: "When I pulled on the brakes the Sinclair carried on, sliding and veering to the kerb [sic]," reported *Motor*'s Kathy O'Driscoll. "As a concrete lamp-post towered dead ahead, I quickly lifted my left leg out of the vehicle and dragged my foot along the ground… I can laugh about it now, as people were then, but I could have been injured."

Aside from safety and engineering issues, part of the C5's problem was self-image

No joking matter

People laughed because the C5 was meant to look cool and futuristic, but merely made its pilots look ridiculous. That, the safety problems, and the fact it didn't really work as an EV, meant that Sinclair's plans to sell over 200,000 per year were doomed. By August it was all over, with just 14,000 C5s built and only 4,500 sold. The C5 was simply unfit for the purpose for which it was intended, although it might have done well as a simple off-the-road leisure vehicle – a role which many of the remaining C5s have played after being sold at savagely reduced prices after the liquidation of Sinclair Vehicles.

Nowadays there are thriving owners' clubs and a strong modification culture, including a C5 claimed to have reached 240km/h (150mph) and another powered by a jet engine. But the image that sticks in my mind is of a wealthy road in north London where, in the late 1980s, I saw a sad and filthy C5 abandoned by a tree. An expensive toy cast aside because it didn't work. Summed it up well, I thought.

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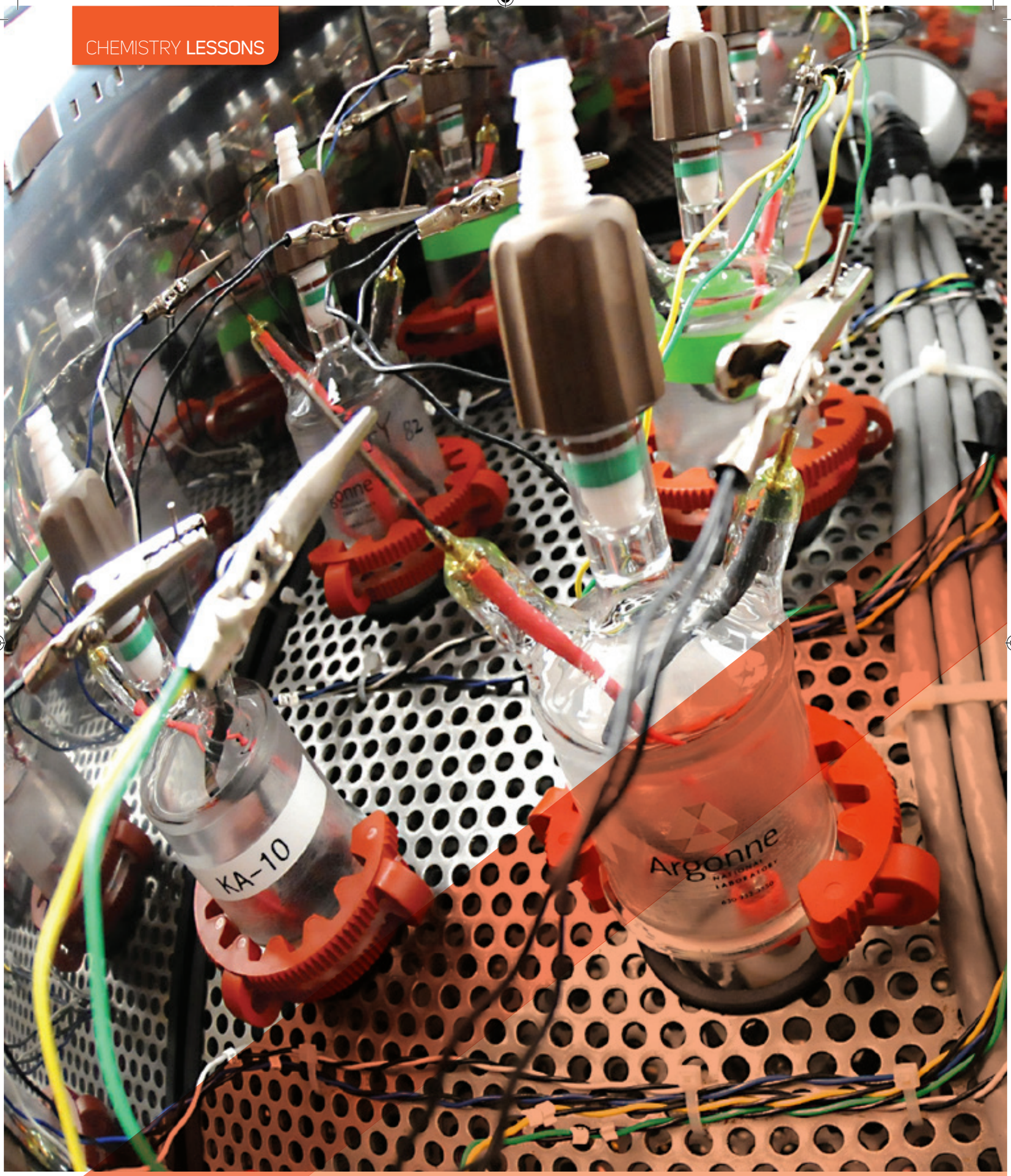
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Chemical all-stars

Electrochemists have become the modern-day alchemists, and the long-term mass-market future of electric vehicles will depend on their very clever minds

WORDS: **JAMES GORDON**

When we think of inspirational automotive figures, the electrochemist, dressed in a white coat and safety goggles, probably isn't top of the list. He or she might not be the visionary designer, the innovative powertrain developer or the super-cool chief dynamist that tests early prototypes sideways on fast proving grounds. No. But it is these so-called ordinary men and women – tirelessly working in leading-edge laboratories around the globe – whose impact on the EV movement might be far greater, so extraordinary is their work.

Why? Because, simply put, their legacy has the potential to affect society as a whole. It is the promise of a world where electric and hybrid vehicles dominate over their traditional IC-engined cousins, but that sustainable transportation utopia will happen only if things on a battery – and cell – level are pushed forward tenfold. The man at the forefront of that movement – Tesla CEO Elon Musk – summed the situation up perfectly last year when he told *E&H*, "Battery chemistry is a tricky thing – it is remarkable how many so-called breakthroughs I read about that turn out to be nonsense. Every time somebody says they have a breakthrough battery technology, I say 'great – send us a sample', but they never do. Either that or they do and it doesn't quite live up to expectations."

Musk's comments provide good grounding – it will take EVs – and therefore battery technology – time to jump from the automotive niche and into the mainstream. Electric car entrepreneur Shai Agassi, the then-CEO of Better Place, told Associated Press in 2011 that he expected more people around the world to be buying EVs than cars powered by gasoline by the end of the decade.

But four years since he made his bold prediction, Agassi's prophecy shows no sign of coming true. So what really does need to happen before electric and hybrid vehicles begin to replace their traditional IC forerunners? And just when will a battery give an EV enough range for it to truly compete with a frugal gasoline three-cylinder or a new-gen long-distance diesel motor?

1. Inspection of a Li-ion battery at the Johnson Controls Meadowbrook facility in Holland, Michigan. Photo: Dan Irving for Johnson Controls

2. Scientists are developing multiple cell chemistries to support the full range of advanced energy storage solutions. Photo: Johnson Controls

RECYCLING OR REUSE?

The question whether to recycle or reuse a battery is perhaps one of the greatest challenges electric and hybrid vehicle manufacturers will face in the next decade, and currently there is no large-scale process in place for the former.

"It's not that the OEMs have taken their eye off the ball," says Isobel Sheldon, business manager for Ricardo's hybrid and electronics team. "On the contrary, many OEMs such as BMW and Nissan are currently putting a lot of thought into recycling lithium-ion batteries.

"The issue is that most batteries have an 8-10-year lifespan and therefore the majority of batteries out there are only half way through their useful lives," she says. "Therefore we have another four years before we see any significant quantities of batteries coming back. So at the moment, the only batteries that do come back are likely to be broken ones. They are going into fault diagnosis and analysis so that the industry can improve the design of batteries going forward."

One alternative to recycling might be to simply reuse the battery. Nissan, for example, is one such car maker that's looking at giving batteries a second life.

For Ulrik Grape of Seeo, reusing batteries could continue to improve the cost profile because there will be a secondary value, he says. The VP also thinks that potential uses include capturing unused energy produced at wind or solar farms; back-up energy storage for domestic grid support and islands markets; and where cars travel no more than 96km (60 miles) each day.

But Sheldon believes that battery reuse could present several challenges around configuration and safety, leaving an unclear path forward for the industry in general.

"One of the fundamental problems that you have got there is that they [the batteries] are all at different voltages and all at different capacities and you are not likely to get all of the same type back in the exactly same configuration at the same time," she says.

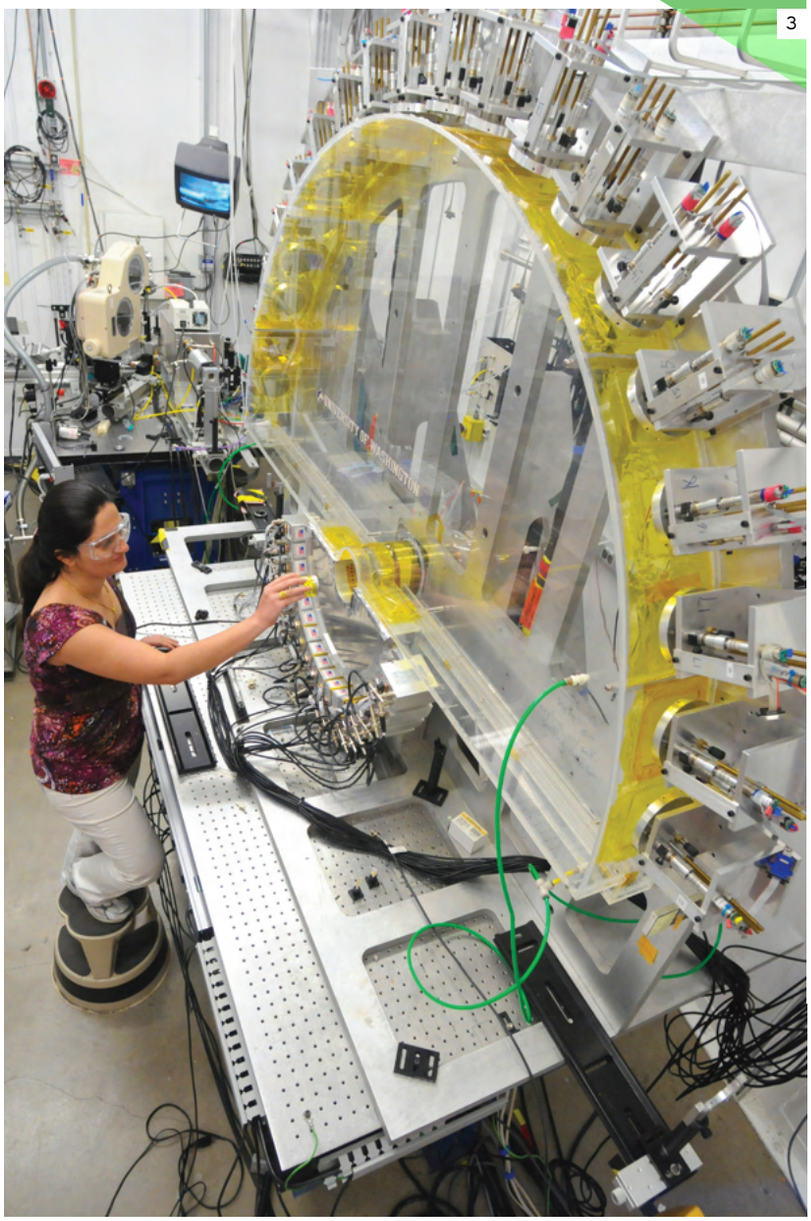
The Ricardo manager also thinks the industry must think carefully about reusing car batteries for domestic energy storage.

"Some of these batteries have got quite volatile chemistries in them. When they reach the end of their life, the risks can increase. There is also an additional hazard in that most electric vehicles operate at several hundred volts DC. And there are two problems with that: one is that you have to convert that into a usable electric form to match the domestic energy supply. The other problem is the risks associated with the use of high-voltage battery systems in a domestic situation where, for example, there may be children present."

"Many OEMs such as BMW and Nissan are currently putting a lot of thought into recycling Li-ion batteries"

Isobel Sheldon, business manager, hybrid and electronics team, Ricardo

3. An ANL scientist loads an in-situ lithium-ion battery into the Low-Energy Resolution Inelastic X-ray (LERIX) system at the Advanced Photon Source (APS). Photo: Argonne National Laboratory



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For industry insiders, it is the painstaking work that goes into battery research and development that will determine whether or not the electric car does become the vehicle of tomorrow.

Currently, the vast majority of EVs use a lithium-ion battery, but massive challenges around energy, power, performance, range, lifetime and cost mean that petrol and diesel vehicles continue to hold sway right now.

Some schools of thought even believe that there is no long-term future in lithium-ion technologies, and electric and hybrid vehicles won't begin to dominate the automotive scene until electrochemists focus their energies on other new breakthrough materials.

But, for the most part, the large majority of engineers, scientists and companies continue to believe in lithium-ion and think that further advances in cell technology could make all the difference. And most also agree that in the near-term at the very least, energy-storage systems will be constructed from an incremental development of existing lithium-based cell technology with improved energy and power density, stability and life.

Take Seeo, a California-based battery development company that truly believes lithium-ion technology will be the EV choice for at least the next decade.

"My personal opinion is that lithium-ion has many years left in terms of its development," states VP Ulrik Grape. "That includes the new cutting-edge technology. I think that battery developers can advance lithium-ion chemistries so that we reach the level where the automotive industry believes that electric vehicles can become highly competitive with traditional ICE vehicles."

He adds, "There is talk of fuel cell technology that may come in, but the fuel cell vehicles I have seen demonstrated use a lithium-ion battery to assist and work with the fuel cells. I believe that lithium-ion is the ideal technology for these kinds of applications far into the future."

Dr Allan Paterson, chief electrochemist at Johnson Matthey Battery Systems, formerly Axeon, also believes that the incremental development of current lithium-ion-based technology is likely to be around for some time.

"At battery pack level, mechanical packaging and cell integration have a role to play," he says. "In this sense, we will continue to be heavily involved in programs and research investigating and developing the tools and capabilities that are key enablers and extenders of lithium-ion cell capabilities."

But for Patterson, in the short- to mid-term, it is improved cell chemistries that will reduce costs and enhance range in electric vehicles.

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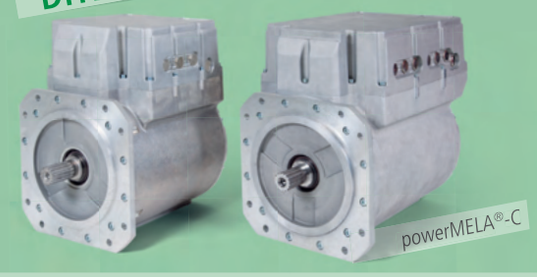

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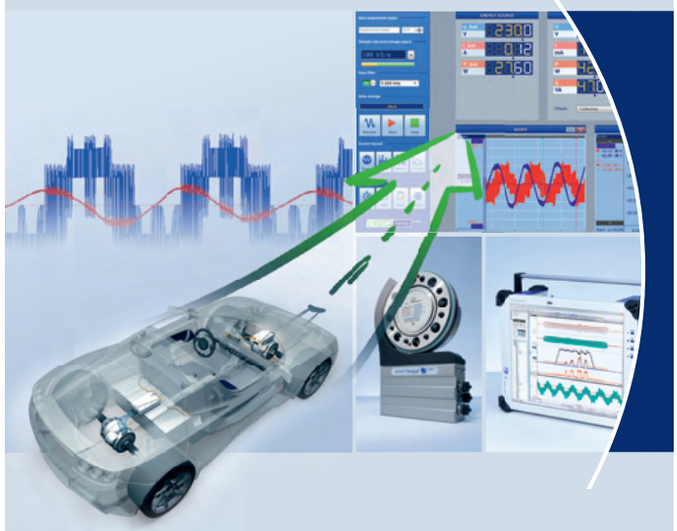

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"The Tesla Roadster and Model S use high-energy 18650 lithium-ion cells, of approximately 3Ah," he outlines. "However, the introduction of improved cell chemistry indicates that a capacity of 3.5Ah can shortly be reached for same format cells, and in the future hopefully closer to 4Ah, thus potentially being able to provide a significantly longer range for exactly the same size pack."

But what about a longer-term outlook, beyond the next decade? Patterson replies, "In the longer term, the novel cell chemistries have a potential to at least double or even triple the energy density of the onboard energy-storage systems and therefore boost the available range for EVs," he predicts. However, the Johnson Matthew chief quickly adds this is unlikely to happen in the next 10 years.

Life after Li-ion

But not all electrochemists believe in a rosy, long-term future for lithium-ion. Dr Mark Crittenden, head of business development at Oxis Energy in the UK, is convinced that there is life after lithium-ion and thinks the industry may see exciting developments much before a 10-year timeframe. Oxis is a leading pioneer of lithium sulfur battery technology, which has some key advantages over competitor chemistries, including Li-ion.

According to Crittenden, lithium sulfur is already being introduced into various applications displacing lithium-ion technology, and he expects the former to be widely adopted over the next few years. Crittenden also adds that Oxis technology has already achieved more than double the energy density found in the battery of a Nissan Leaf.

"Lithium sulfur batteries have several advantages over lithium-ion ones," says the Oxis exec. "The main two advantages are safety and being lightweight. For an electric vehicle, having a lightweight technology means a higher capacity battery can be installed, and thus the range will be improved. If you double the capacity for the same weight, you double the range."

In addition to improving battery power, the phenomenon of range anxiety and the high cost of EVs are also key barriers to widespread EV adoption. Currently, Tesla offers consumers a choice of three offerings in the Model S range. The 85D, which can travel 498km (310 miles) on a fully charged battery, is the most economical vehicle in the S stable, but at US$88,465, it falls outside most drivers' price bracket.

In this respect, Crittenden believes that if lithium sulfur batteries became the battery of

A CASE FOR DEFENSE

It's not just automotive where battery advancements are being felt. Next-generation defense vehicles are also part of the Li-ion product application push. Earlier this year, Thales Australia announced it had selected Saft to deliver Li-ion battery systems that have the potential to power up to 1,300 Hawkei military vehicles.

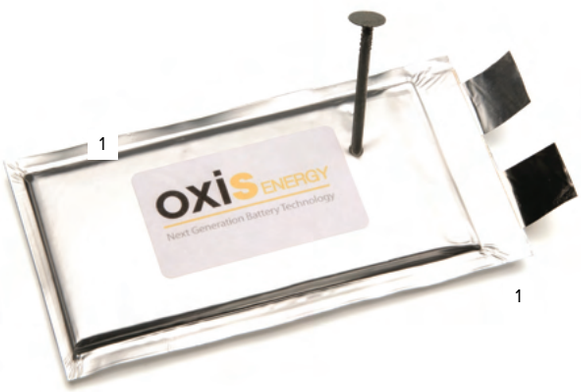
Saft has already begun deliveries of advanced Li-ion batteries for use in prototype vehicles and, upon success, will extend to a follow-on contract for further applications early in the third quarter of 2015.

The Hawkei, which is highly mobile, armed and light, is a helicopter-deployable unit that fulfills a number of operational roles, and uses its small size to move stealthily, remain hidden and provide levels of coverage and safety that are critical. It is equipped with systems that provide unparalleled situational awareness and lethality for a vehicle of this size and weight.

Saft battery technology features a lightweight design within the dimensions of a traditional lead-acid battery, enabling easy integration into a vehicle. The system will have power starting, lights, ignition and silent watch capabilities.

The Hawkei program will allow Saft to further demonstrate the capabilities of its battery tech for military ground vehicles.

"The Hawkei project signals the growing use of Li-ion technologies to power military and defense applications throughout the world," says Thomas Alcide, president of Saft America and general manager of Saft's Specialty Battery Group. "Saft's longevity and system design expertise uniquely positions it to partner in the development of next-generation technologies and applications, and we are honored to be part of this program."



1. Oxis Energy is a pioneer in lithium sulfur battery technology which, it claims, offers improved energy density, greater safety and reduced weight

"For an electric vehicle, having a lightweight technology means a higher capacity battery can be installed, and the range will be improved"

Mark Crittenden, head of business development, Oxis Energy

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choice for EVs, then the cost of running an electric vehicle could be reduced. But by how much, and (perhaps more specifically) would this reduction be enough to get EVs into the mainstream domain?

"Our high volume forecast at the battery level is US$250/kWh in 2020," states Crittenden, meaning that the Oxis forecast would meet the ambitious cost target set by the United States Advanced Battery Consortium.

Air tight

But it's not just the UK innovator that's championing lithium sulfur. Over in the USA, technology and engineering powerhouse Argonne National Laboratory is also a fan. But Lynn Trahey, ANL research integration officer, also thinks that magnesium-ion and lithium-air are top contenders to replace current king, lithium-ion.

However, she believes there are some challenges ahead before tin nanocrystal lithium-ion batteries, which could double the energy capacity of an electric vehicle battery, can become a viable alternative to lithium-ion.

"Tin is an anode material that can potentially replace graphite in lithium-ion batteries," states Trahey. "Silicon and lithium metal are two other heavily researched graphite alternatives. Doubling the capacity of one electrode is always good, but ultimately fruitless if that capacity can't be sustained for hundreds of battery cycles in a full cell configuration at appreciable rates. A compromise is the addition of small percentages of tin and silicon to graphite electrodes, which is one way developers are trying to boost capacity."

For Trahey, metal air and zinc-air batteries are also on the table and should be taken seriously. In fact, the future for metal-air batteries looks particularly bright, she says.

One company attempting to maximize its potential in the battery air arena is Phinergy. On its website, the developer, led by Aviz Tzidon, claims to have successfully integrated an aluminum-air battery system into an EV, providing a driving range that is more than three times the range of electric vehicles now on the road.

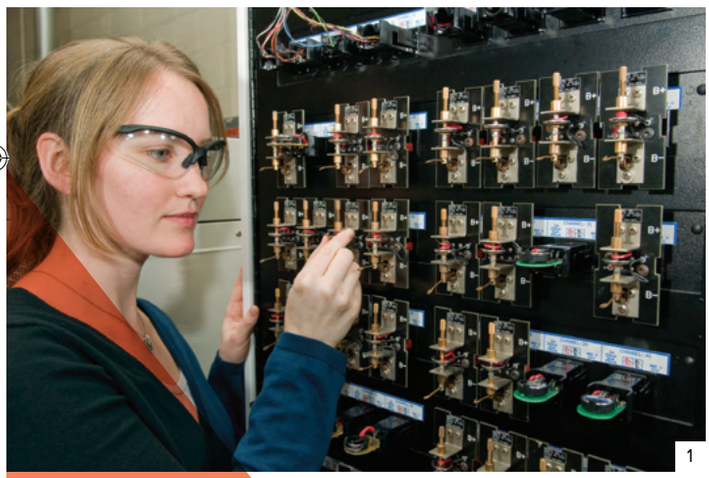
Nobody at Phinergy was available for comment, but ultimately it will be for the OEMs to convince themselves through economies of scale that metal air batteries can replace current and next-gen lithium-ion ones.

Mechanical shift

With the future of automotive electrochemistry being exciting, but less than clear, strategic alliances among key industry players need to be forged. As such, it is not yet clear if car makers will buy batteries from Tier 1 suppliers, create JVs like the Mercedes-Benz and Bosch collaboration, or simply bypass them and seek new partnerships with actual cell manufacturers. For the latter, there's already evidence that this is happening. Toyota, for example, has formed an alliance with Panasonic in Japan, as has Tesla with its Gigafactory investment.

But whether there has been a definite sea change in processes, outlook, and ways of working, is too early to say. The likes of Bosch, Schaeffler and Continental are all ramping up e-powertrain activities, including battery development on the whole, but these three big Tier 1s – in addition to others – declined an interview, citing cell development as not being part of their remit.

Yet that's not to say that the large Tier 1s are not interested in helping to advance battery technology in electric and hybrid vehicles – quite the opposite, in fact. And rather than concentrating on battery cell chemistry, some have even decided to focus their R&D efforts on mechanical batteries and kinetic energy recovery systems.



1. Lynn Trahey, research integration officer at ANL, loads a coin-sized cell on a testing unit to evaluate electrochemical cycling performance. Photo: Wes Agresta/Argonne National Laboratory

SUPER SODIUM

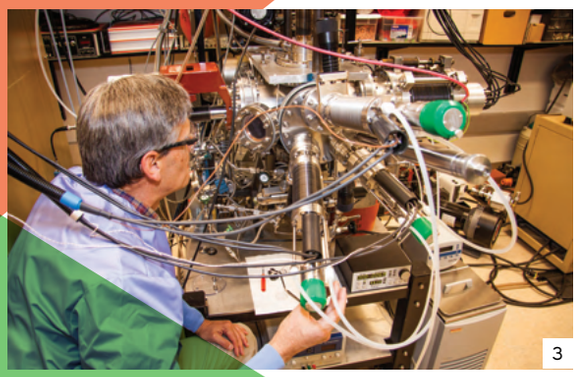
It could be time for a shift from lithium-ion to sodium-ion, as battery R&D innovator Faradion showcased the world's first sodium-ion powered vehicle in May at the headquarters of Williams Advanced Engineering in the UK. The e-bike, say its developers, is a proof of concept to showcase the capabilities of this new battery chemistry.

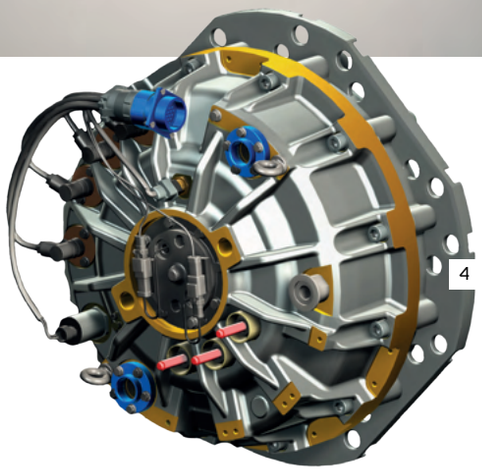
According to Faradion, sodium-ion offers significant cost, safety and sustainability benefits when compared with lithium-ion. What's more, the base materials required for sodium-ion batteries are more easily sourced than those needed for lithium-ion designs, which are only found in a limited number of markets around the world.

The UK developer says sodium-ion batteries are considerably less expensive than their lithium-ion counterparts, offering savings of around 30% in terms of cost per kWh. As well as these benefits, sodium-ion batteries have significant safety advantages too, as they can be transported in a totally discharged state while, by comparison, lithium-ion units must be partially charged when they are transported.

The battery for the e-bike has a total design energy of 418Wh, 250Wh of which has been used in the e-bike. Faradion's sodium-ion cells deliver a specific energy of more than 140Wh/kg.

The e-bike battery pack is made up of four modules, designed and manufactured by Williams Advanced Engineering, and controlled by its own battery management system. Each module contains 12 Faradion cells. The University of Oxford's expertise has been used to maximize battery lifetime and initial test results indicate that, as well as comparable performance, sodium-ion cells offer comparable lifetimes to lithium-ion products.





1. Preparing batteries for controlled environment testing. Photo: Argonne National Laboratory

2. GKN Hybrid Power's flywheel system is an example of R&D focused on mechanical batteries and energy recovery

3. A researcher at the Advanced Materials Laboratory deposits an electrode film for investigation as an air cathode in a metal-air battery. Photo: JCESR

4. GKN's flywheel system is being used to make buses more fuel-efficient

"Operators may invest in buses with Li-ion batteries for some routes as authorities may not allow diesel engines on certain streets"

Jules Carter, chief engineer, advanced engineering technologies, GKN

One prime example of this is GKN Hybrid Power, which is responsible for developing the Gyrodrive electric flywheel system that is being used to good effect to make buses in cities like London more fuel efficient.

Jules Carter, GKN's chief engineer for advanced engineering technologies, thinks that mechanical batteries and those influenced by electrochemistry can coexist in the future. He also says that different scenarios may call for different energy solutions.

"If you are a bus operator, in the future you may invest in buses with lithium-ion batteries for some routes as they [local authorities] may not allow diesel engines on certain streets, such as in city centers, like Oxford Street in London's case," he says.

However, Carter thinks many bus operators will want to employ the Gyrodrive system in their fleets, as it costs around US$61,500 annually to fuel the average London bus and the GKN technology can lead to fuel savings of around 20%.

"The energy-storage system weighs 60kg [an equivalent electric battery pack weighs about 400kg], so the operator benefits as the bus doesn't have to carry the excessive weight of a battery. And the flywheel can be fitted under the seats," he adds.

So, the next time you see a celebrity driving a high-powered electric vehicle, a designer waxing lyrical about the styling of a new EV, a powertrain chief getting an award for a revolutionary electric propulsion system, or even reading about how good a new EV's ride and handling is, spare a thought for the diligent and dedicated electrochemist – that modern-day alchemist – whose life's work has helped ensure the concept of e-mobility has been released from the R&D lab and onto the open road.

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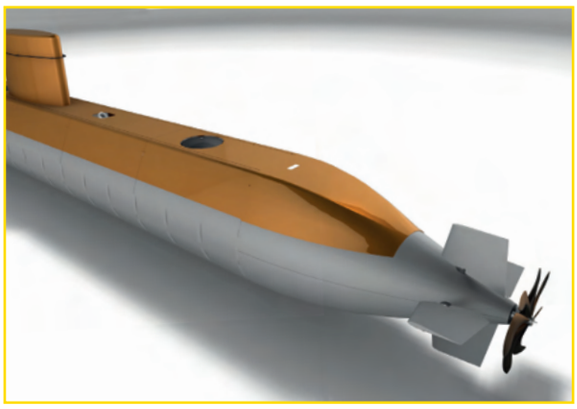

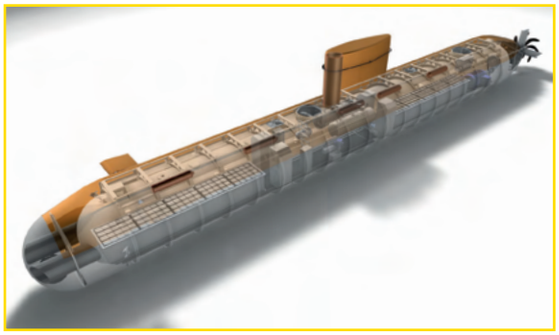

- Li-S is a safe chemistry that does not react aggressively when damaged and continues to provide reliable function. It withstands abuse such as short circuiting, crushing and even the puncturing of cells.
- The continuing development of a Li-S battery will enable greater endurance at higher speeds for transit to survey sites which are often in remote locations, resulting in fewer launches and recoveries.

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High voltage!

48V battery systems have been hailed as the next step in affordable mild hybridization, so surely it's only a matter of time before the automotive industry adopts them en masse?

WORDS: **JACK CARFRAE**

You'd have to go as far back as the 1950s to find a car that didn't operate on a 12V electrical system. Granted, some of the core components of today's hybrid and electric vehicles run at higher voltages, but the conventional dozen volts has dominated for decades. However, all that now seems set for change.

New cars, particularly those in the large premium segment, are reaching the limits of their electrical demands. Couple that with the ever present need to increase economy and reduce emissions, and there is a case for seriously firming up the battery. But that brings its own set of cost and operational issues and it's no secret that high-voltage hybrids and full electric vehicles are not cheap to develop and produce, nor are all of them even sold at a profit.

This is where 48V technology comes in. Seen as the next step between the current 12V arrangement and complex, expensive and high-voltage EVs, 48V lead-acid batteries allow for a moderate amount of hybridization, can fuel power-hungry components and, next to hybrid and EV systems, are comparatively affordable.

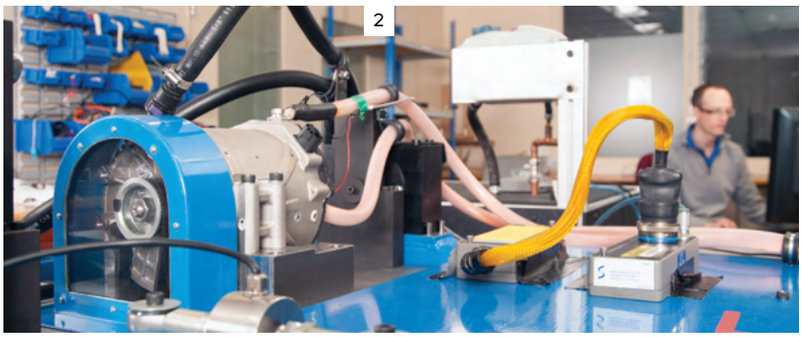
Powering change

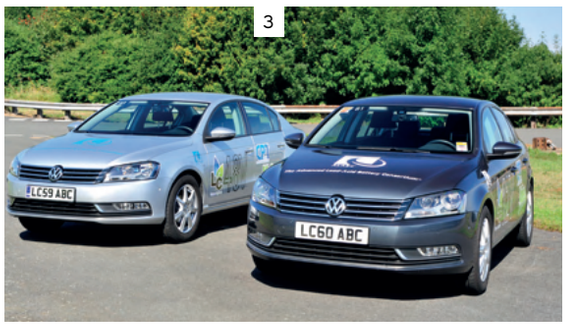
Also known as lead-carbon batteries, the technology frees up more opportunities for electrification – but doesn't go as far as driving the wheels. Changes typically take the form of a starter generator motor in place of the alternator and/or an electric charging system for extra power. Among the claimed benefits are increased fuel economy and the ability to have smaller IC engines with the comparative performance of much bigger units.

"Our cars already incorporate a large number of power-hungry consumers and we are close to reaching the limits of capacity that a conventional configuration can provide"

Jens Koetz, head of electrics, electronic concepts, connectivity and energy systems, Audi AG

With the RS5 TDI concept, Audi has made its intention clear to adopt 48V technology





1. Rigorous testing of battery technology has shown that higher voltage systems accept charge better than 12V batteries

2. CPT's environmental generating durability test rig is capable of testing its 48V belt integrated starter

3. CPT and EALABC's Passat-based vehicles operate on two different voltage systems: one on 12V, the other on 48V

Audi is one of a handful of manufacturers that has made public its plans to incorporate the technology, having previewed 48V concept versions of its A6 TDI and RS5 TDI models. "Our cars already incorporate a large number of power-hungry consumers and we are close to reaching the limits of capacity that a conventional configuration can provide," admits Jens Koetz, head of electrics, electronic concepts, connectivity and energy systems at Audi AG. "The nascent potential in numerous new technologies, such as the electrically powered compressor or e-booster, which improves performance by using electrical power rather than exhaust gases to spool up a turbocharger at low engine speeds, can only be fully realized with a 48V system on board.

"As an additional benefit, the higher voltage system also permits smaller cable cross-sections, and therefore lighter cable harnesses with lower power dissipation – a small but nevertheless important contributor to the reversal of the weight spiral."

And it's that electrification of boosters and other such components that has the potential to deliver major improvements in efficiency. The European Advanced Lead-Acid Battery Consortium (EALABC) is one of the pioneers behind the technology and project coordinator Allan Cooper outlines the possibilities: "The work we have been doing in the past three to four years on super hybrids [another term for 48V lead-carbon battery vehicles] has shown that, for not a lot of cost, you can have CO_2 savings in the region of 20% or more, especially with the

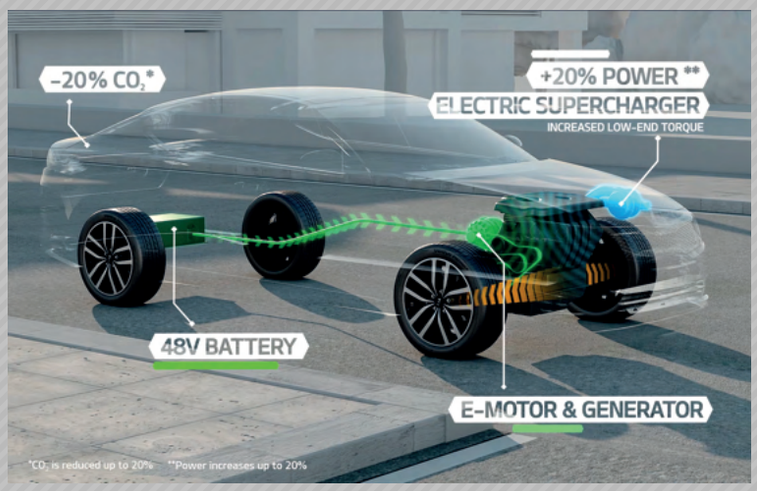
Future generation Kia vehicles will be available as mild hybrid models

TURNING UP THE VOLTAGE

It's not just Audi that has publicly signaled its intentions to run with 48V systems soon. Hyundai-Kia also has designs on the technology for production vehicles, having recently displayed prototypes with belt-driven starter generators and electric superchargers.

In addition to the power and efficiency gains, Kia maintains that 48V batteries are 98% recyclable at the end of their life and far easier to recycle than lithium-ion products. Powertrain head Jurgen Grimm even told *E&H* last year that he wouldn't be surprised if others soon followed Hyundai-Kia's lead with lead-carbon batteries.

CPT's CEO, Pascoe, also believes fellow manufacturers will follow suit as the decade unfolds: "More exotic and niche vehicle applications will happen in 2016. The early adopters – they're the normal candidates – will appear in 2016 to 2018 and the early volume followers will be 2018 to 2019."



combination of an electric supercharger and electric starter generator."

In conjunction with the EALABC, low-carbon powertrain specialist company Controlled Power Technologies (CPT) has developed a pair of VW Passat-based vehicles, one operating on a 12V system, the other on 48V, with various electrified components. "With the 12V vehicle we got a 7.5% economy improvement," reveals CEO Nick Pascoe, "and with the 48V vehicle we got around 16-17% on the NEDC. We are still working on achieving a balance between acceptable drivability and fuel economy."

"With the 12V one we got a 7.5% economy improvement, and with the 48V one we got around 16-17% on the NEDC"

Nick Pascoe, CEO, CPT

Big demands

The general consensus is that it's large cars, such as the Passat and typical Audi products, that are crying out for more voltage. Not only are they heavier than an average supermini or family hatch, they also pack more equipment and electronic luxuries, many of which take their toll on overall fuel economy. "48V is driven by the premium car segment," reaffirms Pascoe. "They're heavy vehicles, around 1,500kg, and have a lot of features. The best way of getting fuel economy with these cars is by capturing energy during deceleration – they're heavy so there's a lot more energy to capture."

This is where the regenerative element comes in, as the higher voltage systems are better able to accept charge where 12V batteries would typically deteriorate. "With lead-acid [12V] batteries, if you push a lot of charge into the battery you get an effect called sulfation," says Pascoe. "If you switch to lead-carbon [48V] then the battery can accept more short-term, intense charges. Regeneration saves the parasitic load of running an alternator, which is around 3%."

Having a battery with four times more power than the average system brings its own safety concerns but, say the specialists, 48V is still well below what is widely regarded as the safe limit and no special treatment is needed during development or for the car itself. "60V is widely regarded as being about the safe limit for a human being to get a shock," confirms Cooper. "Some of the Honda and Toyota hybrids use 140V and 270V, but at 48V you will just get a nasty kick. It won't kill you."

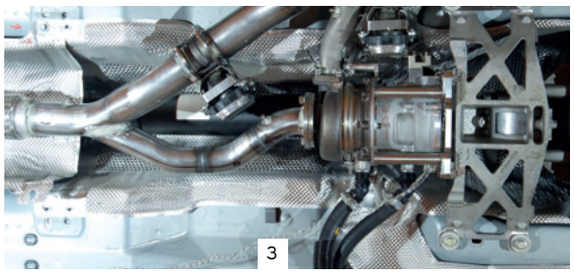
Yet despite such promise from 48V technology, 12V systems are not expected to die out completely, and nor

should the former be considered a complete replacement for the latter. "48V won't become the new 12V, but you will see dual systems," predicts Cooper. "Low-voltage systems are still necessary for electric windows and dashboard lights, which would be expensive to change all at once. Heavy power uses and whole regenerative systems are going to 48V."

And as this kind of technology becomes more common, batteries and moderate electrification are set to play a bigger role, too. Pascoe outlines the thinking: "Suddenly you're saying that for this configuration, [the car is] not going to be an electric machine but it's heading in that direction, so who takes responsibility for that? Is it the electrical engineers, is it drivetrain team or is it someone else? These are huge organizations that are having to evolve very quickly. For years the battery was always something you just stuck somewhere but now it's a huge consideration. Some of the really complex and interesting components are no longer so because they are being simplified, and conventional components such as the battery are becoming more complex."

"Some of the Honda and Toyota hybrids use 140V and 270V, but at 48V you will just get a nasty kick. It won't kill you"

Allan Cooper, project coordinator, EALABC



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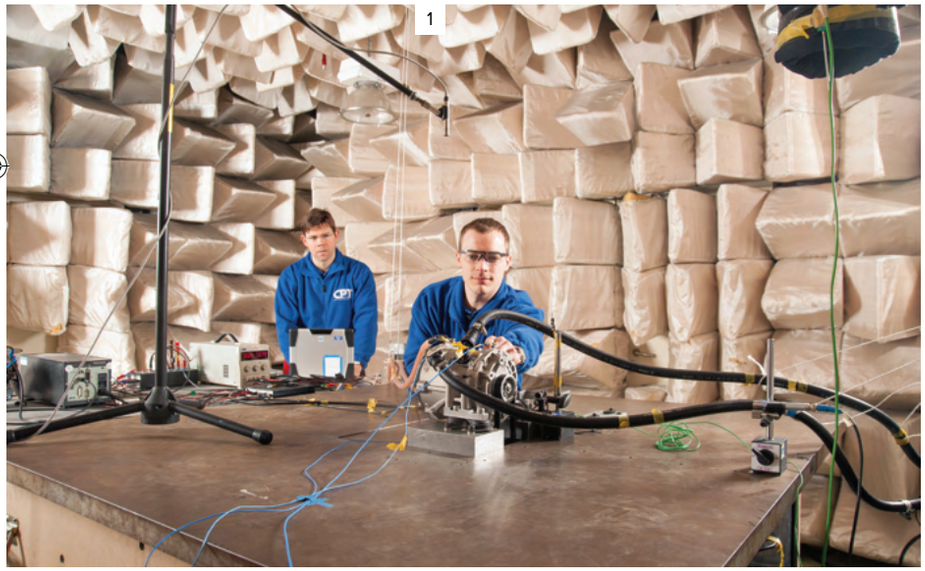

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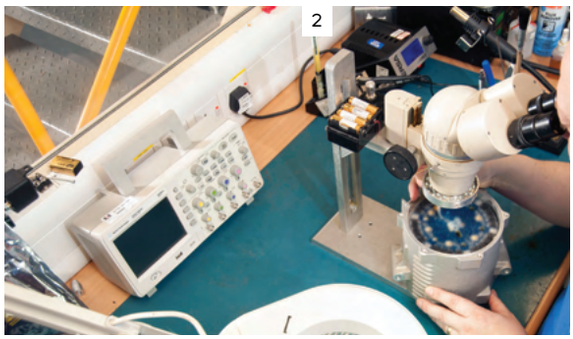

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1. A battery with four times more power than the average system could be cause for concern, but 48V is well below the safe limit

2. CPT's SpeedStart belt-driven integrated starter generator unit undergoes regular forensic examination

3. CPT's Tigers thermal energy recovery system is installed in Jaguar Land Rover's VIPER (Vehicle Integrated Powertrain Energy Recovery) technology demonstrator

POLE POSITION

Given the headway the technology is making with OEMs, it's perhaps not surprising that 48V batteries have also appeared in motorsport. Formula 1 teams have adopted the technology in the interests of saving weight, as Angus Lyon, director of Rockfort Engineering, explains: "Things like 48V fuel pumps and fuel systems are quite common now. It's all basically high-power systems because it allows you to go to a lower current draw, lower losses in the wiring loom and lighter weight wiring, which obviously for something like F1 is a key thing."

Lyon says that increased speed is also a boon: "It's partly because of response, because 48V gives you a lot more kick, so you can change things more dynamically. Think of hydraulic or mechanical actuation; electric is a lot quicker responding."

The downside, however, is the effect the new technology has on smaller specialists – both in motorsport and the automotive development and testing arenas: "The only big issue is that it's brought an unexpected cost and complication. Typically labs would be outfitted with variable voltage and current supplies but they'll go up to something like 24V because they're all used to running at 12V. This is the kind of thing that won't be a problem for OEMs and big companies because they'll go out and get good quality lab equipment.

"For around US$200 you can get a fairly good quality current and voltage supply that does up to about 18V and that's what your average small company will be doing. With 48V, suddenly all that is null and void and it's harder to go and get nice, cheap, cost-effective equipment.

"It's not really a problem per se, just more an unexpected step to have to try and kit your labs out with a full secondary set of equipment for testing and measurements."

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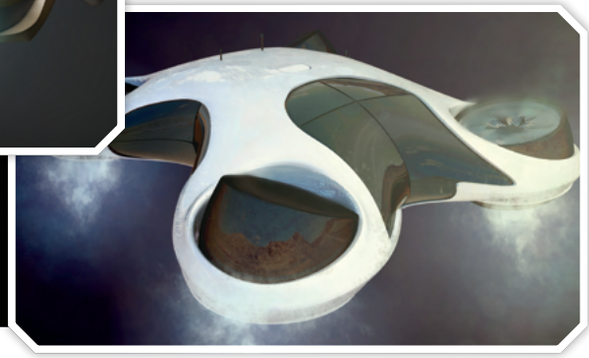
Designs for life

CGTrader, a rapidly growing online community for 3D graphics and printing designs, recently unveiled the best entries for its Future Vehicles Challenge, a competition that tasks 3D design engineers the world over to envisage how society will travel as sustainable transportation evolves in terms of technology and acceptance. Here are just some of our favorite (and wackiest) design concepts...



FERRARI INEO

Designed by Viktor Uribe Chacon, Sabin Florian Melinte and Francesco Binaggia, in cooperation with the Ferrari World Design Contest, the 1+1-seater Ineo features a V8 engine, magnetic brakes, tilting wheels and deformable flaps, while the vehicle's interior is dominated by a large display, designed to deliver information and navigation data to the driver's racing-style seat position, which the designers suggest also reflects the position often adopted by video gamers.

PEUGEOT EX-1

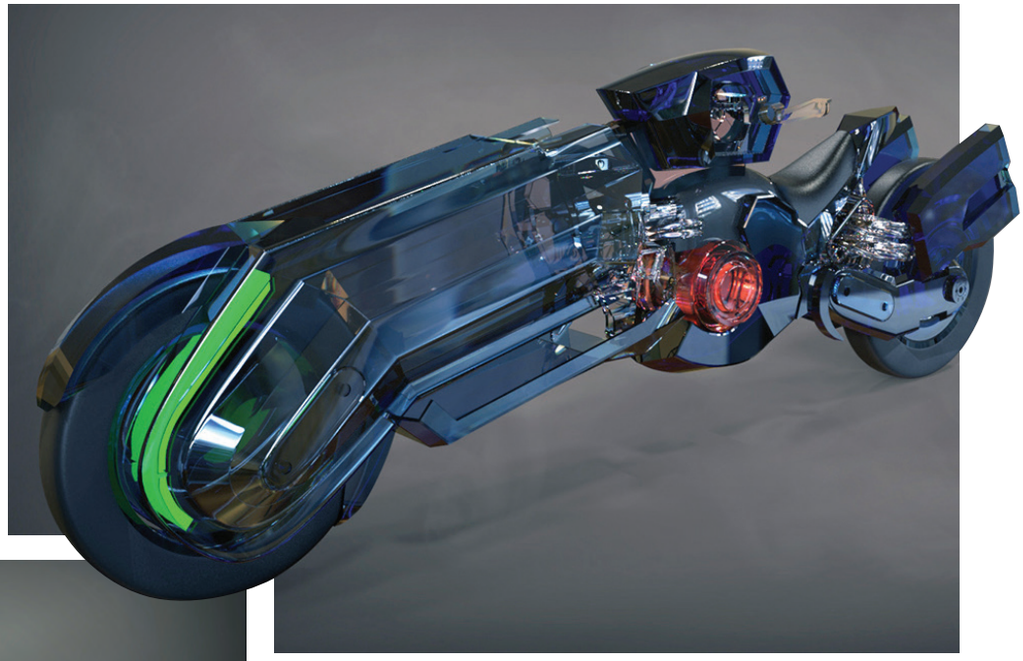
As part of Peugeot's 200th anniversary celebrations, the OEM designed the EX-1 as a concept electric vehicle. Shaped like a water droplet (around a closely grouped pair of rear wheels), the EX-1 is a two-seater roadster powered by an all-electric zero-emissions propulsion. Peugeot has built a physical version of the EX-1 – powered by two electric motors for a total system output of 340ps and 480Nm of torque. The EX-1 also broke six speed records for a vehicle weighing less than 1,000kg.

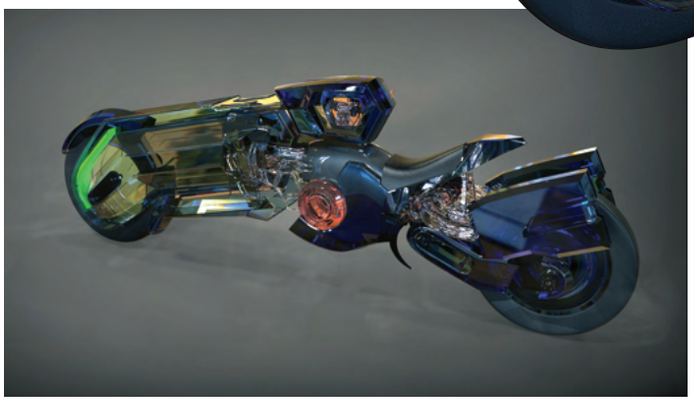
ASTON MARTIN CC100

Inspired by the DBR1 of the 1950s, Aston Martin's CC100 features an open split cockpit, cutaway doors and twin rear buttress. Designed by Miles Nurnberger for the OEM's 100th anniversary, the CC100 is powered by a naturally aspirated V12 engine, mated to a hydraulically actuated automated sequential manual 6-speed gearbox. The concept's top speed is limited to 290km/h (180mph) and will sprint from 0-100km/h in just over 4 seconds. It may not be the most eco-friendly of designs, perhaps, but this concept is so stunning that we simply had to include it.

DYNASTY

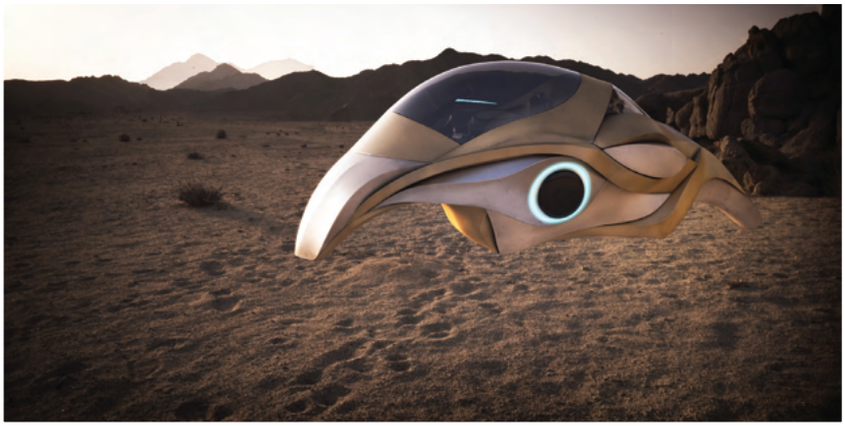
Designer Yavuz Selim Balcioglu opted for a radical reimagining of motorcycle design in his entry to the competition, envisaging two-wheel transportation as a key element of getting commuters from one place to the next. Balcioglu drew on futuristic science fiction movies for his design, and opted for an electric powertrain – something he believes is key to a healthy environment. Previously based in Canada, Balcioglu now lives in Turkey. He is a prolific designer, having worked on more than 2,000 pieces. He also recently won an Autodesk design challenge.

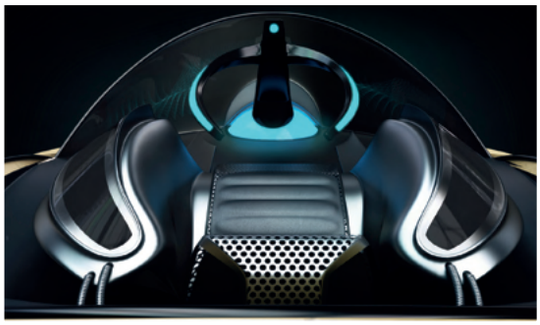




SANDBLASTER

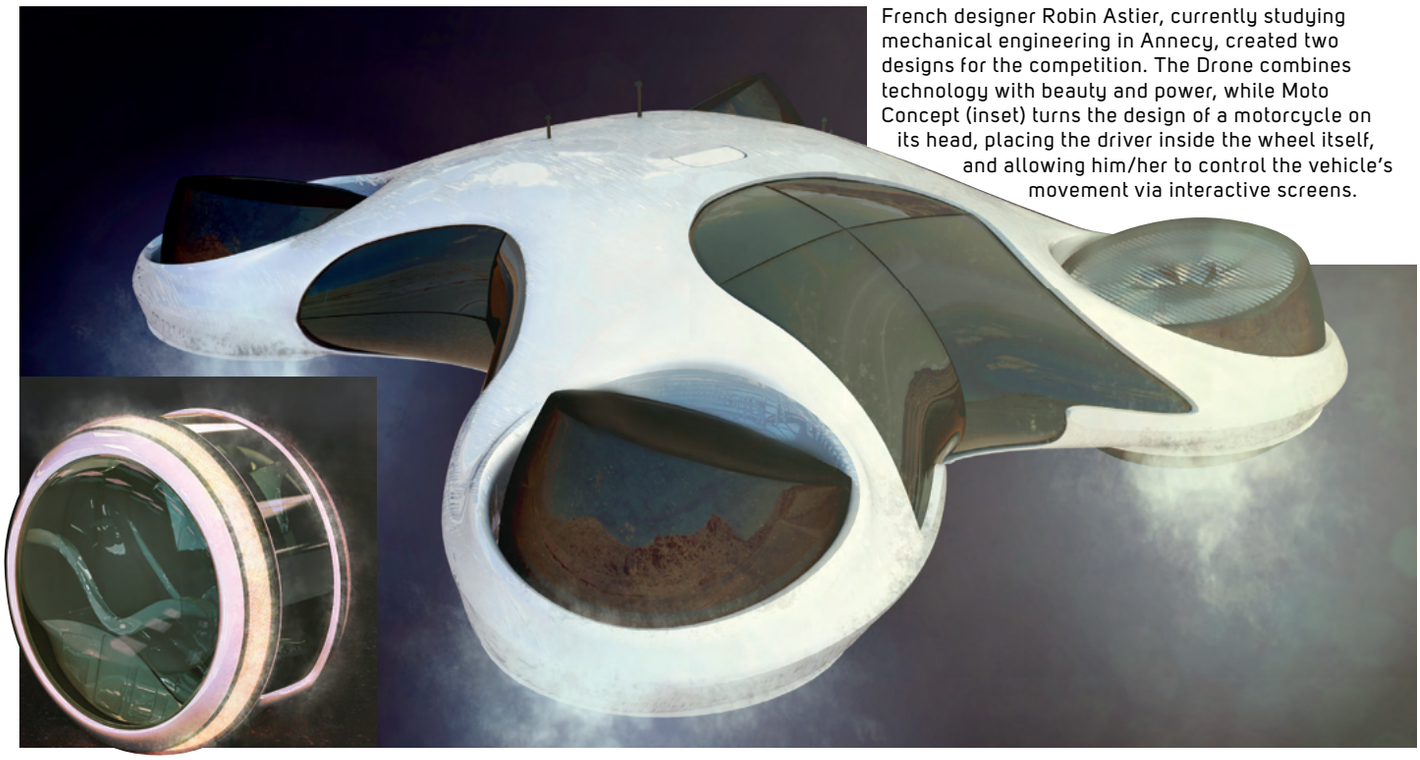
In designing his entry to the competition, Okan Mutlu Akpinar from Turkey imagined a dystopian future where sand dunes have covered the face of the planet, and created a flying vehicle adapted to take advantage of the altered environment. Designed for a world where people cannot travel without making use of aerial vehicles, Sandblaster uses sand and chemical components to manufacture fuel. The vehicle takes design cues from fluid forms, which enable it to be blend in with the sand dunes that dominate its environment.





DRONE & MOTO CONCEPT

French designer Robin Astier, currently studying mechanical engineering in Annecy, created two designs for the competition. The Drone combines technology with beauty and power, while Moto Concept (inset) turns the design of a motorcycle on its head, placing the driver inside the wheel itself, and allowing him/her to control the vehicle's movement via interactive screens.



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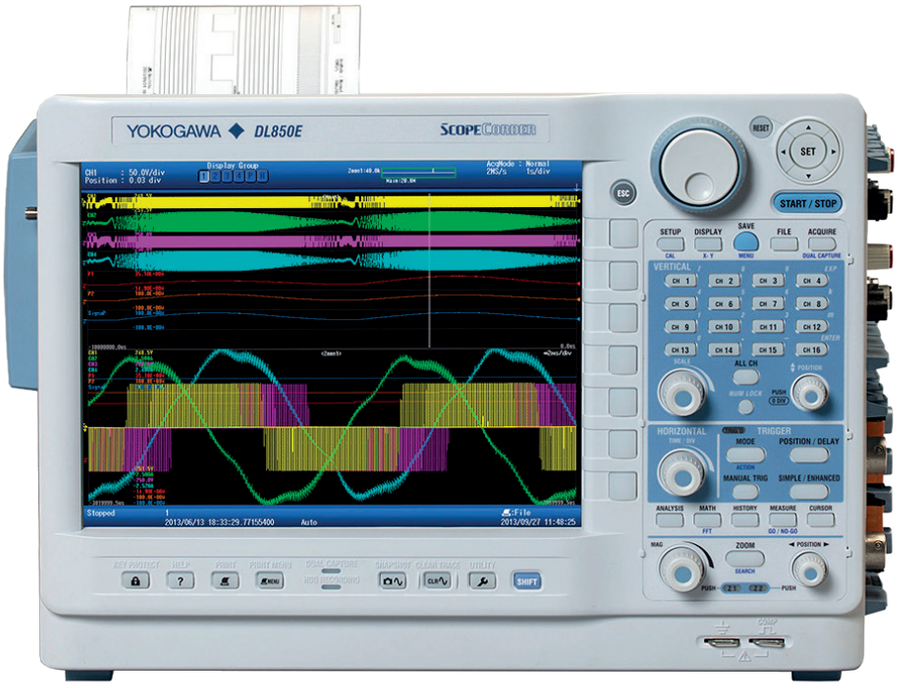

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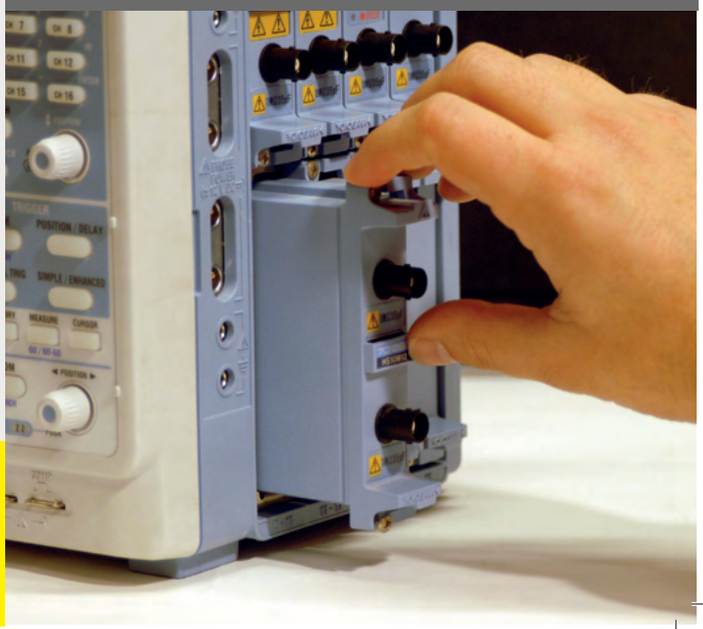

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A BYD ebus starts full service in London. The Chinese OEM has had spectacular success around the world, with its ebuses taking to the streets of many city centers

Ticket to ride

Electric buses are now on the roads of major cities around the world – and that's just the start of things to come

WORDS: **STEVE BANNER**

Convincing understandably cautious public transport operators that an electric bus full of passengers will not run out of power in the middle of the morning rush hour and leave them all stranded and late for work – and very cross about it too – has been a challenge for manufacturers the world over. But it is one they appear to have overcome.

Last year saw a 12m-long electric bus, built by Chinese manufacturer BYD and in service with City-Trafik in Copenhagen, Denmark, complete a 325km (202-mile) run on a single battery charge, with an average of 40 passengers on board. And when the bus returned to its garage it still had 8% of its original charge left. A stunning outcome.

A BYD ebus operated in and around the same European city by rival operator Arriva clocked up a – still-healthy – 240km (150 miles) on a single charge and, like its rival, still had 8% left at the end. What's more, its electric heating system was in full use for much of the journey. Another remarkable result for the Chinese OEM.

Such real-word operating data in part answers another criticism of electric buses – their alleged inability to cope with cold weather.

Operator Transdev appears confident in the state-of-the-art powertrain technology now driving these new-generation electric buses, and as a result is putting two 12m BYD creations into service in the Swedish city of Eskilstuna in November this year, where winter temperatures can fall as low as -37°C.

The key advantage of electric buses as far as urban areas are concerned is, of course, the absence of exhaust emissions on a local level, although critics understandably point out that in countries where electricity is generated by burning fossil fuels all that happens is that the pollution is displaced elsewhere. Yet that becomes less of an issue if city center atmospheric pollution is so bad that the air is barely breathable in the first place.

That is the situation throughout much of China, so it is hardly surprising that some of the country's big cities have decided to opt for battery-powered public transport.

Having already acquired 50 units, last year Nanjing ordered 600 electric buses from – yes, you've guessed it – BYD. Dalian ordered the same number plus another 600 for delivery this year.

And what's more, recharging buses need not take forever, either. The pair of 12m BYD ebuses operating in the UK in central London with Go-Ahead are to be plugged in for around five hours, but will then be able to complete a 17-hour shift, says the manufacturer.

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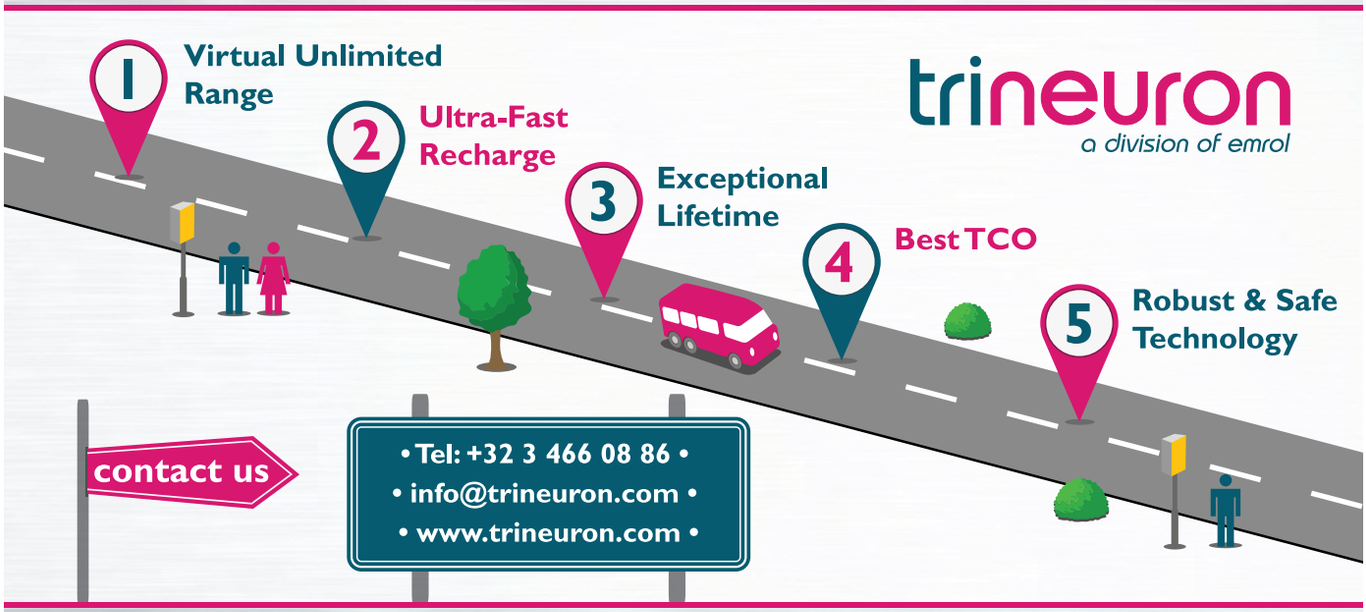

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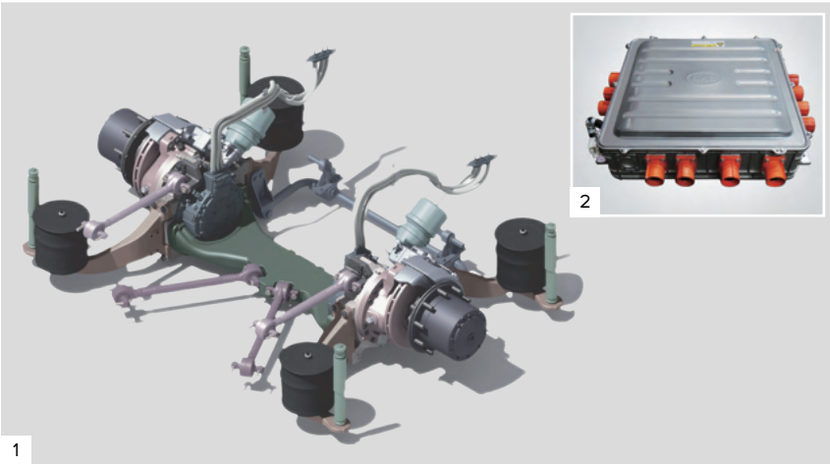

If that's not impressive enough, two hours will soon be a realistic figure given the pace at which charging technology continues to develop. Furthermore, the consistency of routes buses allow operators the opportunity to top up batteries at certain fixed points along the highway.

Charge stop

Last year saw eight Northern-Ireland-built electric Wrightbus StreetLite 9.6m buses go into service with Arriva in the UK on a 24km (15-mile) route through the middle of Milton Keynes.

A 120kWh induction charging plate is installed in the road at each end of the route. The vehicles can stop above a plate and use it to top up their batteries during a 10-minute halt. Doing so replaces two-thirds of the energy consumed during the run.

Looking rather like a manhole cover and said to be vandal proof, the charging plate contains the primary coil. A plate containing the secondary coil is lowered from the StreetLite, and the power jumps across the gap and charging begins.

1. BYD's in-house-developed rear-drive axle technology lies at the heart of the company's electric bus applications

2. A BYD high-voltage distribution box, used in ebus drivetrain design

3. The motor controller controls forward and reverse movement of the vehicle's driving motor

"Power is being consumed at the rate of 1.44kWh to 1.45kWh a mile on average," explains John Miles, Arup/Royal Academy of Engineering research professor in transitional energy strategies at the University of Cambridge. "Over the next two to three years we should be able to make the case that an electric bus is cheaper to operate than a diesel bus."

The Milton Keynes buses are on the highway thanks to a cooperative effort involving a variety of bodies including Arup, the University of Cambridge and Wright Group. Miles is also director of the project, which has received support from the UK Department for Transport's Green Bus Fund.

The research professor makes the point that periodic induction charging allows a lighter battery pack to be fitted. As a consequence, the StreetLite EVs tip the scales at a comparatively modest unladen weight of 9,720kg.

Bulgaria's Chariot Motors suggests that one way of cutting unladen weight is by using ultracapacitors rather than batteries. A pre-production Chariot using this power source has now been in service in its native country for more than a year.

COACH JOURNEY

Electric buses traveling on fixed routes and always returning to the same charging points make sound sense – but what about an electric coach that might be asked to take golfers to Portugal's Algarve one week and transport skiers to the snowy slopes of Switzerland the next?

BYD thinks such a notion is viable and unveiled a 47-seater battery-powered coach with a claimed range of upwards of 305km (190 miles) in the USA in January. The two-axle C9 will be followed by the bigger tri-axle C10, plus a smaller executive coach called the C6, by the end of the year.

But the C9 has one drawback that BYD admits to: because the batteries take some of the space in the under-floor lockers, the amount of room available for passenger luggage is restricted.

That would limit its use on touring work, but there seems no reason why the C9 could not be used to shuttle commuters in and out of city centers along a predictable route with a charging point at each end. Those types of commuters are likely to be more interested in finding somewhere they can plug in a laptop once they have boarded than in being able to stow a big suitcase, and a battery coach will always have electric power in abundance.

In a further BYD development, the Chinese company also recently unveiled a 120-passenger articulated electric bus in the USA with a claimed real-world range of over 275km (170 miles).

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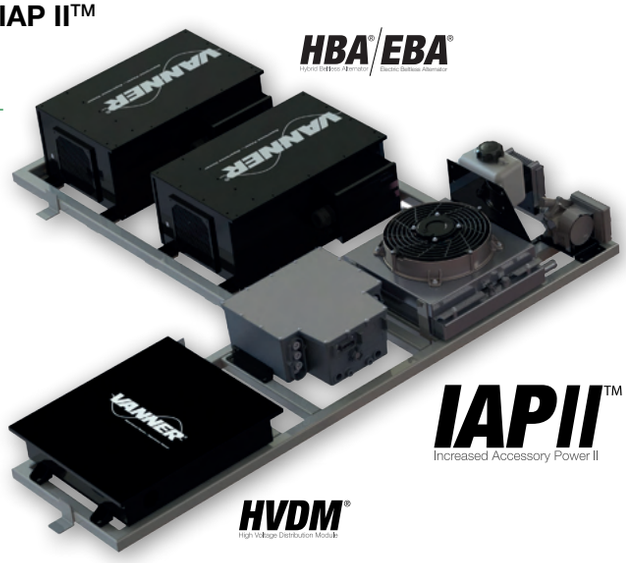

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1

Diesel-electric hybrid bus applications can also benefit from induction-charging systems. Late last year, Scottish operator Lothian Buses and Volvo extolled an approach that makes use of roof-mounted rails as opposed to a plate in the road. The technology enables the Volvo 7900H 12m hybrids run by Lothian, which is owned by the City of Edinburgh, to travel for nearly 8km (5 miles) solely on battery power.

Meanwhile, in its home country of Sweden, Volvo has started real-world testing of the ElectriCity, its new all-electric bus, on the streets of Gothenburg. Volume production is scheduled to start in 2017.

Counting the cost

Despite such engineering and technology inroads being made, diesel-powered buses still vastly outnumber pure electric buses worldwide and the relative economies of scale mean that for the time being the latter are more expensive than the former.

For example, the 13 BYD 12m ebuses that will go into service in the UK with Nottingham City Council later this year will cost one-third more than their diesel equivalents.

Recognizing their environmental advantages, the British government is part-funding their acquisition with a US$2.2m (£1.4m) grant from the Green Bus Fund. The US$3.3m (£2.1m) balance is being met by the city's workplace parking levy. At present 45 electric buses are already in service in Nottingham.

UK government funding for the purchase of low-emission buses will be given a fresh boost with the launch of a US$47m (£30m) package by the Office for Low Emission Vehicles, with the funds being available from April 2016 to March 2019.

In a departure from previous fiscal arrangements, money from the fund will be open to support the construction of the charging infrastructure, as well as to buy the vehicles themselves.

But the UK is not the only country willing to subsidize electric bus acquisition and support. Stadtwerke Münster, which operates the bus network in the city of Münster, Germany, has just taken delivery of five VDL Citea Electric buses.

One of them is part of the SEB project (rapid charging system for electric buses in public transport) that is subsidized by the German Federal Ministry of Education and Research. The other four are part of the ZeEUS – the Zero Emission Urban bus System – project part-funded by the European Commission and coordinated by the UITP, the international association for public transport.

All the buses are being deployed on the same fully electric route, which has a rapid charging station at each end. Another station has been installed at the bus depot for good measure.

Yet while electric buses are expensive to acquire, they are comparatively cheap to run so far as the power they consume is concerned.

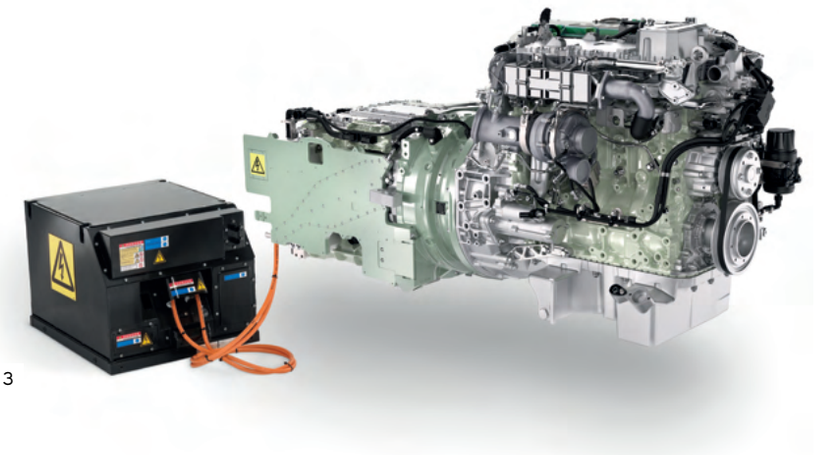
In the Netherlands, six BYD ebuses have been operating on the island of Schiermonnikoog for just over two years.

1. A Wrightbus StreetLite travels its 24km route through Milton Keynes

2. A Volvo 7900H hybrid bus, operated by Lothian Buses, in service in Scotland. The vehicle can cover nearly 8km in pure-electric mode

3. Volvo's hybrid bus powertrain technology is widely acclaimed

2



3

"Electric buses represent the future, there's no doubt about it. I do not see hybrid technology as the long-term solution"

Enrico Vassallo, chief executive officer, Optare

The electricity they use costs €0.85 (US$1) per kilometer compared with a likely €1.10 (US$1.25) per kilometer at a bulk purchase price if they happened to be fitted with diesel engines instead.

At that cost saving rate, the electric buses will break-even after five to six years in service with operator Arriva. The company actually intends to keep the vehicles for up to 15 years, thereby taking advantage of a more than healthy payback.

Some thirty-five BYD ebuses have been ordered for implementation at Amsterdam's Schiphol Airport – a purchase of particular importance, given that all major airports are set to face increased scrutiny of air quality in the near future.

Payback time varies from country to country and depends on local electricity prices and the size of any state subsidy that may be available. With UK government largesse, the payback time for a 12m ebus will be around four years, says BYD. Without it, the figure would be to closer to five years, it adds.

1. An Optare single-decker electric bus plugged in at a battery charging point

2. Optare is expanding into double-decker e-vehicles with the MetroDecker

3. A VDL Citea Electric bus, in full operation around the streets of Münster

Life after death

Electric buses connecting a city's main public transport network, in turn ensuring far better air quality, is all well and good, but batteries eventually have to be disposed of, which raises another set of environmental concerns. However, BYD believes that the iron-phosphate batteries it uses in its applications remain capable of holding three-quarters of their charge after a decade of service and can be switched to all sorts of static applications thereafter. Iron-phosphate batteries, the company believes, have a lower energy density than some of their rivals and are slightly heavier, but they remain cool when in operation, making them both reliable and safe – all of which are key considerations so far as passenger transport is concerned.

In general, battery-powered buses tend to be single-deckers, but UK manufacturer Optare aims to change all that later this year with the launch of an electric version of the MetroDecker double-decker bus.

Part of Ashok Leyland of India, which is in turn part of the Hinduja Group, Optare already produces electric single-deckers, including battery-powered versions of the MetroCity. Seven of these applications have recently been ordered by Arriva for use in London.

Set to appear in the fleet later this year, they will operate on Route 312, which will become the first in the UK's capital to be run entirely with fully electric buses. They will join battery MetroCities already employed on this service, which runs between South Croydon and Norwood Junction in South London.

"Following an initial trial, we are satisfied that the technology is robust enough to stand up to the rigors of operating in an intense urban environment," states Arriva London's commercial director, Peter Batty.

The timing is particularly apt given that an ultra-low emission zone is scheduled to be introduced in central London in 2020.

"Electric buses represent the future, there's no doubt about it," adds Optare's chief executive officer, Enrico Vassallo, in a final remark. "I do not see hybrid technology as the long-term solution."

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Another dimension

At first glance it might look like a niche Renault Twizy rival, but deep down there's much more to the **Life** than just being a new-generation quadricycle EV

WORDS: **JOHN EVANS**

At Germany's Aachen University, a rival to Tesla Motors is starting to take shape. Just like the self-styled 'disruptive tech' California-based company, e.GO does things differently from its established peers and it, too, builds only electric cars. Well, so far just the one. And it's a prototype.

The Life, previously called the C16, is an electrically powered two-seat, open-style vehicle weighing less than 450kg that, in Europe, is classed as a quadricycle. When finally signed off in 2017, it will be a direct rival to the Renault Twizy. Its anticipated retail price is US$13,600 (€12,500) – around the same as the French vehicle. So far, so Renault.

e.GO, manufacturer of the Life two-seater quadricycle EV, has made heavy use of 3D printing during project development

However, e.GO likes to describe itself as "the same but different". Look behind the curtain at the Life's gestation and that description certainly holds up. For example, when it emerged at the end of 2014 as the plain old C16, it was the world's first 3D-printed prototype car in so much as its body panels were printed, with the vehicle's structure, and mechanical and safety-critical components being formed of metal.

"The university has the world's largest multimaterial 3D printer," explains Alexander Weis, project engineer on Life. "It's a Stratasys Object1000 that can produce industrial-size models. By avoiding the expensive and time-consuming trouble of making special tools and presses to form panels from metal, it helped speed up the C16's development time. We gave it our CAD/CAM files and it did the rest."

Time shock

However, if you think the machine produced the Life's panels in the time it takes to print a few meeting notes, then think again. The entire process actually took around three months.

"The team was shocked that the printing wouldn't be done overnight," says Michael Anton, senior application engineer at Stratasys. "I had to add some hours onto the data quality. If you have huge parts, the data conversion needs special care to achieve the right quality and to avoid visible triangles or rough surfaces. We needed a high resolution for a smooth surface. Even so, it was still much more cost-effective than tooling up to make metal parts."

Anton's relationship with e.GO goes back to a related company called StreetScooter. Also formed at Aachen University – this time in 2009 and led by professors Achim Kampker and Günter Schuh – StreetScooter

1

1. The Life is the first in a proposed line of small, affordable vehicles that make use of alternative principles and production methods

2. Aside from the Life, the proposed future e.GO range will also include the four-seater Booster

designed and produced a small, electrically powered and affordable short-distance delivery vehicle whose smaller prototype parts were printed by the Object1000's forerunners. The company and vehicle have since been acquired by Deutsche Post DHL, with Kampker remaining as a director. Today around 150 StreetScooters shuttle around Germany helping to deliver the post in an eco-friendly, sustainable way.

In 2013, Schuh stood down from StreetScooter to help found e.GO and realize his dream of launching a new generation of small, affordable electric cars designed, developed and produced in different ways, and on different principles, from established car makers. His first product is the Life.

The Object1000 3D printer produced the car's parts in digital ABS, a durable formulation that is capable of withstanding temperatures of up to 200°C. That's around 50°C lower than the automotive industry's requirement for materials that are utilized in areas close to the engine and batteries. It's a target that eludes 3D printers such as the Object1000 because of their polyjet technology, which is similar to an inkjet printer's and can't work with such heat-resistant material.

"For the moment the printer is great for printing prototype parts and helper parts for things such as robot arms," states Anton. "However, 20 years ago there were just two systems available and three materials. Today we have five major 3D-printer technologies and about 1,250 materials. In five years we'll have more than 2,000 materials, many of which will be stiffer and more resistant to higher temperatures as well as faster printer speeds. Then we might see 3D printing of end-use parts, including more critical ones."

But given the way that e.GO intends to develop its products, the Object 1000's role looks to be far from over. To achieve its goal – which Weis describes as, "providing advanced, electric-powered mobility that is fun, convenient and affordable" – e.GO relies on as many as 50 suppliers, including major industry names such as Siemens, to collaborate and innovate on areas such as the powertrain and the electrical architecture, all in real time, which ultimately means frequent change is a given.

Not only that, the team at e.GO is using scrum engineering to steer the project, as Weis further explains: "Traditional OEMs front-load the development period over an extended time before they launch. The idea with scrum is to learn from the prototyping. It's the same approach as is used in computer engineering, where they make a program, test it, learn from it and make a better one.

"You learn by taking small steps, all the time building and learning faster. Ultimately your solution will be better than waiting too long to design and develop in the conventional way."

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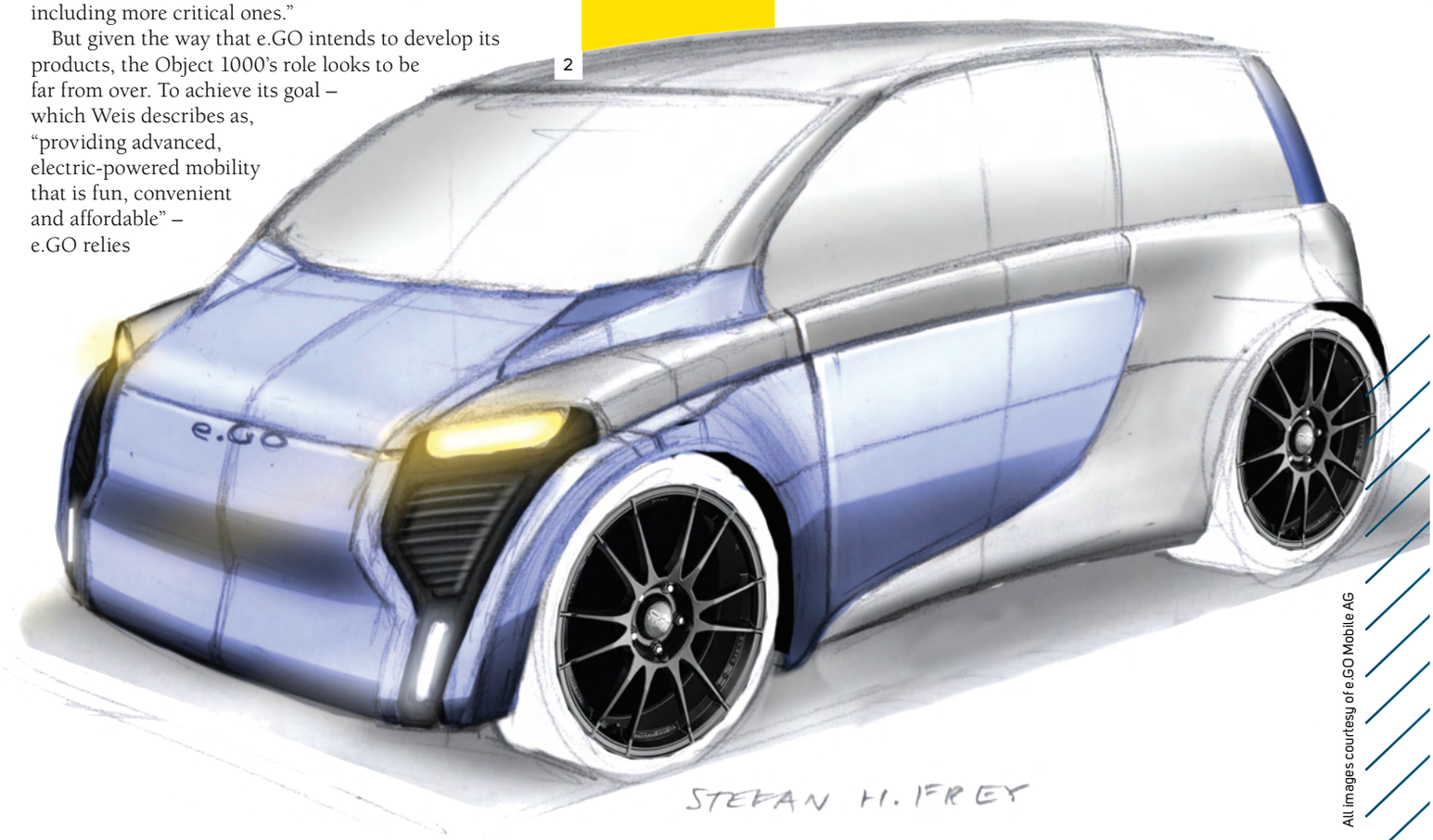

All images courtesy of e.GO Mobile AG

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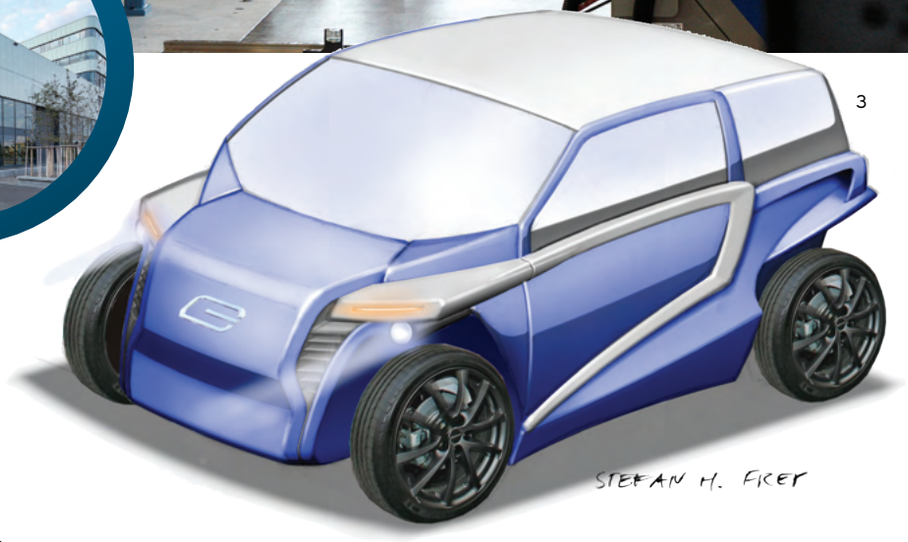

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For the larger suppliers, e.GO's method is a golden opportunity to learn with a small, ambitious company and develop products and solutions that they can take to their larger, core customers as the world car market evolves and expands. For e.GO, this engineering approach makes the project more cost-effective, quicker and more responsive to technical developments on the job and elsewhere.

"It enables us to incorporate the latest thinking and technology," states Weis. "For us, scrum engineering is as radical – and effective – as 3D printing."

It helps that the Life is of modular construction, enabling sections to change without affecting the whole unit. Another important factor is that the vehicle has been engineered from the start to be electrically powered.

"This has helped to reduce costs substantially," admits Weis. "For example, the VW e-Up, originally a gasoline-powered model, costs up to €25,000 (US$27,250) whereas our e.GO Life will cost up to €12,500 (US$13,600)."

This year the team will build five prototypes, and next year 100 beta versions for market testing. All being well, the company anticipates pumping out thousands of cars – but they won't all be Lifes. The company is developing a three-model range comprising the Life, a smaller single-seater called the Fit and a four-seater called the Booster. This latter development is far more ambitious than the others and could give e.GO a toehold in the lucrative small family hatchback market. According to Weis, it could be "faster than a Porsche from the traffic lights, up to around 40km/h [25mph]".

Given such potential, Schuh is naturally excited by the new vehicles, but the professor is especially impressed by the durability of their electric motors, the possibilities of 3D printing, and the fact that their upgradable electrical architecture could make them responsive to further advances in technology.

"Such a new-generation vehicle could last at least as long as a conventional car, so about 30 years," he predicts. "This allows multiple resales and the possibility of including technical and visual overhauls as developments occur and tastes change."

The prototypes and the planned 100 beta cars will be built at the university, but if sales take off and volumes pick up, a new production facility will have to be built beyond the campus.

"Our scrum engineering approach will enable us to seize opportunities as they arise and, if the market likes our cars, expand our range," says Weis of the future. "In 10 years, as Tesla is for the sports car, so e.GO could be for smaller vehicles."

1. Depending on demand, e.GO will consider additional production facilities

2. Currently, e.GO prototypes and beta cars will be built at Aachen University

3. A rendering of the e.GO Life, which will form part of a key three-model range

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VITAL STATISTICS

Dimensions: 2,125mm (L) x 680mm (W) x 1,130mm (H)

Wheelbase: 1,485mm

Ground clearance: 130mm

Seat height: 790mm

Total weight: 250kg

Dunlop tires: Front 120/70ZR17M/C (58W); Rear 200/55ZR17M/C (78W)

Motor: Mugen (ex-Mission) oil-cooled, 3-phase brushless motor

Power: 110kW

Torque: 220Nm

Battery: Maxell, laminate-type Li-ion, 370V+

Zero compromise

WORDS: **GRAHAM HEEPS**

Ample proof of the power of motorsport to advance technology lies in the success of the TT Zero race on the Isle of Man, where the winning lap speed has increased from 154km/h to 192km/h in only five years. We profile the 2015 race-winning **Mugen** entry

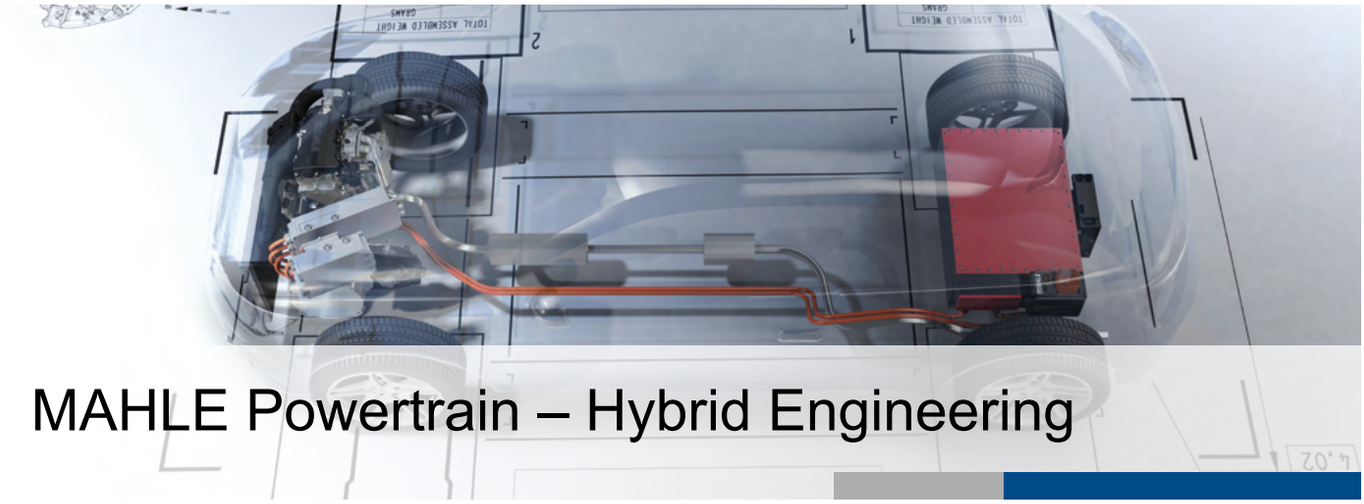
After crushing the opposition in 2014, when Mugen's Shinden San electric motorcycles finished 1-2 and nearly five minutes clear of their closest challengers, the Japanese team returned to the Isle of Man TT Zero race in June 2015 with an improved version of its most successful machine to date.

Mugen knew that the competition would be tougher this time around – in particular from US-based newcomer Victory Racing – so looked at every area of the motorcycle that already held the electric lap record around the Isle of Man's famous 60.7km (37.7 miles) Mountain Course.

"We made a raft of relatively small changes this year that added up to better performance," explains Colin Whittamore, general manager of Mugen Euro, the company's fully owned European subsidiary. "The [carbon-composite] frame was the same basic design but there were changes to accommodate a revised battery pack. Maxell remains our technical partner for batteries and the cells were very similar to 2014, but their layout was changed to improve cooling." The pack is protected inside a carbon-composite enclosure.

The bodywork of the Shinden (the name translates roughly as 'God of Electricity') was changed to reduce drag and assist cooling, too. The rider position was also altered as part of the aerodynamic program, helping unlock a higher maximum speed. The revisions helped to optimize the performance of the air-cooled battery pack, the water-cooled powertrain electronics and the oil-cooled electric motor, contributing to increasing its power by 10kW to 110kW.

The 2014 motor was designed in conjunction with Mission Motors, but with Mission no longer trading, the development, testing and assembly of the 2015 motor and



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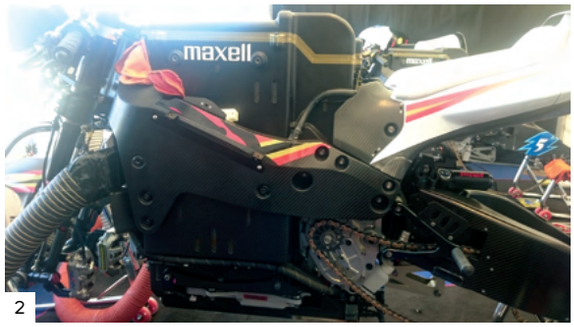

1. The Mugen's distinctive livery reflects its 'God of Electricity' moniker. Photo: Pacemaker Press Intl

2. The Maxell battery pack sits vertically within the Shinden's composite frame

3. Power from the electric motor is transmitted via a conventional chain drive

its controllers was brought in-house to M-Tec, Mugen's parent company, in Tokyo, where expertise is being built in the area of electrified powertrains.

Further changes to the bike included to the rear swing-arm, which looked the same but was structurally redesigned for extra strength: "We're starting to push heavy bikes faster than they've ever been before," as Whittamore notes. The rear brake caliper was also changed while at the front, a set of prototype Showa air forks was adopted. Around 10kg was shaved from the bike's weight – down to 250g – as a result of the various component changes.

Racing prep

The updated bike was named Shinden Yon (4 – San means 3) and underwent early testing in Japan before two examples were sent to the UK for the race. The machines were prepared at Mugen Euro's facility in Milton Keynes, UK – a substantial part of which is sublet to Honda as the European base for its Formula 1 hybrid engine program.

In the week before the team's departure to the Isle of Man, a further day's testing was completed at the Castle Combe racetrack. Whittamore, whose role is to help with coordination and logistics, and act as English-speaking spokesperson for the team, acknowledges that it's hard to conduct representative testing for the Mountain Course, given that it consists entirely of public roads.

"There's no way in real terms to simulate the Isle of Man circuit and with our [one-lap] race, once you've set the bike off, that's the last you see of it until it's complete," he says. "That means every lap of practice is crucial for data gathering. Unfortunately, in first practice on the Friday before race week, one of our bikes had a technical issue and didn't complete the lap. Saturday practice was canceled so that was another two laps' worth that we didn't have, meaning we had only one lap of data from a

CONTRASTING FORMULAS

John Thornton, assistant editor of E&H, *reports on the culmination of the inaugural FIA Formula E Championship season, at London's Battersea Park, and compares the experience with Formula 1*

It's perhaps unfair to compare the nascent Formula E with its more established older sibling, but having witnessed Formula 1 (F1) live once before, at the 2013 Italian Grand Prix, it's difficult not to.

First, there's the sound (or lack thereof). Instead of the visceral, ear-splitting scream that soundtracked my Monza experience, courtesy of the now-defunct 2.4-liter naturally aspirated V8s, the noise produced by Formula E's Spark-Renault SRT_01E race cars was markedly quieter (noise decibel levels are approximately 80dB, which is 10dB higher than an ordinary car, yet 50dB lower than the old F1 V10s). Such was the muted atmosphere that spectators could comfortably observe the race mere feet away from the track. Indeed, the combination of tire road noise and electric motor whine made for a futuristic whir akin to life-sized Scalextric toy cars crossed with a vacuum and a jet aircraft.

Second, the city location (southwest London's Battersea Park) instead of the more remote Donington or Silverstone and affordable admission (US$25 as opposed to US$155) resulted in a more youthful, family-oriented crowd than F1. In total, 60,000 tickets were sold for the two days in London.

Uniform powertrain components were used in Formula E's debut season but Graeme Davison, vice president of technology at Qualcomm (supplier of the wireless charging system used for the BMW i3 and i8 course cars), revealed regulations will allow new powertrain manufacturers in the 2015-16 season. "The OEMs will only be able to build the electric motor, inverter, gearbox and cooling system – the chassis and battery will stay the same," he said. Eight manufacturers will compete, with existing teams Andretti, Abt Sportsline, e.dams-Renault, Venturi Automobiles and Virgin Racing Engineering (with DS) all building their own powertrains.

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1. Knowledge gained from the TT Zero program fed into 2013 Mugen's Super GT title win with a CR-Z

2. Mugen rider John McGuinness celebrates his second TT Zero victory

3. McGuinness at speed on the Mountain Course

potential four! We ran our two laps on Monday, but opted not to participate in the rearranged Tuesday session as it would have meant running the bikes Monday, Tuesday and Wednesday for the race. We didn't want to potentially compromise our race strategy by putting the batteries through three heat cycles in three days, so going into the race, we had about half the data we could have had. I'm not sure whether we could have gone quicker, but we would have known whether we could have turned the power up slightly more."

The team's reluctance to commit to three heat cycles in three days shows the relative lack of technology maturity for the TT Zero bikes compared with their ICE-powered cousins, but they're also different in positive ways, according to Whittamore.

"Riders like a consistent bike," he explains. "One of the characteristics of an electric bike is its smoothness and consistency. Acceleration is progressive, with no gearbox to unsettle the bike, and there is no fuel draining out, so the weight is the same at the start and the finish, which means the handling remains unaltered all the way around the lap."

Controlling power

Another way in which the rider's life is made easier on the Shinden Yon lies in Mugen's removal of control over the power output – for most of the lap at least.

"Electric bikes are pretty much infinitely variable," he expands. "You can keep turning it up until you either run out of power, or reach the maximum of what the motor can put out. Our bike's output during the race is 95% predetermined. You could have your rider manage the power, but from our point of view, riding the bike quickly around the track is what the rider does best. If you can take away the range anxiety and let the rider concentrate 100% on riding the bike to its maximum, then he'll go faster."

Mugen uses the data it has collected during the practice sessions – motor speed and temperature, and battery drain are among the channels monitored – to set a race power level that produces the necessary speed, but still enables the rider to complete the lap. The one exception to this is a mode switch on the bike that is designed to reduce power in order to manage the motor heat on a demanding uphill section of the course.

During the 2015 TT Zero, Mugen's race-winning British rider, John McGuinness, highlighted the pitfalls of handing power control to the rider by inadvertently launching the bike off the start line in the lower-power

WHY TT ZERO?

Motorcycle racing was big business for Mugen from the early 1970s to late 1980s, since when it has been best known for tuned road cars and its racing exploits on four wheels. It built F1 engines in the 1990s and currently oversees the turbocharged units for Honda's Civic World Touring Cars. So why did this internal combustion engine specialist opt to compete in TT Zero?

The answer lies in a desire to foster young engineers and conduct developments in a new area of technology. The Shindens are said to be the pet project of Hirotoshi Honda, founder of Mugen's parent company, M-Tec, and the son of Soichiro Honda, who started the eponymous car and motorcycle maker. It's said that the Shinden's distinctive white livery and even the riders' white overalls are specified by the company founder and specifically designed – like the bike's name – to appeal to the younger generation.

"The more you get into it, the more passionate about it you become," admits Whittamore. "Six years ago we were an engine company with not much of an eye on electric powertrains, but we've realized their potential in racing. The knowledge we've gained will help us in the future, but already we've raced a [Honda] CR-Z, which was the first hybrid car to win a GT championship in Japan when it won the GT300 class in 2013. The information we've gathered from the Shinden program helped with that and going forward it will only become more important. Already, a big chunk of our Milton Keynes facility is turned over to batteries and electronics because that's the way Formula 1 has been going."

THE OPPOSITION

Whittamore freely describes Victory Racing's 2015 debut showing as "very impressive". The Polaris Industries-owned US manufacturer entered two bikes, which finished third and fourth with lap speeds of 179km/h and 175km/h respectively.

"Competition is crucial to TT Zero," Whittamore acknowledges. "I'm sure MotoCzysz [which won the first four TT Zeros] would agree that until we came along, they were worried they were going to be the only ones meeting and breaking the targets, which is crucial to maintain the public interest. If we reached the point where we knew we could turn up for the next 3-4 years and always win, there wouldn't be the same incentive as having somebody catching up with you and knowing you have to work harder to go faster.

"As with all motorsport, competition will rapidly increase the rate of development," he continues. "It forces you to take a risk when the safe option might be, say, to turn it down to 70%. Our most memorable year was 2013, when both MotoCzysz and Mugen had a chance of winning and we got beaten by 1.5 seconds. Ten months later, we were still smarting at what we'd felt was as a lost victory and when we came back in 2014, we had a sledgehammer! We're aware that Victory is getting closer and that Sarolea made a huge leap this year [from 150km/h to 170km/h]. There are rumors that MotoCzysz might return, or that another manufacturer might come in, and the stronger the grid is, the more credible TT Zero is – so long as we're going faster!"

Lee Johnston rounds the Gooseneck on his way to third in the 2015 TT Zero. Photo: Dave Kneen/ Pacemaker Press Intl

mode, so was a little slower away than he might have been. However, his Shinden Yon had still reached 60km/h from a standing start by the time it passed through the first timing beam, just 30.9m from the actual start line, which is comparable with the acceleration performance of the TT-headlining, ICE-driven Superbikes.

Mugen receives some technical help and setup advice at the TT from the highly experienced Padgetts Racing team, run by Clive Padgett. Mugen's second rider, New Zealander Bruce Anstey, rides petrol-engined bikes for Padgetts, and McGuinness has also ridden for the team in the past.

"Clive knows what Bruce likes in a bike, the finer details," says Whittamore. "Rider psychology is especially important on the Isle of Man – if they're comfortable on the bike, they'll be fast on the bike."

John McGuinness on his way to victory on the Mugen Shinden Yon. Photo: Picturesports.co.uk

The future

As the speed of the TT Zero bikes has risen, the non-powertrain factors that have such an impact on the performance of mature-technology ICE bikes, have come increasingly into play.

"When you're doing 100mph lap speeds, it almost doesn't matter what the rest of the bike is like – it's all down to the battery and motor," he argues. "As you get closer to 120mph with a 250kg machine, other factors come into play. You have to think about the dynamics of the bike and about reducing drag, for example. We don't have a limitation on the battery at the speeds we're doing at the moment, but there are heat limitations – we are managing heat as much as we're managing battery energy storage.

"However, I think we will naturally see a leveling off [of performance gains]. You can't keep finding 6-7mph every year although 2mph – the difference between 2014 and 2015 – is still a fair chunk for a TT bike to find in a year. Since 2012 we've gone from a 102mph lap, to 109mph, 117mph and now 119mph, so the curve is starting to flatten, and I think it will flatten quite dramatically at some stage in the near future. I'm not quite sure what the 'natural' speed is for current technology – certainly over 120mph – but whatever that speed is, it'll be pretty much all you can do with current batteries and motors. Then it'll be about finding tenths and fractions, as we do in the rest of motorsport. TT Zero is still unusual in that you can find big chunks and the golden keys are there to be had."

One area that might be addressed in the future is tires: off-the-rack Dunlop KR106 and KR108 Superbike rubber is currently used, but bespoke tires might offer a performance gain by enabling the riders to carry more speed through corners, and thereby maintain precious momentum. In the longer term, advances in battery power density will make weight reduction possible. The Shinden Yon is considerably heavier than a 1,000cc Superbike, for example: even in road trim, McGuinness's Senior TT-winning Honda CBR1000RR Fireblade weighs around 50kg less than his TT Zero race machine.

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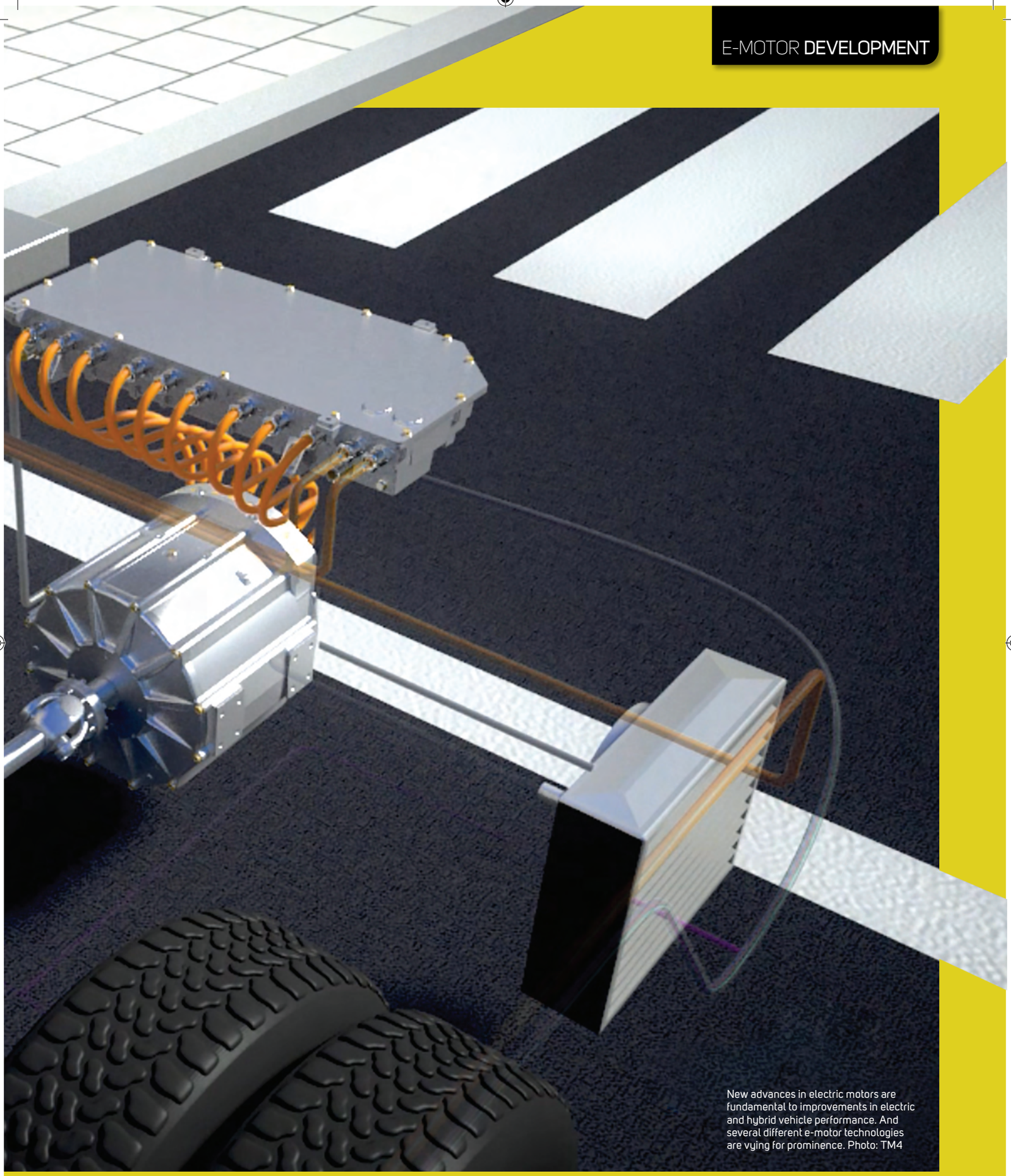
Power play

As development of electric motors continues to play a key role in the EV and HEV arena, time will tell if the market will be dominated by a single technology, or shared between a number of variants

WORDS: **KARL VADASZFFY**



New advances in electric motors are fundamental to improvements in electric and hybrid vehicle performance. And several different e-motor technologies are vying for prominence. Photo: TM4

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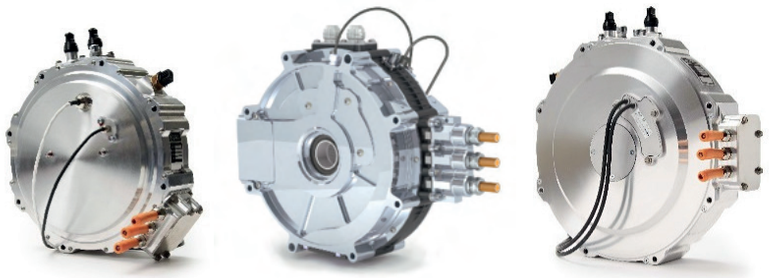

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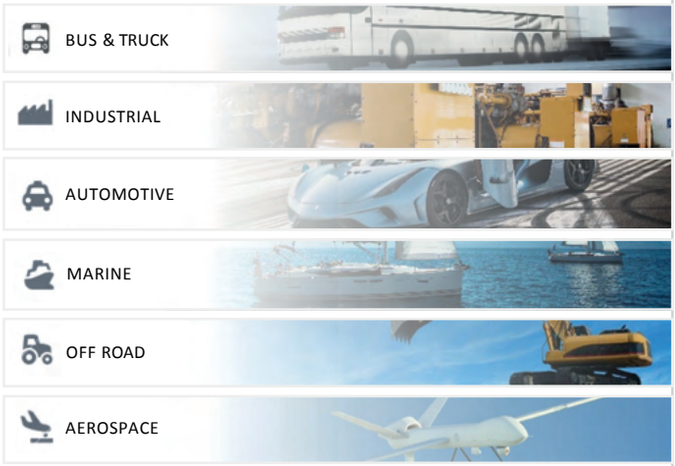

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Central to the improvement of electric and hybrid vehicular performance is the development of electric motors, but different constraints are inevitably placed on the technology depending on the application in which it is used.

With the increasing demand for high-tech electric motors, permanent magnet synchronous machines have emerged as a leading solution. They provide considerable torque and speed in a small package, resulting in savings in space and, usually, weight.

But a challenge remains: the price. Ulrich Huber, project manager at Sensor-Technik Wiedemann, which uses permanent magnet machines in its powerMELA system (a motor or generator whose key element is a 140kW machine), warns, "Fuel savings are not as high as expected, and probably not enough to be a reason to electrify. So the introduction of more regulations would help move things along.

"In addition, many of our customers are used to mechanical systems, but they're not used to having high-voltage electricity, so the ease of integration of these components, engineering-wise, is a big factor."

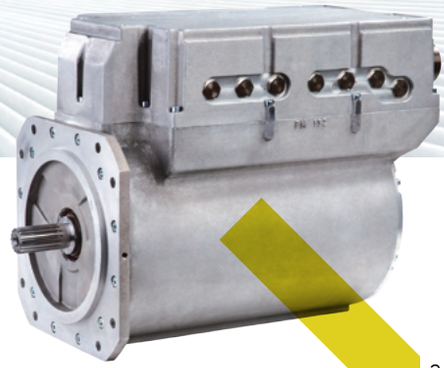
Driving down costs

The cost of electric motors will, of course, come down as volumes increase, but there's already much work being done to explore how else their cost could be reduced. "While production isn't as industrialized as with combustion engines, you can decrease costs by getting rid of certain materials," Huber explains. "Currently, lots of copper is used, so reducing the amount of copper, or using aluminum instead, is being explored." The latter is, however, more difficult to work with because contacts are more challenging.

Regarding permanent magnets, Huber suggests there are investigations into removing them altogether, and he cites alternative machines as possibilities for the future, provided improvements are made: "Switched reluctance motors or excited motors are options, but their power density isn't competitive enough yet."

Electric drivetrain specialist TM4 also primarily uses permanent magnet motors. Christian Pronovost, senior product manager for the supplier, comments, "We offer motor technologies with surface bound permanent magnets (SPM) or interior permanent magnets (IPM) where, instead of being at the surface of the rotor, the magnets are embedded into the rotor." He explains that using SPMs provides more power at high speed, whereas IPMs offer more starting torque.

Pronovost says that work is being done to reduce the number of magnets used, due to unpredictable price fluctuations. But, he cautions, completely removing them would compromise machine performance, resulting in losses in efficiency, starting torque and maximum power. However, he reveals that tests have demonstrated that it is possible to reduce the number of magnets by at least 50%, while keeping performance at expected levels.



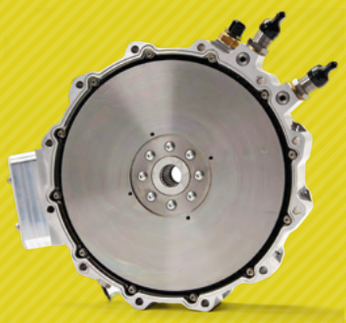
1. Pistenbully equipment makes use of Sensor-Technik Wiedemann's powerMELA technology (Photo: Kässbohrer)

2. Sensor-Technik Wiedemann's powerMELA system employs permanent magnet machines

NO YOKE

UK company YASA Motors has developed and manufactured advanced axial flux motors and generators based on Yokeless And Segmented Armature (YASA) technology. For a given power and torque requirement, this approach delivers a much smaller and lighter electric motor. Importantly, the technology costs less than alternatives due to the highly efficient way in which it uses magnetic material.

Initial commercial adoption was in high-performance cars, but markets now include the off-road, marine, industrial and aerospace sectors. The electric motors can be used in reverse as generators and this has proved its worth in mobile power generation, where space and transportation weight are critical.



To give some idea of how powerful these axial flux motors can be, the YASA-750 develops torque of up to 800Nm and continuous power of 75kW, with a speed range of 0-3,250rpm. These characteristics make it suitable for diesel generation and direct-drive applications.

The higher speed YASA-400 is radially compact with a diameter of just 280mm and produces up to 400Nm and 85kW, with a wide speed range of 0-7,500rpm, making it ideal for traction and generation applications. Both of these motors are capable of achieving power densities of up to 10kW/kg.

The compact size and relatively simple construction mean that they can be retrofitted into existing designs, for example replacing diesel engines with a much smaller package, with lower noise, less vibration and reduced maintenance.

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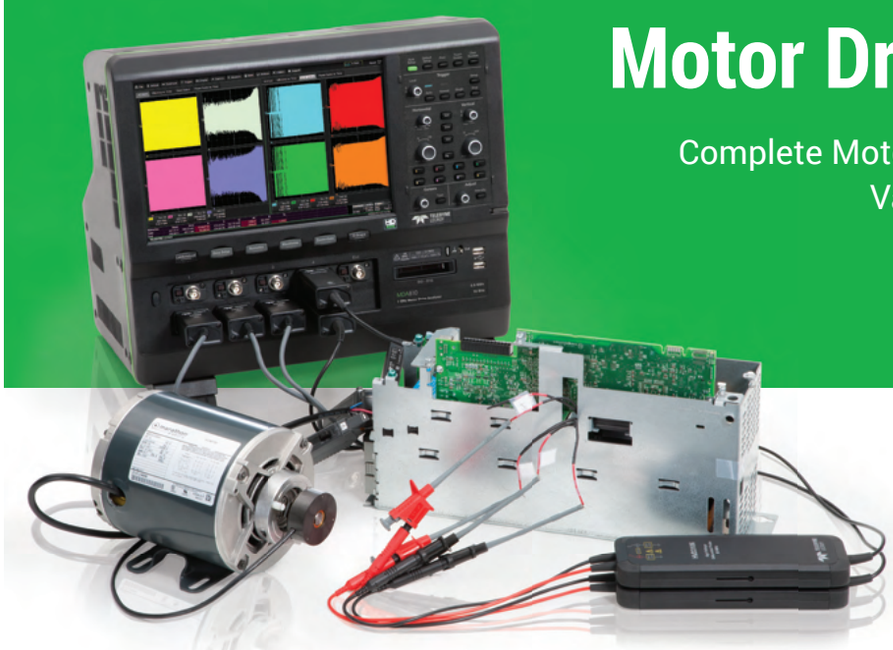

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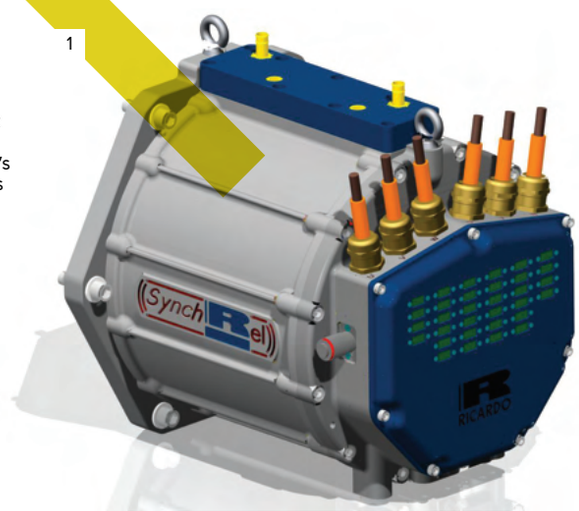
Ricardo, however, has recently developed a prototype 85kW synchronous reluctance drive for use in EV traction applications, as an alternative to permanent magnet traction drives. The design, which uses a conventional distributed stator winding, features low-cost materials, simple manufacturing processes and basic construction. A rotor is made from cut steel laminations, which are used to direct and focus the flux across the air gap. Maximizing this flux linkage between the stator and the rotor means that performance can be optimized in a light, rare earth element-free design. "By bringing together state-of-the-art simulation technology with advanced electric machine design, we have created a highly credible next-generation EV motor concept that shows considerable promise," states Will Drury, Ricardo team leader for electric machines and power electronics. "The Ricardo prototype is now built and will be rigorously tested to validate the extremely positive results that it has shown in simulation, and as a concept that provides an exceptional balance of performance, compact package, light weight and low cost."

1. Ricardo's RapidSR electric motor offers an alternative to permanent magnet traction drives

2. The prototype RapidSR system is currently being tested to validate Ricardo's positive simulation results



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Bigger picture

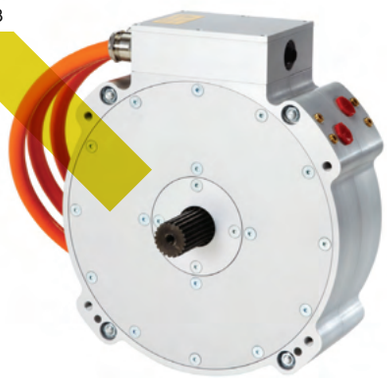
Roger Perthen, executive director at AVL Trimerics, argues that considering only the electric machine isn't usually broad enough. "Look at it from a module/system perspective – the electric machine with power electronics and controls included," he advises. "Technology and components are determined by functional requirements – power, torque, packaging, the application it is used for and safety features. And also cost, if you're going into series development." But he concurs that permanent magnet motors currently dominate, accounting for around 80% of his company's business.

GKN, a leading global supplier of automotive driveline components and systems, offers brushless permanent magnet synchronous e-motors from suppliers with its gearboxes. Mark Cordner, hybrid and integration team leader at GKN EVO eDrive Systems, says, "For mainstream automotive applications, we frequently achieve a torque density (gravimetric) of 11Nm/kg and above (considering an 18-second peak rating).

3. GKN's AF130 (axial flux, one-stage, 30mm casing)

4. All the motors GKN sells for conventional passenger vehicles are one-stage machines, and can also be stacked on a single shaft for use in commercial and industrial applications

3



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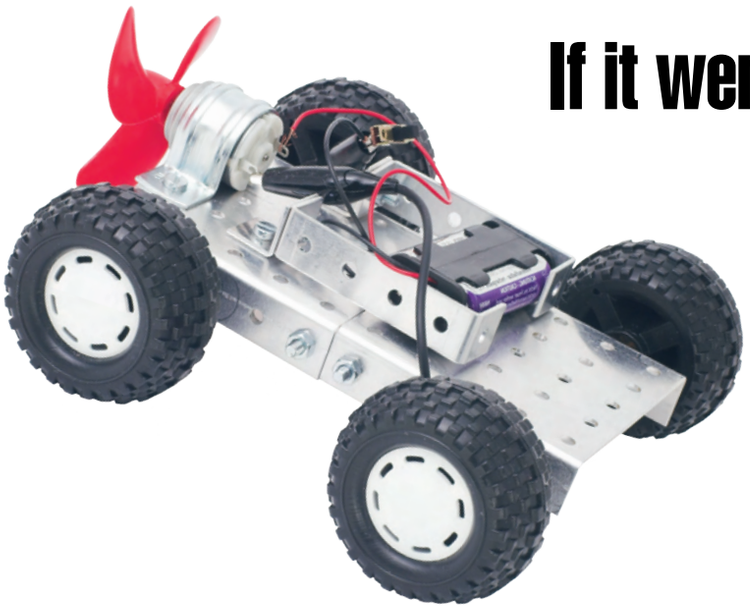
"Our axial flux e-motors have a length/diameter ratio of 0.5 or less. Comparing this with radial flux e-motors, whose lengths typically exceed their diameters, our products are inherently suited to applications where there's a constraint on axial length – for example, for HEVs, where the target is to package the e-motor within the length of the standard torque converter from an automatic transmission."

The axial flux e-motors from GKN EVO, a joint venture with GKN, have two flat stators (the static component consisting of a laminated electrical steel core and copper windings) and a disc-shaped rotor sandwiched between them. This configuration doesn't require a yoke to complete the e-motor's magnetic circuit, which means the e-motors typically have low inertia, as there's no need to add a steel yoke to the rotor. Instead, the yoke is included on the back of the stators and can therefore be manufactured from the same laminated steel that's used to make the rest of the stator.

The company is working on developing motors with higher operating speeds to increase machine power, while keeping the high torque to achieve better use of magnet



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material. A further focus is the integration of electric machines into hybrid powertrains to achieve highly compact powertrain solutions.

Future developments

Most recently, TM4 has been working on electric and traction motor innovations, exploring multispeed transmissions, single-speed transmissions and direct-drive motors. Pronovost explains, "Our direct-drive motors go into the differential of the vehicles, so it's not a direct drive to the wheel."

TM4's Motive product range is used in conjunction with a gearbox in passenger vehicle applications. For larger vehicles with less efficient transmissions, the company's direct drive motors (part of the Sumo product family) do not require a gearbox. "They offer sufficient torque to enable the motors to be connected directly to the rear differential of a bus, for instance," Pronovost adds. "They don't need a gearbox that loses efficiency, brings up reliability problems, needs maintenance and adds costs. But cost is added to the motor so, while the total cost of ownership of the vehicle is reduced, the initial system cost is about the same."

Although he believes that permanent magnet motors will remain the optimal choice for applications with strict packaging constraints, AVL Trimerics' Perthen believes the future of hybrid development will be based on an integrated concept: "There'll be a new approach using an induction machine with higher speed to reduce the size of the machine, using a shaft parallel mounted approach.

"Plus, the cost of an induction machine is an advantage, so it could be an alternative to permanent magnet motors in some applications, particularly hybrids.

"Our direct-drive motors go into the differential of the vehicles, so it's not a direct drive to the wheel"

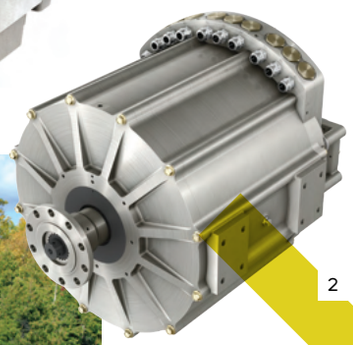
Christian Pronovost, senior product manager, TM4

1. TM4's CO200 forms part of the Sumo MD six-phase system for medium-duty truck and bus applications

2. The LSM280 features in the Sumo HD nine-phase system for heavy-duty truck and bus applications

3. Novabus, a primary application of TM4's electric motor technology

1



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"Another advantage involves safety. With permanent magnets, there's the induced voltage [back EMF] and failure torque issues, which you have to develop countermeasures against, increasing development effort.

"However, while induction machines have the same power as permanent magnet motors, they have 20-30% more volume, so they would be ideal for applications that have more space, perhaps not along the axle but at the side, or for pure-electric vehicles."

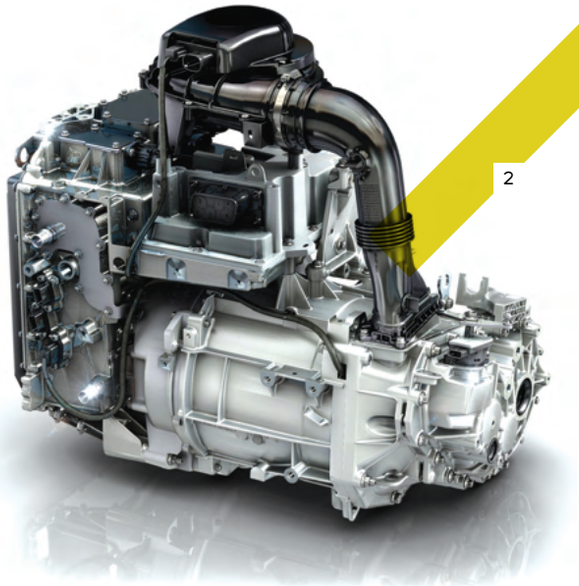
AVL Trimerics is exploring the use of externally excited synchronous machines, which solve the safety issues presented by permanent magnet motors and have a similar packaging space and efficiency. The cost of these machines falls between permanent magnet and induction, although they require contactor parts, which increases the overall required packaging space.

Perthen is also involved in research into materials. Because rare earth magnets have a higher sensitivity to heat, the materials used in the design of the machine can be an important factor in reducing losses. "We're looking at sheet metal developments to reduce iron losses in the machine," says Perthen. "These are currently made of transformer steel, but when it comes to improved materials, we have to work out whether they'll add cost."

Perthen believes machines that provide high power density, such as transversal flux designs, could represent a future option. But, he points out, they're costly to develop and produce: "Technology like this can be used in motorsport. Plus, they use a special material for their stator design – soft magnetic composite that's produced by few companies."

AVL Trimerics is also developing cooling technologies to benefit electric motors. "Sophisticated cooling is important to increase the machines' power density,"

1



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Perthen confirms. "Besides using traditional cooling methods like air and water jackets, we have developed machines with oil-spray cooling and direct-winding cooling."

For hybrid applications, the company is developing electric machines that don't influence surrounding components, not only by considering material choices, but by focusing on the machine's design – for example, where to position power electronics. "Machines with integrated power electronics could reduce side effects such as electromagnetic noise," adds Perthen.

1. Increased use of ultracapacitors, such as those developed by Maxwell Technologies, could improve electric system performance

2. Renault recently unveiled a new compact synchronous motor, capable of producing 65kW and 220Nm

3. AVL Trimerics has also developed electric machines with direct-winding cooling

Power provision

Wider use of ultracapacitors, which can provide burst power for a wide range of functions, has the potential to benefit the performance of electric systems. "In vehicle propulsion, the acceleration phase is where all the power demand is and where the maximum greenhouse gas emissions are generated," says Michael Everett, vice president of advanced power/energy development at Maxwell Technologies. "Anything to electrically propel the car during the acceleration phase, rather than propel it using the combustion engine, will improve fuel economy and reduce emissions." Maxwell's ultracapacitors are capable of over a million charge-discharge cycles (depending on the application) with nominal degradation in performance. "Overall, a power device like an ultracap, coupled with a low-cost battery, is the ideal solution for providing both the power and energy requirements in an EV," he explains.

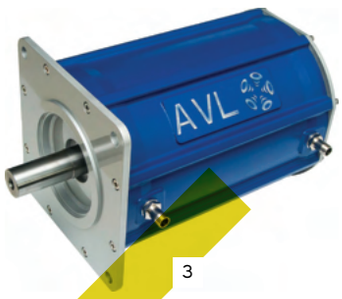
Moving forward, there is a need, Everett continues, to address the relatively low energy density levels of ultracapacitors, adding energy so that they can provide high power for longer, or even fulfill an energy function. Additionally, improving the environmental tolerance range up to 125°C (from a current maximum operating temperature of 65°C) will serve to expand the ultracapacitor use model.

OEM attention

Increasingly sophisticated electric motors will be fundamental in the ongoing development of the electric and hybrid vehicle movement, and OEMs are also taking steps to advance e-motor technology in-house as part of their future vehicle plans. At the end of 2014, Renault announced the development of a new compact electric motor, which delivers similar performance to existing units but in a package that is approximately 10% smaller. The motor, developed in-house by the French OEM, is a synchronous unit with a wound rotor and delivers 65kW and 220Nm of torque. Air-cooling the motor simplifies the system, with only the power electronic controller requiring water-cooling.

"When it comes to improved materials, we have to work out if they'll add cost"

Roger Perthen, executive director, AVL Trimerics



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What's more, Renault says improved management reduces charging times under normal conditions.

The benefits of further e-motor development are clear, and investing in improved or alternative motor technologies can enable OEMs such as Renault to pass on real performance enhancements to customers – integration of the newly developed motor in the Zoe increases the vehicle's range by 14% on the NEDC. As car makers and suppliers continue to push for improved performance and efficiency in hybrid and electric vehicles, it's safe to assume that further developing the e-motor will be at the heart of future progress.

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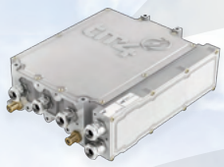

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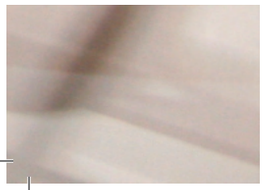
electric & hybrid vehicle technology expo

September 15-17, 2015



Electric showstoppers

Leading professionals from the world of EVs will be gathering in Novi – and there's plenty for them to talk about

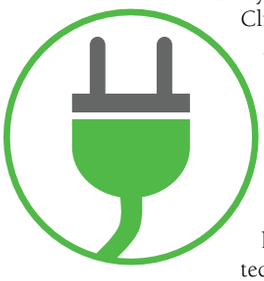
Being held in the automotive capital of the USA – Detroit, Michigan – Electric & Hybrid Vehicle Technology Expo and Conference provides a platform for the industry's leading companies to showcase the latest developments in EV manufacturing. Furthermore, delegates to the three-track conference will be able to listen to presentations by leading innovators and commentators on research, technology, regulation and the market.

Over the three days of the expo (September 15-17) visitors can also join the action in the main hall, where they can attend the always-popular free-to-attend Open Tech Forums covering a variety of hot industry topics. Sessions will be running all day.

Embedded in the global events calendar as the premier automotive event for emerging and sustainable technology, Electric & Hybrid Vehicle Technology Expo provides a unique opportunity for leading executives, scientists and engineers to network and do business in a friendly and professional environment. The show does not merely serve the industry, but for three days a year it *is* the industry – all gathered under the same roof. First opened in 2013 alongside the world-renowned Battery Show, Electric & Hybrid Vehicle Technology Expo has been growing in size and attracting increasing numbers of visitors every year.

The show attracts leading automotive and off-highway vehicle engineers, business leaders, technical experts, consultants and R&D professionals looking for greater e-mobility efficiency and safety, while reducing overall costs. With a 30% increase in exhibitors since last year, this September the event expects to host more than 5,000 attendees.

Building on last year's success, the 2015 exhibition features an even more comprehensive range of leading suppliers including: Omron, Delphi, Hongfa, DeweSoft, ATS Automation, Kostal, Brammo and Freescale, all displaying their wares on major booths. In addition, the show's partner, EDTA, will be launching the new Electric Village, which will display the latest electric and hybrid vehicles and EVSE solutions from ClipperCreek, IES Synergy, BTCPower, AeroVironment, CurrentWays and Powercube.



Popular with attendees and exhibitors alike, Electric & Hybrid Vehicle Technology Expo attracts a lot of praise. Last year Jay Schultz of Parker remarked, "This is a great event for companies who manufacture vehicles, who assemble electronic and hybrid powertrains, to get different types of technologies that go into those products. As a supplier of those technologies, we see many of those companies go by the booth and it's been a great event!"

Wellington Y Kwok of Caterpillar also enthused, "I believe this is one of the best-organized conferences, if not the best, I have ever attended. The technical content was extensive but not overwhelming. The exhibitors were well represented, and the exhibition area was easy to navigate. Of course, the food, drink and networking opportunities are great too. I am looking forward to returning to the show next year, and years after."

This unique exhibition runs alongside The Battery Show and, for the first time, Critical Power Expo, an event dedicated to back-up energy storage.

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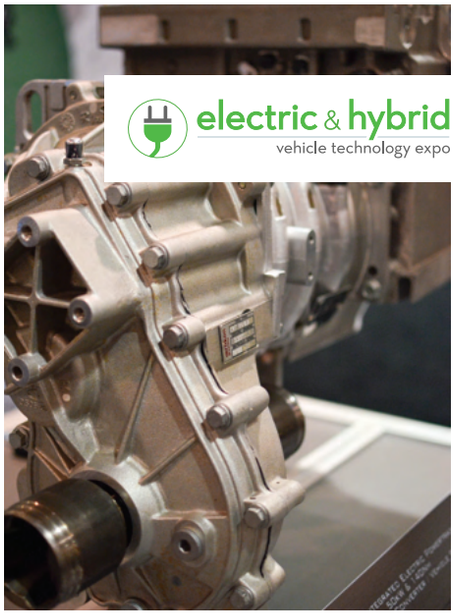
A SNAPSHOT OF THE INDUSTRY

In 2014 there was a 13% increase in attendance at the growing event, with a 27% increase in exhibitors, and a 13% increase in conference delegates. Participating companies included Ford, GM, Tesla, Continental, Chrysler, Bosch, Nissan, Volkswagen, BAE Systems and John Deere.

Among the exhibitors this year are: Omron Automation and Safety, a leading global provider of machine safety and automation solutions; Delphi, a global supplier of technologies for the automotive and commercial vehicle markets; Dewesoft, a provider of hardware for in-vehicle and lab data-acquisition applications; Horiba, which offers tools and expertise to optimize e-motor and powertrain development, including simulation capabilities; Hongfa, a global designer and manufacturer of relays, contactors and circuit protection; ATS Automation, which designs and builds automated manufacturing equipment; Kostal, a specialist in connectors for high-reliability automotive applications; Teledyne LeCroy, a supplier of oscilloscopes and analyzers; Southwire, a manufacturer and innovator of electrical and electronic wire and cable products; Parker Hannifin, which includes a broad array of HEV and EV drivetrain motors and inverters in its portfolio; Freescale Semiconductor, a supplier of microcontrollers, digital networking processors, analog and power-management, RF and sensing solutions; Murata, which designs and manufactures ceramic-based passive electronic components and solutions, communication and power-supply modules; and Amphenol, which answers the interconnection needs of HEVs/EVs and battery systems.



EXCLUSIVE NETWORKING RECEPTIONS

An invitation is cordially extended to all conference delegates and speakers, exhibitors and visitors to attend this year's dedicated networking events during the show. Visitors have the opportunity to maximize the value of their time at the show in a relaxed, professional environment, meeting technical leaders, scientists, engineers, project leaders, buyers, senior executives and other potential business connections.

This year's receptions take place between 4:30pm and 6:30pm in the exhibition hall. The first is on Tuesday, September 15, sponsored by EnerSys. The second is on Wednesday, September 16, and is sponsored by Delphi.

ELECTRIC & HYBRID VEHICLE TECHNOLOGY INTERNATIONAL MAGAZINE

Electric & Hybrid Vehicle Technology Expo originally grew out of *Electric & Hybrid Vehicle Technology International* magazine, a well-known international publication. Although the expo now exists as its own business and brand, the relationship between print and show continues. Visitors are welcome to stop by at Booth 1658 to pick up a free copy of the very special 20th anniversary issue of *Electric & Hybrid Vehicle Technology International* and to meet publication director Simon Edmands.

EXAMINING THE KEY BUSINESS AND TECHNICAL ISSUES IMPACTING THE INDUSTRY

Integral to Electric & Hybrid Vehicle Technology Expo is its conference, which provides critical insight from the market's leading Tier 1 suppliers, as well as passenger car, transport, heavy-duty, off-highway and industrial vehicle OEMs, whose representatives will discuss emerging technology trends and the best ways to develop product strategies and technical roadmaps to meet regulatory and emissions requirements. Furthermore, the comprehensive three-track conference will provide a holistic view of what is driving current and future demand for energy storage, and assess how the industry can align its R&D efforts, strategy and investment decisions.

The key themes at this year's conference are: regulatory impacts on technology roadmaps; heavy-duty, commercial and transport vehicle market trends and opportunities; electrification and hydraulic technologies for off-highway and industrial applications; energy storage and light electrification solutions to meet emissions requirements; and vehicle light-weighting.

The breadth and depth of topics covered, as well as the quality and expertise of the speakers, have attracted a growing number of delegates. Conference organizers say they intend to build on positive feedback by increasing the content offering for EV-focused delegates with more sessions on specific applications and sectors such as off-highway.

Speakers from Tier 1 suppliers, light-duty, heavy-duty and off-highway OEMs will include:

- Maxime Ouellet, chief program manager, Nova Bus, a division of Volvo Group of Canada;
- Mihai Dorobantu, director, Technology Planning and Government Affairs, Eaton Corporation;
- Kenneth Gould, e-Mobility technical systems engineer, Porsche Cars North America;
- Arlan Purdy, product manager of Energy Storage and Emerging Technology, Raymond Corporation.

Subjects that will be of direct interest to delegates include: EV range and charging requirements; manufacturing costs; regulation; technology trends for medium and heavy-duty vehicles; retrofitting; enabling technologies for e-buses; the combination of electrification and hydraulics; beyond Li-ion; vehicle and battery system safety; next-generation materials; and the EV/hybrid market outlook.

Arlan Purdy, Raymond Corporation

Kenneth Gould, Porsche Cars NA

Maxime Ouellet, Nova Bus

Mihai Dorobantu, Eaton Corporation

THE DELEGATES' VIEW

The 2014 conference attracted glowing endorsements. Bradley Smith, general manager, US4R, Nissan North America, told organizers, "The conference has been fantastic – a great forum for exchange of ideas, understanding viewpoints from others and meeting new people." Eric Lalliard, chief engineer of Hybrid Air, PSA Peugeot Citroën, commented, "It's very interesting to hear about the different architectures of hybrid technologies at this conference." Michael Duhaime, global director, Electrified Powertrain at Chrysler Group, said, "It was very good to see a very diverse audience from many regions around the world." Juergen Wiesenberger, head of hybrid electric vehicles, North America, Continental AG, was also highly complimentary: "A good venue to share and learn more about EV technology and ongoing research. The conference was organized efficiently around highly relevant topics, setting the stage for networking opportunities."

Such comments from industry professionals are not given out lightly, and reflect the importance of this well-run event in the business calendar.

"A good venue to share and learn more about EV technology and ongoing research"

Juergen Wiesenberger, head of hybrid electric vehicles, North America, Continental

EXHIBITION OPENING HOURS

TUESDAY, SEPTEMBER 15
9:30am – 4:30pm
(followed by a networking reception)

WEDNESDAY, SEPTEMBER 16
9:30am – 4:30pm
(followed by a networking reception)

THURSDAY, SEPTEMBER 17
9:30am – 3:00pm

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Kenneth Gould,
e-mobility Technical Systems Engineer,
Porsche Cars North America

Paul Cantin,
Project Leader – New Product Development,
New Flyer Industries

Deborah L. Gordon,
Executive Director, Regulatory Issues
& Hybrid Programs,
Allison Transmission

Matt Horton,
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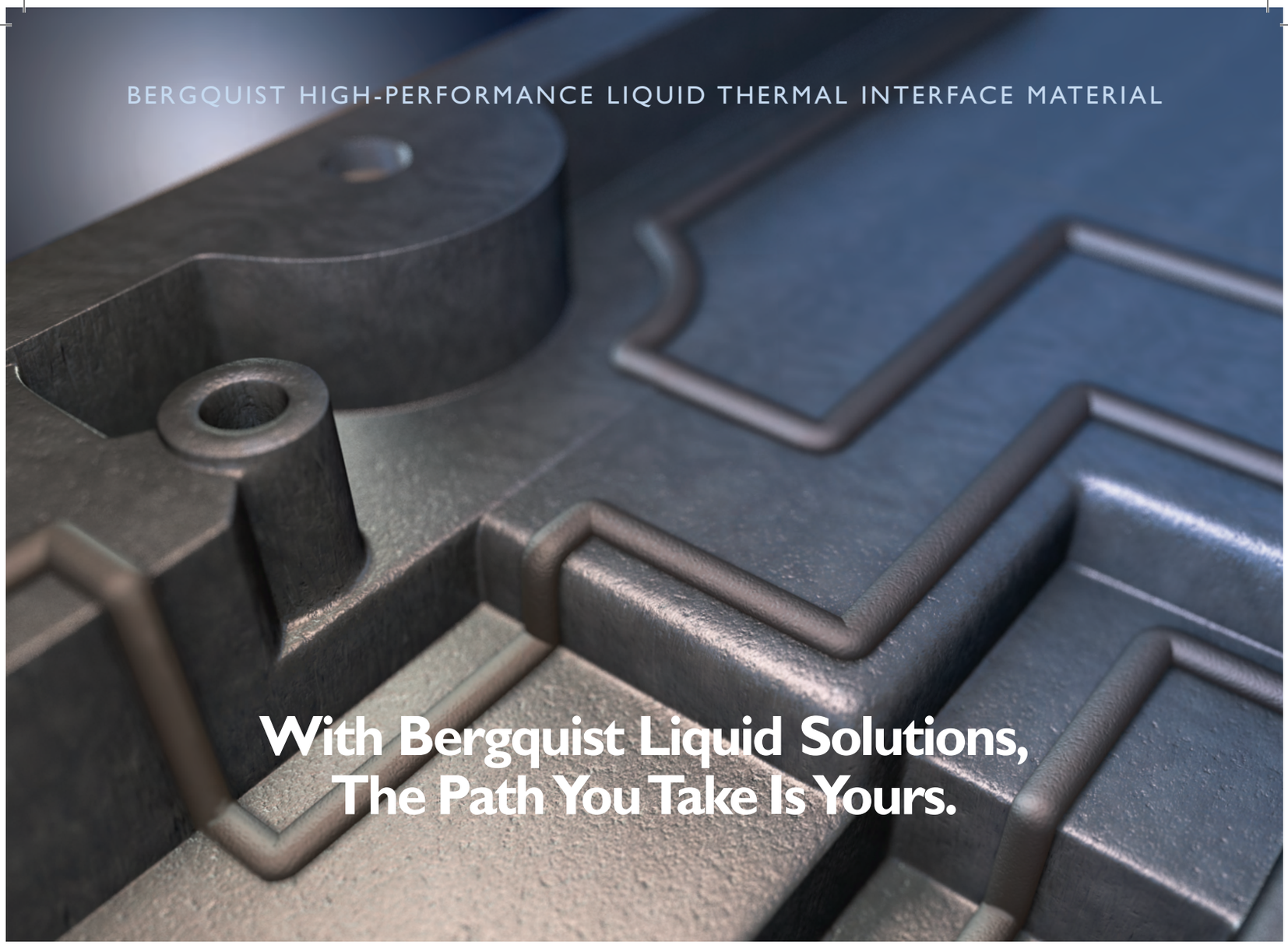

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Power play

Power electronics can be used to benefit e-mobility while responding to the requirements of an increasingly demanding automotive industry

WORDS: **KARL VADASZFFY**

Bel Power Solutions is a leading provider of power conversion and power management solutions, with a portfolio of e-mobility products that have been developed over the past four years.

Stefan Naude, the company's engineering director, describes the automotive market as an "evolving industry", adding that EVs "have high-voltage battery banks that need their high voltage to be transformed to voltages that can be used in the vehicles. Batteries need charging and the energy can be used to provide exportable power from the vehicle.

"We've realized that our customers need isolation. They need to have a safe working voltage that's isolated from the high-voltage batteries. Power products are normally mounted in a vehicle in areas that aren't protected by the cabins – underneath the chassis, for instance, in areas where you really need to have a rugged design, and it needs to be fully protected against environmental conditions."

Such battery systems have to be extremely efficient, compact and lightweight, Naude explains. "For a unit that's around 30 liters in volume, customers expect to achieve 15kW, if not more, and the weight needs to be in the range of 30kg." And Naude believes that the industry will expect even greater strides in these areas in the future, revealing that the next-generation products from Bel Power Solutions are expected to weigh 25% less. This, he hopes, will be achieved in two to five years' time.

Bel Power Solutions' DNC Series of 4kW DC/DC converters creates DC voltages in hybrid and electric vehicles that's suitable to power low-voltage accessories

"We've realized that our customers need isolation. They need to have a safe working voltage that's isolated from the high-voltage batteries"

Stefan Naude, engineering director, Bel Power Solutions

Where to charge?

A current industry debate, Naude says, is about whether a charger should be installed on a vehicle as an onboard charger or whether charging should be done at a charging station: "The question is, where does the industry go? Put a charger on every vehicle or develop the infrastructure that enables the charging of vehicles everywhere? The latter would be particularly challenging with regard to heavier vehicles – buses and trucks, for example – as well as for off-road vehicles, which are our key markets.

"In addition, it would be ideal if the charger was more versatile. It could be bidirectional, feeding back the power that's put into it. So when the battery is fully charged, it could provide the power as an auxiliary, where you can use the vehicle to power up an external AC accessory."

A future trend, he predicts, is combining power units into one box, "instead of having multiple black boxes that

offer different functions. Then you wouldn't need to have lots of high-voltage power lines and coolant loops connecting box-to-box. This on its own reduces volume. I don't think the direction we'll go in will be so much about making individual units smaller; it's rather going to be about consolidating units into one."

All bases covered

To this end, Bel Power Solutions offers five series of products. Its DNC Series is a 4kW DC/DC converter that creates DC voltages in EVs and HEVs that are suitable for powering low-voltage (12/24V) accessories, replacing the conventional alternator. The device's high power output makes it ideally matched to a range of medium- to heavy-duty on- and off-highway vehicles.

The INV Series, for similar vehicles, is a DC/AC inverter that converts high-voltage DC power into the split-phase AC power that's required to drive AC accessory loads direct from the high-voltage DC drives or battery bus. It enables high-voltage DC bus voltages to be used with 120V or 240V AC accessories. "It could be implemented on a utility vehicle that's used as a workhorse and can power up air-conditioning or power tools, for example," adds Naude. "Or on a bus where power outlets can be provided so that passengers can use their electrical items."

The company's INVCH Series is a bidirectional 15kW inverter charger that converts AC to DC voltages in charge mode, and converts DC voltages to pure sine wave AC to power accessories. "You can provide energy to a vehicle's auxiliary or export that power as needed," comments Naude. "It's not just a simple charging technology."

The BDC Series (bidirectional conversion) provides peak energy in an application where there's a generator. However, instead of oversizing it for peak demands, a solid state solution is used. "With this unit, the vehicle's battery system is used to provide the peak power energy," explains Naude. "There is a really big market for this because it will result in substantial savings being made in overall generator costs.

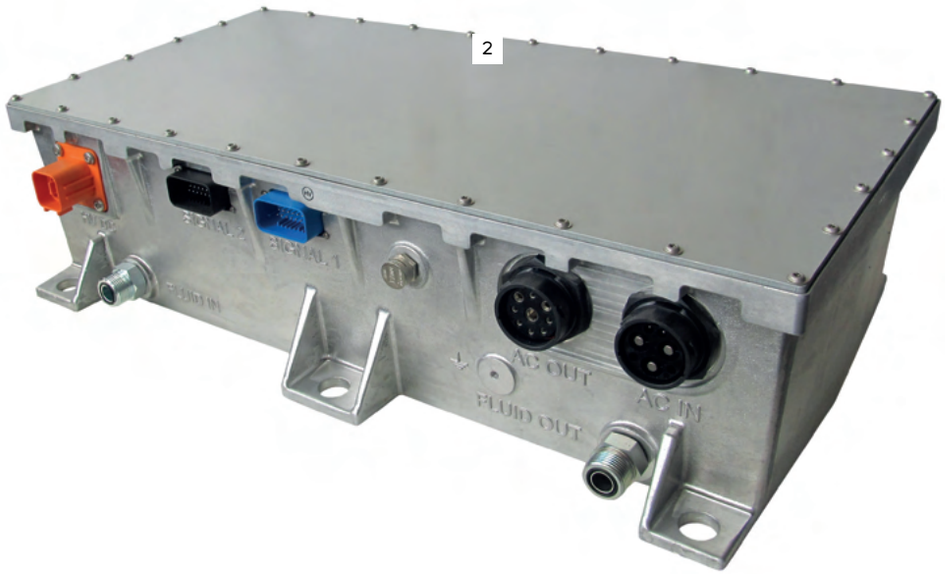
"Applications would be in the agricultural industry, where a diesel engine powers up a generator and most of the auxiliary tools are provided through a low-voltage bus. Then, on that low-voltage bus, if you need to provide power back to the generator that's providing power for the vehicle's drivetrain, you can use the low-voltage power to supplement short durations of peak power that the generator would have to provide."

Finally, MOGE is a recent product from the company. It's a motor generator unit where the vehicle's alternator is replaced by a generator, using its energy to electrify the vehicle. "So, in the case of an air-conditioned truck with a cabin on the back that is used for the transportation of cold goods," says Naude, "you no longer have to pipe coolant through copper pipes. You can electrify the whole thing, including power from a wall outlet when the vehicle is stationary. And the power from the generator then also provides the power back to the batteries."

> "The question is, where does the industry go? Put a charger on every vehicle or develop the infrastructure that enables the charging of vehicles everywhere?"
>
> Stefan Naude, engineering director, Bel Power Solutions

1

2



1. Bel Power Solutions' 350INV60-120-240-9G is a high-efficiency DC/AC inverter that converts high-voltage DC power into the split phase AC power required to drive AC accessory loads directly from the high-voltage DC drive or battery bus

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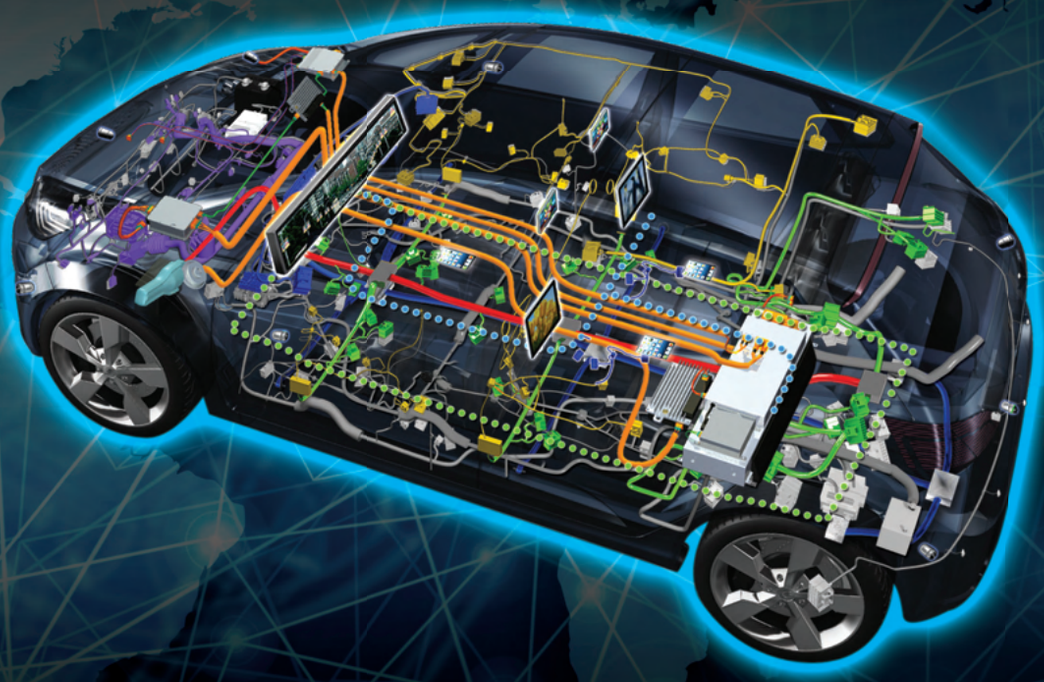

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Innovation for the Real World

The appropriate selection of specialized graphite and carbons for rechargeable batteries, and the right choice of fillers for conductive polymers, can offer a wealth of advantages for EVs and HEVs

Material gains

WORDS: **KARL VADASZFFY**

The history of Imerys Graphite & Carbon's involvement in carbon manufacturing stretches back more than 100 years. The Swiss company offers high-tech, high-performance solutions based on specialized graphite and carbons, producing a variety of synthetic and natural graphite powders, conductive carbon blacks and water-based dispersions.

Dr Michael Spahr has been Imerys Graphite & Carbon's director of R&D since 2007. He was awarded his PhD for research into materials for lithium-ion batteries. He reveals that the company has two main focuses in the automotive industry – carbon materials for rechargeable batteries and fuel cells, and fillers for conductive polymers.

"The rechargeable batteries are mainly lithium-ion," Spahr explains. "There is a particular challenge because the requirements for large-scale batteries are becoming increasingly specific. Here, there is a divergence between the requirements of portable and automotive applications.

"For portable applications, the main driver is energy density; batteries are becoming thinner, while the requirement for energy is increasing, especially with cell phones. On the automotive side, energy density, which translates into driving range, is equally important, but more must be considered – durability, cycling stability and cost." And cost remains one reason why the technology is not yet as widely adopted by drivers around the globe as originally hoped.

Increasingly, there is a divergence between battery requirements in portable applications and those found in the automotive sector

Timely reminder

When it comes to durability, Spahr suggests that of the active materials being used today, there is a trend toward employing synthetic rather than natural graphite: "The cycling stability is supposed to be better." It is important to remember, however, that "There is not only one synthetic and one natural graphite. There are different kinds."

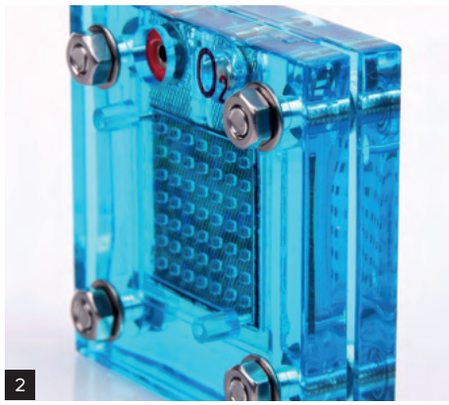
Range has been a challenge since the introduction of EVs, and while great strides have been made, Spahr argues that there is still much work to do: "The driving range is in part determined by the size of the battery, so this remains restrictive and explains the requirements for cells with higher energy density. In recent years the capacity of Li-ion batteries has been constantly improved by using carbons with greater crystallinity or better compressibility, positively influencing the density of the negative electrode, but further material developments still have to be seen with these as well."

"It does not make sense to work on automotive systems that should contribute to CO_2 reduction, while generating CO_2 through the actual production of battery materials"

Michael Spahr, director of R&D, Imerys Graphite & Carbon

"We are also working on new negative electrode materials based on carbon composites with metals, forming lithium alloys, but the drawback is cycle instability and durability"

Michael Spahr, director of R&D, Imerys Graphite & Carbon



Imerys has developed materials, under the C-NERGY brand, that are used as active materials in lithium-ion batteries. Spahr explains, "In addition to performance, we considered aspects like the environmental friendliness of the process, the sustainability of the products, and overall CO_2 generation – it does not make sense to work on automotive systems that should contribute to CO_2 reduction, while generating CO_2 through the actual production of battery materials. So we developed a technical platform with a process that is flexible, to enable us to vary the properties of the active materials and to fulfill the specification demands of our cell manufacturer customers."

Spahr suggests that discussion in the industry about natural graphite as the material for the future is somewhat misleading. "The by-products created in today's low-yield natural graphite processes are not harmful to health, but these by-products cannot be used in other applications, so it is a waste of natural resources. The pitch used in most natural graphite-based processes is harmful to both health and the environment, and its use in production processes is becoming increasingly restricted by EU regulations."

Imerys's process, therefore, does not use pitch. "The higher yield and being a pitch-free process offer major advantages environmentally," he claims.

R&D focus

Part of Spahr's R&D drive is on new additives and finding new negative electrode materials: "We are researching new carbon additives in the positive electrode that make the electrode conductive at lower carbon concentrations – therefore helping to maximize the amount of positive electrode material used – or that improve positive electrode density for a higher cell capacity. We are also working on new negative electrode materials based on carbon composites with metals, forming lithium alloys, but the drawback is cycle instability and durability. There is not yet a composite solution with a similar charge and discharge stability to graphite."

1. Imerys's development of specialized graphite and carbons is improving rechargeable battery tech

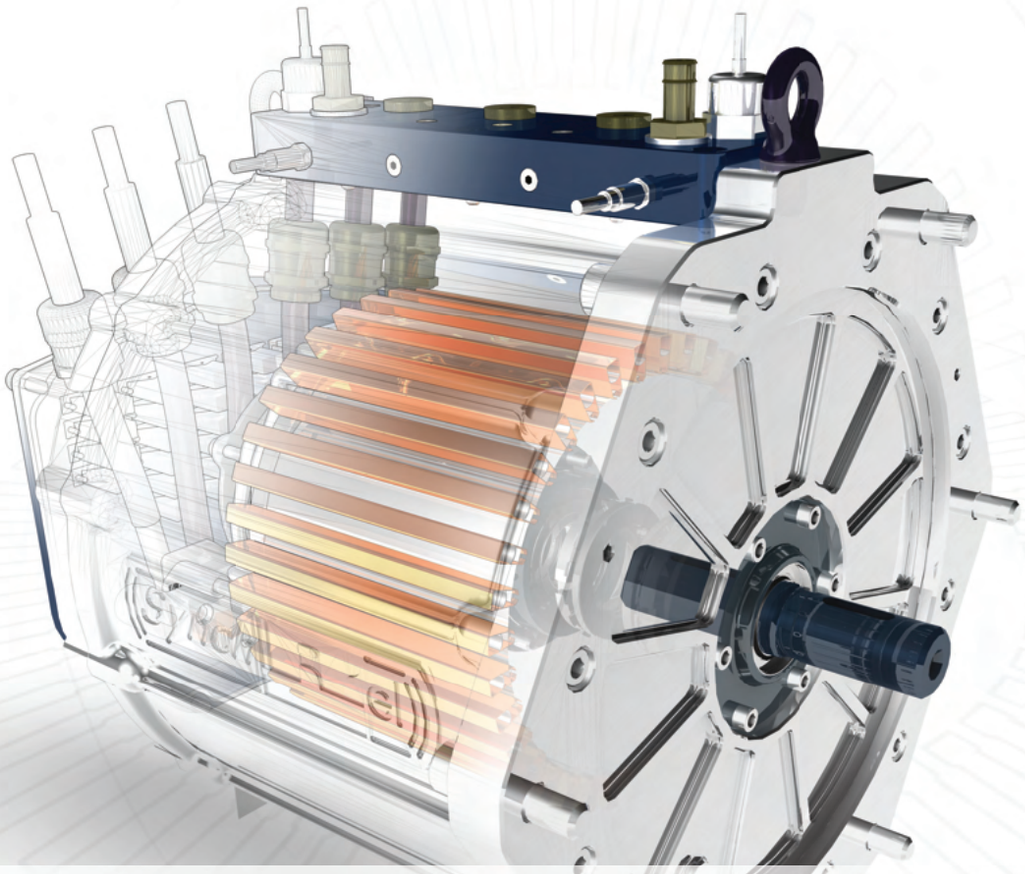
2. Imerys automotive R&D focuses on carbon materials for rechargeable batteries, fuel cells and fillers for conductive polymers

3. Graphite materials have been developed for use as active materials in lithium-ion batteries

Imerys also offers conductive additives – conductive carbon black and special graphite materials used in the positive and negative electrodes of Li-ion batteries – and has developed a carbon additive used in the negative electrode of the advanced lead-acid batteries that are used in micro hybrid cars. They help to improve cycling stability of the batteries, especially if they are operated in the high-rate, partial-state-of-charge mode.

"Lead-acid batteries offer the best performance if kept charged," Spahr says. "However, in cars with stop/start and regeneration of brake energy, what is becoming more important is good charge acceptance, as well as keeping a battery at a 50-70% state of charge to overcome the problem of limited cycling stability. Carbon additives help to make improvements in cycling stability and charge acceptance."

For fillers for electrically and thermally conductive polymers, Imerys has developed an application for its conductive carbon blacks. This solution is particularly beneficial when electrical conductivity of polymers with electrical resistance in the range of 10^0-$10^9\Omega$/sq is required, especially for polymer applications where electrostatic charge protection is requested. "Thermal conductivity is increasingly important," Spahr adds, "particularly in developing more energy-efficient systems, requiring thermally conductive polymers that enable heat dissipation and heat exchange. Another application is insulating materials in which the carbon acts as an infrared-reflecting filler. The addition of optimized carbon filler creates more efficient insulating materials."



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Diesel hybrid design

A cost-effective diesel hybrid demonstrator vehicle developed by a consortium of companies offers increased power output while lowering fuel consumption

Working closely with the Hyundai Motor Europe Technical Center, Valeo and battery manufacturer East Penn – a member of the Advanced Lead Acid Battery Consortium (ALABC) – AVL has developed a cost-effective diesel-hybrid demonstration car that delivers 25% more power than a typical, similar engine with no hybridization, while requiring around 15% less fuel.

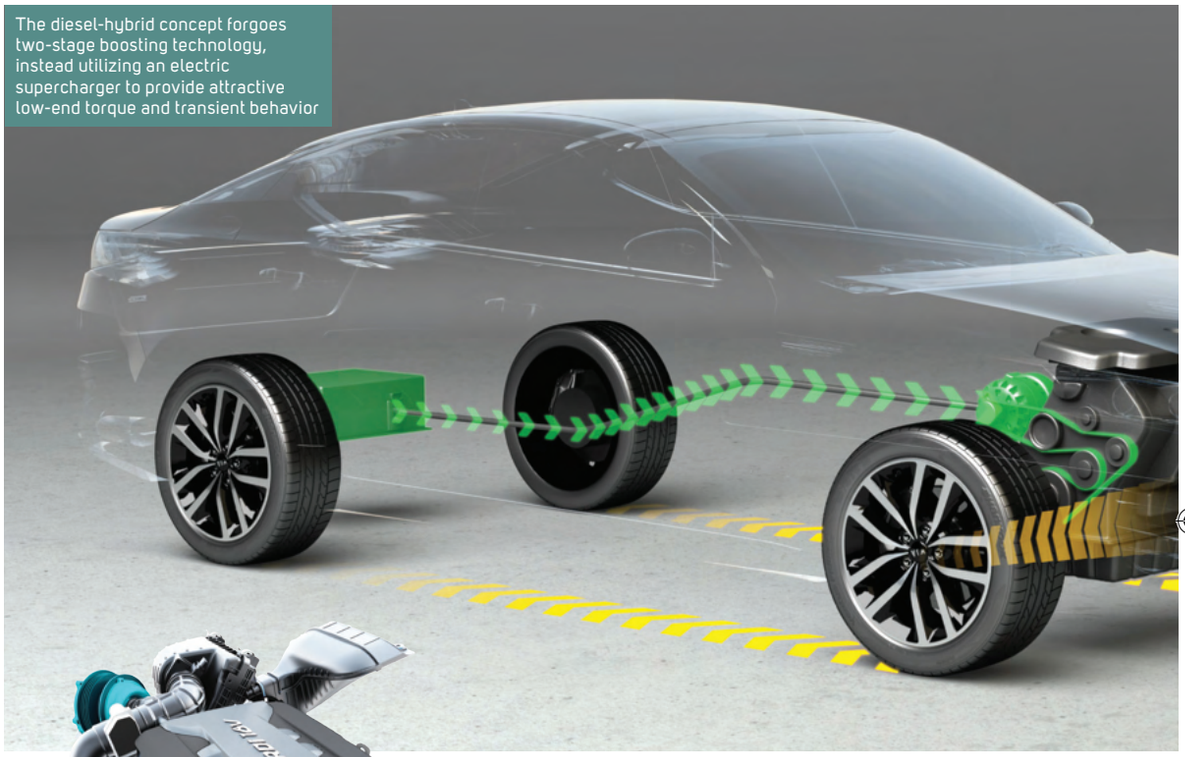
This innovative 48V diesel-electric powertrain is another large step toward meeting future CO_2 fleet emission targets with a cost-efficient mild hybrid system. It logically followed another successful development of a 48V gasoline-powered hybrid drive system in collaboration with the ALABC.

The diesel-hybrid system is based on a 1.7-liter diesel engine fitted with a single-stage VTG turbocharger. Typically, a power output increase of 25% would necessitate the implementation of a two-stage system to offer both high power and low-end torque. AVL's hybrid concept instead uses an electric supercharger to provide attractive low-end torque and transient behavior. The hybrid concept also features a belt-driven starter generator (BSG) with a peak output of 14kW, and a 48V lead-carbon battery.

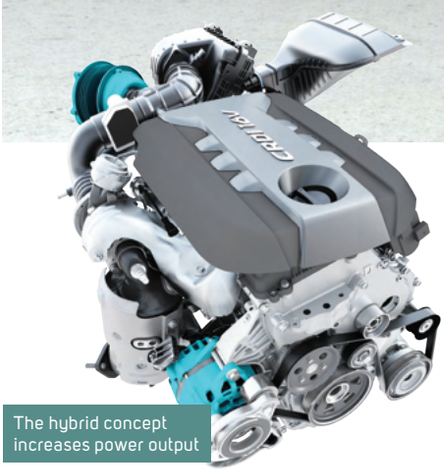
Normally the potential for reducing fuel consumption levels in a mild hybrid system is observed to be approximately 8-10%, but in this particular application, the aim of the hybrid concept is to utilize accompanying measures in the engine and transmission systems to achieve a reduction in fuel consumption of approximately 15% as an overall system result for a manual transmission.

To address customer demands, the system also features the option to drive short distances in electric-only mode. This function is not ideal in terms of energy efficiency, but for customers, the opportunity to park using electrical power or to drive under electric power in urban stop-and-go traffic situations is very attractive. During development of the hybrid system, great emphasis was placed on modular design. For example, the BSG is installed exactly where the conventional alternator would be situated – with only minor modifications, the component can be replaced and the belt drive adapted.

The hybrid system's electric compressor is designed as an independent component that is installed upstream of the gas-driven turbocharger, ensuring full separation of engine operation and electric supercharging. As the electric compressor permits immediate boost pressure build-up, the extended transient turbo lag (produced by the bigger turbocharger) can be compensated for. As soon as sufficient exhaust gas is available for the turbocharger,



The diesel-hybrid concept forgoes two-stage boosting technology, instead utilizing an electric supercharger to provide attractive low-end torque and transient behavior



The hybrid concept increases power output

The project involved a consortium of partners

the electric compressor is switched to bypass mode. Due to the system's modular design, it is not necessary for vehicles in lower performance classes to have an additional compressor – the mild hybrid drivetrain system can be implemented with the BSG alone. Besides offering increased starting convenience and change-of-mind functionalities, the 48V BSG is capable of maximizing regenerative energy capture. Both the electric supercharger and the BSG were provided by Valeo. The 48V lead-carbon battery modules are manufactured by East Penn, a member of the ALABC Consortium.

AVL's role in the development of the 48V drivetrain was significant. The company's main task was system design. AVL simulated and defined the powertrain architecture, which made it possible to calculate fuel consumption and performance potentials. In addition, AVL Schrick in Germany was responsible for the entire prototype setup – the mechanical and electric integration of the drive system. AVL teams in Graz and Regensburg jointly carried out the development and integration of the hybrid system's control software. AVL North America was responsible for battery pack design. Another special feature of the demonstrator vehicle results from AVL's collaboration with its division in Turkey: a human-machine interface (HMI) in the form of a tablet PC that is able to display and influence energy flows in a graphically appealing way. The entire development of the 1.7-liter diesel engine on the testbed, as well as the engine-internal optimization measures (friction, combustion, piston bowl, for example), was carried out by Hyundai Germany. Further optimizations are planned for the diesel-hybrid system's emission behavior – due to the degrees of freedom gained by the air path and the BSG, raw emissions can be improved dynamically. This also helps to support temperature management for exhaust aftertreatment, which can lower the cost for aftertreatment components and extend the operating window.

The main objective of the system development is to reduce fuel consumption by 15% (compared with currently available non-hybridized systems), while achieving higher rated power performance. As a result, the diesel-hybrid system gives customers added value, noticeable in the enhanced driveability – unlike measures that merely serve fuel consumption reduction alone. This capability makes the 48V hybrid an extremely attractive drive system that can, in the future, be produced cost-effectively in series in a large number of Hyundai models.

AVL partnered with Hyundai Motor Europe Technical Center, Valeo and East Penn

For over a decade, AVL has gained extensive experience with 48V technology, for both gasoline and diesel applications. Based on the company's integrated system competence (including all elements of a modern powertrain, such as engine and transmission, power electronics and e-machine, batteries and controls) and its experience in modular upgrading of existing concepts, the company is able to deliver solutions that maximize driving pleasure, while also lowering emissions.

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Underbody enhancements

Affecting everything from weight reduction and battery position to aerodynamics and inductive charging, advanced underbody design can play a vital role in electrified vehicles

Every area of a vehicle comes with its own challenges for manufacturers and suppliers. And the underbody is an area that has been receiving particular attention in recent years.

Thanks to Röchling Automotive, this very terminology for underbodies may have to be fundamentally changed, as the interior floor, underbody and chassis are combined into one component.

This development arises from OEMs' desire to reduce weight and improve aerodynamics. While the overall construction of vehicles has changed very little over a long period of time, the materials used and their degree of integration has seen much more rapid innovation. Röchling Automotive can combine the functions of the interior floor, underbody and chassis by using floor elements made of its Stratura material. The company is also working hard on the integration of metallic elements.

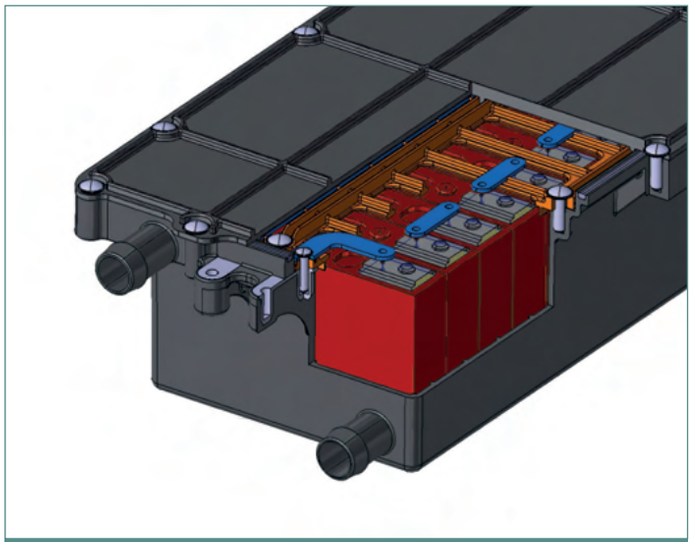
A special focus is being placed on the lightweight electric cars of the future. With these cars, every kilogram counts. Röchling can already serve these needs with several sample components with various material structures. The supplier was a participant in the Light eBody project, for instance. As part of this program, which focused on sustainability and efficiency, multiple suppliers and automotive manufacturers worked on the development of an industrial-scale lightweight body for an electric vehicle. Röchling's floor element, made from Stratura, combines the interior carpeting, high-tech acoustic insulation material and the chassis floor plate.

The continued rise of alternative drive concepts has led to a reconsideration of floor plates and underbodies. Keeping an eye on the development of the technologies and assembly procedures used in modern vehicles is not always easy for suppliers. However, concepts using low-weight reinforced thermoplastics have turned out to be very flexible. Typically based on a non-woven material concept, new properties can easily be introduced into the material by combining glass fibers with thermoplastic fibers such as polypropylene and polyester.

The floor element, made of Stratura, combines the floor carpeting, acoustic insulation material and the chassis floor plate

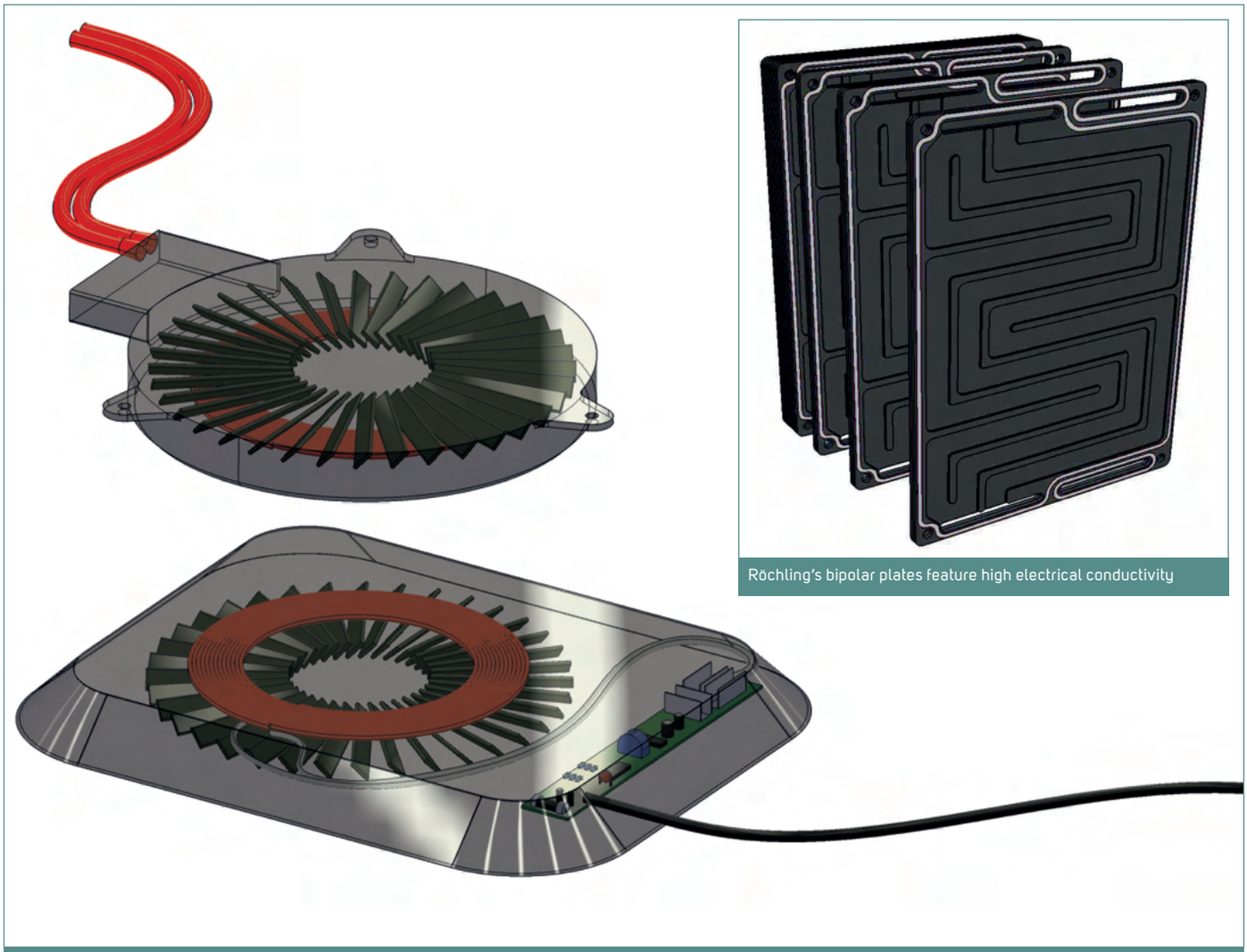
The integration of metallic foils and structural metallic elements requires more skills, such as the calculation and simulation of stresses, and the development of appropriate assembly and connection concepts. The main goals – to reduce weight and enhance NVH characteristics and therefore the comfort of the driver – are to remain the key drivers of further development in this field.

A lot of ideas regarding improved aerodynamics, including active guidance of the air by active speed lips, were born in parallel. According to Röchling, active speed lips improve a vehicle's drag coefficient by up to 10 counts. Small design modifications can enhance the underbody airflow and therefore also have an effect on fuel consumption levels. In addition to this, underbody components can positively influence driving performance, particularly in critical situations such as high-speed driving, or when there is uplift at the rear wheel axle. Under these circumstances, optimally shaped underbody parts help to improve the safety of the vehicle.



Röchling Automotive's solution for a battery stack with integrated cooling capability

The underbody is also the best location for performance batteries. One particular aspect of low-emission vehicles that has, to date, contributed to the holding back of



Röchling's bipolar plates feature high electrical conductivity

Inductive charging represents an important advance in electrified vehicle technology, and forms a fundamental part of Röchling Automotive's approach to new business

customer acceptance in the market, is their limited range. This has resulted in a flood of investments into innovations and technological developments aimed at improving batteries. For several years, Röchling Automotive has been among those suppliers developing new solutions related to batteries – especially in the area of cell frames with integrated cooling functions and insulating sheets. Very special solutions for the cooling and encapsulation of batteries have been developed.

Last but not least, inductive charging and fuel cell components have been part of the Röchling approach to new business and green cars. Conductivity within plastics is as challenging as it is fascinating. The limits have been changed, positively, in terms of functionality and safety. This also applies to the ion exchanger needed in fuel cell vehicles. Here, Röchling Automotive has developed an elegant solution that fulfills all technical and commercial expectations in a very clever way.

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Double-sided chip cooling

The implementation of a power module concept with double-sided chip cooling can produce high power density with low stray inductance while overcoming cost and weight constraints

Stricter emission standards will push electrification toward a wider range of vehicles. With range-extended electric vehicle systems being introduced to more vehicle platforms, space constraints become a major challenge. Whereas the electric motor can be integrated in or near to the transmission in the drivetrain, the inverter box has to be placed in the usually cramped engine compartment in order to electrify an existing car platform. As a result, the inverter box has to be as small as possible. Since box size is mainly defined by the power modules employed, they have to become smaller.

Typically the overall size of a power module is defined by the power consumption of the power electronic chips used, and the ability to cool these chips to stay below a maximum junction temperature. A novel power module concept with double-sided chip cooling helps to overcome massive space and cost constraints, while enabling high power densities with very low stray inductance, and package resistance improvements enabling high inverter efficiencies.

The guiding principles for module properties were that it was to be very small, and that the thermo-mechanical symmetry of the stack should prevent thermo-mechanical deformation of the module due to differences in coefficients of thermal expansion in the actual materials employed. In addition, internal electrical isolation was key – the module can be attached to a cooler without the need for external electrical isolation. Also, for an improved protection scheme, the power module is able to integrate on-chip sensors.

Infineon's novel power module combines double-sided chip cooling with electrical isolation of the heat sinks. Electrical isolation is provided by direct copper bonded (DCB) substrates. Heat is then transported to the lower heat sink by soldering the chip directly onto the substrate. Heat to the upper heat sink is realized by spacers, which adjust the height of the module. This markedly improves manufacturability and provides the necessary space to integrate multiple safety features such as current sensors and temperature sensors. The signal pins of the chip are connected by wire bonds, whereas the emitter current of the IGBTs is conducted by the massive spacers soldered on top of the chip. Figure 1 displays a cross-section schematic of the module.

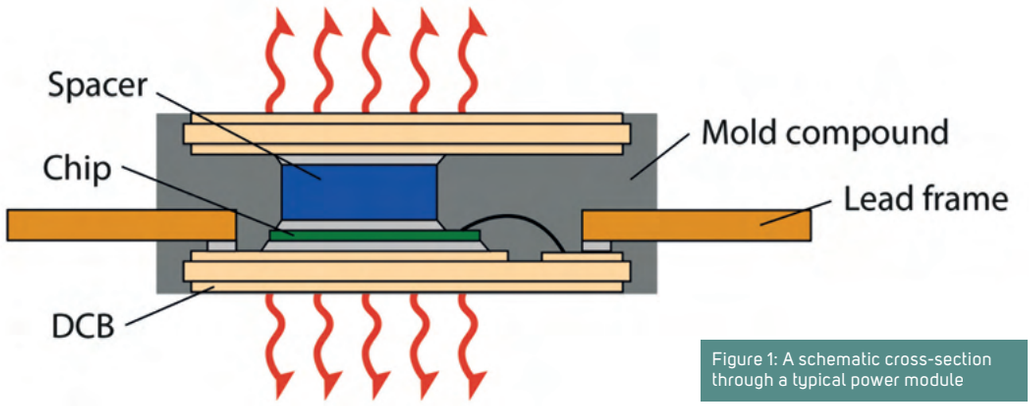

Figure 1: A schematic cross-section through a typical power module

The current prototype comes in a half-bridge configuration inside a transfer-molded package with lead frame interconnects. Figure 2 displays a prototype of a module with double-sided cooling.

Molded power modules are made with materials that have different coefficients of thermal expansion. This results in a bi-metal-like and

Figure 2: The compact DSC half-bridge dual outline module has power terminals on one side and gate/signal connectors on the opposite side for simple connection to the gate driver board

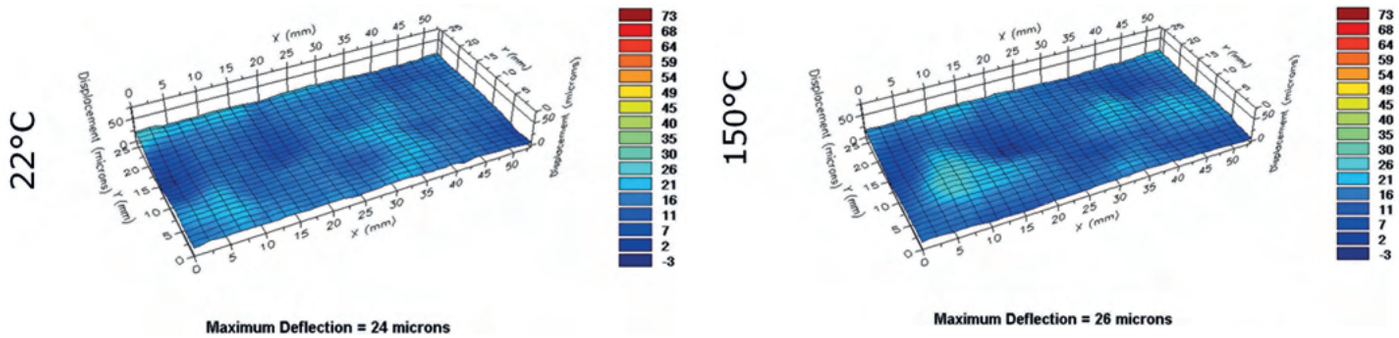

Figure 3: A comparison of module topology at 22°C (above, left) and 150°C (above, right) without any visible signs of flexing or bowing of the module over temperature

temperature-dependent bowing of the module. The deformation over the temperature cycle induces a change in the thermal resistance from chip to heat sink. This results in a pumping out of the thermal interface compound over many thermal cycles, causing fatal overheating of the module. To prevent such effects, the stack of the DSC module was designed symmetrically. The surface topology measured at 22°C and 150°C is compared in Figure 3,. As expected, there are no visible signs of flexing or bowing of the module over temperature.

By employing the double-sided chip-cooling scheme, the thermal resistance is reduced by adding a thermal path from the chip top surface to the top DCB. This results in an overall improvement of the thermal resistance by 70% – though in this case it is possible to achieve a thermal resistance junction of 0.11K/W.

For optimal cooling and the elimination of mounting-related issues, the DSC modules can be exposed to the cooling liquid (direct cooling). This method results in a substantial improvement of the thermal resistance by more than 30%. This allows use of the same module for applications of up to 40% higher power. That said, it should also be mentioned that the construction of a cooler now includes the development of a reliable sealing scheme. The comparison between indirect cooling (with cooler attachment using two different thermal interface compounds) and direct liquid cooling is depicted in Figure 4.

As well as the major performance parameters defined by the chip technology, module technology can make important contributions to the electrical performance. Stray inductance is one major parameter, defined by module size and the careful routing of the current path through the module. Presently, a value of only 13nH was achieved – 40% lower than reference modules – which results in a reduction of switching losses by 25%.

In addition, full area connection by the spacer and the short electric paths in the small module improve the package resistance by more than 50%, which also contributes to higher system efficiencies.

Each IGBT comes equipped with an on-chip current sensor for overcurrent protection and an on-chip temperature sensor for derating and fast shut-off in case of over-temperature.

The new double-sided cooled power module features internal electrical isolation. Thanks to its symmetrical design, it is extremely stable and there are no thermo-mechanical deformations. When compared with standard modules, it also displays superior thermal performance, which will be further improved by employing direct liquid cooling. Heat cross-coupling is strongly reduced, so the power module can perform with a much higher power density. Finally, low package electrical parasitics, namely low stray inductance and low package resistance, help to improve energy efficiency.

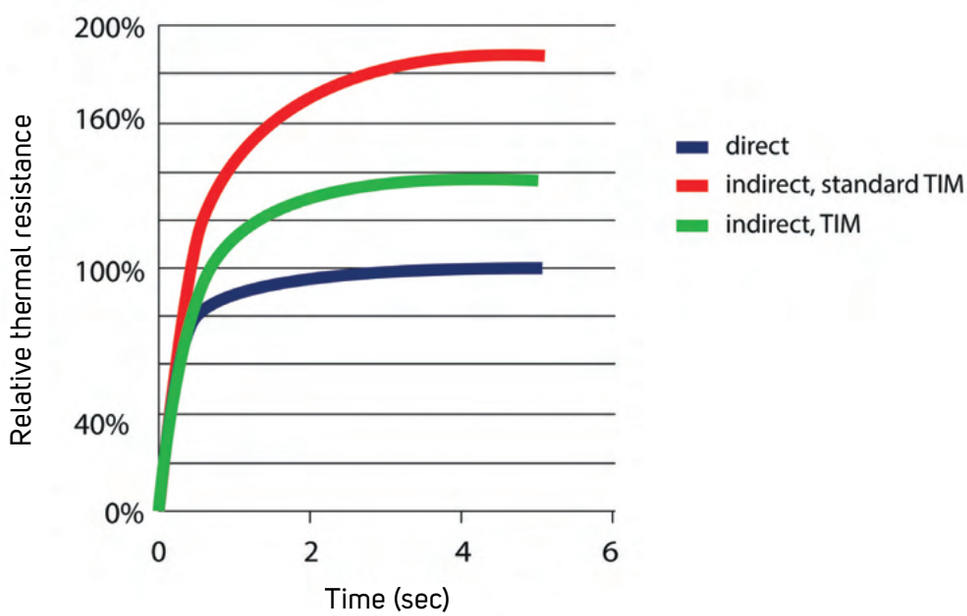

Figure. 4: A comparison of the thermal performance of indirect cooling with two different thermal interface materials (TIM) and direct liquid cooling

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Interconnect options

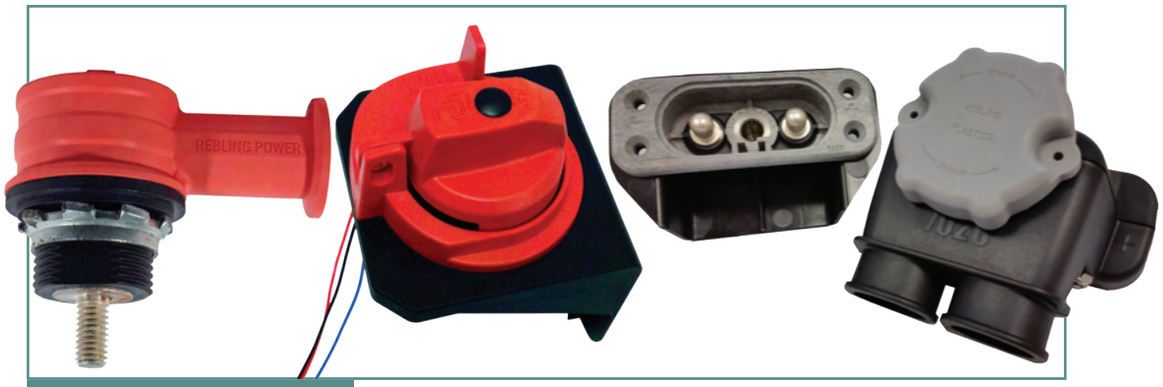
Selecting the most appropriate power electric connections for a given application can play a critical role in the system design process, and can help avoid subpar solutions

Every engineer has made the mistake of leaving a trivial detail until the end of a project, and then been forced to scramble for a subpar solution as the deadline approaches. Separable electrical connections, also referred to as interconnects, tend to fall into this category. Now, however, it is possible to plan for these seemingly minor details and easily find the option that completes a design.

Firstly, it is important to consider what type of interconnect solution best suits the requirements of the individual application. Separable connections can be categorized as: terminals, in which a conductor is electrically connected to another conductor using a reversible method such as a nut; switches, where the conductors are affixed to poles and electrical connection is made via a moveable component; and connectors, in which two conductors are held in housings and mated manually to create the electrical connection.

The type of connector best suited for a particular design depends on a number of factors, including the number of connection cycles, the time or labor allowed to install the device and make the connection, and the price point. This is summarized in Figure 1, where a score of 1 indicates the most desirable (fastest, least expensive, most durable) and 3 the least.

It is also important to consider what electrical ratings will be required. Electrical ratings are measured in voltage and current.



Separable electrical connections can be categorized as either terminal, switch or connector. Selecting the most appropriate type is vital

INTERCONNECT TYPE	CONNECT TIME	INSTALL TIME	PRICE	DURABILITY
Terminal	3	3	1	3
Switch	1	2	2	1
Connector	2	1	3	2

Figure 1: The relative advantages and drawbacks of different types of interconnect

Voltage ratings can refer to a couple of properties. One is the ability of the separated contacts to resist arcing, sometimes called galvanic isolation. A second, more common rating is the dielectric withstand voltage, which measures electrical insulation from the environment and from other conductors.

Current rating, sometimes called ampacity, can be determined in a number of ways, all of which are related to I^2R (resistance times the current squared). Underwriters Laboratories has set a 30°C temperature rise as the standard for rating continuous current. Cables are rated based upon an NEC standard for reaching 75°C or 90°C from a 30°C ambient. Higher ratings can be achieved by using the heat deflection temperature as the limiting factor, and the highest rating is the current that causes thermal runaway. Thermal runaway is the result of increasing resistance with increasing temperature levels, which will eventually lead to the conductors melting.

Whichever way products are rated, it is important to be very clear on what ambient and temperature rise numbers were used so that products can be the subject of a fair comparison. It should also be noted that interconnect ratings can be affected by cable size or even a slight breeze.

Engineers should also ensure that they consider what additional features the interconnects may need. Additional electrical features may be the most critical of an application. For example, live connect/disconnect operations create arcing, which will quickly degrade the wrong type of contacts.

Other features should also be considered, including environmental resistance (salt, thermal shock, for example); IP rating in the mated, mounted, and free states; flame rating; chemical resistance; temperature range; vibration; shock; EMI shielding; cable size (conductor and insulation); keying or a means of preventing cross connection; fuse integration; and termination type (stud, bolt, clamp).

The ratings mentioned here are generally tested in accordance with strict standards. Contact should be made with a knowledgeable manufacturer to address this trivial, but critical, part of a system.

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Cost-effective EV batteries

Combining comprehensive battery design solutions with expanding production levels makes it possible to offer frugal yet practical power solutions for industrial and vehicle applications

Octillion Power Systems (OPS), based in Hayward, California, USA, is a provider of advanced lithium-ion batteries for industrial and vehicle applications. Part of the SinoEV Technologies family of companies, OPS delivers comprehensive battery design solutions with a cost-competitive advantage by taking a 'design locally, build globally' approach to the marketplace. The result is a company that has cracked the code on how to deliver a viable EV solution that can compete with the IC engine.

The proof can be found in the recent launch of the iEV5, which was launched by JAC at the Beijing Auto Show in April, showcasing a SinoEV 25kWh lithium-ion battery. The iEV5 is powered by an electric motor with a 68ps output and a 70Ah lithium-ion battery, sporting a range of up to 200km and a top speed of 120km/h. Charging takes eight hours on 220V. Using a fast charger, the battery can reach 80% of capacity in less than 2.5 hours. Selling at a price of US$15,000 after green-car subsidies from central and local governments, JAC and SinoEV are increasing production to meet an expected demand of 1,000 vehicles per month for the remainder of 2015.

Achieving this scale of production was part of OPS's long-term growth strategy of building production capacity organically with demand, while targeting a key market poised for growth in the electric vehicle sector. Also inherent to the company's planning was leveraging pre-existing cell-production infrastructure through key partnerships with the world's leading cell makers. OPS then used its systems engineering expertise to design one of the most advanced, cost-effective battery solutions.

The JAC iEV5 pure electric vehicle has a top speed of 120km/h and range of 200km. Its 70Ah Li-ion battery can be charged to 80% in just 2.5 hours

In approaching new designs, OPS takes a technology-neutral approach to cell chemistry and form factor. Based on detailed application engineering, OPS evaluates and selects a cell configuration optimized to meet customer requirements. OPS has designed multiple packs using standard 18650 small format cylindrical cells, prismatic cells and pouch cells, using cell chemistries such as lithium-ion NMC, lithium iron phosphate and lithium titanate.

Experience-based performance improvements from real-time field data have enabled OPS to achieve Tier 1 supplier-level reliability and quality control. The data collected also assists in thermal and electrical simulations, which help in future product updates, improving energy density and predicting cell cycle life at the pack level.

OPS conducts cell-level, module-level, pack-level and vehicle-level tests to verify performance and fine-tune its products. Safety is of extreme importance and multiple levels of testing help mitigate any potential safety issues.

OPS has validated multiple lithium-ion battery packs through rigorous automotive tests, including drop tests, extreme temperature tests, penetration tests and crash tests. Packs are also subjected to internal thermal runaway tests that eliminate any concern about thermal propagation. Robust battery packaging, combined with experience in manufacturing, helps OPS deliver safe products to its customers.

High-volume production is critical to achieving lower costs per kilowatt-hour at the battery-pack level. OPS currently produces more than 24MWh-worth of battery packs each month for automotive and other applications, and has seen tremendous demand for its high energy density and competitively priced lithium-ion battery packs. The company is already expanding to its third manufacturing facility to meet customer demand, which will take annual production capacity to more than 1GWh.

Outside of the China market, OPS has made major inroads into the US, European and Australian markets. The company is focusing on grid energy storage and heavy-duty vehicles in these markets. Heavy-duty applications provide an excellent opportunity to deploy all-electric vehicles. Electric transit buses, garbage trucks and shuttles provide opportunities for huge cost savings. Coupled with advanced high energy density and competitively priced offerings from OPS, heavy-duty electric vehicles will provide the highest return on investment of any vehicle class.

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INSPIRED WORK

Performance e-motors

Advanced axial flux motor technology can provide high power levels and torque density in a compact package, making it suitable for use in a range of on- and off-road applications

The development of very small and lightweight high-performance electric motors is creating some exciting opportunities for both on- and off-road vehicle designers. UK-based YASA Motors is pioneering the manufacture of advanced axial flux motors capable of world-leading levels of power and torque density. These motors are the smallest, lightest electric motors and generators in their class.

Based on the company's unique Yokeless And Segmented Armature topology, the motors use less material more efficiently to provide higher torque and power densities than any comparable motor or generator. This also results in inherently lower-cost products than competitor motors developed for high-volume production.

YASA Motors manufactures a range of standard electric motors, including the YASA-750, YASA-400 and the soon-to-be-launched YASA-P400 series for high-volume manufacture. All YASA products are designed to be integrated into customers' products with minimal application engineering. In addition to standard products, YASA Motors' design and development team is accustomed to making a variety of modifications to standard motors, as well as to bespoke and custom motors, based on the company's patented technology for customers with medium- to high-volume applications.

In one commercial application, three YASA motors have been used to power the Koenigsegg Regera, which is claimed to be the fastest accelerating and most powerful production car ever. The Regera uses two direct-drive YASA 750 motors delivering 1,600Nm/360kW on the rear axle for traction, and a single engine speed YASA 400 motor-generator unit delivering 350Nm/160kW of electrical power generation, torque gap filling and starter motor functionality.

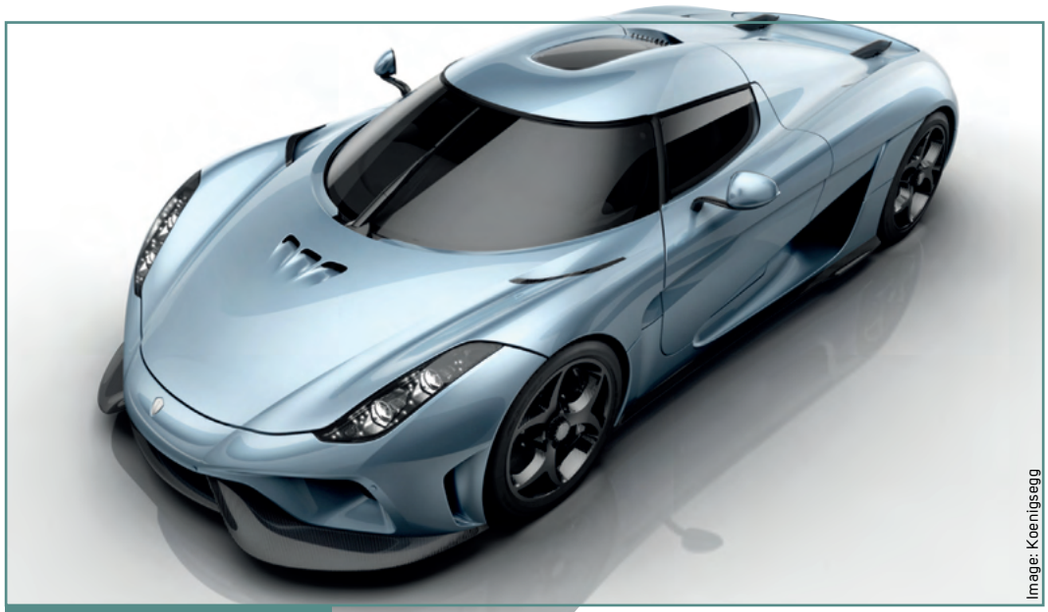

Image: Koenigsegg

Above: The Koenigsegg Regera uses three YASA electric motors that produce 710ps of additional power

Below: YASA motors are powerful yet compact and require little engineering

The use of three YASA motors in the Regera represents the most powerful hybrid electric design seen in a production car, providing up to an additional 710ps from the electric motors alone, and greatly reducing vehicle weight. It is a fine example of how YASA-produced motors can enable stronger hybrid capability in powertrains constrained by both space and weight.

In another example from the world of high-performance vehicles, YASA provided a high power and torque density electric motor for the Jaguar Land Rover (JLR) C-X75 supercar program. The YASA-400 motor produced for JLR pushed the boundaries of what has been possible in automotive electric motors, and addressed issues of power, size, weight and efficiency. The end result was a 22kg motor, no larger than a cake tin (280 x 75mm), delivering up to 180kW and 400Nm of torque. YASA was shortlisted for an SMMT award for automotive innovation for its achievement on this project.

YASA is finding that the customer benefits of high power, low space requirement and ease of integration will be seen not just in land-based vehicles, but also in commercial, industrial and marine applications. In one example, an emergency utility vehicle has been designed with motors that provide drive during the journey to an incident, and can then be reversed in order to act as generators, providing high levels of on-site emergency utility power.

In addition to vehicle applications, the unique YASA axial flux motor technology is ideal for mobile applications such as hydraulics replacement and power generation, traction and propulsion, as well as hybridization. Small, light electric motors will play an increasingly large role in meeting the strict emissions targets being set globally in a wide range of industries, and also in the requirement for greater efficiency through electrification.

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As off highway vehicle manufacturers continue to search for technologies that can bring greater fuel savings and reduced CO^2 emissions, innovation, electrification and hybrid technologies are emerging as a global trend. GKN Land Systems, a leading supplier of technology differentiated power management solutions and services, has a number of new technologies in this arena.

NEW eDrive CONCEPTS FOR THE OFF-HIGHWAY SECTOR:

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Further information on the new products can be found on the internet at **www.gkn.com/landsystems/**

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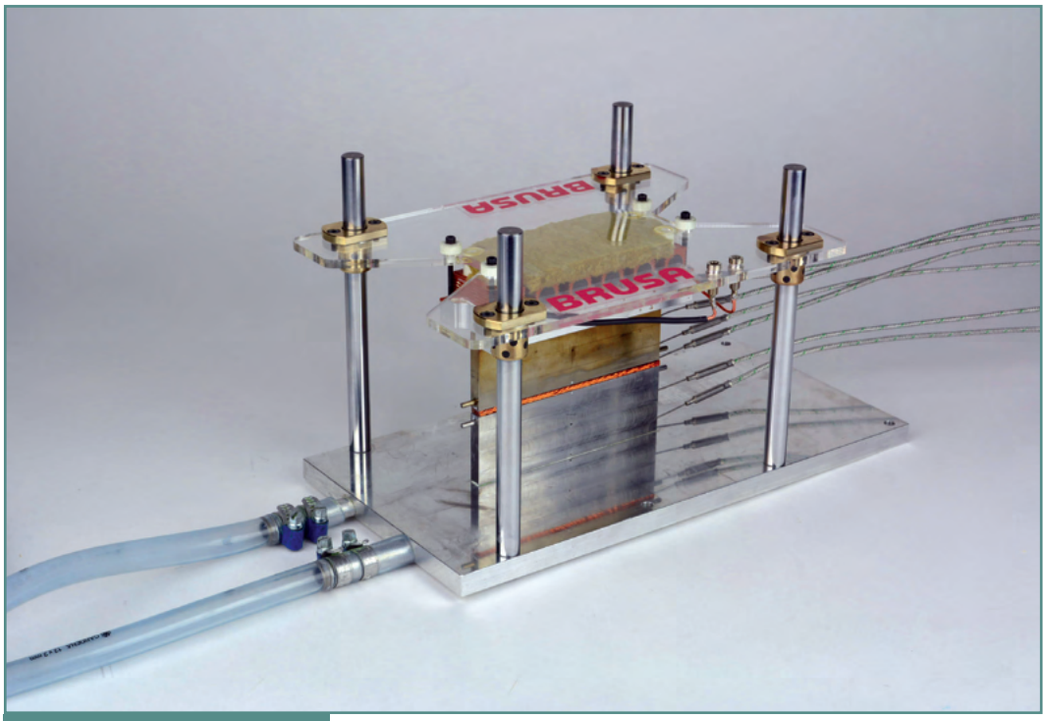
Innovative winding design

A newly developed winding design can enhance thermal conductivity in electric motors, thereby increasing power density without the associated rise in the total cost of materials

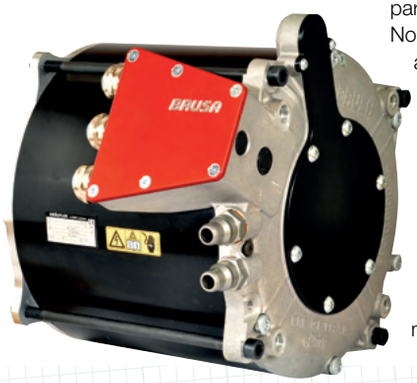
For more than eight years, Brusa Elektronik has been engaged in the research and development of a new economical winding solution. The result is a technological breakthrough that fully addresses the needs of the automotive electric vehicle industry with both a cost- and production-efficient winding.

The distributed winding is well established in motors for electric vehicles. This winding is actually one of the main cost drivers, due to the high investment required in production facilities and labor costs. Even though the winding is largely composed of copper, its thermal conductivity toward the cooling jacket is quite low. Therefore the winding is the main resistance from a thermal perspective. As little was known of methods to increase the thermal conductivity of the winding, a measurement test bench was constructed. With this facility in place, many variations of winding probes could be measured, and a knowledge base for the thermal conductivity of the winding could be established.

With this knowledge, a reliable thermal model of the winding was developed and used to increase thermal conductivity by up to a factor of 10. With the increased thermal conductivity, simulations of the motor could be made and compared with conventional pull-in windings. The results showed that the current density in the motor could be more than doubled. Due to these promising results, a prototype was built and tested, which confirmed the results of these simulations. The increased thermal conductivity enables more compact motors to be built without compromising performance. Because of the increased power-density ratio, less material is used, resulting in lower costs. And with the added benefit of production automation, this innovative technology offers high savings in both material and production costs compared with pull-in windings.



Precise test bench measurements (above) have led to the development of more compact motors (below) that use fewer materials and cost less



Besides this extremely low thermal conductivity, the use of conventional pull-in windings is also likely to prove unfeasible given the numbers of EVs forecast for 2020. Currently, manual labor is still a major cost driver in electric motor production. Use of the pull-in winding method for the forecast demand of 2020 will likely require parallelization of production lines. No economies of scale can be applied, and production prices would be kept high. The production methods for the newly developed winding are better suited to high volumes on a single production line, and 100% automation. This guarantees lower production costs per motor.

Further savings can also be made by combining this winding technology with new market trends such as higher rotation speeds or optimized rotor topologies. When using higher rotational speeds, this technology becomes of particular interest. As the stator diameter decreases, the challenge is to reach a high enough heat evacuation when using a much smaller cooling area. To achieve the required high power densities, this technology is key. Brusa Elektronik is convinced that the new winding technology will be groundbreaking for future motor production, as power density is increased, quality and automation is improved, and significantly lower production costs are achieved.

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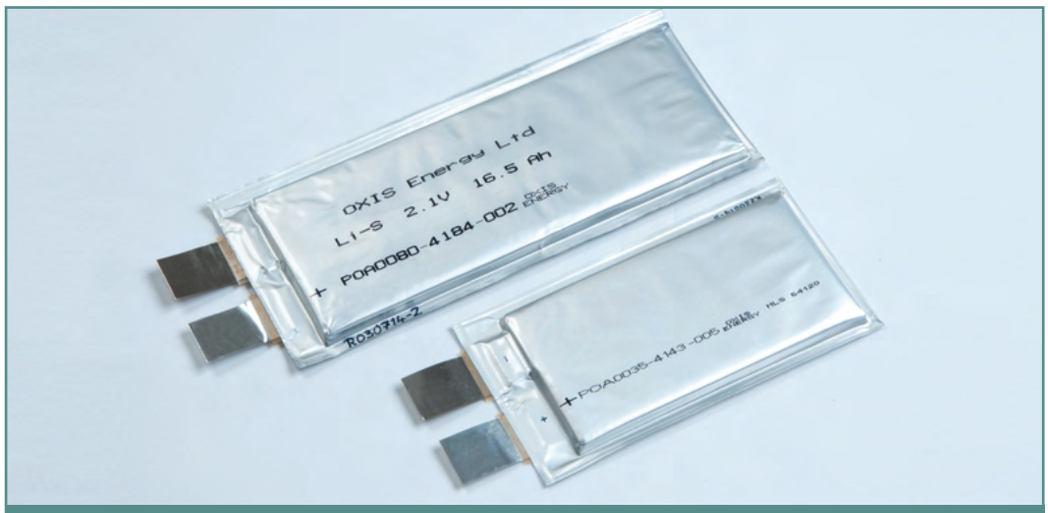
Bespoke batteries and cells

Establishing and maintaining a working relationship with experienced cell chemistry developers generates a number of important benefits for producers of electric vehicles

When designing an electric vehicle, engineers always strive to develop the best solution for the project's requirements. When it comes to the battery, they are often faced with a difficult challenge: fitting such a large system into the vehicle while maintaining safety, vehicle performance, thermal management, cost and a number of other factors. Many of these decisions are shaped by the chosen cell's performance characteristics. This then raises two design questions: which cell meets the needs of the vehicle they are currently designing, and how can the design be easily upgraded when the vehicle range is refreshed?

To help answer these questions, it is best to go to the people with the most knowledge of how a cell behaves and how it will evolve in the future – the cell chemistry developers. This is especially important when seeking to adopt a cutting-edge battery technology such as lithium sulfur (Li-S), either in the short term, or as a long-term plan for the future of a vehicle range. As such, Oxis Energy is developing rechargeable Li-S battery chemistry for vehicle applications as a part of the wider Innovate UK-funded Revolutionary Electric Vehicle Battery (REVB) project, as well as part of other initiatives. As part of this research, Oxis has already exceeded 300Wh/kg for energy density and forecasts 400Wh/kg by the end of 2016, as well as working to address the power and cycle life needs of EVs. However, not all of this work is materials-based. A major element of cell performance also depends on the mechanical design and packaging of the cell.

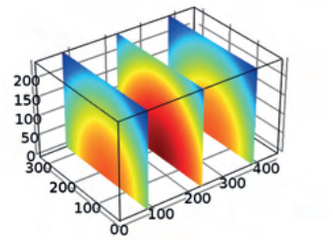
By engaging early with cell developers such as Oxis, vehicle and battery designers can gain some key advantages. The first is to understand the cell behavior and the reasons behind it. For example, Oxis has considerable knowledge of how cell chemistry behaves under a wide range of conditions, and has built working electrical and thermal models to replicate this. The models will enable more rapid and accurate design of both the battery management system (BMS) and thermal management systems for the battery.



One size does not fit all, so Oxis can change pouch cell dimensions in order to meet the needs of specific applications

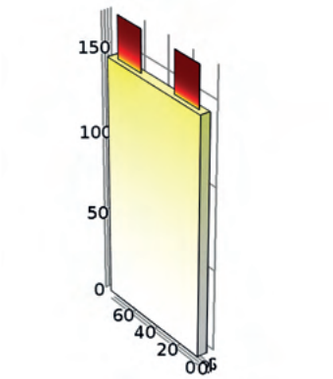
The second advantage is the ability to vary cell dimensions to suit the vehicle and the battery design philosophy. For example, if the vehicle designer would prefer large cells to reduce the complexity of the pack, but also make sure that no space is wasted, Oxis can fully develop a custom-sized cell to meet the precise needs of the battery and vehicle. This cell design service ensures the best possible solution for the system being designed, whether it is for a new vehicle or a new version of an existing model.

Finally, a close working-based relationship with a cell developer such as Oxis means that designers can plan effectively for the future, as they can review improvements as they are made, as well as provide input to research roadmaps. This approach will also ensure that the cost of updating products is kept low, as Oxis can integrate the chemistry directly into the same cell format that is already in use.



Above: Slices of a battery's thermal response, built from smaller cell models to predict real-world response

Below: A model of battery cell thermal response during use, built from first principles and real data



Working with Oxis to understand the chemistry in greater detail, and developing a bespoke cell for a project's specific needs, enables designers to produce the best possible solution for a current vehicle, and maintaining this relationship makes it easy to update that vehicle in the future. Companies in the vehicle market and other sectors have already adopted this approach; Airbus is notable among these for the work it is undertaking with Oxis for space and aerospace applications.

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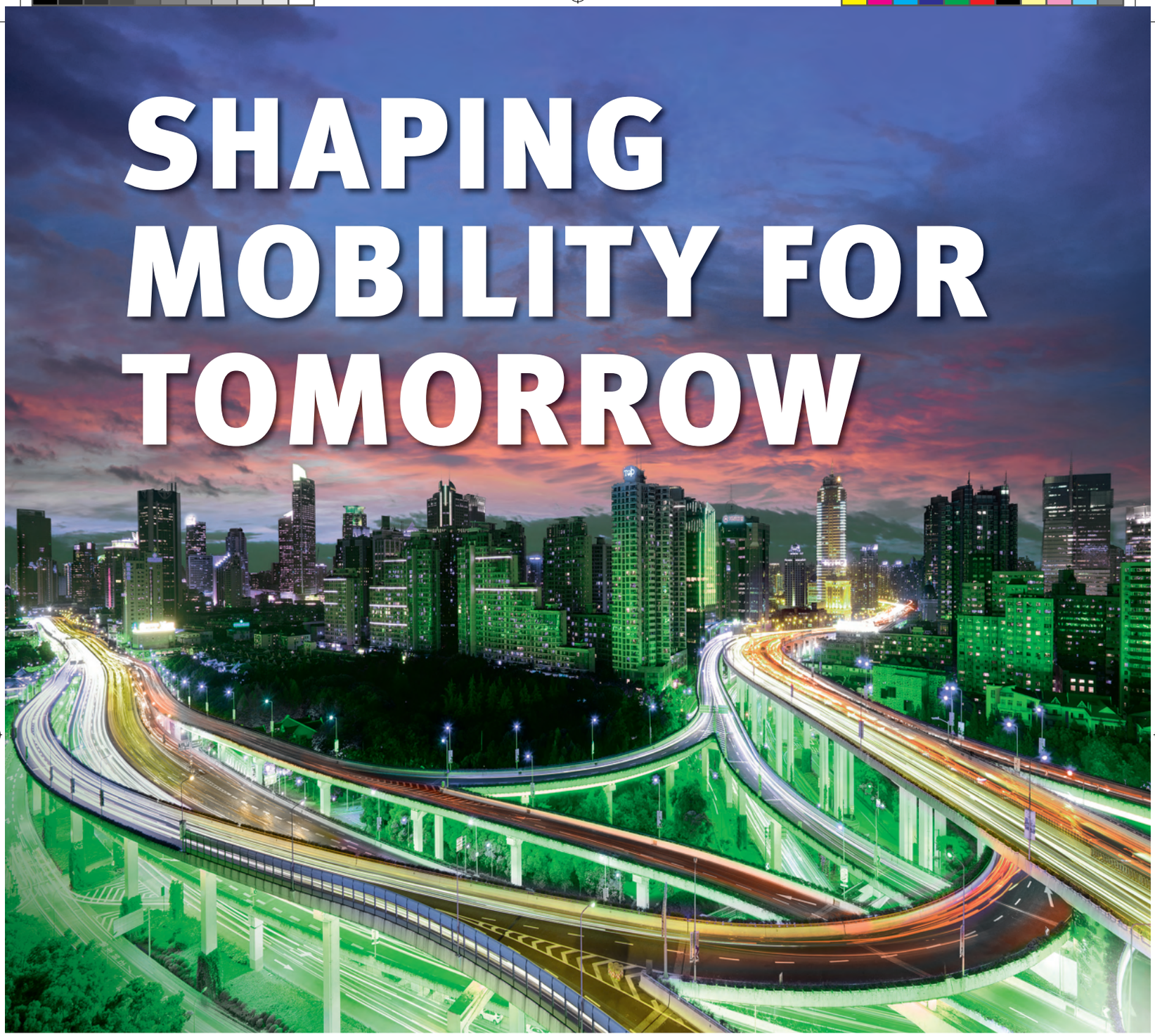

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Barrier-sealed connections

Implementing silicone-free, barrier-sealed cables in the engine compartment can prevent the transfer of fluids via capillary action, and reduce defects in electronics and sensors

If cables in the engine compartment are not completely sealed, fluids can cause technical defects in the electronics or sensors of road vehicles. So, to protect the AdBlue dosing system in its diesel vehicles, Jaguar Land Rover relies on barrier-sealed and silicone-free anti-capillary cables by Huber+Suhner.

Products located in the engine compartment of road vehicles come into contact with a variety of fluids, from engine oils, through cleaning agents, to condensate. This means that cables often need to be sealed via expensive and time-consuming processes – unless the cable itself provides a barrier to liquids.

In barrier-sealed anti-capillary cables by Huber+Suhner, a grease-like filling material prevents such fluids being conveyed through the cable due to capillary action, and damaging electric devices and sensors at the other end. "We had potential technical issues with the capillary action of the wires in our selective catalytic reduction (SCR) system," says Jonathan Goodacre, project engineer, EDS components team at Jaguar Land Rover. "We were therefore looking for a product that reliably solves the problem of the capillary effect in cables."

The SCR system consists of a catalyst, an AdBlue injection unit, an AdBlue tank and a dosing control unit. AdBlue, an aqueous urea solution, is injected into the exhaust pipe in a controlled way by this system. The chemical reaction this induces ensures that harmful nitrogen oxide in the exhaust gas is bound and almost completely eliminated. The SCR system in Jaguar Land Rover diesel vehicles thus reduces emissions output to a minimum, without adversely affecting the performance of the vehicle itself.

Tier 1 Jaguar Land Rover suppliers must now work with Radox anti-capillary cables by Huber+Suhner as a mandatory condition

Wires in the SCR system in Jaguar Land Rover vehicles had potential technical issues prior to installation of Huber+Suhner's barrier-sealed and silicone-free anti-capillary cables

The anti-capillary cable by Huber+Suhner now enables barrier-sealed connections within the SCR system. It is a silicone-free product that also solves another problem that can arise in AdBlue handling. "Contact between AdBlue and silicone can cause foam in the core," says Steve Foster, sales manager at Huber+Suhner. "At the moment we are the only supplier of silicone-free anti-capillary cables that barrier-seal the core without this undesirable effect – and over the entire length, not just at the ends of the connection."

Jaguar Land Rover has worked with Radox battery cables by Huber+Suhner for years. The entire portfolio of anti-capillary cables is now extending the scope of supply with immediate effect. Tier 1 Jaguar Land Rover suppliers such as Delphi, Leoni and Lear are required to work with these products as a mandatory condition. Following this release, other Radox battery cable cross-sections were approved. Huber+Suhner has therefore once again been able to successfully position itself in the market with premium quality and extremely reliable products.

Huber+Suhner is a global company, headquartered in Switzerland, which develops and manufactures components and system solutions for electrical and optical connectivity. With a portfolio of cables, connectors and systems – developed from the three core technologies of radio frequency, fiber optics and low frequency – the company serves customers in the communication, transportation and industrial sectors. Huber+Suhner's products deliver high performance, quality, reliability and long life – even under the harshest environmental conditions. The company's global production network, combined with group companies and agencies located in more than 60 countries, puts Huber+Suhner close to its customers.

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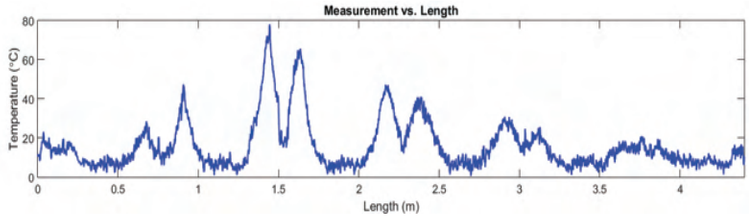
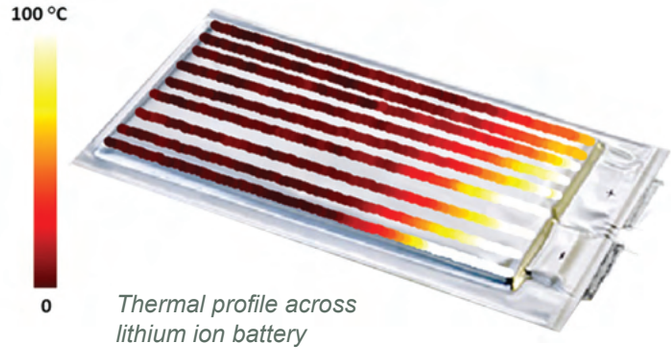


Display of temperature data captured by our ODiSI



Thermal profile across lithium ion battery

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Flywheel energy storage

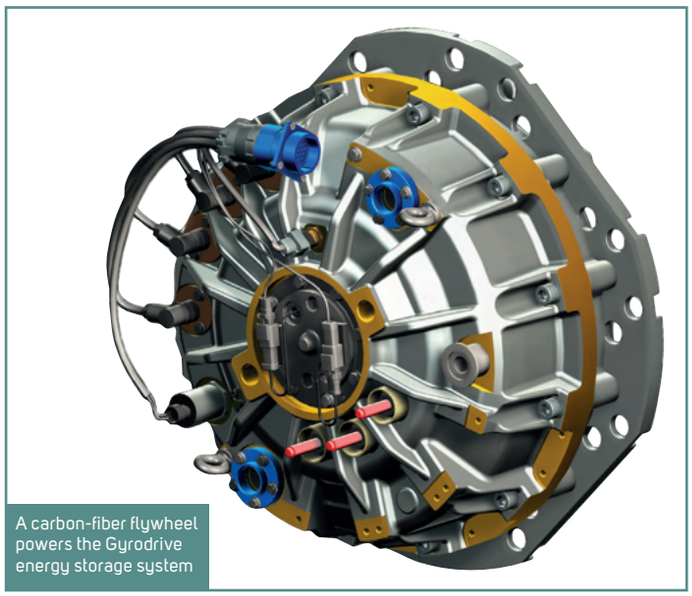
Adapting energy-storage technology from high-performance motorsport for use in commercial vehicle applications can contribute to fuel saving and emissions reduction

The world of motorsport has produced a technology that can save fuel and cut emissions from buses, trucks and trains. GKN has developed Gyrodrive, a flywheel energy-storage system that has beaten battery hybrids on the racetrack and now plans to repeat its winning formula on bus routes. The company is working to scale up production to meet demand for cleaner, cheaper public transport.

The principle behind GKN Hybrid Power's Gyrodrive system is simple: when the vehicle brakes, an electric generator turns the kinetic energy into electricity. This power is used to drive an electric motor to accelerate a high-speed flywheel. The spinning flywheel stores the energy until the vehicle needs to accelerate, at which point the process reverses.

The flywheel's rotational speed is key to storing more energy. GKN's Gyrodrive system uses a lightweight carbon fiber flywheel that spins at more than 36,000rpm. The concept has proved its safety, durability and savings in top-level motorsport.

Originally devised as a lightweight solution for hybridizing F1 race cars, the technology was subsequently adopted by endurance motorsport, where its durability, reliability and high performance made it ideal for the Le Mans 24 Hours.

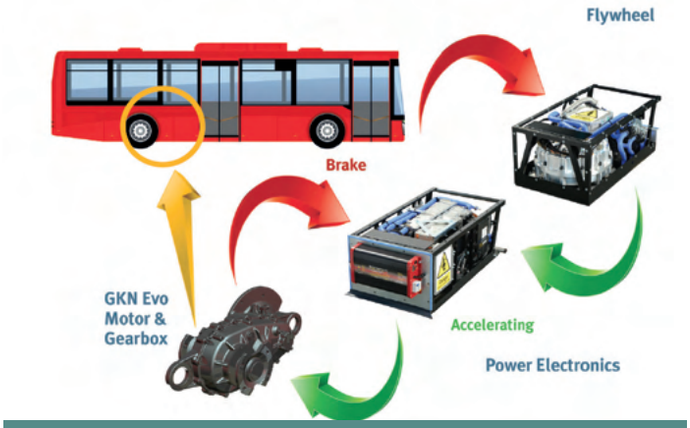


A carbon-fiber flywheel powers the Gyrodrive energy storage system

The hybrid category at Le Mans has become one of the most hotly contested prizes in automotive engineering. It is a technological arms race in which the world's OEMs compete to prove their leadership in hybrid technology. And year after year, the hybrid Audi R18 e-tron quattro with its Gyrodrive hybrid system onboard has proved impossible to beat.

"Competing for its fourth straight victory in 2015, Gyrodrive has earned the respect of the OEMs for its performance, fuel savings and staying power," says Jules Carter, head of advanced engineering at GKN Land Systems.

The development team behind the flywheel technology could see there was huge potential beyond motorsport, realizing the benefit of fuel savings from capturing braking energy in the stop/start drive cycles on city buses, trucks and trams. Who knew that the total kinetic energy of a race car is so similar to that of a double-decker bus? Buses may not be as fast, but their mass balances the equation perfectly. The durability and simplicity that has made Gyrodrive so successful in motorsport translates into a big advantage for the technology over lithium-ion battery hybrids.



Inside a bus, the Gyrodrive system can reduce fuel consumption by up to 20%

"Anyone with a well-used laptop or phone knows the performance of lithium-ion batteries fades," says Carter. "That lack of durability isn't acceptable in commercial vehicles."

The duty cycle of a city bus also has a lot in common with that of a race car. The heavy cycle of frequent braking and accelerating with only short pauses at bus stops means that a battery system can add up to two tons to the gross vehicle weight, limiting passenger capacity and reducing income.

For bus applications, the lightweight composite flywheel in the Gyrodrive system stores enough energy to stop and start the bus from around 50km/h. "This is about 1.5MJ – roughly the same energy as a large whiskey or the equivalent volume of diesel. Over a full day, the stop/start cycles amount to an overall fuel reduction of up to 20%."

A London bus covering roughly 560,00km a year at an average of 47 l/100km uses 26,500 liters of diesel. The reduction Gyrodrive can deliver depends on the rout e, but can result in savings of 5,300 liters of diesel every year, as well as 14 tons of CO_2 – bringing a major benefit to air quality.

Stop/start technology is by no means restricted to city buses and it is easy to see the technology's potential in delivery and refuse trucks as well as other modes of transport. GKN's investment in affordable hybrid technology paves the way for a fuel-saving technology that will be in demand globally. With a track record for turning proven technologies into global solutions, GKN – with Gyrodrive – is ready to compete in a far bigger arena.

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Advanced Battery Testing

Illustration: Dean Armstrong/NREL

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Powering Formula E

The all-electric racing series acts as a testbed for the development of burgeoning EV technologies promoting advances in a range of electrified drivetrain systems

Formula E is a 10-race championship for single-seat electric-powered race cars and forms FIA's flagship event for the promotion of sustainable mobility. The championship also provides a new testbed for EV technology, stimulating battery, drivetrain, motor and engine management development. For the inaugural championship, all 20 drivers are using Spark Racing Technology's Spark-Renault SRT_01E race car, which can achieve 0-100km/h in just three seconds and has a top speed of 225km/h.

The carbon fiber and aluminum chassis, designed and built by Dallara, is lightweight and strong enough to be fully compliant with the 2014 FIA crash tests, the same tests as those used to regulate Formula 1. And beneath the Kevlar honeycomb bodywork is some very innovative technology.

Above left: Beneath the Spark-Renault's bodywork is leading-edge motorsport technology, including a 200kg lithium-ion battery pack protected by a Faraday cage and thermal blanket (photo: Formula E). Above right: The McLaren MGU used in Formula E has the highest power-to-weight ratio of any electric motor in the world (photo: McLaren Electronics Systems)

The FIA has limited the battery weight to 200kg to encourage improvements in energy density, and the output can be no more than 28kWh. The battery unit is designed and manufactured by Williams Advanced Engineering, a sister company to the famous Williams Grand Prix Engineering. Lithium-ion chemistry, favored by manufacturers of mid- and high-end commercial EVs, was chosen because it offers the best energy density of any battery technology. However, lithium-ion batteries have been known to overheat and burst into flames. Consequently, Williams adopted the Formula 1 approach for Formula E by building the battery unit inside a Faraday cage and thermal barrier.

Williams also incorporated a liquid cooling system into the battery pack to control the battery temperature. In addition, each battery pack incorporates a master control system that monitors the voltage and temperature of each cell to see if a particular cell is discharging more rapidly or heating up more quickly than expected. Engineers can remotely shut down cells or limit the battery pack's overall output to keep temperatures down or extend the range at the cost of outright performance.

Charging is currently via a wired connection; however, Qualcomm's Halo division has developed an inductive charging technology to allow a car to charge while sitting on a powered pad. The company claims the technology can deliver up to 20kW so that a battery could, in principle, be fully charged from empty in approximately 90 minutes.

The Spark-Renault's motor-generator unit (MGU) comes from McLaren Electronics Systems, and traces its lineage back to the P1 hybrid supercar. In the race car, the unit produces 200kW for qualifying before being restricted to 150kW during races, with limited use of an additional 30kW for overtaking. Weighing just 26kg, the MGU has the highest power-to-weight ratio – 7.7kW/kg – of any electric motor in the world today.

The MGU uses a brushless synchronous motor, which does away with the mechanical commutator used in conventional motors, replacing it with an electronic device that improves reliability and durability. Another advantage of this motor type is that it can be made smaller and lighter than a brush type. However, brushless synchronous motors require electronic management for proper operation. The management unit uses inputs from sensors that indicate the position of the rotor to ensure that the stator coils are energized at the correct moment. Such precision timing allows for accurate speed and torque control, as well as ensuring peak efficiency. In the case of the McLaren MGU, the end result is an electric motor with an efficiency of up to 96%.

The MGU becomes a generator when the brakes are applied, aiding retardation and supplying power to the batteries. Power comes from a high-voltage, three-phase electrical connection from an inverter that is connected to the battery pack. When combined with the ECU, and powered from a 535V DC bus, the unit can then be controlled via torque and/or speed demands using a CANbus.

Leading electronics distributor Mouser is supporting the China Racing Formula E Team, and is joined by Vishay, a leading supplier of semiconductor and passive components, and Molex, a leading provider of technology ranging from connectors to cable assemblies.

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Desktop sound modeling

Sophisticated file conversion means that analysts can hear the consequences of their latest design changes by efficiently combining CAE and test data on their own computers

Vehicle developers must consider NVH earlier in the design process, so CAE analysts are increasingly making use of virtual prototyping. However, these prototypes must effectively interface with real-world testing. Virtual prototypes and previous-iteration vehicles must be tested and provide input and feedback into the CAE models. But if this collaboration is to be effective, the dialog must go both ways. This is where auditioning sound and vibration characteristics of CAE models comes into play – helping to merge the spheres of testing and CAE.

Brüel & Kjær's software enables CAE designers to rapidly process their latest design into a highly authentic sound model, so they can experience how the entire vehicle would sound with that newest component installed. Consequently, their fellow CAE analysts and test engineers can listen to the very latest iteration, or hear alternative prototypes back-to-back, and evaluate them with nothing more than their ears – providing a valuable subjective evaluation to supplement graphs and curves.

As the system operates equally well with test and/or CAE data, combinations of these can be used. So real-world data measured on a prototype can supply the sound sources, such as the drivetrain, and CAE data can be used for a vibration path transfer function – such as a newly designed engine mount.

Listeners can hear vehicles in different modes of testing, such as constant speed, wide-open throttle/overrun, or any other test profile. Then, on the screen, they can view up to nine detailed contribution diagrams of the sound, in order to help identify the most important contributions. They can synchronize the readouts for different design alternatives, making it very easy to perform A-B comparisons. They can also interact with the sound files by applying filters, to tailor the sound to produce the desired effect.

Brüel & Kjær's CAE Auditioner allows analysts to compare sound profiles and audition the sound of CAE models from their desktop

The key to this new capability is CAE Auditioner from Brüel & Kjær. It takes seconds to convert files from major CAE design codes into sound models. Then, with Brüel & Kjær's Time Insight user-interface, an analyst can listen to and compare the sound profiles, to audition their sound models from their desktop.

In use, analysts can listen to the vehicle sound and identify critical frequencies, speeds and RPM. They can also modify different source strengths and paths, and evaluate the results. This gives effective, targeted feedback into their design processes, accurately indicating which part should be updated.

In order to take advantage of the strength of CAE models at predicting changes, the software has a change-modeling capability. This takes the difference between design iterations and applies it as a filter, giving an accurate impression of the effect of design changes in CAE – rather than absolute values calculated purely in a CAE program.

When people from a number of departments are involved – such as testers, managers and designers, each with their own particular languages and individual approaches – an intuitive method of evaluation like this is invaluable for rapid and effective communication. It also allows non-experts to get involved in early decision making, because they can make subjective evaluations. And by joining CAE and NVH, it helps test engineers from both areas to share and develop their ideas together, thereby improving confidence.

With better decision making in less time, a more effective NVH process results – one where designers of all disciplines can make the very best use of all data at all times.

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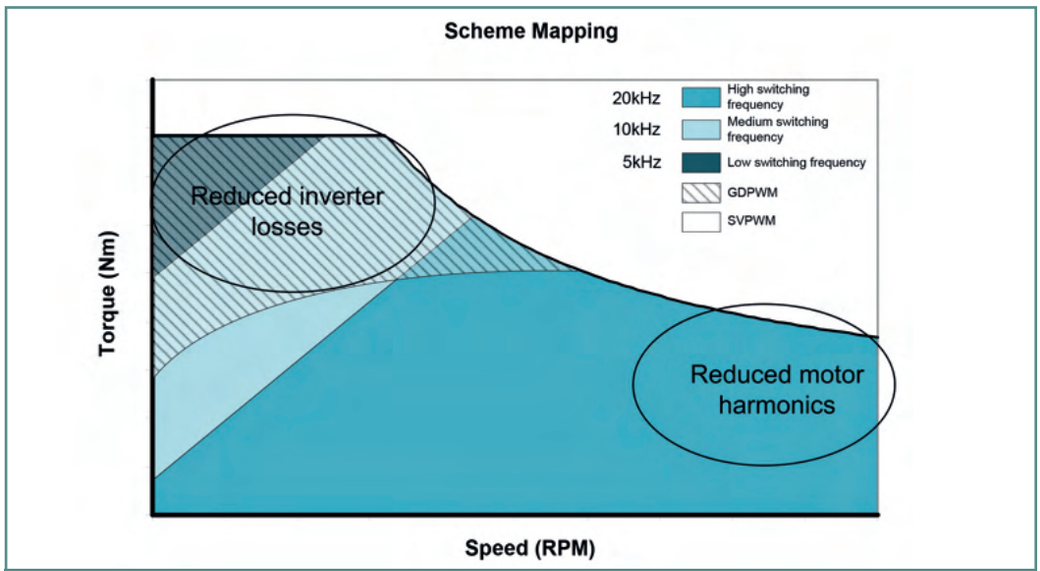
Optimizing powertrains

Advanced optimization strategies for e-motors and power inverters can help maximize IGBT module output for enhanced efficiency in commercial vehicles

With more than 25 years of experience in the vehicle electrification market, TM4 has become known for its advanced expertise in the field of power electronics, which has enabled the company to implement breakthrough technologies in its inverters. One of these technologies is the patented Reflex gate drive technology, which increases current output of IGBT modules by up to 100% in a variety of operating conditions, making TM4's inverters some of the most power-dense off-the-shelf products on the market.

TM4 is also known for taking a multiphase approach for its high-power inverters, which are used in commercial vehicle and bus powertrains, offering six-phase and even nine-phase inverters along with similarly designed motors. These inverters are composed of independent subsystems, giving an increased level of safety. The multiphase approach also leads to a reduction of the phase current, enabling a reduction in the total amount of copper used in the high-voltage phase cables, hence decreasing the overall cost of the harnesses and enabling easier integration by tightening the cables' bending radius.

Ultimately one of the keys to optimizing the hardware design and the control software of inverters acting as motor controllers is having an in-depth knowledge of electric motor design, as they both influence one another's behavior during operation. Not only should electric motors and inverters have the highest possible efficiency as standalone products, but when designing a truly efficient powertrain system, the challenge is to keep the combined efficiency of these components at the highest level possible. TM4 has achieved this by working on two means to optimize the pulse width modulation (PWM) signal: the carrier wave form and the carrier frequency.



TM4 maintains the efficiency of its inverters and electric motors through the optimization of the pulse width modulation signal via a variable switching frequency in order to reduce inverter losses and motor harmonics at higher speed levels

TM4's electric and hybrid powertrains are produced in Boucherville, Canada

For instance, TM4 uses a variable switching frequency that is able to increase along with the electrical frequency of the motor, which is dictated by its rotational speed. Varying the switching frequency makes it possible to reduce motor harmonics at high speed, without having to increase the switching losses of the inverter at low speed. However, faster switching time leads to larger switching overvoltage. This is where Reflex technology is important, as it uses the parasitic inductance in the IGBT module as an overvoltage feedback and injects it into the gate driver as negative feedback in order to control and prevent overvoltage. This technique permits better use of the IGBT, therefore resulting in much higher performance gains.

Over the operating range, space-vector PWM (SVPWM) is used for the highest frequencies since this technique leads to reductions of up to 30% in motor harmonics compared with another type of modulation – generalized discontinuous PWM (GDPWM). However, GDPWM is also used in some conditions, such as low level RPM operation. This modulation technique permits stopping one IGBT during switching, when current is at its highest rating and where conduction losses are also potentially the biggest. This process can result in a reduction in switching losses of up to 50% compared with SVPWM over this operating range.

At TM4, the proximity and capabilities of electromagnetic and power electronics teams working together under one roof has led to the development of highly efficient electric and hybrid powertrains optimized for their target markets and applications. These systems and more are being produced at TM4's Canadian facility, which is located in Boucherville, as well as at Prestolite E-Propulsion Systems' facility in Beijing, China. Both of these facilities are equipped with numerous high-volume, flexible and automated production lines, as well as a large range of dynamometers and test cells in order to provide the highest levels of product validation and certification.

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INQUIRY NO. 513

Hybrid powertrain validation

A comprehensive and flexible suite of testing tools, software and equipment is key to achieving complete powertrain validation throughout all phases of the V-cycle

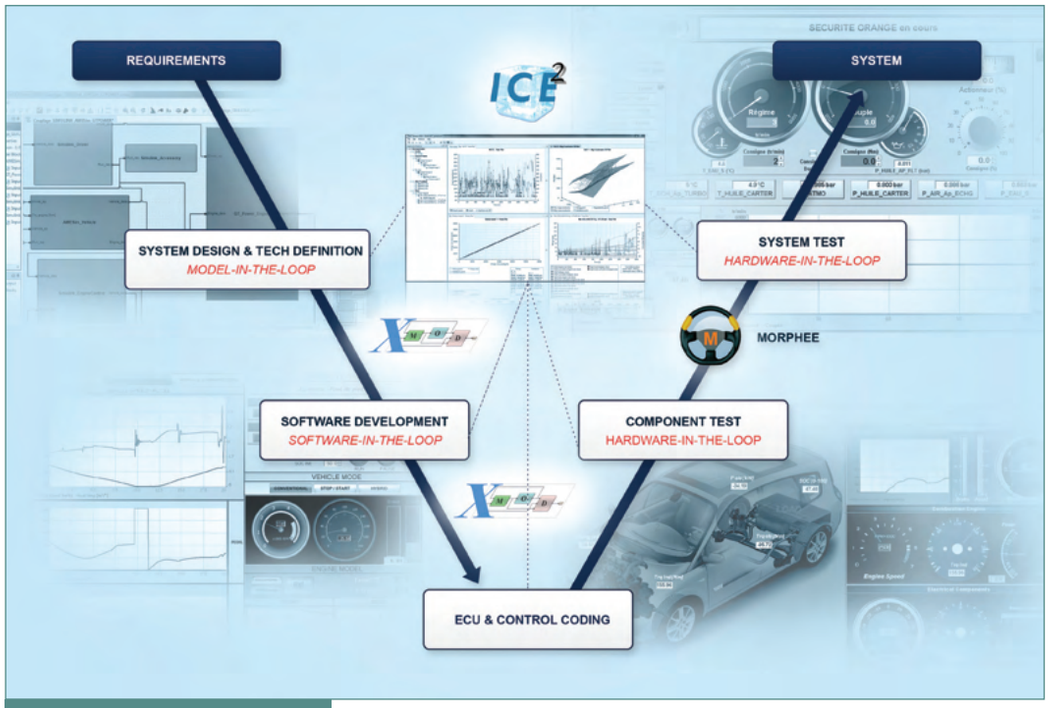
To develop a new hybrid powertrain is to inaugurate new methods and new validation tools. The process of validation is no longer sequential; the simulation, control systems and testing teams collaborate throughout all steps of the project. Thus, the variety and complexity of interactions between the powertrain system components requires constant exchanges between the teams. It's a new way of working that the D2T tools allow.

D2T – a member of FEV – provides a comprehensive and flexible suite of tools, software and equipment to achieve complete powertrain validation across the V-cycle, using a collaborative framework and workflow, system interoperability and know-how transfers, from MIL/SIL to the complete system XIL and EoL tests. Parameters, results, methodologies, models and much more can all be commonly integrated and shared across the organization.

The first piece of the suite is an advanced co-simulation and heterogeneous model integration tool called xMOD. Suitable for the development phase of powertrain and ECU/TCU, it offers a powerful framework for MIL/SIL up to HIL development tasks using complex and heterogeneous models. Thanks to unique numerical technologies, model complexity can be executed in real time. And as it can manage standard interfaces such as FMU, ACI, MCD3 and many more, the tool can interconnect with a range of other calibration and application tools and automation systems, providing excellent model execution and a large number of simulation capacities. Finally, this tool provides important cost savings on testing times and license fees.

The second piece of D2T's suite is Morphee, a leading automation system that integrates ease of operation with leading technical specifications. It is flexible and scalable and can be used with any type of testbed. With a large customer base, this tool is already one of the most cost-effective all-in-one systems for automation, simulation and calibration. Sharing high-quality EtherCAT I/O systems for HIL and physical tests, the same quality of measurement can be guaranteed for any type of testbed or HIL system. Furthermore, models and system simulations can all be reused with the same complexity at real testbeds and without being recompiled or modified.

The third and final piece of the suite consists of a flexible and open online and offline calibration workspace that achieves complex calibration cases with an unlimited level of parameter variation and number of operating points or maps optimized globally. Important gains in time and data quality can also be made when using this important online calibration tool. For example, optimization of the engine can occur before the end of the test, when enough points are available to gain a sufficient response quality. That optimal point can be immediately measured and verified with the same engine conditions and fully automatically without requiring engineer support and data exchanges. Thanks to the latest validated ACI interface, this tool can be easily connected to any AuSy, or integrated directly into an existing Morphee system.



D2T's suite of tools, software and equipment, which includes xMOD, Morphee and an online/offline calibration workspace, enables the common integration and sharing of vital information across organizations

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INQUIRY NO. 514

Silicon carbide technology

The quest to increase power-to-weight ratios in motorsport continues, and silicon carbide power modules are being used to achieve a step change in power electronics performance

In 2009, McLaren Applied Technologies was first approached to develop the electric drive system for the McLaren P1 road car. Key to the requirements of the world's first hybrid supercar was that the addition of an electric drive system must improve the car's performance on the racetrack – this demanded power-to-weight ratios that had only previously been seen in Formula 1 KERS systems. As such, McLaren Applied Technologies took on the challenge of developing an e-motor, motor control unit and 14V DC-DC converter capable of bringing race car performance to the road.

When the McLaren P1 hypercar went into production four years later, McLaren Applied Technologies had established a strong position as a supplier of automotive-qualified electric drive systems. The e-motor and MCU-500 used in the P1 provide up to 120kW of mechanical output power with a total mass of 42kg. This includes an integrated 14V DC-DC converter – subtracting the weight of this device, the MCU-500 is capable of delivering more than 20kW/kg. The e-motor produces approximately 4.5kW/kg.

The P1 e-motor and MCU-500 caught the attention of Spark Racing Technology as it prepared to supply the racing cars for the inaugural season of the all-electric Formula E racing series. McLaren Applied Technologies was chosen to supply the electric drive systems for the series' racing car – the Spark-Renault SRT_01E – an application which demanded even higher power-to-weight ratios. Further development of the system resulted in the e-motor achieving more than 7kW/kg.

The relentless push toward higher power-to-weight ratios in motorsport continues, with a trend toward very high-speed motors as an efficient way to achieve high performance from a small component. This puts new demands on the motor controller, so McLaren Applied Technologies is now supplying its inverters with silicon carbide MOSFETs in order to achieve the high switching frequencies required for efficient, high-bandwidth operation. SiC devices also offer an opportunity to reduce cooling system weight thanks to lower switching losses, higher junction temperature limits, and better thermal conductivity levels.

McLaren Applied Technologies' e-motor and MCU-500 were developed for use in the McLaren P1, and later used in Formula E cars

The challenges involved in high-performance SiC inverter design have called on several of McLaren Applied Technologies' key capabilities, including mechanical design, advanced materials, thermodynamics, simulation, electrical design, real-time software and systems engineering. The choice of SiC die has been optimized by running power module tests using different commercially available dies. Module layout and gate driver electronics have also been developed to overcome the difficulties in synchronizing the switching of parallel devices at speeds significantly above 20kHz. Further advances in power density are expected through the optimization of cooling and integration of the latest advances in SiC trench MOSFETs.

McLaren Applied Technologies is also actively involved in ongoing efforts to bring these technologies to lower-cost markets. Working with strategic partners, progress is expected in areas such as switched reluctance electric machines and low-cost SiC inverters.

Exceptional power density is now possible – McLaren Applied Technologies' SiC inverter has delivered a step change compared with the MCU-500. This makes it suited to high-performance applications where package space or weight is at a premium.

Photo: Formula E

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INQUIRY NO. 515

CV interconnectors

Drawing on extensive experience in the automotive sector can produce high-performance, cost-effective interconnection solutions for electric and hybrid commercial vehicle applications

Established as one of the leading manufacturers of high-voltage connectors for the automotive industry, Delphi has turned its attention to solutions that can meet the exacting challenges of electric and hybrid applications in commercial vehicles. Crucially, the company's approach is built around components already in serial production, ensuring that technical excellence is married to both cost-efficiency and a responsive global supply chain.

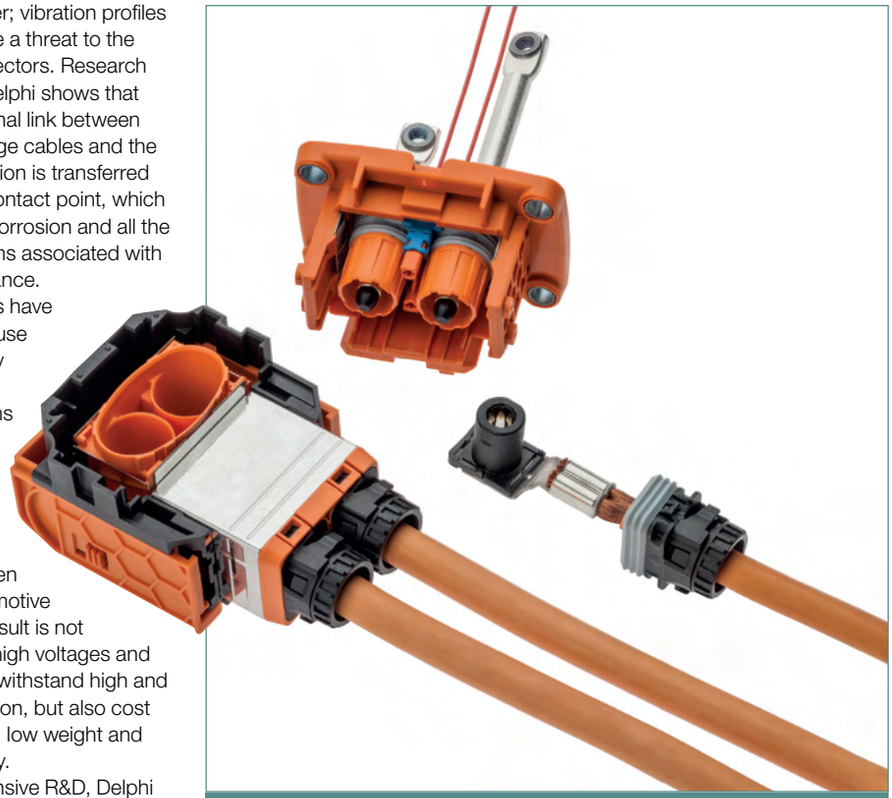
Delphi's commitment to the CV market reflects a rapidly growing demand for electric and hybrid technology across several sectors. These include an increase in the number of transit bus projects in Europe and China. Cities including Paris and London are now actively pursuing green transport strategies, with a commitment to improving local air quality one of the key driving forces. Likewise the Chinese government has put addressing urban pollution high on its agenda.

Similar trends are evident in the truck market, where electrification of urban delivery vehicles offers equally attractive benefits. However, long-distance truck applications are also emerging fast, with hybrid solutions promising between 15-20% in fuel savings. For tractor manufacturers, electrification offers a viable means of achieving greater reliability and efficiency over more conventional hydraulic systems.

While the benefits of electrification are clear, so are the challenges in terms of interconnection. Larger sized vehicles have higher power requirements and therefore higher voltage systems. In pure electric designs this typically means up to 1,000V, as compared with the 400/600V employed in automobiles. Furthermore, in buses, trucks and tractors, operating environments are much tougher; vibration profiles in particular pose a threat to the integrity of connectors. Research conducted by Delphi shows that with a conventional link between heavy high-voltage cables and the connector, vibration is transferred to the terminal contact point, which causes fretting corrosion and all the potential problems associated with increased resistance.

To date, OEMs have been obliged to use industrial, military and aerospace solutions. In terms of weight and cost, these are far from ideal. Delphi, by contrast, has drawn on a proven portfolio of automotive products. The result is not just support for high voltages and the capability to withstand high and prolonged vibration, but also cost competitiveness, low weight and ease of assembly.

Following intensive R&D, Delphi now offers CV manufacturers its serial production two-way RCS800 and RCS890 terminals and housings (200kW+) and Apex HV280 (up to 40kW). Already designed to handle voltages of up to 1,000V, attention has focused on the testing and validation necessary to reassure OEMs these products are ideally suited to CV application. However, to address vibration, the severity of which shouldn't be underestimated, the development of new accessories has been required. In CV applications, connectors are typically subject to forces of up to 40*g* with even more destructive low-frequency vibration, compared with just 5*g* in electric automobiles. Delphi's answer is a patented high-vibration cable strain relief system that securely tightens the cable to the RCS800/890/Apex HV280 housing and eliminates the risk of vibration being transferred to the terminal. Fully functional low-volume products have been completed, with serial production planned for the end of 2015.



The RCS890 2 W connector has been designed with cable strain relief properties

Research confirms that a turning point has been reached in the adoption of electric and hybrid technologies for CV applications. For example, by 2020 it is predicted that annual global demand just for electric transit buses will likely reach 15,000 units, up from only several hundred at present (according to *Automotive World*, March 2015). For its part, Delphi is committed to extending its leadership in high-voltage automotive interconnection into this emerging market. As such, OEMs can be confident in sourcing high-voltage interconnection solutions that have their roots firmly in the automotive domain; ones that meet the challenges of 1,000V systems and tough operating conditions, along with the wider commercial and engineering considerations that will be equally critical to the success of a new generation of vehicles.

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INQUIRY NO. 516

Smart low-voltage hybrid

Harvesting energy in a 48V hybrid vehicle via the installation of a belt-integrated starter-generator could prove to be the basis of intelligent powertrain electrification

According to Controlled Power Technologies (CPT), its LC Super Hybrid program has been a huge success in demonstrating 48V hybrid technology to OEMs. This large family-friendly tech demonstrator has a 1.4-liter gasoline engine for efficiency, but with the driveability of a big powertrain delivered by means of torque assistance from CPT's SpeedStart belt-integrated starter-generator (B-ISG).

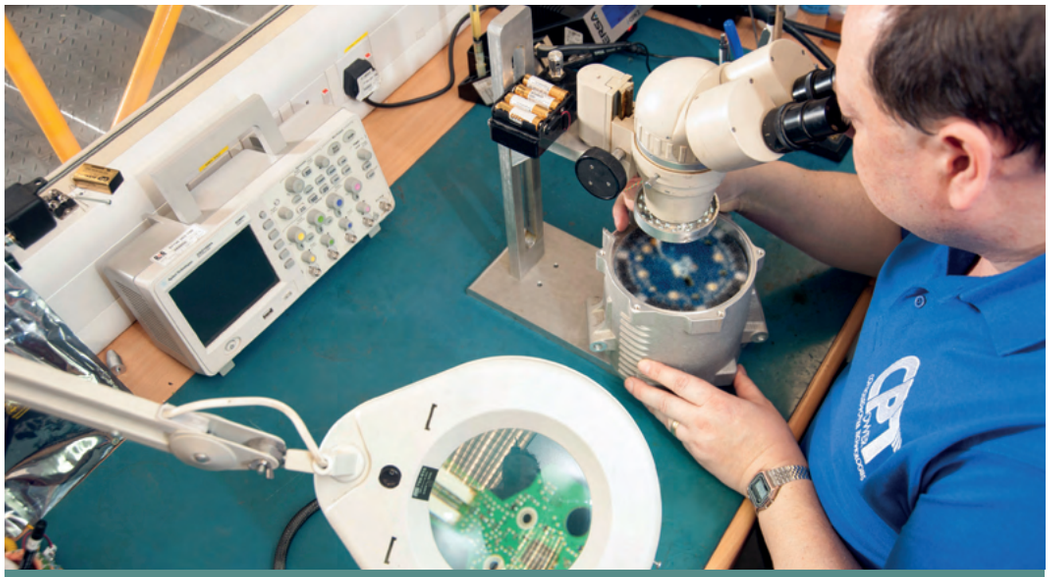
As legislators bring in the new Worldwide harmonized Light vehicles Test Procedures (WLTP) test cycle, expected from 2017 onward, car makers will notice higher acceleration rates – albeit not as aggressive as in the real world. In addition, the stop/start fuel economy benefit in the New European Driving Cycle (NEDC) is effectively halved from 5% to 2.5%.

The NEDC, meanwhile, is still used as the reference across the European Union for fuel economy measurement. Even in this relatively gentle test cycle, power is required to accelerate and decelerate, and some energy can be recovered.

"This is the basis of intelligent powertrain electrification," says Nick Pascoe, CEO of CPT. "You take all opportunities to harvest energy."

Over the NEDC four times as much power is used to accelerate a large car as used to decelerate it, so it is possible to recover some energy in every deceleration. However, the final braking event is about 30 seconds long, which presents a challenge because sustaining high power levels in electric machines generates heat. CPT addresses this issue with switched reluctance (SR) motor-generators, which can be water-cooled.

Analysis of the NEDC suggests 25kW peak generating capability is required to take full advantage of the recuperation opportunity in the cycle. However, about 80% of the available power can be covered at half this level. This makes a 10kW machine a good compromise, able to return energy to the crankshaft to assist accelerations.



CPT electronics technicians thoroughly examine all SpeedStart switched reluctance motor-generators prior to installation

The 48V LC Super Hybrid (left), based on a 12V VW Passat (right), achieves a fuel economy improvement of 13%

This is how CPT approached its first calibration of the LC Super Hybrid, and in doing so achieved a 13% fuel economy improvement at 48V compared with 7.5% at 12V – itself a useful improvement over the typical 5% stop/start benchmark.

"It seems counter-intuitive that the main fuel economy benefit is when you put your foot on the gas," states Pascoe, "but instead of delivering fuel to the engine you actually provide some power assist to the crankshaft using electrical energy, which can then be replenished."

CPT's control strategy has since been further optimized. The result of this second calibration is expected to boost fuel economy improvement by several more percentage points.

Thus, moving to the WLTP will not only align this new test cycle more closely with the real world, it will also increase the dynamic characteristics required from mild hybrids. In order to increase electric boosting and energy harvesting, a fast transient response is essential, which further lends itself to electronically controlled SR motor-generators.

Of equal importance is the thermal capability of the motor-generator for a 15-second acceleration or deceleration event. Here, the major division in the industry is between conventional claw pole machines, which lend themselves well to air-cooling, while SR machines are better suited to water-cooling.

Air-cooled machines cost less, but are typically limited to a few seconds of running at peak power (perhaps 10kW) before getting too hot, which means that most of the vehicle's kinetic energy is then lost through the brake system and will never make it to the battery.

With an SR machine the copper windings and power electronics that get hot when current is flowing remain stationary, which makes water-cooling feasible, and this means longer duration motoring and generating events.

"We've developed SpeedStart for 12.5kW," says Pascoe, "and can increase this to 15kW for even more aggressive real-world driving."

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INQUIRY NO. 517

Control and monitoring

A prototype battery-powered train required years of industry experience to be applied to the design and development of a specialist intercommunication and master battery system

The first battery-powered train to run on the UK's rail network in more than half a century carried its first passengers in January 2015, and Sensor-Technik UK provided a system that was integral to the successful outcome of the trial project. The groundbreaking trial marked an important milestone in the 18-month-long project and is to be used to demonstrate the viability of an eco-friendly battery-powered train for the 21st century.

Valence Technology, a leading manufacturer of lithium-ion battery technology with which Sensor-Technik UK has worked for over seven years, was contracted by train manufacturer Bombardier Transportation to provide the battery power for the train. The overall aim of the development was to bridge the gaps between electrified sections of the rail network, and to enable trains to run on branch lines in locations where it would be too expensive to install overhead electrification.

Clockwise from above: the prototype battery-powered train, which featured a range of specialist intercommunication equipment and battery systems; STW's ESX-3XM control unit with EB06 expansion board; the ESX-TC3G telematics unit

Commissioned by Valence Technology, Sensor-Technik UK was asked to design and develop an intercommunication and master battery system (MBS) that would sit between the battery packs and the train control and management system. The intrinsic chemical stability of the cells, together with secondary safety controls – firewire detection, isolation and containment measures – on board, provided the elements for safety approval of the system on passenger services. For this application, the DC power supply was split across two separate packs of batteries, with each containing six Valence U-BMS (battery management systems). The system design required that each pack have a dedicated master controller and all be linked together by a dedicated CANbus, to which the train was connected, to provide overall system-level data.

For the master controller, Sensor-Technik UK selected the STW ESX-3XM unit with EB06 expansion board. The ESX-3XM is a compact electronic controller providing the end user with multiple control, monitoring and interface options. As standard, the ESX-3XM has a powerful 32-bit Tri-core processor, four separate CAN channels and room for up to three expansion boards – providing wide I/O capabilities and system functionality.

Each ESX-3XM is responsible for monitoring the state of each U-BMS in the pack, managing faults and analyzing operational data to produce pack-level data, which is then transmitted to the train controller for control action. The bespoke control algorithms that were developed for use in this application were based on the many years of experience Sensor-Technik UK has built up in advanced control and measurement application development and design.

As a result, Sensor-Technik UK was also tasked with providing a remote monitoring solution for the trial, giving access to relevant operational data for key stakeholders as well as detailed remote diagnostics for Valence engineers. To accomplish this, Sensor-Technik UK provided the latest telematics unit from STW – the ESX-TC3G. This is a Linux-based communication and teleservice module of exceptional capability. Alongside standard interfaces such as RS232, USB and Ethernet, the module offers wireless communications via Bluetooth, 2G/3G and WLAN. In addition, the built-in GPS/GLONASS module continuously provides the unit's current position.

Sensor-Technik UK is the UK and Ireland distributor for Sensor-Technik Wiedemann. A member of the Wiedemann group of companies, it was set up in 2001 as a distributor and system integrator of the STW product range. Sensor-Technik UK complements its extremely capable range of hardware with innovative engineering services. From software to cable looms, Sensor-Technik UK is a one-stop shop for control, measurement and integration.

Valence Technology was the first company to introduce large format lithium-ion batteries and is a leading supplier of enhanced-safety, long-life lithium iron magnesium phosphate battery systems. Headquartered in Austin, Texas, and with an EMEA center in Belfast, Northern Ireland, Valence is the enabling battery technology for numerous products in many market sectors, including motive, marine, industrial and backup.

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To learn more about Sensor-Technik UK, visit: ***www.ukipme.com/info/ev***
INQUIRY NO. 518

Mechanical hybridization

Application of flywheel technology in both hybrid and all-electric powertrains can produce significant performance enhancements without prohibitive price increases

There is a strong consumer demand for low-emission vehicles to be fun to drive, but is there a way to create a hybrid high-performance sports car without the extravagant price tag?

With the weight and power density challenges associated with electric hybrids, designing such a vehicle is always going to prove challenging – in order to deliver serious hybrid power, battery packs need to be relatively large, and electric motors must have high peak-power capacities, making them more expensive.

To achieve real performance hybridization, a more radical technology approach is needed. Imagine a hybrid system that is capable of power density similar to that of a Formula 1 engine, can deliver the pleasing instantaneous torque characteristic of an electric motor, and costs a fraction of the price of battery-based hybridization.

Torotrak Group's fully mechanical Flybrid technology has turned these imaginings into reality. It is a high-power, low-weight, low-cost kinetic energy recovery system (KERS), which has proven its worth in motorsport, commercial vehicles, off-highway and passenger cars.

Flybrid KERS is a fully mechanical flywheel-based hybrid system that stores kinetic energy from vehicle deceleration and transfers it using a compact multiclutched transmission to spin a high-speed flywheel. This stored energy can be released to increase the acceleration performance, giving the driver an extra boost of power and torque. By exploiting otherwise wasted energy, this additional power does not come at the cost of additional fuel consumption or emissions. Its compact size and high power density results in a hybrid system that is ideal for providing a performance driving experience, as well as helping to manage CO_2.

High-power, low-weight, low-cost KERS have been implemented in motorsport, commercial vehicle, off-highway and passenger car applications

While mechanical hybridization is a natural partner in performance ICE road cars, the flywheel system can also be used to handle high-power transient loads in an EV powertrain, thus allowing it to be driven harder with less risk of battery damage or reduced range.

Flybrid KERS coupled with an ICE can behave similarly, in performance terms, to a high-powered battery hybrid – delivering smooth and instantaneous torque to supplement the engine – but at a fraction of the weight and cost. Volvo Cars claimed that its Flybrid-equipped S60 demo vehicle chopped 2 seconds from its 0-60mph time, while the KERS unit weighed less than a third of its incumbent battery equivalent. The energy transfer in Flybrid KERS is twice as efficient as the average electric hybrid configuration because there is no need to convert the form of energy from mechanical to electrical to chemical. Therefore all of the recovered energy is returned to accelerate the vehicle. If this KERS acceleration is applied to the non-driven axle of the car, the driver can also benefit from the added stability and traction of part-time four-wheel drive.

Torotrak's engineers have also recently made huge steps forward in developing the Flybrid hardware. Programs across a variety of sectors have driven them to deliver even greater power density and design life of up to 1,000,000km. The power output of the KERS has doubled in only 12 months. Advances in the clutched flywheel transmission (CFT) and construction of the flywheel now enable the systems to recover as much as 70% of the vehicle's braking energy. Torotrak is now considering the possibility of a vehicle with full KERS braking on both axles; a system that has the potential to render conventional braking systems redundant.

The power density and small unit size of the KERS results in a lower material cost – a critical part of ensuring that Flybrid technology remains accessible. Automotive manufacturers are under increasing pressure to reduce fleet emissions without compromising vehicle performance, and enablers such as Flybrid KERS look set to become a key part of the solution to this engineering challenge.

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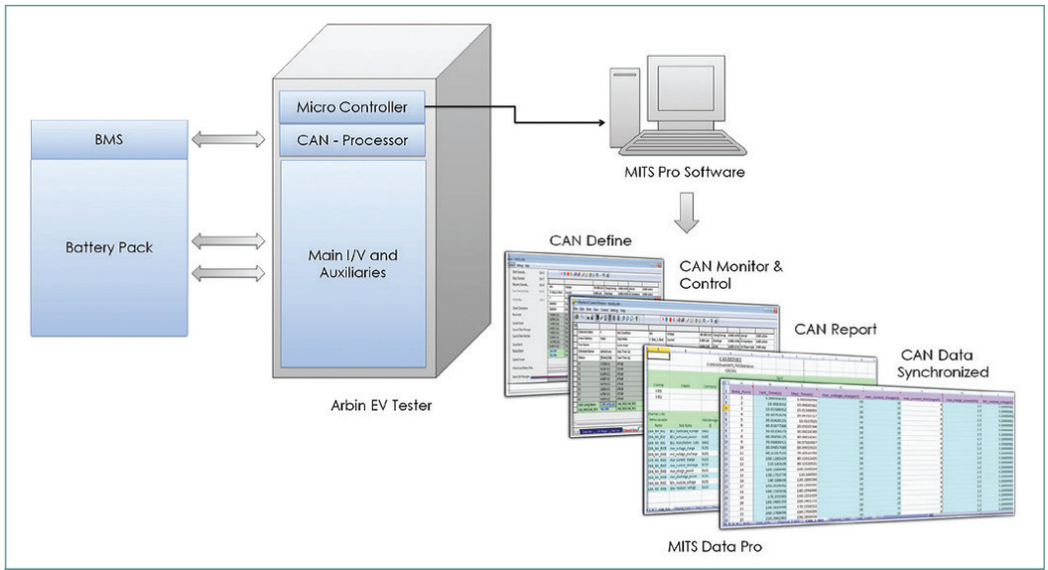
INQUIRY NO. 519

Advanced battery testing

An electric vehicle testing solution line specifically developed for high-power electric and hybrid battery systems can help developers to meet rigorous and varied testing requirements

Energy storage requirements have become increasingly diverse in recent years and continue to evolve rapidly. One particular challenge for researchers, battery manufacturers and OEMs is finding testing equipment that has enough flexibility and the wide operating parameters to support current and future energy storage testing needs. Likewise, many organizations will need to test a variety of different sized battery packs. The testing equipment used in these situations is a major investment, and it is very important that the investment is configured with future growth and expansion in mind.

With more than 20 years of core experience, Arbin has designed and manufactured testing systems for the battery, supercapacitor and fuel cell industries around the world. Arbin's Electric Vehicle Testing Station (EVTS) is a product line specially designed and developed for testing high-power EV and HEV batteries, packs and modules up to 800V. Key features such as efficient regenerative power circuitry, compact designs and high-speed drive profile simulation control make the EVTS products flexible testing platforms for all energy storage device testing.



All of Arbin's EVTS systems enable CANbus communication, including the reading, writing and sending of CAN messages

The EVTS tests high-power EV and HEV batteries, packs and modules

Alongside recent new product developments – such as Arbin's ARPA-e project in conjunction with Ford and Sandia National Laboratories to develop an ultra-high precision test station up to 200A – Arbin has updated its EVTS product line to meet the rigorous requirements of industry tests. Thanks to innovative developments in hardware, software and firmware design, Arbin's EVTS systems can achieve much higher power, provide faster rise times, higher accuracy and faster datalogging. Not only have the datalogging capabilities been expanded significantly, but the simulation control in the updated EVTS equipment has also been vastly improved. Customers can now expect to perform simulations with as many as 300,000 lines per profile with high-speed datalogging during all tests.

A unique feature provided by Arbin is the ability to operate the test station in different modes, including parallel, series and discharge booster mode. The test channels can be used independently or put in parallel for higher current capability, in series for higher voltage testing, or in discharge booster mode for a wider range of voltage output. This functionality provides extreme flexibility and enables the test station to be used for every battery pack in the lab.

As has come to be expected from Arbin's equipment, CANbus communication is readily supported on all EVTS systems.

The Arbin device fully supports the reading, writing and sending of CAN messages, as well as logging, monitoring, setting, controlling and protecting the battery pack being tested. Upon request, Arbin can also follow standard CANbus specifications, such as the SAE J1939 protocol, CANopen or even user-defined protocols. When using Arbin's CANbus there is absolutely no additional third-party equipment, third-party DLL package or third-party license needed.

Industry leaders working in EV, HEV, grid-storage and battery safety applications have come to rely on Arbin to provide complete battery testing solutions.

The EVTS system enhances the company's already extensive product line of standard and custom-engineered systems for testing single cells, modules and large-scale battery packs.

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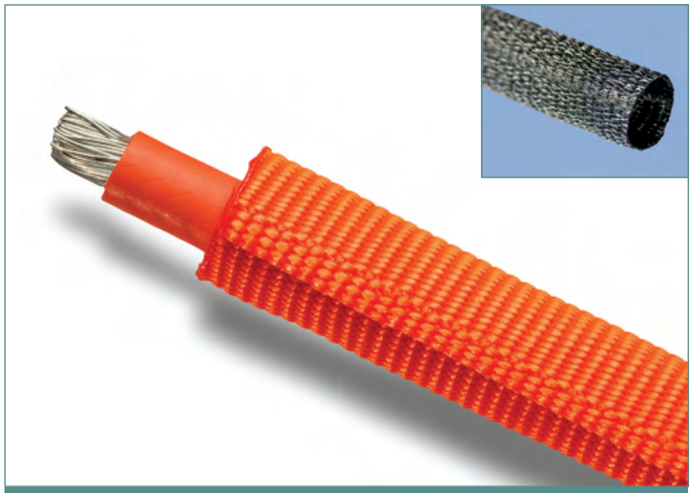
INQUIRY NO. 520

EV harness shielding

A new approach to harness shielding is improving safety and reducing EMI issues, enabling designers to meet the wiring challenges of electric vehicles

The growing popularity of electric and hybrid electric vehicles increases the challenges faced by wiring system designers. Higher voltages and increasingly crowded installations necessitate greater levels of crash protection and electromagnetic shielding with minimum mass and cost. Although unseen by the consumer, recent advances in shielding technology from Federal-Mogul are helping to keep even the most complex hybrid and electric vehicles functioning reliably, while containing high voltages safely in the event of collision damage.

To avoid the high kinetic energy of a section of vehicle structure impacting the wiring harness during a collision without resorting to heavy metallic shielding, the new approach draws heavily on bulletproof vest technology. "Conventional rigid shielding works by spreading the impact energy over a wider area to protect the harness inside," explains Philip Marks, director of global product engineering, Systems Protection, Federal-Mogul Powertrain. "We developed a lighter, more flexible solution using exceptionally strong woven synthetic fibers. The high tenacity and elastic modulus of these fibers means that they can withstand high levels of impact energy without tearing, yet are flexible and extremely light, hence their use in bulletproof vests."



Above: CrushShield uses a dual-layer textile construction to absorb energy and disperse crash force over a greater area, while remaining very flexible

Left: Hybrid conductive yarn woven into flexible TwistTube sleeving

The material, called CrushShield, encases the wiring so that high-voltage cables remain isolated from the conducting structure of the vehicle. The rugged, multi-layered construction of the CrushShield fabric absorbs and disperses energy, resisting cuts and abrasions by using a combination of filament properties and weaving technology.

A new test was specially developed to simulate the crash protection capability of CrushShield in the laboratory, using a free-falling mass with an edge representative of any object likely to damage the wiring during impact. Progressively increasing the mass and its height above the cable until sufficient damage is incurred establishes a baseline energy level. After protecting the cable with the shielding, the test is repeated to measure how much additional energy can be absorbed before failure occurs. "In back-to-back comparison testing, CrushShield outperformed corrugated nylon tubing, protecting the harness from up to three times the original crash force," says Marks.

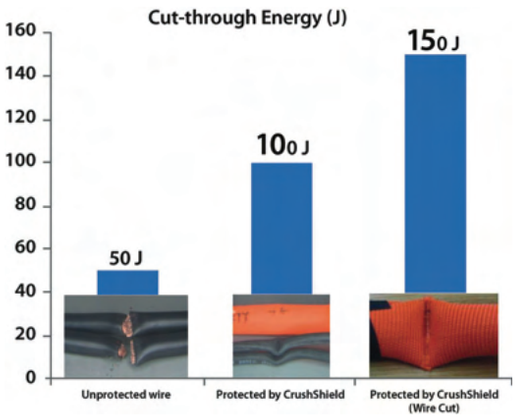
Safety is not the only functional consideration for EV wiring harness shielding. As vehicle electrification increases, so does the susceptibility to electromagnetic interference (EMI), which can affect vehicle component performance. The effects of EMI can range from the minor annoyance of a distorted video display to the loss of a major vehicle function.

A typical high-voltage wire is composed of shielded cable made from multiple layers: an inner core of conductive material; a layer of insulation; a layer of braided metal wire; and an outer insulation material, often covered by additional mechanical protection. The braided metal wire layer inherently provides EMI shielding at low frequencies (below 1MHz), though shielding performance does decline with increasing frequency due to the holes created at the interstices of the braided metal strands. Extra shielding wires or metallic films may address this issue, but compromise weight and flexibility.

"We improved shielding performance across the whole frequency range by using fine strands of metal wire twisted onto polymeric yarn to create a strong, thin, conductive composite yarn," says Marks. "Multiple yarns are precisely placed into a woven or braided textile shield, to produce an optimized EMI shield that is lighter and more flexible than a heavy metal braid."

A case study comparing the two approaches revealed mass savings of 27% with 55% better flexibility and a reduction in bundle diameter of 38%. The technology is now available in Federal-Mogul's TwistTube and FlexFit EMI shielding products.

CrushShield protects wiring from up to three times the energy needed to cut an unprotected cable



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INQUIRY NO. 521

Battery cooling solutions

Reliable, lightweight cooling solutions are vital to hybrid and electric powertrains. Optimum temperature control for lithium-ion batteries can be provided by inter-cell element cooling

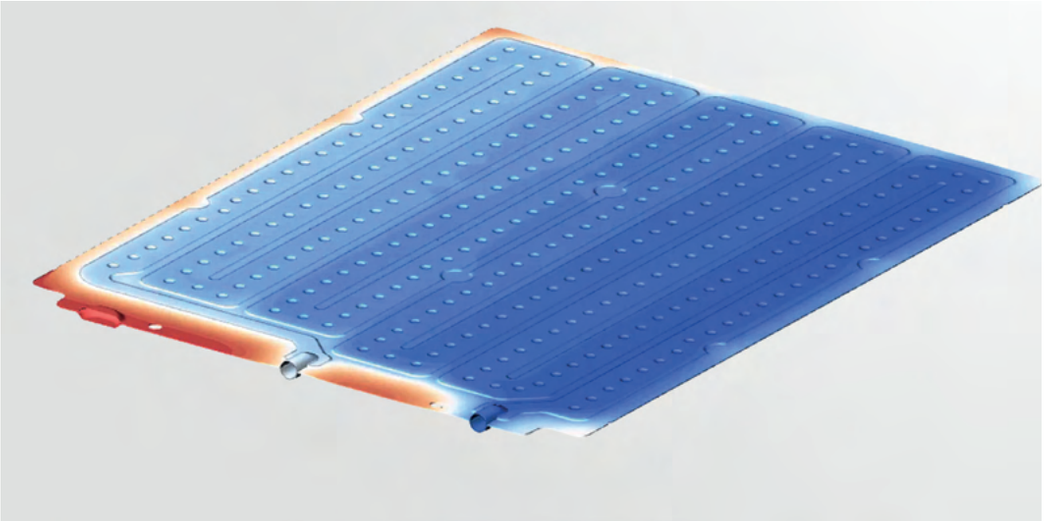
As global demand for hybrid and electric vehicles grows, OEMs are in need of reliable and lightweight cooling solutions for lithium-ion battery packs. Modern, battery-powered light vehicles require an integrated thermal-management system to enable fast charging, rapid warm-up, and full power. Without it, battery temperatures could rise to undesired temperatures, thereby compromising both performance and life span.

Leveraging its heat transfer expertise, clean brazing and precision stamping, Dana's inter-cell element (ICE) plate technology represents a superior thermal solution for battery pack designers. Optimized heat transfer surface design, coupled with an efficient production process, provides an innovative answer for OEMs looking to stand behind their promise of delivering a long-lasting, advanced battery propulsion system.

Used in leading hybrid and electric vehicles, Dana's innovative ICE plate technology represents a cost-effective approach to battery thermal management. The ICE plates are capable of providing both rapid cooling and heating, offering a better driving experience for the end-user and protecting the investment made in the lithium-ion battery pack.

Recognizing the challenges involved in high-powered battery packs, Dana's thermal-management experts apply state-of-the-art engineering tools and software to deliver an enabling technology unlike any other – one that is lighter, cleaner and higher performing. Uniquely configured for each application, these wafer-thin aluminum coolers keep battery cells at a uniform temperature.

Interleaved between lithium-ion cells, Dana's ICE plates remove heat from each cell face, minimizing the thermal gradient. Each plate assembly is also laminated in a dielectric film to provide electrical isolation through the stack, while maintaining low thermal resistance. This configuration helps lithium-ion batteries maintain their optimum operating temperature.



The unique qualities of Dana's ICE plate technology help to ensure uniform cooling in high-powered lithium-ion battery packs

Plus, the company's proprietary flux-less brazing process creates durable components that are contaminant free.

Dana is a Tier 1 partner that works closely with automotive manufacturers to offer optimized solutions that meet the needs of next-generation hybrid and electric vehicles. Using proven engineering processes, Dana solves thermal battery challenges.

Balancing even flow distribution in each ICE plate with minimal pressure drop reduces parasitic pumping losses, enabling pack engineers to harness the most power possible.

A full-service technology manufacturer, Dana has the knowledge needed to devise battery cooling solutions, along with the manufacturing capabilities to bring these innovations to market quickly and efficiently.

Flow paths are designed to minimize temperature variation across the plate and throughout the battery pack

Dana infuses all its ICE plates with considerable expertise and experience. While every battery pack has unique thermal needs, Dana has the knowledge to help automotive manufacturers optimize performance and reliability.

"OEMs can count on Dana for the world's most advanced battery cooling solutions," says Dwayne Matthews, president of Dana Power Technologies Group. "The value that Dana provides is twofold. It's in the ICE plate itself but, beyond that, it also includes all the insight, testing and customization that goes into arriving at the optimal design. Dana's technology provides automotive manufacturers with superior battery thermal-management solutions that are very much in line with next-generation electric and hybrid vehicle needs."

Subjected to extensive testing by both Dana engineers and OEMs, the unique technology of Dana's lightweight ICE plate considerably minimizes temperature variation within lithium-ion battery packs in order to deliver long life and high performance.

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INQUIRY NO. 522

Power at play

In an age of increasing electromobility, the demand for highly efficient modular and individual lithium-ion battery packs in a range of applications cannot be underestimated

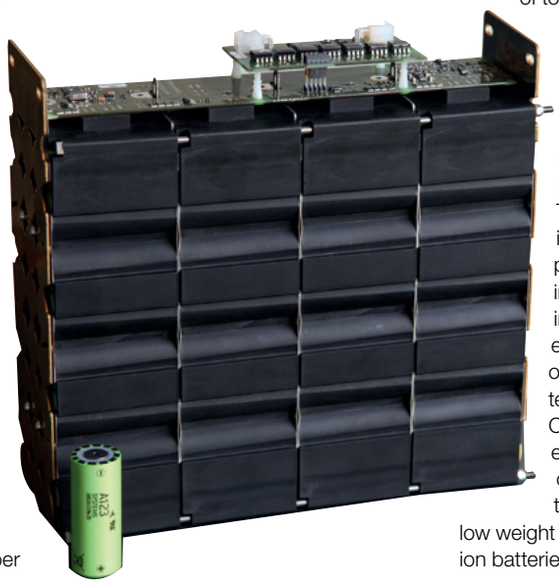
When people are asked to think about the future, the image of electrically propelled vehicles will likely come to mind. Nowadays, such vehicles are no longer the preserve of the movie industry and science magazines, with millions of EVs deployed all over the world. Consequently, the need for engineering know-how in this particular area has never been greater than it is now.

As such, Voltabox Deutschland and Voltabox of Texas have created highly efficient, modular lithium-ion battery systems for almost every vehicle type. Taking advantage of the expertise of parent company Paragon, which has developed and manufactured automotive electronic solutions since 1988, Voltabox's battery engineers base their know-how on more than 25 years of experience in ECU, communication and interface development.

Voltabox's portfolio covers traction batteries for hybrid, trolley and electric buses and intra-logistics such as forklifts and industrial trucks, as well as explosion-protected high-power modular battery systems for the mining industry. It also includes highly efficient, lightweight starter batteries for both motorbikes and cars, as well as modular battery systems for the material handling market along with sophisticated traction hybrid batteries for series sportscars and racing cars.

With a core focus on achieving the highest possible standards, the use of flexible configurator tools and know-how of hardware and software has led to Voltabox developing a number of competitive and groundbreaking solutions. These batteries prove their outstanding characteristics worldwide, daily, in large numbers of tough series applications.

Voltabox's new facility in Austin, Texas, USA (above), furthers the company's enhanced processes for application engineering and production of lithium-ion traction battery systems for EVs (below)



Voltabox and premium battery cell suppliers such as Samsung, Toshiba, K2 Energy and A123 Systems all work together in privileged partnerships. This collaboration results in direct support, preferentially provided information on upcoming innovations, and the earliest possible use of the newest cell technology. Voltabox CEO Klaus Dieter Frers explains the advantages of this philosophy: "With their high energy density, low weight and small size, lithium-ion batteries are superior to all other electrochemical energy-storage systems currently on the market. Furthermore, the number of charging cycles, charging time and usability with low temperatures have been increasing strongly in the last few years and will continue to do so. Consequently, lithium-ion now excels over all other battery technologies, and we have all the prerequisites to handle these advantages in a professional manner and bring the technology and application to the next level."

In July, Voltabox celebrated the grand opening of its new facility in Austin, Texas, USA. About 100 guests participated in the event, which celebrated the company's enhanced processes for application engineering and production.

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INQUIRY NO. 523

Performance measurement

Evaluating the performance and efficiency of electric motors and inverters in electric and hybrid powertrains requires the implementation of sophisticated measurement tools

Within the development process of any part of the powertrain, a number of electrical signals and physical parameters related to mechanical performance need to be measured as part of a complete test cycle. To obtain a total understanding of the overall system performance, measurements have to be taken on the electromagnetic power converter, the power electronics and data from the powertrain management system operating over a vehicle serial bus network such as CAN. Moreover these tests have to be carried out simultaneously to come to an overall optimum solution, rather than optimizing individual components.

Such measurements require an instrument with a high channel count to enable the user to combine several sensor outputs and isolated input channels to measure the electrical system – often involving floating voltage levels – as well as parameters such as temperature behavior, vibration and stress on materials, along with CANbus signals. Ideally the measuring tool also has to be able to perform real-time dynamic testing, including cycle-by-cycle analysis, real-time mathematics and the ability to trigger on calculated waveforms.

The Yokogawa ScopeCorder DL850EV (Vehicle Edition) incorporates CANbus monitoring, and is suitable for use in automotive measurement applications

The ScopeCorder combines the key benefits of a high-speed oscilloscope with those of a traditional data acquisition recorder in a single portable instrument. A ScopeCorder can capture and analyze transient events that might last only microseconds, but is also able to carry out complete powertrain endurance tests over periods up to 30 days.

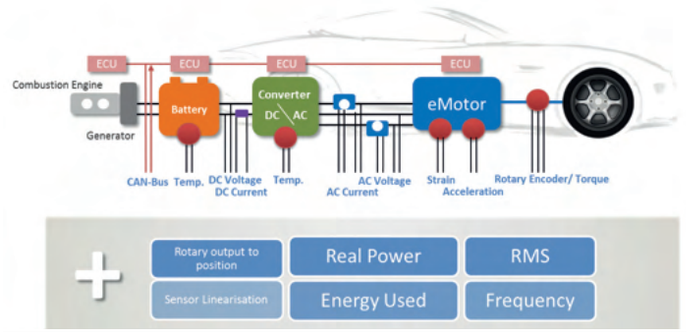
These instruments offer channel isolation, signal conditioning and high channel counts. For automotive applications, a Vehicle Edition of the ScopeCorder is available that incorporates a CANbus monitoring function. This feature enables the user to decode the CAN signal and monitor the physical data transmitted in the powertrain management system.

The ScopeCorder enables engineers to record, verify and study the correlation between communications data transmitted over the vehicle bus and both electrical and mechanical parameters recorded under dynamic conditions. Using flexible modular inputs, it can combine measurements of electrical signals, physical parameters from sensors, and data from CAN and LIN serial buses. It can calculate and display values such as torque; true, reactive and apparent power; and efficiency calculations in real time. The instrument not only provides raw measurement data, but can also carry out real-time analysis as well as showing the results on display as if it were measurement data – all within the unit itself.

Furthermore, it is also possible to set oscilloscope-style trigger conditions on most of the measured or calculated signals, such as active power. This feature makes the ScopeCorder particularly powerful for 'on the spot' dynamic testing and analysis. The measurement results and calculated signals can be viewed and monitored during the measurement as the test cycle progresses. In addition, by transferring the measurement results to the Yokogawa Xviewer Analysis software, a user can carry out more extensive verification and analysis of the corresponding raw data after the measurement is done.

For tests requiring the highest levels of accuracy, the WT3000 power analyzer offers high precision, high accuracy, high stability and the ability to carry out calibrated measurements. Instruments of this type can perform up to six power input measurements, which makes it possible to carry out efficiency tests between the input and output of products such as inverters.

They can also accurately measure highly distorted voltage or current waveforms with high harmonic content. Harmonic analysis can be carried out up to the 500th order from a 50Hz or 60Hz fundamental frequency. This facility is especially important for measurements on new power conversion and power electronics devices. A dual harmonic measurement function makes it possible to simultaneously measure the harmonic content and perform harmonic analysis on two different sources, such as the input and output of an inverter or variable-speed motor drive. The normal power parameters and harmonic data are measured simultaneously, providing faster and more accurate power analysis.



The key electrical and physical parameters involved in the testing of powertrains

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INQUIRY NO. 524

Connection solutions

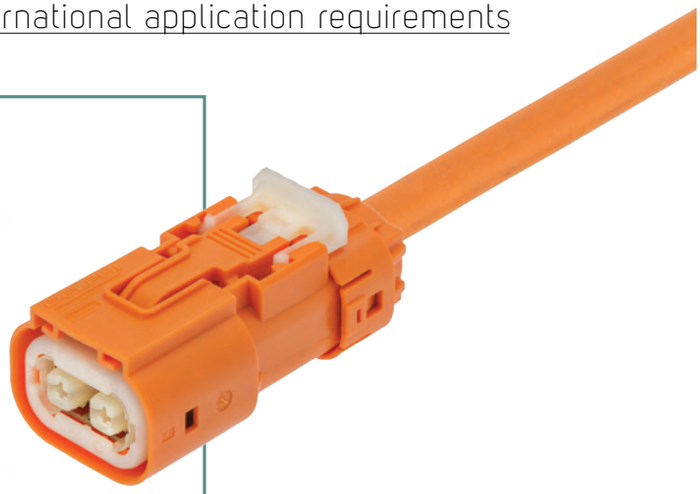
The developing electric and hybrid vehicle industry has created a need for connection and charging solutions capable of meeting different international application requirements

As the global EV/HEV market evolves, Delphi remains committed to working with OEMs and wire harness assemblers to identify new connector and charging solutions and enhance existing technologies. As a world leader in automotive interconnection technology, Delphi is at the forefront of efforts to create new and innovative connectors that meet the demands of this market.

The very latest results of the company's extensive research and development include a family of AK class 1-compliant connectors (2.8mm terminal size) designed primarily for auxiliary devices, and a new generation of mode 2 charging cordsets. Fulfilling the needs of both existing and emerging requirements, these new advanced additions will further extend the company's comprehensive portfolio of products for high-voltage applications.

The creation of the new AK class 1 family addresses the proliferation of auxiliary electrical devices such as air-conditioning units and DC/DC converters. Furthermore, it reflects a determination to meet the different strategies being pursued by OEMs around the world. Specifically, AK class 1 adopts the multicore shielding philosophy – multiple cables with one common shielding braid within a common jacket – complementing Delphi's existing array of individual shielded and peripheral shielding solutions. As a result, vehicle OEMs can draw on a full range of techniques for tackling EMI in high-voltage systems. The new product family will also extend greater choice by incorporating both two-way and three-way formats, along with a broad range of header configurations in order to optimize design flexibility.

Delphi's close relationship with OEMs and wire harness assemblers has also informed a number of performance improvements over existing AK class 1 connectors. These include greater robustness and an increase in current handling capability. The former is of particular significance in the EV/HEV product sector, where devices such as air-conditioning compressor motors are characterized by challenging vibration profiles. Development of the AK class 1 family is now well advanced, with serial production expected in early 2017.



Delphi connection and charging solutions are fully designed to accommodate the requirements of various global vehicle applications

In contrast to the AK class 1, cordsets represent an extremely tangible point of contact between consumer and vehicle. Delphi is now developing a second generation of its proven mode 2 cordset, driven and shaped by IEC62752. However, compliance with the new standard is very much a starting point, with additional features being incorporated based on feedback that is gathered from markets worldwide.

The most notable changes lie in the electronics, but improvements also include better ergonomics, greater durability and more flexibility to meet the needs of different regions. One of the key lessons learned from the first-generation cordset is the wide range of operating environments that need to be accommodated. Improved temperature sensing capability has been added to support more effective monitoring of terminals. Similarly, better protection is provided against DC currents, and other power supply and charging issues such as in-rush currents.

Ergonomics and the user interface also greatly benefit: LED displays are simplified, and Delphi is incorporating a communications module that OEMs can utilize to display messages on the vehicle dashboard. Stronger defense against real-world use of cordsets is also evident, for example in improved IP67 protection against water ingress. In addition, the next-generation design goes further to accommodate the various voltage and earthing systems used in different parts of the world. As with the AK class 1, full production is scheduled for late 2016.

Delphi's systems knowledge, innovative automotive component design and integration skills extend through its entire organization. This helps the company reduce costs, provide peak performance and offer a robust portfolio of EV/HEV components and systems, including charging systems, energy storage systems, connection systems, power electronics, service solutions, electrical centers, powertrain systems and wiring assemblies.

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INQUIRY NO. 525

Electric powertrain testers

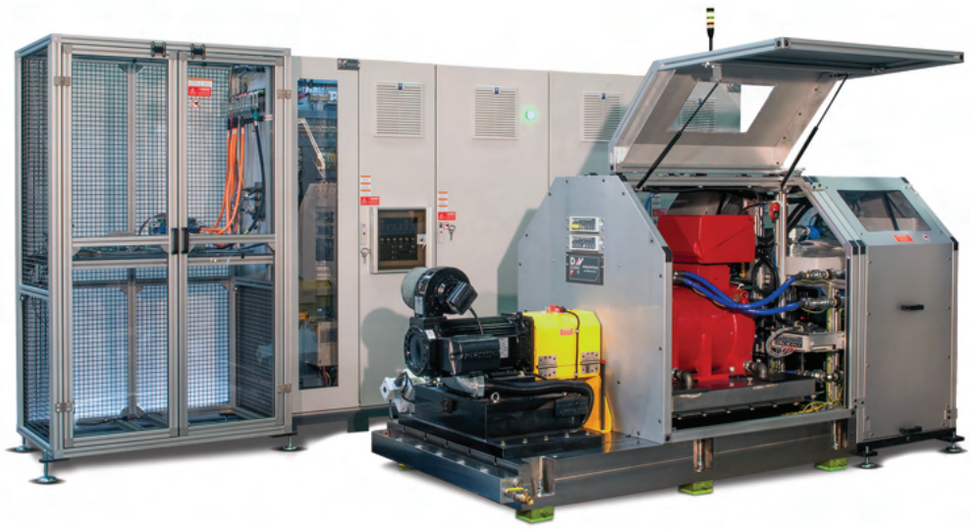
An advanced electric motor and inverter development test bench, tailored to R&D requirements, can enable research into future electric and hybrid drivetrain technologies

Vehicle propulsion is currently undergoing a period of major change with the development of new technologies in electric and hybrid-electric powertrains. One of the latest forecasts from IHS is that, by 2021, eight million hybrid and electric vehicles will be produced every year. This changing landscape has resulted in universities and research laboratories approaching D&V Electronics for testing equipment to progress their development, research and innovation of electric motors and inverters.

In the highly competitive world of electric transportation, D&V was approached by one of Canada's major universities to join forces to work on an advanced electric motor and inverter development test bench that's capable of advancing research into electric and hybrid vehicles. The resulting EPT-150 is a fully integrated, high-accuracy e-motor and inverter development platform. Designed to support the university's automotive research program, the EPT-150 will enable investigation into new approaches to motor and drive design, development and control.

Innovation and technology are at the core of D&V's testing equipment, and specifications for the EPT-150 tester were closely tailored to the university's needs for advanced testing and research. As such, the modular design also accommodates a variety of optional auxiliary support devices, including DUT oil lubrication units, thermal chambers, expandable instrumentation as well as material-handling devices.

The dynamometer contains a 130kW load motor, a battery simulator and D&V's advanced Power Measuring Module (PMM). The battery simulator is an innovative bidirectional power supply, designed to accurately simulate the battery as well as provide low-power operation through the coupled power system. D&V's new PMM is a precision measuring device that can be configured for testing the functions of hybrid motors, controllers and other such devices, synchronizing all data channels to within less than 100 nanoseconds.



The EPT-150 is designed to be a high-accuracy development platform for comprehensive e-motor, inverter and battery pack testing

High-speed data acquisition can be achieved with D&V's real-time Power Measurement Module (PMM)

D&V's tester software suite enables the engineer to fully customize the screens and controls with both manual and automatic interfaces, which are visible on dual LCD displays for an entire system view. Custom plotting for professional reports and a virtually unlimited number of user-customizable tests are just some of the hallmarks of the software platform.

The unique design of the EPT-150 tooling requires an initial alignment and all subsequent installations of the DUT can be carried out quickly and accurately with minimal effort, due to D&V's universal mounting fixture and connections. In addition, the inverter is mounted safely in a caged area that ensures the safety of the researchers, without hindering the accessibility to the inverter that would certainly be required in a developmental environment. In order to minimize the impact at the university's testing facility, the EPT-150 does not require a specialized work environment, which means this solution can be dropped into place and powered up within a week.

The EPT-150 is just one of the latest examples of D&V's technology working with those in the industry and academia to help solve the many challenges of building electric transportation. The university's research into cutting-edge motor and inverter technologies will be used in efforts to create more efficient and reliable electric and hybrid vehicle components.

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To learn more about D&V Electronics, visit: ***www.ukipme.com/info/ev***
INQUIRY NO. 526

New testing facilities

A state-of-the-art engineering test facility will couple full-vehicle testing with advanced simulation to improve fuel economy while maintaining driving performance

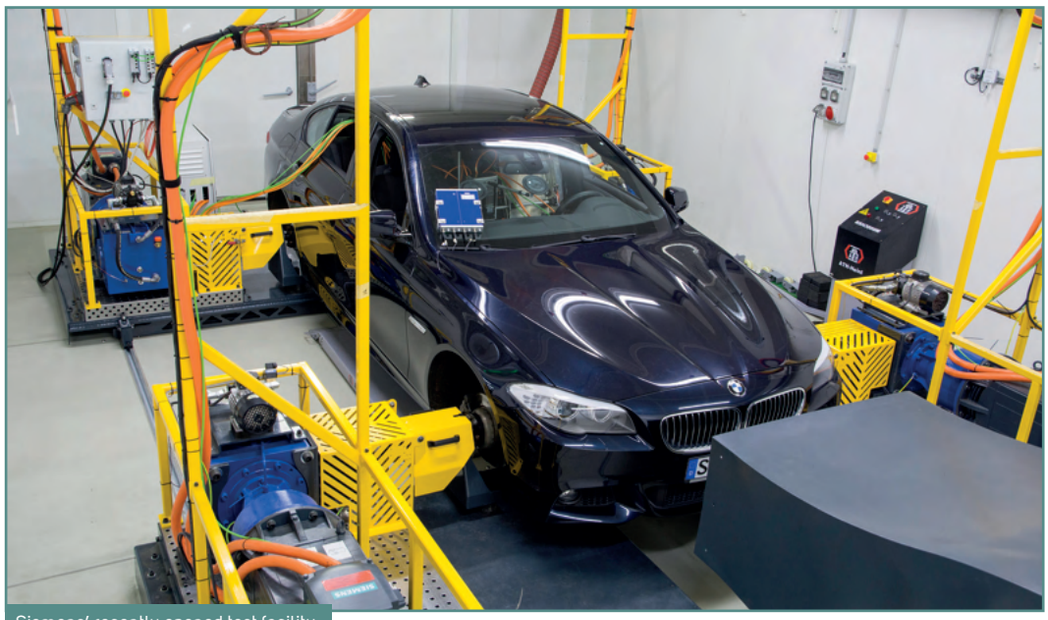
Reducing fuel consumption and emissions is clearly a technology driver. It encourages OEMs and suppliers in the automotive and transportation industry to design new vehicle technologies that help to meet environmental regulations without also sacrificing a vehicle's driveability and performance.

Testing to assess fuel economy has been done for some time. However, matching test data acquired on subsystem test benches with data acquired in full vehicle tests on the road or on dynamometers is something else.

Siemens PLM Software has opened a new, state-of-the-art vehicle energy management test center in Lyon, France. The facility is the first in the industry to couple advanced testing solutions on a full-vehicle level with the in-depth physics simulation necessary to analyze the new generation of hybrid and electric powertrains required by the industry to lower fuel consumption levels.

The test center boasts a number of features, including: a four-wheel, direct spindle drive dynamometer with torques equal to large sedans and SUVs; a temperature-controlled climate chamber with a range of -7°C to +45°C; a 5DOF robot to automatically operate manual and automatic transmission vehicles; a multiphysics measurement system to capture energy flows in different physical domains; measurement and post-processing capabilities to convert test data into energy flow maps; and a team of experts specialized in testing for fuel economy improvements.

LMS Engineering services can successfully balance and optimize seemingly conflicting requirements for fuel economy, driveability and NVH comfort for next-generation systems and vehicles. Leveraging simulation-based solutions with test-based, prototype vehicle integration and optimization solutions, LMS Engineering experts apply the best aspects of both worlds. This methodology increases the accuracy of full vehicle fuel economy test data and subsystem characterization test data.



Siemens' recently opened test facility makes it possible to conduct full-vehicle testing in conjunction with advanced simulation techniques

Balancing and optimizing fuel economy, driveability and NVH comfort by combining testing solutions with physical simulation offers a number of capabilities.

The first is the ability to troubleshoot vehicle attributes. Today, cars have become complex mechatronic systems with highly advanced hybrid and electric powertrain configurations. Superior performance results from interconnected controls linking mechanical, electrical, hydraulic, thermal and combustion physics. Testing in full vehicle conditions assures proper boundary conditions. Testing augmented with system simulation enables engineers to quickly diagnose flaws and identify countermeasures.

A further important advantage is benchmarking and target setting for fuel economy. Good fuel economy is an important brand differentiator and provides a serious competitive advantage. But improved fuel economy often conflicts with NVH, comfort or durability. Achieving well-balanced performance requires setting system targets as part of the development process. Customers turn to LMS Engineering to analyze competitive vehicles or evaluate state-of-the-art improvement potential on current products so they can set challenging, yet achievable requirements.

Another capability is test support for multi-attribute balancing. By bringing the test rig to a complete vehicle, individual component tests are replaced by a single in-vehicle test. This all-in-one approach eradicates the burden of gathering subsystem data from a number of separate testing activities and assures the consistency of measurement conditions.

Using test data efficiently extends simulation with tools such as LMS Imagine.Lab Amesim software to higher dynamics. Low frequency booming, tip-in shock and shifting can now be predicted and balanced with fuel consumption and energy management right from the concept phase. This system simulation approach allows for quick evaluation of architectural modifications in a simulation environment with optimal test and modeling efforts.

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To learn more about Siemens PLM Software, visit:
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INQUIRY NO. 527

Advanced MOSFET design

The latest generation of MOSFET technologies enable automotive designers to achieve efficiency and emissions targets, while also providing more advanced features for users

The efficiency and characteristics of advanced MOSFET technology grants engineers greater freedom when designing the latest vehicle systems

Energy management is a key challenge for automotive designers. Customers and legislators expect improved fuel economy and lower emissions, while users demand better comfort and safety features. The latest generation of MOSFET technologies offer improved efficiency and thermal characteristics that can yield significant improvements in vehicle performance, efficiency and reliability.

Development of power MOSFETs in the 30-100V range, suitable for automotive applications, is currently focused on improving trench gate technology and closer trench spacing, which translates into a smaller die area for a given on resistance and voltage rating, while parasitic capacitances are kept low.

The resulting devices have significantly better figures of merit. For example, the RDS(ON)A value of a 100V N-channel device fabricated using Toshiba's latest-generation U-MOS 8 process is approximately half that of a comparable U-MOS 4 device. U-MOS 8 also delivers a 60% reduction in RDS(ON)Ciss over U-MOS 4. RDS(ON)Ciss has a major influence on drive losses that have a significant impact on power supply and motor control circuits.

Dynamic performance is also improved with U-MOS 8 devices delivering the benefit of 50% shorter ringing at turn-off compared with the U-MOS 4 generation. The reverse recovery behavior also exhibits a smaller oscillation frequency, therefore making the U-MOS 8 suitable for motor control applications.

Key improvements in package performance are vital to increasing reliability, as well as supporting higher peak current ratings and greater current density for high-power applications, such as electric power steering (EPS) and hybrid-drive inverters. The wirebonds of traditional power MOSFET packages limit current-carrying capability and are a common point of failure. Copper clip technology in the latest DPAK+ package replaces traditional bondwire connections with copper clips that have a large contact area and are attached directly to the chip metallization.

Copper clip technology features in Toshiba's TO-220SM(W) power package, which is comparable to the conventional D2PAK (TO-263) outline and has a source pin more than three times wider. This delivers increased current capability, up to 200A, within a smaller (13 x 10mm) overall footprint – for example 40V/200A (TK200F04N1L) or 100V/160A (TK160F10N1).

For smaller devices serving low- to medium-power applications, a number of new package types are emerging that deliver improved thermal performance. For example, the latest DSOP Advance package has the same footprint as the popular 5 x 6mm SOP, and introduces an architecture that exploits double-side cooling to enable increased power dissipation and improved reliability. In the DSOP package, the source electrode on the upper surface of the die is connected to a large electrode on the top side of the package, which makes possible an enlarged drain electrode on the underside. This maximizes utilization of the package surface area for greater power dissipation.

The package and silicon technologies in today's latest U-MOS 8 MOSFETs allow for high current ratings of up to 200A in industry-standard packages, enabling MOSFETs to replace conventional mechanical relays in high-power load-switching applications. This allows small and lightweight control units to deliver significantly enhanced reliability.

Toshiba has taken advantage of the small outline of the PS-8 package to create its TPD7104F pre-driver for single high-current MOSFETs. This driver integrates all the necessary logic control and protection circuitry, as well as a charge pump to generate the gate voltage needed for high-side gate control in PWM applications.

The trend toward ever-greater electrification is firmly entrenched. Power electronics technology has a major role to play in helping deliver future generations of cars that achieve better fuel economy, lower emissions and greater reliability, while also offering state-of-the-art comfort and safety.

As engine-driven ancillaries such as water and oil pumps are replaced with electronically controlled alternatives, traditional relays are being replaced by semiconductor-based alternatives, and therefore power MOSFETs are increasingly used throughout conventional ICE, hybrid and electric vehicles.

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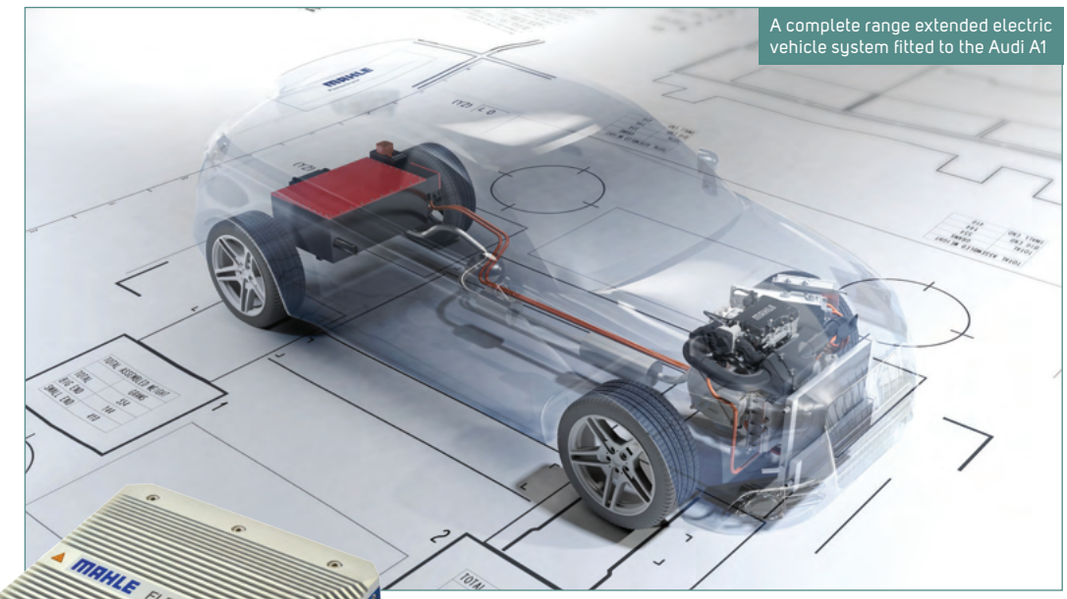
INQUIRY NO. 528

Drivetrain solutions

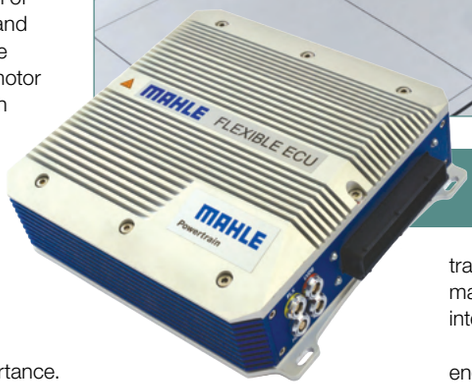
Engineering specialists offering complete integration of drive systems are sought after by vehicle manufacturers keen to develop powertrain strategies across their ranges

All major OEMs operate platform strategies with complete drivetrains developed and shared across wide product ranges. But the proliferation of engines, transmissions and hybrid drive systems increases the complexity of the control and integration tasks. Many OEMs are now turning to experienced engineering service providers (ESPs) to support their in-house drivetrain development activities.

Notwithstanding the challenges of emissions, performance, energy efficiency, and weight and cost reduction, a new critical paradigm has emerged – the integration of complete drivetrain systems and components. In the future, the IC engine, gearbox, electric motor and associated systems (such as thermal management) will move closer together to become a single, unified system that must be considered a functional unit. For ESPs, the expansion of their core capabilities toward complete propulsion and drive system integration is of growing importance.



A complete range extended electric vehicle system fitted to the Audi A1



Mahle's flexible ECU (MFE) controls a wide range of engine and vehicle systems

Hybrid vehicles in particular represent a major challenge in development and optimization, since there are numerous possible drivetrain configurations, each with its own merits and disadvantages. Engines can be powered by petrol, diesel, CNG or biofuel. Electric motors can be mounted separately, integrated within the engine or transmission, or mounted in the wheels. In certain vehicles, multiple motors are deployed. Batteries also vary in shape, size, weight, voltage, power rating, chemistry and location in the vehicle.

Electrical and electronic devices used in hybrid architectures include inverters, converters, generators, engine and vehicle control units, actuators and sensors. Both the cooling and thermal management systems have become increasingly complicated and include radiators, heat exchangers, intercoolers and condensers, evaporators, bypass valves, multimode pumps, fans and thermostats.

The conventional choice of either manual or torque converter automatic transmissions now includes electromechanical, dual-clutch, CVT and single-speed gearboxes coupled to conventional differentials and epicyclic or planetary final drive configurations. This expansion in transmission configurations offers many opportunities for the further integration of hybrid components.

Full hybrid vehicles use an IC engine, which is not necessarily the primary power source or method of propulsion. A combination of motors, which can be connected to the engine, transmission or separately connected to the wheels, can act as torque-fill, propulsion or generation devices. As such, the engine may be required to operate continuously, or infrequently, depending on the operating strategy of the hybrid system, battery state of charge or driver demand.

The engine may be required to start and run at high outputs in a short space of time, become the primary propulsion source and operate similarly to a conventional vehicle, or may not be used very frequently at all. This variation can lead to new challenges for the engine in terms of its optimum design and durability requirements. High loads following a cold start can lead to premature wear and thermal stresses, while prolonged periods of non-use present challenges to the fuel purge system, component corrosion, oil quality and fuel degradation. The requirements of onboard diagnostics (OBD) may also require periodic engine operation to check system performance and integrity even if the base operating strategy does not call for it. The rapid development of these new vehicle types, and their differing operating strategies, could lead to revisions to legislation regarding OBD and emission testing. This presents a moving target for OEMs, meaning vehicle systems must be reconsidered during production.

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INQUIRY NO. 529

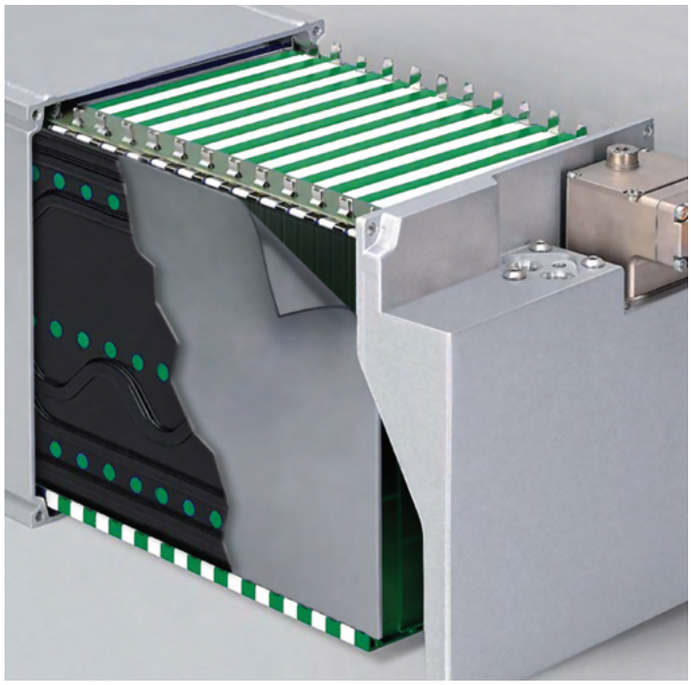
Thermal interface inroads

The expanded use of high-tech thermal interface materials in electric vehicles is helping to deliver better heat management in system-critical components

The automotive requirements for power generation, power conversion and power storage are necessitating increased use of thermal interface materials (TIMs) in the EV market. The widespread use of TIMs in the power conversion industry has prompted the need for a variety of material solutions over the past several decades. From the introduction of thin, thermally conductive and electrically insulating pads designed to replace mica and grease in the 1970s, to more recent advances in temperature- and vibration-stable high-performance thermal grease replacements, the TIM product families have matured to offer several media to fit countless applications.

Many of these materials have been designed to lend themselves well to the high-volume automation environments of the automotive manufacturing industry. Thermally conductive thick compliant pads, low-modulus thermally conductive adhesives, and liquid dispensed products that cure in place are already common thermal interface products used in the automotive market. As the power conversion industry merges with automotive systems, thermal and mechanical requirements for TIM materials are demanding higher and higher levels of performance.

High heat levels within a motor can decrease its efficiency over time and reduce its working life. Many systems are not limited electromechanically, but do have thermal limits, especially in their duty cycles. Oil cooling of the motor can help reduce the temperature of the overall system. However, the slots that house the magnets in the rotor can have large gaps that trap air and work as an insulator by preventing the magnets from transferring heat into the rotor.



Above: The Gap Pad 1000HD was specially designed for applications that require high durability

Left: Liquid polymer materials offer effective thermal management to ensure consistent performance and long-term reliability of electronic devices

The use of low-viscosity TIMs can fill these voids and ensure a good thermal interface between the magnets and the rotor housing. In the stator, mechanically robust thermal interface materials have been used to replace dielectric covers to assist in interfacing wires to the stator core. Liquid dispensed, form-in-place TIMs have also been used to interface the core to the housing. Displacing the air with a thermally conductive medium can help to prolong the efficient life of the motor.

The effective management of heat in power conversion systems (DC/DC modules, inverters and onboard charging modules) comes in a variety of forms within EV systems. Removing heat from the power components is fundamentally important, but these polymer-based TIMs can offer additional benefits in the systems. A large toroid with a delicate ferrite core can benefit from the thermal conductive properties of the TIMs, while the low-modulus characteristics can protect the unit from damage associated with assembly and vibration. Large bus bars can be electrically isolated and thermally interfaced with pad-based or liquid-dispensed TIMs. And furthermore, some polymer-based insulated metal substrates can even replace more fragile types of ceramic base-plate technology.

Power storage systems have some of the largest requirements for thermal management materials. The concerns over electric vehicles' life and safety are most often associated with the lithium-ion battery and thermal issues. New products on the market are being designed to coat prismatic lithium-ion cells with a thermally conductive dielectric layer. These products can replace the conventional shrink-wrap coatings – that act as a thermal barrier – while offering higher dielectric integrity that is resistant to wear under vibration.

Compliant TIMs are also used to interface the varying topography of the bottom of the cell pack to the cooling system, enabling consistent temperatures across the battery pack. In turn, this can also help prevent charging and discharging at different rates, which can lead to premature degradation of the battery cells.

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INQUIRY NO. 530

Fast-charging standards

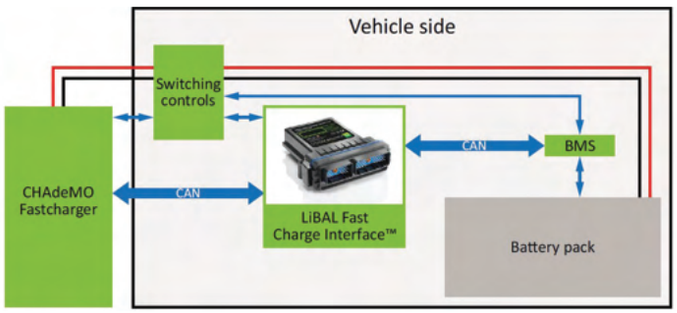
New modular deployment of a standalone fast-charging interface for electric vehicle applications can greatly reduce the integration burden on manufacturers

Fast-charging standards and the associated technologies are a hot topic in the electric vehicle industry. Although the principal requirements and the topology for fast charging are standardized by the International Electrotechnical Commission (IEC), there are many specific national and international standards that are being developed throughout the industry. The IEC 62196 standard defines four principal modes of electric vehicle charging. Mode 1 and Mode 2 are conventional 'slow' charging modes that use a regular AC wall socket, while Mode 3 defines the principal operation of AC fast charging using offboard electric vehicle supply equipment. Meanwhile, Mode 4 defines the principal operation of DC charging via the use of an offboard fast charger.

The IEC 62196 fast-charging standards include CHAdeMO, a Mode 4 standard developed and owned by a Japanese corporate consortium; GB/T 20234, a combination of Mode 3 and Mode 4 developed by Chinese standardization authorities; and the Combined Charging System (CCS) standard, which is a combination of the Mode 3 and Mode 4 fast-charging standard owned and developed jointly between the European Automobile Manufacturer's Association and the Society of Automotive Engineers.

In this complex world of national standards, the manufacturer of an electric vehicle is presented with the difficult choice of which standard to implement on its vehicle. Developing and maintaining support for safety critical and complex communication protocols can be very taxing on development and testing budgets for electric vehicle manufacturers, particularly smaller manufacturers and makers of niche vehicles.

Lithium Balance's range of multivoltage battery management systems can be used for many electric vehicle applications



The Fast Charge Interface is limited to a CANbus connection to the battery management system, making it easy to integrate and universally applicable

Furthermore, access to the fast-charging equipment for the purpose of interoperability testing can be difficult to obtain if you are not part of the consortium developing the standard in question.

However, by using a standalone fast-charging interface, the overall integration burden on the vehicle manufacturer can be considerably reduced. In addition, a single vehicle type can be equipped with support for several fast-charging standards that target different markets. At Lithium Balance, the Fast Charge Interface has been developed using an Automotive Safety Integrity Level D microcontroller for integration into all types of road vehicles. The Fast Charge Interface contains all the required hardware and software to support the various fast-charging standards, thus enabling the fast-charging capability to be deployed in a modular fashion.

In order to make sure that the Fast Charge Interface is simple to integrate and universally applicable, the interface has been limited to a CANbus connection to the battery management system (BMS). Any information to the driver, vehicle control systems or onboard charging devices will be managed by the BMS, just as if the vehicle were charging using the onboard charger. The Fast Charge Interface uses the information from the BMS to control the fast-charging process in a way that is consistent with the parameters for safe battery operation set by the BMS.

The Fast Charge Interface also plays an important role in the safety architecture of the fast-charge enabled vehicle. On one hand, there is the energy-storage system of the electric vehicle, with many safety requirements relating to fire hazards, electrical hazards and so forth. On the other, there is the charging station with a safety architecture relating to electrical hazards, grounding faults, sparks and so on.

The Fast Charge Interface acts as a bridge between the systems and must be included in the safety case for both, which means an extremely high level of reliability is required. This reliability is achieved by via a combination of component selection, hardware design, software design and safety mechanisms for all identified failure modes where single point faults can lead to violations of the safety goals for the Fast Charge Interface.

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INQUIRY NO. 531

Analyzing e-machines

A combination of expertise and state-of-the-art facilities can improve the selection, design and full testing of e-machines and controllers for hybrid vehicle applications

The hybrid electric vehicle market is evolving quickly, and is demanding high-efficiency electric machine and controller designs. Developing markets include numerous types of traction motors, starter generators and turbo applications. OEMs, Tier 1s and traditional motor firms are all keen to access the new markets for e-machines and maximize the return on their investments.

Many varying machine types are used, including interior permanent magnet, induction machine, switched reluctance, synchronous reluctance, and synchronous reluctance permanent magnet assist. All have key advantages and disadvantages.

Ricardo has market-leading knowledge in the application-specific selection, design and testing of these machine types and their associated power electronic modules and control algorithms.

Ricardo offers comprehensive benchmarking analysis, including cutting-edge simulation, motor testing, teardown assessment and materials analysis. Performed by key technical experts across the global business, the company's approach can provide in-depth, detailed commentary on design benefits, disadvantages and areas for optimization. Market-leading designs have been interrogated and reports generated after full analysis, down to component-level, which includes materials analysis (in particular the electrical steel and magnet grades), as well as semiconductor selection and cooling system approach. A full suite of electrical measurements is completed to characterize the winding resistance, inductance, and insulation breakdown properties, and to provide accurate input data for simulations. A full winding schematic can be generated for insulation material and construction, including thermal capability, as well as detailed circuit schematics for power electronics. Using these outputs, advanced CAD drawings are produced that include skew and segmented stator or rotor topologies with expected tolerances. Having completed a full teardown, the electric machine is then tested practically in order to provide both continuous and peak measurements for the torque speed, thermal performance, efficiency levels, windage and friction losses, and so on.

Ricardo's benchmarking analysis includes generating reports down to component level for parts such as hybrid electric rotors

Electromagnetic and thermal simulations using the measured data are created in a range of tool suites (SPEED, Opera, MotorCAD, MotorLAB, MotorEMag, MagNET MotorSolve and others). All these models output the electric machine performance across the full speed torque curve and give detailed flux plots to evaluate the saturation and peak load thermal performance for boost mode use. Full drive-cycle analysis is then simulated using the benchmarking output; this provides instant machine and inverter efficiencies for comparison of designs. For passenger car designs, where vehicle range is a crucial selling point, drive-cycle analysis (such as NEDC) can provide realistic driver inputs for machine selection.

Ricardo invests in developing roadmaps for technologies, both in the marketplace and with predicted release dates that are determined from discussions with suppliers and developers. Using this information, a new development program can quickly decide which path is the most suitable for a given application, with predicted results measured against benchmarking data.

Ricardo has all the in-house expertise and capability necessary to perform drive-cycle HIL testing, battery testing and power electronics testing – all the way from four-wheel drive test rigs through to single electric machine torque versus speed versus efficiency plots – using automated test processes to ensure reliable, repeatable and robust results.

These test facilities can be used in conjunction with e-machine and power electronic testing to give extremely realistic results for in-application performance. The company also possesses advanced test facilities that combine highly accurate measurements with fast sampling time to provide full-machine characterization with either an OEM's inverter or Ricardo's in-house controller.

Together, this combination of expertise, facilities and capabilities has been successfully applied to deliver highly accurate assessments of today's cutting-edge automotive e-machines and power electronics – thus enabling Ricardo to provide leading-edge consultancy on future e-machine and power electronics designs and applications.

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INQUIRY NO. 532

Powertrain control systems

A scalable, modular approach to vehicle electrification can enable the manufacture of zero-emissions medium- and heavy-duty vehicles on existing production line facilities

Vehicle electrification can be undertaken using a scalable, modular approach with Motiv Power Systems' electric Powertrain Control System (ePCS). The ePCS is a product that enables conventional truck builders to easily and quickly build trucks with zero-emission, all-electric powertrains on their present assembly lines. This has been aptly demonstrated through installation of the ePCS on first-of-their-kind electric vehicles in the medium- and heavy-duty sectors.

The Motiv ePCS is the key part of Motiv's upfit packages, which combine all the components that electrify vehicle chassis such as the Ford E450, Ford F59 and the Crane Carrier COE2 chassis. These flexible upfit options have already been used in diverse vehicle applications including school buses (Figure 1), shuttle buses, walk-in vans, work trucks and refuse trucks. And while electric vehicles in the medium- and heavy-duty sectors have long been of interest to the industry due to the cost stability of electricity as a fuel type, vehicles have been slow to come to market. The engineering costs associated with developing new vehicle types makes it hard for new vehicle builders to enter an already saturated marketplace. However Motiv works within this space as a partner with existing vehicle builders to expand their portfolio to include electric versions of their existing vehicles.

Within the Motiv ePCS are a variety of components that make the single product suite capable of electrifying any truck or bus with a variety of commercially available battery packs and motors. One such component is from Semikron's off-the-shelf SKAI2 converter family (Figure 2), which covers an electric power conversion range of 10kW to 150kW. These converters have been developed specially for vehicle electrification, such as light trucks and buses, agricultural and construction machinery, marine applications and cars. They are manufactured in high volumes and therefore greatly reduce the cost hurdle on the way to vehicle electrification. Motiv adds the intelligence to Semikron's electric power conversion, enabling it to integrate with the rest of the upfit package and vehicle components.

Figure 1: A diverse range of vehicle applications, such as school and shuttle buses, use the flexible uplift options of the Motiv ePCS

At the heart of Motiv's ePCS is the adaptive power converter (APC) – a programmable voltage converter that enables multiple battery packs to be independently managed. The iAPC contains a buck-boost converter pulling large amounts of power to run the motors on the vehicle and capturing power back during regenerative braking. Multiple APCs are on every vehicle, with one managing each battery pack, which enables the system to intelligently modify the power load to maintain an optimal operating environment.

Figure 2: Semikron's SKAI2 converter family covers an electric power conversion range of 10-150kW

Motiv's ePCS is robust and flexible enough to handle vast energy requirements ranging from 80kWh to 200kWh with multiple battery packs. Motiv has also used this APC to demonstrate multiple battery chemistries on the same shuttle bus, something not possible with any other electric truck builder today. The ePCS includes Motiv's own charger, which rectifies three-phase AC grid power for recharging the main batteries when the vehicle is plugged in. This 60kW onboard charger communicates with the APCs to charge the batteries while optimizing the system's health.

This approach to building all-electric vehicles using off-the-shelf components and an upfit package that works with commercially available chassis types is more market friendly. Motiv-equipped vehicles apply extensive engineering in the ePCS to an emerging market, with substantially reduced costs. While electric vehicles remain expensive due to the higher upfront costs (including battery packs not required on a gaseous fuel vehicle), this process of working with OEMs means expertise is efficiently employed across the industry and fits into an existing model that customers are comfortable with.

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INQUIRY NO. 533

Flexible manufacturing

Automation solutions capable of handling complex components and adapting to rapidly changing production needs are vital to the manufacture of advanced vehicle platforms

The increasing electrification of the vehicle presents automotive manufacturers with formidable challenges. OEMs and suppliers encounter three dilemmas when developing and manufacturing highly connected vehicles and e-mobility platforms of the future: hierarchical production processes in fixed footprints that do not share data freely; lack of real-time, in-line quality inspection and correction processes for complex miniaturized electronic components; and ERP systems that can collect, analyze and respond to rapidly changing production needs. Omron continues to develop machine automation solutions that support advances in manufacturing flexibility.

While the automotive industry has implemented sensors, robotics and computerized automation for many decades, these systems are largely organized in hierarchical fashion within individual data silos, and often in a closed, hard-wired network environment that's largely disconnected from IT and enterprise service-based networks. What's more, to complicate matters, automotive and industrial standard manufacturing equipment is still largely constrained by a huge installed base of legacy workflow, equipment and standards. The rising tide of consumer-driven customization in vehicles, however, requires flexibility all along the continuum of vehicle production, while providing security and safety on the shop floor.

New solutions had to be worked out for the installation of high-voltage components as well as the handling of these complex electrical systems during all stages of production. The ability to manufacture ever-decreasing packages with real-time quality inspection and tracking has become critical. New requirements for joining processes, forming, orientation and electrical isolation require novel tracking solutions.

The Sysmac NJ Series controller with SQL Direct Link and NA Series HMI delivers real-time data to visualize complex e-component processes

E-motor and high-voltage battery systems represent some of the largest and most complex bills of materials in the vehicle today. They also represent new technical challenges for automation, safety, joining processes, measurement, testing and inspection, yet are often subject to legacy assembly processes. The fast and ever-changing needs of these factory workflows demand flexible assembly lines that can quickly reconfigure their activities. ERP solutions that lead to adoption of the Internet of Things and Industry 4.0-based technology can resolve part of the dilemma. However, they rely on real-time high-velocity analytics and large quantities of high-quality data.

Anticipating the need to harness big data connectivity, Omron began developing new capabilities for its Sysmac controllers in 2011. SQL Direct Link was built into the NJ-Series Machine Automation Controller, an ultra-fast PLC with an EtherCAT- and EtherNet/IP-capable platform. The Sysmac NJ SQL controller can feed line data from factory-level products and devices, such as sensors and vision systems, directly to an enterprise's existing SQL database without the need for additional computers or software programming. While middleware solutions typically take seconds to transmit a datalog entry, the Sysmac system transmits in real time, so there is negligible impact on line speed. Since the Sysmac system is capable of linking and collecting log data in real time from all equipment involved in a given process, as well as individual products that pass through the production, management and operators are able to monitor and visualize complex e-component manufacturing processes at a system-wide level through to an individual operation, from beginning to end. The intelligent assembly value chains created have the potential to self-diagnose, communicate, and control each other autonomously with significantly reduced intervention. While true Industry 4.0 realization is still in its infancy, this solution offers a platform with which to realize a truly smart factory.

Omron is a world leader in automation and safety products. In addition to providing automation and safety support to traditional component and vehicle assembly, Omron has extensive experience in semiconductor, motor, electrified powertrains, battery, and connected technology assembly.

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INQUIRY NO. 534

Implementing 48V tech

A new generation of power generators, using 48V technology, can deliver hybrid levels of fuel efficiency, with a minimal increase to the total cost of manufacture

The argument of how to power vehicles has been taking place since auto makers started building them. It's a 150-year-old argument.

The modern argument is as complex as the technology behind it. Increased regulations on both emissions and fuel economy, environmental concerns, and objections to a reliance on fossil fuels combine to make a convincing case for hybrid and electric vehicles.

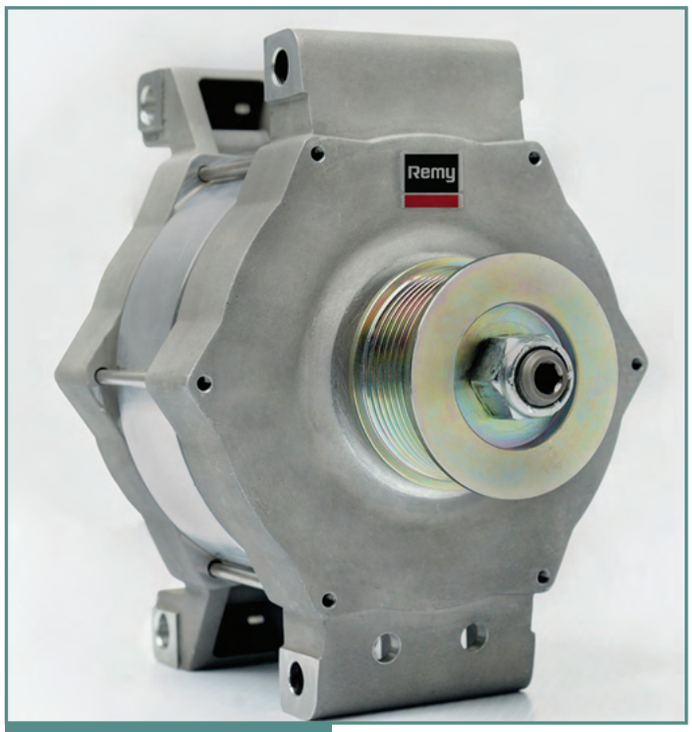
But the consumer isn't buying it. According to Edmonds, electrified vehicles accounted for only 2.7% of the market in 2015 through April, down from 3.4% the previous year. The internal combustion engine is still the unchallenged frontrunner.

The reasons for the internal combustion engine's dominance are easy to understand. Hybrid and electric vehicles are more expensive than their gasoline-powered counterparts, and the argument that electrified vehicles "pay for themselves in five years" morphed into something closer to 10 years when fuel prices dropped from US$4 per gallon to US$2.66 on average. It appears that everybody wants to save the world until they have to pay for it themselves.

Then there's range anxiety, lack of charging stations, and, on all but the elite-class vehicles, performance compromises.

It remains inevitable, however, that adoption rates of electric vehicles and hybrids will increase in time. Advanced technology will solve battery life, driveability, and manufacturing issues, just as new ideas have gradually improved vehicles over the past century.

It's important to accept the fact that vehicle electrification is more evolutionary than revolutionary. For the average consumer to convert, the industry will need to deliver a variety of vehicles that provide the desired driving experience at a justifiable price. Realistically, this may take 5-10 years, and will require serious perception adjustments.



Remy offers motor/generators with outputs from 12 to 700V, including the high-power density 48V three-phase IPM machine pictured above

Meanwhile, electrification technology exists today that can substantially increase fuel economy and enable emissions compliance without significantly adding manufacturing costs or sacrificing driveability. Forward-thinking organizations are using 48V technology to bridge the gap between today's internal combustion engine-powered vehicles and tomorrow's electric dream machines.

The difference made by 48V technology is anything but subtle. It can deliver hybrid-like fuel efficiency levels for lower manufacturing costs. On vehicles with downsized engines, it can minimize – and even negate – driveability issues.

Remy International is as committed to vehicle electrification as anyone. The company is North America's largest independent designer and manufacturer of electric traction motors for hybrid and electric vehicles.

Still, Remy believes that 48V technology is a game changer. The company has seen proof that even small steps can lead to remarkable increases in fuel efficiency.

The implementations of 48V technology include belted alternator/starter (BAS), integrated starter/generator (ISG), and other advanced high-output alternator technologies. These designs employ an electric motor in place of a standard alternator to add power to a vehicle's drivetrain in the form of start/stop and power assist, or by allowing regenerative braking. General Motors, Hyundai, Audi, BMW and others are employing these technologies.

It's easy to adopt a cause, easy to call for change. But it takes time to deliver a viable technical solution that makes economic sense for most people. And it's impossible to reimagine the transportation industry – a vital part of the economy – overnight.

While development continues on the technology of tomorrow, it's also possible to provide environmentally responsible vehicles today – at attractive prices that improve efficiency and fuel economy without also sacrificing vehicle performance. It's a solution that's very hard to argue against.

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Reaching zero emissions

Thanks to the elimination of mechanical subsystems, transit agencies seeking alternative fuel types to improve air quality are considering an open path series hybrid architecture

Reducing emissions and fuel costs has been the objective of public transit services for more than 15 years, with the end-state of zero emissions on the horizon. With increasing mandates on emissions levels, zero-emissions technologies are becoming more prevalent, more fuel cell and electric buses are beginning to populate the roads, and transit agencies are seriously evaluating these technologies for integration into their fleets.

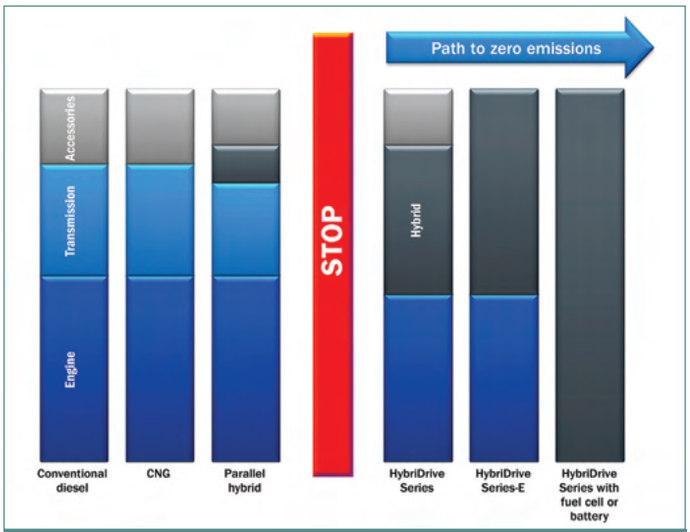
Transit agencies and cities, however, have much to consider when choosing a propulsion solution. Some agencies are careful to protect themselves from iteratively changing from one new technology solution to another as such an approach is cost-prohibitive. For instance, conventional diesel, CNG or parallel hybrid powertrains depend on mechanical subsystems and can't achieve full zero-emissions operations. Therefore agencies must consider these factors when planning for future infrastructure investments and staff training.

Many transit agencies are considering an open path with series architecture. A series hybrid is a core system architecture, enabling bus electrification by eliminating mechanical subsystems and delivering different solutions that will lead to a zero-emissions path. Today, a series hybrid is offered by as many as five OEMs, presenting a variety of sustainable combinations of power and fuel sources. In the case of BAE Systems' Series-E propulsion system, transit agencies may combine diesel and battery, or fuel cell and battery.

A series architecture enables a reduction in engine displacement and torque, and elimination of the conventional transmission. It also enables full accessory electrification, limited zero-emissions operations, or total zero-emissions operations by replacing an engine with a fuel cell or larger energy-storage system.

The Series-E electric power and propulsion system enables route flexibility and builds fleet commonality for transit agencies

Before making the leap to an all-electric solution and investing in the infrastructure that comes with it, transit agencies must weigh all the associated costs and commitments. BAE Systems' Series-E electric power and propulsion solution is a logical step toward the EV end state. Series-E provides electric power to accessories and electric propulsion without the worry of purchasing charging infrastructure, and doesn't require extra time or a location to recharge. As Series-E is equipped with an onboard charger, there's no need to stop and recharge to enable its zero-emissions travel. A bus powered by Series-E can run without range or performance limits, and is flexible enough to run on EV route segments one day and long-range commuter routes the next. Series-E enables transit agencies to build commonality across their fleets instead of having dedicated vehicles for specific routes.



The path to achieving full zero-emissions operations requires series architecture

The results of a study by M J Bradley noted that the greenhouse gas emissions that transit agencies are most concerned about are greatly reduced with a series hybrid compared with a CNG or diesel powered vehicle.

In the short term there is much to consider when embracing full EV solutions, including infrastructure costs, the price of batteries, the weight and load of the battery, and the range needed to travel. As all these newer technologies begin to develop, standards will become clear and available and much more will be learned.

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Hybrid architecture

The development of an innovative axle-split drive system, and the expertise to integrate it, provides car manufacturers with the tools to create the next generation of plug-in hybrids

It's hard to change buying habits – and even harder when the product in question is a car. But two vehicles in the past year have succeeded in changing the way people feel about plug-in hybrid technologies. Thanks to vehicles such as the plug-in hybrid BMW i8 and Porsche 918 Spyder, consumers are starting to see e-mobility differently.

It's not just about the way these cars look. Is there also a different philosophical approach to hybrids emerging that is reflected in the technology used?

"Auto makers aren't just looking to make their next car more efficient; they want to create new driving experiences," says GKN Automotive CEO Andrew Reynolds-Smith. "We are developing the systems that are helping to bring a new generation of electric drive vehicles to life. Our experience in mechanical systems, software control and vehicle integration is enabling auto makers to connect drivers to the road in new ways."

The rise in prominence of axle-split hybrids is being facilitated by eAxle technology. A conventional or hybridized engine provides the primary power to either the front or rear wheels, with the other axle driven by an eAxle module.

The technology responds intelligently to deliver an instant high-torque all-wheel-drive (AWD) experience, a useful pure-electric range, or a refined, efficient parallel hybrid mode. No other hybrid architecture offers such a strong combination of efficiency, traction, dynamics and packaging.

Integration expertise is key to realizing the technology's potential, as demonstrated through GKN's leadership in all-wheel-drive systems. GKN is the only global Tier 1 that can work with a customer to deliver a complete AWD driveline and integrate it into the vehicle. The company's software experts know how to get the best out of the hardware to tune the vehicle-level attributes that its customers want to give to end users.

A new generation of axle-split hybrid vehicles is using GKN's eAxles to create new driving experiences

GKN's 2-speed eAxle enables the electric drive to boost vehicle performance across its speed range

Porsche awarded GKN Driveline Technology Partner status for its development of the acclaimed high-performance eAxle for the 918 Spyder. GKN Driveline's eAxle module supports full-electric mode and all-wheel drive, and provides a boost function.

"Realizing our vision for a super sportscar capable of setting a record lap time on the Nürburgring and achieving fuel efficiency of 3 l/100km placed huge demands on our engineers and suppliers," explains Porsche powertrain manager Christian Hauck. "GKN Driveline's role in the development program and its innovative eAxle module is what earned the company Porsche Technology Partner status."

The BMW i8 uses an innovative 2-speed eAxle from GKN to deliver a similar, but distinctly different, combination of AWD dynamics and plug-in efficiency.

Until its launch, electric and axle-split hybrid vehicles had only used single-speed transmissions that had to disconnect at certain speeds to prevent the electric motor from overspinning. GKN's 2-speed eAxle solution was the first to enable the electric drive to boost the vehicle's performance across its entire speed range.

As GKN Automotive's president of engineering, Peter Moelgg, explains, "It pays to work with the company that pioneered eAxles. The Porsche and BMW programs were the perfect opportunities for our team to demonstrate how integrating the right technology can improve both fuel efficiency and dynamic performance."

With more and more programs partnering with GKN on eAxles, the company's expertise in eAxle design and production is going from strength to strength. As cars and commercial vehicles improve fuel economy and CO_2 emissions, GKN is helping companies to ensure that vehicle hybridization also creates the emotional pull they need to succeed globally.

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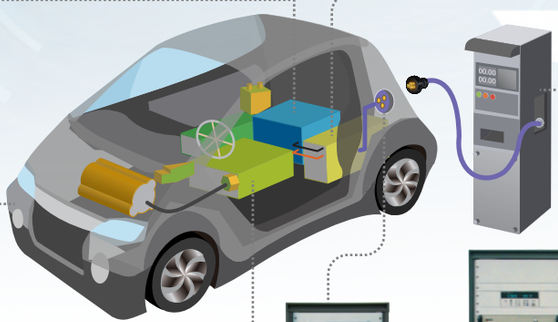

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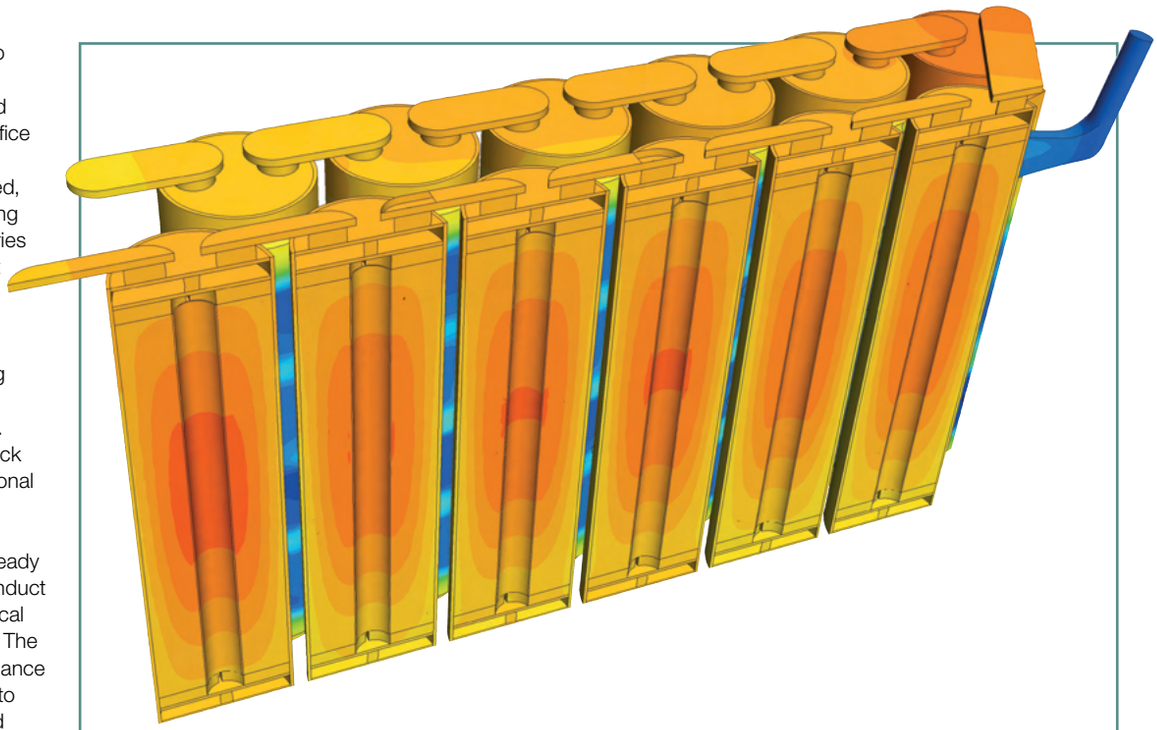
Designing batteries faster

The Computer-Aided Engineering for Electric-Drive Vehicle Batteries project is accelerating the development and lowering the cost of lithium-ion batteries for electric-drive vehicles



An ambitious software development project is fast tracking lithium-ion battery development and reducing overall costs

In June 2011, CD-adapco embarked on a software development project co-funded by the Vehicle Technologies Office within the US Department of Energy. Now recently completed, the Computer-Aided Engineering for Electric-Drive Vehicle Batteries (CAEBAT) development project targeted the automotive and lithium-ion battery industries with the goal of driving down development time and enabling greater market penetration of advanced EDV power systems.

The project's origin dates back to a RFP, managed by the National Renewable Energy Laboratory (NREL). This dovetailed with an initial CD-adapco capability already available in STAR-CCM+ to conduct flow, thermal and electrochemical analyses on Li-ion pouch cells. The proposal submitted was to enhance the existing capability to apply to all battery cell form factors, and specifically the more challenging spirally wound designs.

This ambitious project required partners who could deliver the necessary key technology and validation to demonstrate the value and accuracy of the proposed method. An obvious choice to help with the mathematics and problem definition was CD-adapco's long-term partner in the field of battery analysis, Battery Design LLC. Johnson Controls also came on board as it has a broad range of wound cells, which are ideal to use as validation cases for such technology. The team was completed with the addition of A123, whose pouch cell was studied in order to ensure that the methods developed worked across all cell shapes.

With the team in place and the proposal selected by the judging team to receive funding, the first phase involved detailed software development, in-turn producing an industrially relevant and easy-to-use electrochemical and thermal model that can be applied to wound electrode battery types. The resulting simulation technology is applicable both at the cell and module level of analysis and the fidelity of the model can be controlled by the user, depending on the application's desired output and level of accuracy.

During the second phase of the high-tech project, five cells from two manufacturers, spanning three cell shapes (stacked, cylindrical and prismatic wound electrodes), were used to validate the computational model, which had been developed using real-world drive cycles at both the cell and module levels.

To further enhance the simulation methodology, a database featuring 12 contemporary electrolyte formulations typical of those used in modern lithium-ion batteries was added to the software. This enabled a more complete physics-based simulation to take place. In addition, a complementary calendar-aging model was created to fully work alongside the cell performance models, preconditioning them to the aged state. The approach was also extended into system level space using either an electrochemical technique or reduced order models. Finally, best practice methods for timely generation of future electrochemical techniques by users were developed and the simulation models were integrated into STAR-CCM+ for combined flow, thermal and electrochemical simulation across a range of length scales without redundancy.

The methods developed during the pioneering CAEBAT project are now available in CD-adapco's STAR-CCM+ software and in the application-specific tool Battery Design Studio. Furthermore, through linking the flow, thermal and electrochemical simulations into one environment, a highly accurate solution can be obtained, spanning multiple scales and computational domains, from system models to highly resolved complex 3D models.

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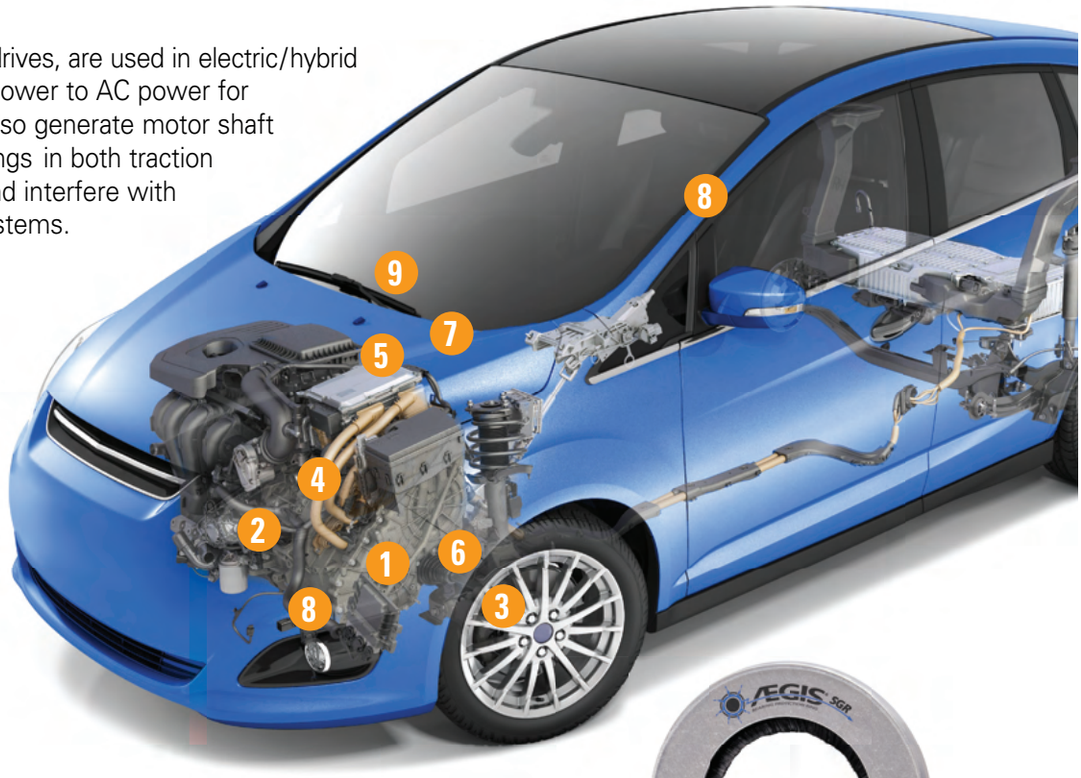
Protect Electric Vehicles from Bearing Damage and EMI/RFI

Inverters, or variable frequency drives, are used in electric/hybrid vehicles to convert DC battery power to AC power for traction motors. But, inverters also generate motor shaft voltages that can damage bearings in both traction motors and coupled systems and interfere with electronic or communication systems.



Bearing Damage:

1) ***Traction motors***
2) ***Transmission bearings/gears***
3) ***Wheel bearings***
4) ***Gasoline engine bearings***

EMI/RFI:

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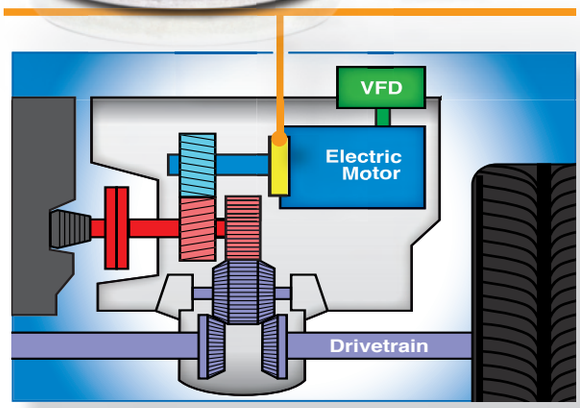

Download "Protecting Electric Vehicles from Bearing Damage and EMI/RFI" white paper at: www.est-aegis.com/EVwhitepaper.

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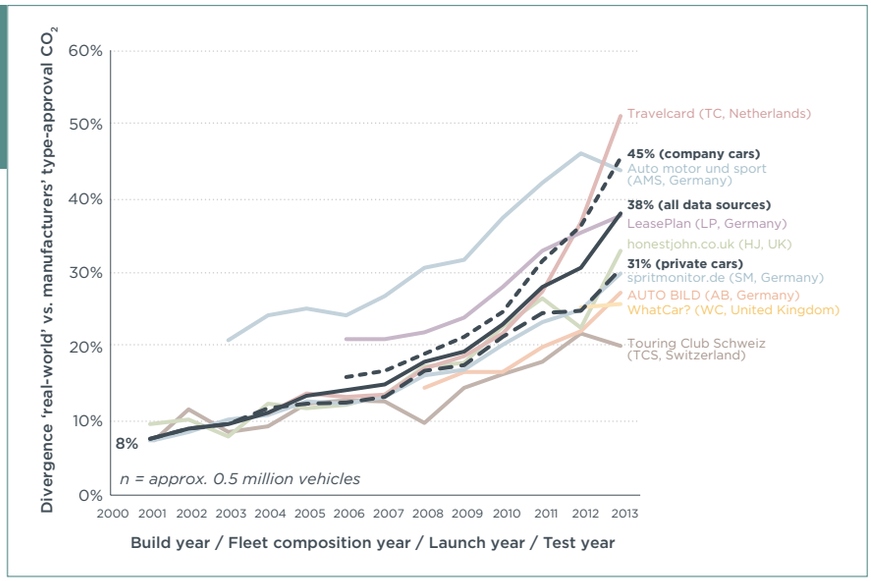
Streamlining development

Refining the tools and data available to OEMs for use in electric and hybrid drivetrain concept comparisons can lead to better-informed design decisions

The *raison d'être* for hybrid and electric vehicles is to have better energy efficiency and hence lower CO_2 emissions. Many articles carry a similar theme: the demand of meeting EU guidelines to reduce CO_2 emissions. Romax Technology, a global provider of software and services for the design, analysis and optimization of transmissions and drivelines, stresses the importance of not forgetting the customer in the quest for fuel efficiency.

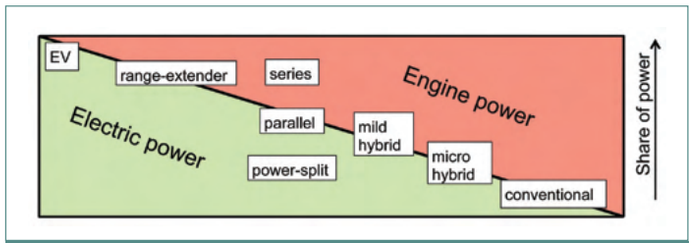
Since 2001 the gulf between official and real-world CO_2 emission figures has widened from 10% to 40%. Impressive CO_2 figures may look good for marketing purposes and for government bureaucrats, but unless real-world figures are improved, the consumer (and the environment) will be ignored.

The divergence in real-world and manufacturer-approved emission figures has widened from 10% to 40% since 2001



Of course OEMs have a challenge in designing EV and HEV drivetrains anyway. Gone are the days when the choice was between manual and automatic, 4- or 5-speed, and ratios that could be selected via some clear and definable logic. EV and HEV design is altogether more complex, with numerous options for layout, types and relative sizes of power source/storage, changes in operation mode and so on. All of this explains why, if you go to any automotive conference, one OEM may stand up and announce: "This is our hybrid – it is the optimum and here are the NEDC simulation results to prove it," only for another to unveil a completely different hybrid and make exactly the same claim.

With such a complex challenge, OEMs could be forgiven for not wanting another variable – drive cycles – to be included in the design process. And yet the consequences of ignoring such cycles are serious. Customers lose faith in low-carbon vehicles and the market is flooded with competing technologies that cannot be judged on a like-for-like basis, with the result that no single technology has the chance to build up the economies of scale required to reduce manufacturing costs and enable low-carbon drivelines to compete with the incumbent conventional powertrains. In short, the new, low-carbon drivetrains fail to meet their principal objective of substantially reducing CO_2 emission production by the traveling public.



There are many power source considerations when designing EV/HEV drivetrains

For 25 years, Romax Technology has been tackling the design problems other companies thought insurmountable, and developed solutions that can be used in the design of better drivelines. Pick any car in the street and the chances are that its driveline will have been designed with at least some element of Romax's technology.

Now Romax is applying the same approach for technical innovation to the design of EVs and HEVs. The target is to achieve two key goals that were hitherto impossible within the time constraints of a practical design project. The first is to scan across the full range of options for HEV drivelines, allowing radically different designs to be compared on a like-for-like basis. The second is to enable large quantities of drive-cycle data, from many sources, to be included at the concept selection stage so that designs that are robust in many driving conditions are used.

The ProtoDrive project, which is funded by Innovate UK, involved a consortium led by Romax and including CMCL and the University of Sheffield. Now in its final stages, European OEMs are working with Romax to demonstrate the value of the technology through case studies.

By working with these OEMs on their design projects, Romax soon realized that the manufacturers couldn't assess all of the design options rigorously or on a like-for-like basis as the tools being used were not fast or informative enough. Consequently, design decisions were based on gut feeling rather than hard, quantitative data. Romax is setting out to rectify this.

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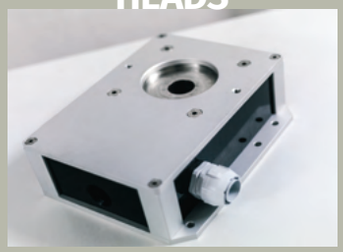

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Retrofitting electric buses

The conversion of diesel airport buses to full-electric powertrains provided a unique opportunity to completely rework the technical layout and interior design of the vehicles

Based in Vila Nova de Gaia, Portugal, CaetanoBus is a market leader in the production of airport buses. Its Cobus vehicles operate worldwide, transporting travelers from airplanes to terminals and vice versa. Now the company is taking a big step into the electrical age by offering airports a unique and affordable way to reduce their carbon footprint and save money: a full retrofit with good-as-new results. The key to CaetanoBus's electrical rebuild strategy is getting the right power to the right system efficiently and without taking up too much space. For this the company called on the technical expertise of Lenze Schmidhauser in Switzerland, which has proved to be a valuable partner throughout this undertaking.

"Airports are under a lot of pressure to reduce their carbon footprint and save costs," says José Costa, head of vehicles and chassis development at CaetanoBus in Gaia, who has many years of experience in airport applications, and terminal buses in particular. "There are many bus suppliers taking their first steps in the electric age. But when it comes to buses for airports, where available space and loading capacity is of major importance, there are no cost-effective, fully electrical solutions. Together with many partners, CaetanoBus has come up with a unique overhauling concept whereby old Cobus 3000 buses are given a second, fully electric life."

Fully electric buses can help to reduce an airport's carbon footprint

Lenze Schmidhauser's Mobile product platform features in the retrofitted CaetanoBus

Diesel-powered buses were converted for electric operation

After stripping the old diesel-powered buses, CaetanoBus engineers had a unique opportunity to totally rethink the technical layout and interior design. "The main things we looked at during the redesign were, of course, the environmental and operational parameters of the new eCobus, as well as the manufacturing costs," Costa explains. "We needed to fully capitalize on the low-emission and low-noise capabilities of e-driving, while coming up with a safe, reliable and cost-effective solution. With important partners such as Lenze Schmidhauser, we've created the first fully electric and economically viable airport bus in the world, which reduces the energy costs of moving people around at an airport by an impressive 75%."

Lenze Schmidhauser's sales and marketing manager, Jonas Schuster, understands the call for compact automotive-grade converters. "One of the problems companies like CaetanoBus face when designing their fully electric alternatives is a lack of available automotive-quality components. The only things they can get their hands on are industrial components, which are big, bulky and often have moving parts, such as a fan for cooling. To address this, we came up with our Mobile platform in 2012. It allows producers of commercial vehicles to harness all the benefits that high-volume car manufacturers have, without the premium price tag. Our customers have only to specify their power requirements, and we will integrate that into one tight and robust water-cooled aluminum enclosure.

"For CaetanoBus we put together one Mobile DCU 15/PSU 5.6 and two Mobile PSU 5.6 units to power the air conditioning, various auxiliary systems and the dashboard. And since Mobile is a modular platform, we managed to produce and deliver these units based on a standardized production process."

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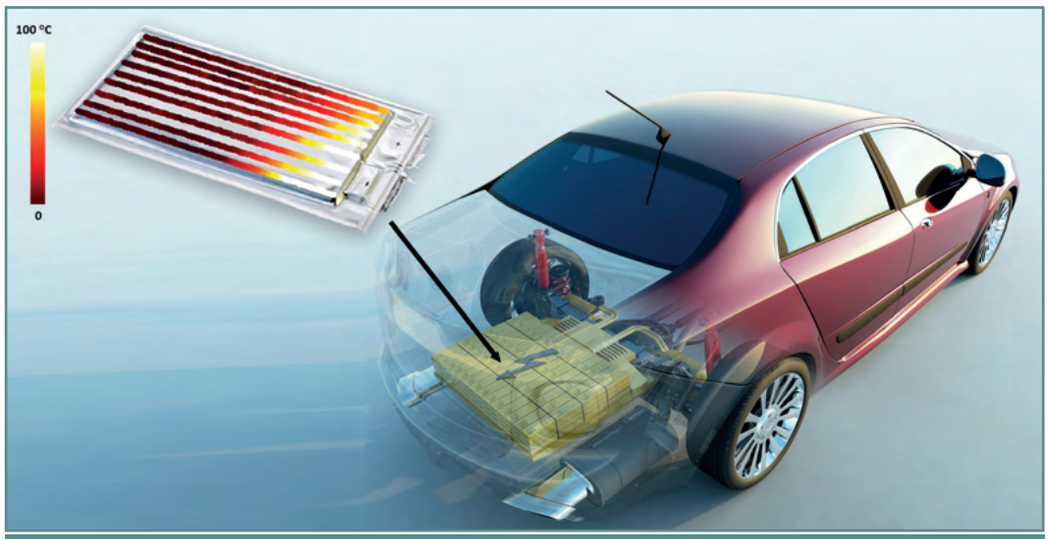
Fiber optic sensing

Distributed fiber optic sensing to determine strain and temperature can be used to streamline battery research in modern EV design, speeding new technologies to market

For decades to come, environmental concerns will be a driving force in transforming both power generation and transportation infrastructures toward a more sustainable footprint. Electric power generation capacity is shifting to a greater percentage of renewable resources that provide the power to recharge hybrid and electric vehicles.

It is widely accepted that the limiting factor preventing a faster conversion to hybrid and electric vehicles is battery technology. While great progress has been made in expanding storage capacity and lowering cost, batteries remain a focal point of research and development in the electric and hybrid vehicle industry. Engineers are faced with the difficult challenge of greatly improving performance and reliability while maintaining operational safety. Improvements in battery technology are often made incrementally and are the result of a continuous process of design iteration and testing. The test environment for electric vehicle batteries is extremely challenging, and obtaining high-quality test data for temperature distribution under all operating conditions is essential.

Luna Innovations of Roanoke, Virginia, has developed an advanced strain and temperature measurement system that uses unaltered fiber optic cable as a distributed sensor. When illuminated with laser light, fiber optic cables have the equivalent of an optical fingerprint. This fingerprint changes in a predictable and repeatable way in response to changes in strain and temperature. When installed inside a battery, a single fiber forms a sensor that replicates a virtually continuous line of discrete temperature sensors with millimeter spacing between sensing points.



The Luna Optical Distributed Sensor Interrogator (ODiSI) (below) is an advanced strain and temperature measurement system helping engineers to overcome energy storage system design challenges for electric and hybrid automotive applications (above)

Unlike conventional temperature sensors, distributed fiber optic sensors are corrosion-resistant, immune to electromagnetic interference (EMI) and inherently dielectric. Fiber sensors can be embedded in the battery and placed directly in contact with the battery's cells without causing short circuits. A single fiber cable can provide an accurate and complete picture of the temperature distribution in the battery under all operating modes. As such, temperature data can be displayed versus length, or individual points can be selected anywhere along the fiber sensor and displayed versus time.

The Luna system uses standard, unaltered fiber cable – as a result, sensor location, measurement density and gauge length can all be changed dynamically through software. This reconfiguration of the distributed fiber optic sensor can be done in minutes, as opposed to the hours it would take to re-instrument a battery with conventional sensors.

The utility of the Luna distributed fiber optic sensing system goes beyond the thermal evaluation of batteries and can be used in a number of other challenging test conditions related to hybrid and electric vehicle design. Fiber optic cables, given their dielectric nature and inherent EMI immunity, perfectly measure the temperature of a vehicle's inverter and the many printed circuit boards used in an electric vehicle system. Additionally, the ability to measure strain can be used to determine the stresses within key structural components of a hybrid or electric vehicle.

The design of battery systems for hybrid and electric vehicles is complex due to the high number of variables involved and the need to make assumptions about the aggregate operating conditions of vehicles in service. High-resolution data provided by Luna's distributed fiber optic sensing system allows engineers to converge on solutions faster and speed the introduction of new products into the market with higher degrees of confidence for long-term reliable operation. Luna's distributed sensing system is 21st century technology specifically developed to help engineers overcome challenging design problems in the energy storage and automotive industries.

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Advanced testing facilities

Located in northern France, CRITT M2A is an independent research and development center currently specializing in four main testing activities: NVH, engines, turbochargers and electrical testing.

In order to apply an environmental policy based on the development of energy solutions, CRITT M2A made the decision to open an electrical testing center. This new department enables characterization of the electrical and thermal behavior of batteries used in the automotive, railway and aeronautic industries.

By September 2015, 96 single battery cells and five battery module test systems will be set up and operational. These additional facilities will perform different cycles in climatic controlled environments. In addition to high performance in terms of dynamics and precision, the company's test systems incorporate specific features such as ripple simulation, battery management system communication and impedance spectroscopy measurements.

The next phase of the electrical testing center is already underway, and will include two battery pack test systems, one electric motor test bench and an additional turbocharger test bench dedicated to e-turbo applications.

Thanks to its extensive testing capabilities and expert support, CRITT M2A offers a flexible testing structure, able to be adapted to specific customer requests, and carried out with the highest levels of confidentiality.

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INQUIRY NO. 542

Boosting power density in semiconductor modules

Electric traction inverters for automotive applications face an ongoing trend for mating power electronic components and mechanical assemblies. This can include the integration of inverter components with electric machines, transaxles, gear assemblies or transmission parts. The merging of both worlds must be supported by the development of compact and robust multichip IGBT power modules that offer the highest power densities.

The more common electric motor designs in the automotive industry do little to compromise in order to accommodate heat-sensitive electronics. On the contrary in fact, it is expected that semiconductor assemblies are adapted to the mechanical and thermal environment of an engine compartment.

Danfoss proposes a new concept for a compact and directly liquid-cooled power module which is suited for use in automotive traction applications. It comprises a newly developed high-performance liquid-cooling system combined with the most recent bonding and joining technology, encapsulated in a hard-resin package using a robust epoxy compound. The resulting design is capable of meeting even the most stringent automotive traction inverter requirements. Prototypes were manufactured and tested with regard to electrical, thermal and lifetime characteristics, and have subsequently proven their flexibility and performance.

Power loss measurements, supported by simulations and theoretical research, have proven that ~20% more current can be drawn from the same amount of semiconductor surface by using the proposed approach, compared with standard bonding processes and cooling.

The concept is designed for the increased junction temperature requirements that are expected in future generations of semiconductors. The new Danfoss technology line-up is ready for series supply at short notice. It is manufactured in a state-of-the-art ISO/TS 16949-certified production site.

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INQUIRY NO. 543

Permanently engaged starter system

To improve the system behavior and the starting performance of the internal combustion engine in combination with a stop/start system, BorgWarner is developing a compact permanently engaged starter system (PES) with a dry-running one-way clutch that provides easy integration into an existing powertrain. In conventional stop/start applications with a pinion shift starter and the starter ring gear permanently fixed to the crankshaft, it is not possible to restart the engine – especially under its self-load speed – until the crankshaft is rotating at very low speeds or has completely stopped.

The PES system from BorgWarner provides the same performance as belt-driven systems but has the simplicity of a pinion starter. As a plug-and-play application, it is located in the dry environment between the engine and the transmission. For this reason, there are high demands regarding the resistance of the system against corrosion and contamination. The PES system can be integrated into a flexplate or flywheel depending on the powertrain; it has interfaces to crankshaft, crankcase and starting device. It replaces the original starter ring gear and uses existing interfaces with only minor modifications to the powertrain.

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INQUIRY NO. 544

In-wheel propulsion systems

The success of cars such as the Tesla S and Nissan Leaf shows the auto industry embracing electric drives, but the most radical changes are yet to conquer the market.

In the mission statement of Elaphe Propulsion Technologies, the emphasis is on using innovation to advance users' everyday travel. The result is a light, powerful in-wheel drive that uses no gears, leaves more space for passengers and luggage, and uses advanced torque vectoring to keep the car safely on its way. Elaphe's motors deliver extremely high torque density, but weight saving has a hidden advantage –material costs are brought down by squeezing 650Nm out of every 10kg of active material – a cost that must be kept down if the economics are to play out.

Reducing the complexity and number of the parts is one of the main development goals of Elaphe's research and development team. Compatibility with existing parts is one of the intriguing things about Elaphe solutions – the use of off-the-shelf bearings, brakes and rims is a huge advantage during development and helps reduce total cost of ownership of the system.

Throughout development, Elaphe has strived to be involved in industrial vehicle development projects, and the bottom line is more than 10 different, fully functional vehicles – used on road, gravel, mud and snow – where Elaphe's integration, know-how and solutions have been developed.

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INQUIRY NO. 545

Range extender platform

KYMCO launched its K-REX range extender platform at EVS28 with K-REX-11, a production-ready 11kW unit developed for the KYMCO UXV hybrid farm utility vehicle. KYMCO is already supplying a range extender engine derived from a scooter platform to a European OEM. A similar option is available for range extenders derived from KYMCO's 3-50kW engine range.

K-REX-11 features a starter generator directly coupled to a 474cc single-cylinder engine with twin balance shafts and separate engine/generator cooling circuits. The engine is controlled by an ECU with an electronic throttle body that enables CANbus communication to the VCU. The combustion system has been optimized for selected operating points achieving around 235g/kWh BSFC. Emissions control is achieved with a close-coupled three-way catalyst.

The UXV hybrid program positions KYMCO as a leading range extender supplier. The K-REX platform can be configured to provide up to 15kW as a single-cylinder unit and up to 30kW as a twin.

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INQUIRY NO. 546

Reliable and compact onboard vehicle power

A new vehicle-based power inverter that is lighter, smaller, cheaper and more efficient is changing the game for exportable power capability in medium to heavy trucks. The technology is designed for rugged commercial and military vehicles where high ambient operating temperatures and extreme conditions can reduce the performance and reliability of other power inverters.

DRS Technologies recognized the market needs and capability gaps that were proving frustrating to operators of these systems and developed the 2kW Export Power Vehicle Inverter that converts 28V DC battery power to clean 120V AC power.

The 2kW Export Power Vehicle Inverter was engineered in order to be environmentally sealed and convection-cooled, eliminating the need for costly and bulky water-cooled inverters. The inverter can be installed in a number of different locations on the vehicle, including the undercarriage, giving integrators numerous installation options. The high durability means that the inverter can be submerged in water up to one meter, and protects it from solid objects, dust intrusion and extreme weather and environmental conditions.

To ensure the 2kW inverter reaches the highest possible levels of efficiency, DRS makes use of advanced gallium nitride transistors, which operate faster and with lower heat and reduced power losses. The result is a smaller, lighter, lower cost, and more efficient power inverter than those currently available anywhere in the marketplace.

DRS's 2kW Export Power Vehicle Inverter was designed to satisfy highly reliable and rugged vehicle requirements and follows a strong lineage of DRS state-of-the-art innovation and experience that meets the sophisticated power needs of its customers.

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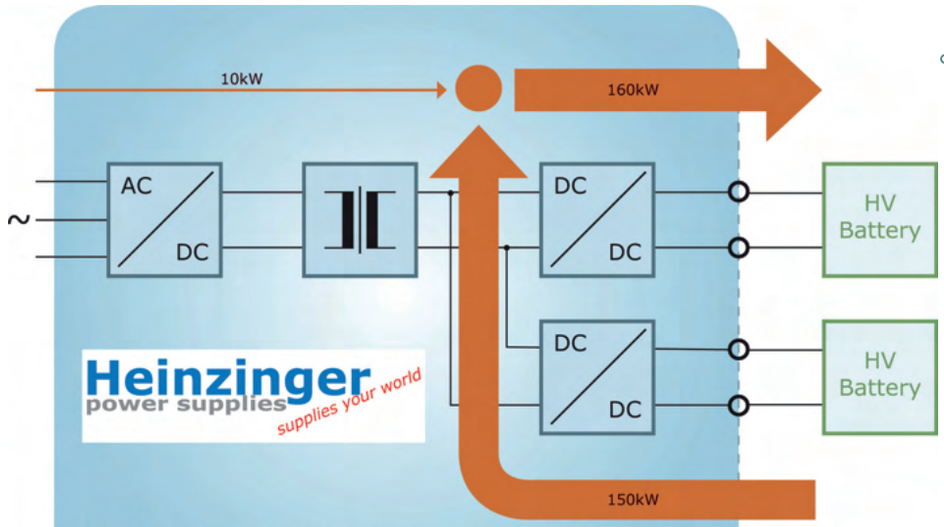
INQUIRY NO. 547

Energy recovery systems

With its ERS series, Heinzinger offers a bidirectional, highly dynamic test bench system with active energy recovery. The units are available as off-the-shelf products from 50kW up to 250kW. It is possible to scale up the power by combining units. With its broad output voltage range, the ERS series perfectly supports test procedures for so-called 'smart hybridization' at 48V DC, as well as test procedures for drivetrain applications up to 1,200V DC along the supply chain.

It is possible to upgrade the system to a two-channel version with independent control of the output channels. Making use of a two-channel version grants additional added value. With this configuration, it is possible to balance the energy in the output circuits, with only losses having to be taken from the grid. Each output channel is designed to handle up to 250kW. It is therefore possible to handle up to 250kW in the output circuits of a 120kW or 160kW unit. Another highlight of the two-channel version is the ability to increase the power for one output channel. With intelligent regulation of the test run, the output power of one of the channels can even exceed the maximum unit power. It is possible, for example, to run 250kW in one output channel of a two-channel version of a 120kW unit.



Heinzinger ERS series energy balancing between the output channels

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INQUIRY NO. 548

Electric and hybrid vehicle components and connector assemblies

Frost EV Parts is a supplier of components and connector assemblies for electric and hybrid vehicle projects. The company holds stock of all items it supplies, in order to offer delivery within 48 hours. Orders can be placed online on the company's website, where there is a wealth of technical information on the products it supplies. Visitors to the website can download PDF specification sheets and drawings to aid their designs, and designers can choose products knowing that there will be continued availability. There is no minimum order quantity and cable is cut to size, so customers do not have to purchase a complete reel.

Frost EV Parts works closely with market leaders including Kostal, Coroplast, Tyco Electronics and Delphi. The company is approved to manufacture and supply complete high-voltage connector and cable harnesses, which are assembled and tested according to the manufacturer's processes – once again, with no minimum order quantity. Frost EV Parts offers full technical support, advising on harness design and product choice.

Frost has designed the first ever high-voltage cable assembly builder, which is available for use on the company's website. It is a very user-friendly program, which enables the user to design their connector and cable assembly online. Options of connectors and cables are given and the program only allows compatible choices. The assembly is costed and given a unique part number, which can be ordered online and delivered within five to seven days.

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INQUIRY NO. 549

Bus powertrain technology

Almott is a developer and manufacturer of a variety of products primarily designed for use in the automotive vehicle, bus and transit bus markets. The highly technological products are machined and assembled in order to improve application efficiency and decrease emissions and operational costs. Products available from Almott include: brushless permanent magnet synchronous motors, liquid- and air-cooled and designed to be used in electric and hybrid vehicle applications up to 130kW; brushless air-cooled alternators up to 750A, with voltages of 12-48V; and motor alternators up to 20kW, designed for 48V hybrid eco-drive systems. The company's products will be on display for visitors to the Busworld Kortrijk Exhibition held from October 16-21, 2015.

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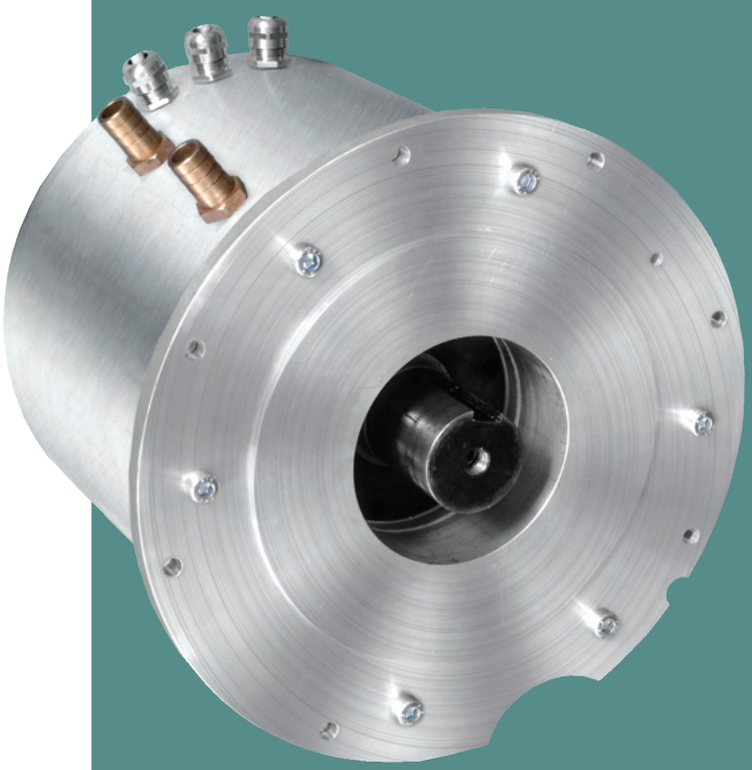

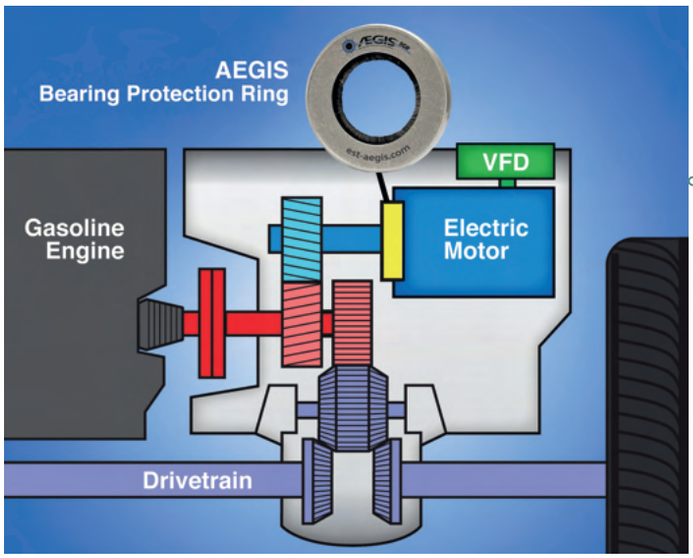

Shaft grounding rings to protect traction motor bearings

Electric and hybrid vehicles are prone to problems that result from variable frequency drive (VFD)/ inverter control of traction motors. The heart of every electric vehicle is an AC three-phase traction motor/generator. Yet the batteries that power these motors provide direct current. So, inverters are needed to convert DC to AC. But VFDs induce voltages (on the shafts of traction motors) that can discharge through motor bearings, destroying them through electrical discharge machining and creating electromagnetic interference (EMI or RFI) in vehicle systems.

Because inverter-induced voltages follow the path of least resistance – wherever it leads – insulated bearings and other partial mitigation measures merely shift damage to other components such as transmission bearings and gears, wheel bearings, or even the bearings of a hybrid's gasoline engine.

Proven effective in over a million installations worldwide, Aegis Shaft Grounding Rings channel damaging inverter-induced shaft currents away from bearings safely to ground, protecting not only AC traction motors, but equipment and systems connected to them.

In addition, by eliminating stray currents that produce electrical interference, Aegis rings can also eliminate EMI/RFI problems with onboard computer controls, wireless sensors, AM/FM radio reception, Bluetooth communications, and personal electronic devices. A white paper, *Protecting Electric Vehicles from Bearing Damage and EMI/ RFI*, is available from Electro Static Technology's website.

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INQUIRY NO. 551

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Considering battery pricing

Batteries are a popular topic for industry debate these days, but when selecting the right one, price is certainly not the only criterion. Belgian lithium-ion battery specialist Trineuron is especially keen for customers to avoid the most common pitfalls when comparing quotations.

It is vital to ensure that the quotes being compared meet the application's specifications. It is common to discover that not all of them do. And when the quotes exceed the specs, does that really add value?

Pricing is easy to compare, but attention should be paid to the specific needs of the application. If energy is required, then it's important to consider the cost per kWh, but if power is more important to the user, attention should be given to cost per kW.

Some batteries will last for 250 cycles, while others will reach 25,000. This should be kept in mind when comparing pricing, and cost should be calculated per cycle, so it's possible to determine what a battery will cost per cycle or per day.

Lifetime specifications, if tested to the same conditions, are a good way of comparing technologies. These should not, however, be used to calculate the expected life in a particular application. Depth of discharge, temperature, power, maintenance, and so on, are all factors with a huge impact on life.

Most batteries suffer when used down to the last electron. The usable energy varies between 60% and 100%.

Battery specialists sometimes get a bit overexcited when it comes to their own technology. Consider which guarantees are being offered against the risks of premature failure.

It is also important to consider all service and battery replacement costs to determine total cost of ownership.

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INQUIRY NO. 552

Hall sensor technology in automotive applications

Hall-effect sensors are widely used in automotive contactless current sensing applications, especially in high-power applications where both power dissipation and voltage isolation are critical. In order to measure the magnetic flux generated around a current conductor, the structure depicted here is conventionally used. The Hall sensor is placed in a ferromagnetic core air gap and generates a voltage drop proportional to the primary current. The Hall voltage is then amplified and adjusted to have a desired transfer curve, depending on the current range.

These adjustments are typically done at room temperature once mounted in the application, but the thermal stability has to be guaranteed at supplier factory trimming. With Six Sigma offset drifts and gain drifts totaling <1.5% over -40°C to 150°C, Melexis is at the forefront of the industry.

In addition to thermal drifts, the other dominant parameter is variation in sensor accuracy over lifetime. This can be induced by mechanical stress (originating from various sources such as soldering, over-molding, temperature cycling and humidity) and can reach up to 8% if no measures are taken to keep it under control. The root of this variation resides in the piezo-Hall effect, making the Hall plate sensitive to stress to a second order. As it is impossible to avoid all sources of stress, Melexis has developed, validated and deployed a patented stress sensor technology, which brings lifetime drift to <1%. The technology is integrated in the latest MLX91208 and MLX91209 products, which are also fully AEC-Q100 qualified.

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INQUIRY NO. 553

Race-tested springs in production EV/HEV applications

Designers of consumer electric and hybrid vehicles are taking a page from the racing playbook, and using Bal Spring canted coil springs to improve vehicle efficiency, performance and reliability.

The Bal Spring, offered by Bal Seal Engineering, mechanically fastens, conducts electricity, and shields sensitive electronics from the harmful effects of EMI/RFI. The spring enjoyed early adoption in high-end Formula 1 and Formula E platforms and has gained use in a broad range of advanced production EV/HEV applications, including power management, regenerative braking, steering, infotainment, and driver information systems.

The Bal Spring effectively manages high, medium and low current with minimal heat rise. The spring's highly conductive properties and unique design enable it to provide superior shielding against EMI/RFI, particularly in high-frequency, small-package applications. Its independent coils compensate for misalignment and surface irregularities, ensuring optimal charging efficiency and current transmission – even under shock and vibration.

When used in mechanical fastening applications, the Bal Spring latches, locks or holds with forces that can be precisely controlled to meet virtually any connection requirement. The spring resists compression set, and can withstand thousands of insertion and removal cycles.

Bal Seal Engineering specializes in helping OEMs in developing performance breakthroughs. The company's products, which also include fluid seals and electrical contacts, employ Bal Spring canted coil spring technology.

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INQUIRY NO. 554

Performance power cables for harsh operating environments

Vehicle power and control systems continue to grow in complexity, and must function in harsh environments and under a range of stresses. It is essential to have power cables that can readily fit within tight spaces and can perform reliably when subjected to continual vibration, extreme temperature variations, and hostile fluids. To address these issues, Champlain Cable, a leading manufacturer of high-voltage power cables, has developed the EXRAD HVFX line of cable products.

Backed by Champlain Cable's 60 years of experience manufacturing high-performance wire and cable, EXRAD HVFX cables are designed to withstand and perform in the harsh environments in which these systems operate. Not only are these cables rugged, they also offer cost and weight savings due to their excellent thermal capabilities, higher ampacity, longer life and lighter weight. Built with high tear strength and abrasion resistance, these cables have a tight bend radius, making them flexible enough for confined spaces. And, with Champlain Cable's cutting-edge irradiation cross-link technology, these cables have high dielectric strength and provide superb fluid resistance with no outgassing (resulting in no impact on electronics or inner components).

Tested in accordance with SAE1654 and rated at 1,000V from 150°C -200°C in accordance with ISO6722, these high-voltage cables are available in shielded and unshielded configurations with either AWG or ISO metric size conductors.

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INQUIRY NO. 555

Wound component electrical safety test analyzer technology

Chroma has announced the industry's first wound component electrical safety test (EST) analyzer that combines impulse winding, AC/DC hipot, insulation resistance, and DC resistance test measurement functions.

Chroma's 19036 Wound Component EST Analyzer has 5kV AC/6kV DC high-voltage output, 5kV insulation resistance, 6kV layer short impulse voltage, and four-wire DC resistance measurement with a maximum output of up to 40 channels. Capable of outputting and measuring AC 100mA/DC 20mA, Chroma's 19036 analyzer is suitable for testing to high-power motor standards such as UL 1004-1. The instrument's 500VA design is also compliant with the output power requirements of EC/UL. Wound component applications include electric vehicle motors, servomotors, ascension motors, transformers and solenoid valves.

Chroma's 19036 Wound Component EST Analyzer impulse winding test imposes a non-destructive, high speed and low-energy voltage impulse on the device under test for analysis and comparison. The purpose of impulse winding testing is to discover potential defects, such as layer short, corona or partial discharge – flaws which are usually difficult to find in wound components during early phases of design and production. Analysis of the impulse test can be determined by area size, differential area, flutter value or the Laplacian method.

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Power analyzer capability for three-phase motor drives

Teledyne LeCroy has announced the MDA800 Series of motor drive analyzers (MDAs), which combine three-phase power analyzer static (steady-state) calculations, unique dynamic three-phase power and mechanical motor analysis capabilities, and high bandwidth (1GHz) embedded control system debug, in a single instrument.

The MDAs are based on the HDO8000 oscilloscope platform and have eight input channels as standard (with 16 digital channels available as an option) with 12bit resolution, 2.5GS/s sample rate, up to 1GHz bandwidth and up to 250Mpts/Ch acquisition memory. A complete set of serial trigger/decode and analysis software options, and a wide variety of voltage and current probes, are available to use with the MDAs.

The MDAs will be used by designers and manufacturers of motors, motor drives, variable frequency drives, variable speed drives, industrial automation and motion control equipment manufacturers. Design engineers who integrate motors into their designs (vehicles, power tools, appliances, elevators, fans, blowers, compressors, pumps, and so on) will utilize the product to validate proprietary controls and complete drive system designs. For those who design three-phase systems without motors, the MDAs can be used for basic three-phase power system analysis and debug as well.

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INQUIRY NO. 557

Advanced ultracapacitors

Ioxus, a leader in ultracapacitor technology, has launched its flagship product, the iMOD X-Series line – a single design that comprises 23 modules ranging in voltage from 16V-128V. Three cell sizes are offered – 1200F, 2000F, and 3000F – enabling customers to match their ultracapacitor requirements to these new products. Customers will never need to order a custom module again; all X-Series modules are standard products.

The X-Series product line is UL-810A-rated, ISO16750-3 4.2.2 shock-rated, and ISO16750-3 Table 12 vibration-rated, and was designed with the highest shock and vibration specifications in mind, and features industry-leading mechanical design which incorporates built-in thermal management and a 5kV AC hipot test rating. The housing incorporates standardized T-Slot mounting guides on three sides, in order to allow for any configuration in mounting with standard off-the-shelf hardware. Front-facing terminals allow for the easiest connection when configuring multiple modules; this eliminates the need for heavy, long cables, which can be difficult to manage and can cause safety issues. The modules are also designed for mounting in a standard rack, which has been used in the field to reduce system-level space requirements by up to 60% over competing products, and has been used to date to deliver up to 40MW in a single installation. Any of these modules can be ordered with CAN communications to meet customers' specific requirements.

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INQUIRY NO. 559

Parylene conformal coatings for protection of automotive electronics and components

Modern automobile designs continue to advance in terms of their electronic content – in both quantity and sophistication. Offering excellent moisture, chemical and dielectric barrier capabilities, superior thermal and UV stability, and a low coefficient of friction, Parylene conformal coatings have provided automotive electronics and components with a level of protection that remains unmatched by many of today's conformal coating materials.

Parylene conformal coatings are applied in a vapor deposition polymerization process. Because there is no liquid phase in this process, there are no subsequent meniscus, pooling or bridging effects; thus dielectric properties are never compromised. The molecular 'growth' of Parylene coatings also ensures not only an even, conformal coating at the thickness specified by the manufacturer in question, but because Parylene is formed from a gas, it also penetrates into every crevice, regardless of how seemingly inaccessible, ensuring complete encapsulation of the substrate without blocking small openings. Parylene is typically applied in thicknesses ranging from 500 angstroms to 75 microns, and as a result is extremely lightweight, offering superior levels of protection, but without the addition of perceptible dimension or mass to delicate components.

Parylene coatings are RoHS- and REACH-compliant and have proven to provide metallic whisker mitigation in lead-free solder applications. Parylenes are ideal for protecting circuit boards, sensors, MEMS, LEDs, elastomers and other surfaces and components that need reliable, long-life performance in harsh automotive environments.

Additional information on the properties and benefits of Parylene conformal coatings is available from industry leader Specialty Coating Systems.

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INQUIRY NO. 558

Sensing angular shaft position for optimization in electrical powertrains

The Electrical Motor Position Sensor (EMPOS) addresses the control needs of synchronous electric motors used to drive all-electric and hybrid vehicles. The sensor accurately measures the angular position of the rotating shaft to optimize control of the motor inverter. EMPOS offers significant advantages in terms of integration and EMC robustness. Furthermore, it integrates signal processing to deliver the angle in either analog or digital form.

EMPOS is based on inductive eddy-current technology, and features primary and secondary windings printed on a PCB and connected to an ASIC. When a high-frequency AC current is injected into the primary winding, a magnetic field is generated, causing eddy currents to circulate in the teeth of a trigger wheel fixed to the rotor. The sensor then measures the voltages induced in the secondary windings in order to determine the angular position of the toothed wheel.

The sensor components are encapsulated in a sealed package to make them robust with respect to the motor environment. Positional information is delivered to the motor controller in the form of an analog sin/cos or digital angle signal. The sensor provides a compact and cost-effective solution to measure angular positions at very high speeds with a high degree of accuracy. Prototypes are available from EFI Automotive for testing on customer facilities.

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INQUIRY NO. 560

Lithium-ion battery solutions for smart city transport applications

Lithium-ion batteries are a key enabling technology for the new generation of electric or hybrid buses and trucks, which put the emphasis on both optimal performance and reliability. Saft's integrated modular system approach to the industrial scale deployment of Li-ion battery solutions makes electric vehicles a practical reality for even the most demanding smart city applications, thanks to the benefits of high energy density, low weight, and long cycle and calendar life.

A typical example is Saft's Ion'Drive 630V battery system, which delivers the range for electric buses to fulfill their daily travel routines on a single charge. It also supports the high power current experienced during rapid 'opportunity' charging, at bus stops for instance, enabling unlimited driving range.

The compact, lightweight Li-ion battery system makes it possible for a bus to carry the same number of passengers as with a conventional drivetrain. When installed on an electric delivery truck, a Li-ion battery system offers an enhanced payload capacity with silent, pollution-free operation. Integrated control and a battery data communication system also offers the embedded intelligence that enables operators to track the operation of their vehicle fleets in real time.

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Advanced modular inverter for drive systems

The new, breakthrough PD400 inverter from John Deere Electronic Solutions offers a modular approach that enables drive system engineers to build a system configuration that closely matches their application's specific electrification needs.

The modular design approach adds flexibility and cuts costs by merging multiple electronics into a single or dual configuration, and reducing the number of interfaces and connections with its internal bus structure, making it ideal for a wide range of applications with high-voltage, high-power requirements.

Within a single or dual inverter power stage, customers can choose multiple power levels with a maximum peak current of 550A and 400A continuous current from each inverter in a dual configuration. Optional DC/DC converters and brake choppers can also be added for either configuration, and the modular bus capacitor is available in different sizes.

The PD400 has a control card architecture that supports advanced motor control functionality, and is designed to work at maximum efficiency with complete monitoring capabilities to enable control under various operating conditions. The thermal management system is liquid-cooled for robust and reliable performance over the system's life.

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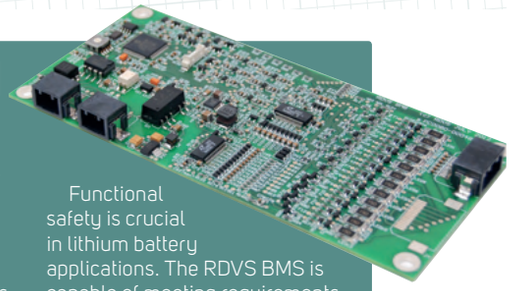
INQUIRY NO. 562

Choosing the best BMS



There are a huge variety of battery management systems (BMSs) available on the market, and understanding which one is right for a particular battery application can be difficult.

A BMS must be adaptable to meet each individual chemistry's requirements, and then must meet the interface requirements of the system it is connected to. A fully customizable BMS platform can eliminate the frustration of a locked-down system.

A complete understanding of the requirements of the whole system, whether it is a vehicle or stationary power application, results in better performing cells and improves battery life and state of health.

Working with the team that designed the application's BMS means questions can be swiftly answered, easing the process for any modifications or re-spins. Trusted support that works on an engineer-to-engineer basis makes all the difference.

Functional safety is crucial in lithium battery applications. The RDVS BMS is capable of meeting requirements for ISO26262 and IEC61508 as required for certain applications. It is extremely important to work with partners who understand how to apply a safety-case to a particular system and who are knowledgeable on a range of functional safety standards.

RDVS has been developing BMSs for the past eight years. The BMS possesses a number of features and design choices – even allowing customers to use their own code for many functions if they prefer – that make it comprehensive for most customers' needs.

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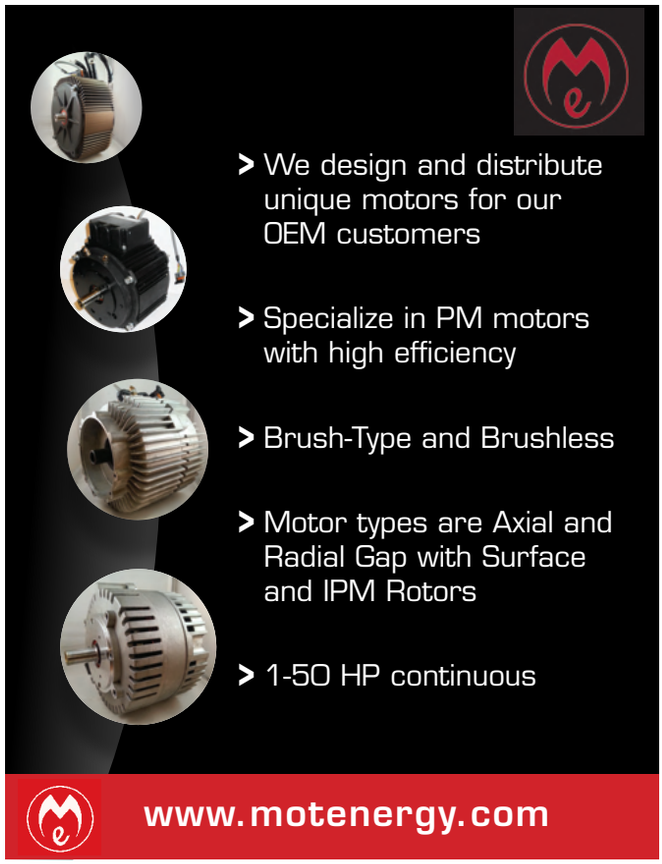

Dynamic, bidirectional power units

In the electric and hybrid vehicle industry, a flexible, reliable and safe energy system can be essential to both the test bench for product development and for use in end-of-line testing.

The ERS series of units from PPM Power meets this requirement by providing a highly dynamic, bidirectional power unit that is capable of transitioning between sync and source modes continuously. In sync mode, the power is transferred back to the AC supply/grid.

The standard ERS power range is from 50-250kW, with a variable output voltage range capability up to 1,000V, both in sync and source modes. The units are available in both single and dual output channels, with outputs floating and fully isolated from input. The input range is standard three-phase AC.

Typical applications for the units include drivetrain testing, DC motor testing and inverter testing. Battery testing and simulation can be carried out using available software. Control of the unit is managed via IR touchscreen panel on the unit, or remotely from a PC or via CANbus.

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INQUIRY NO. 564

The past, present and future for electric vehicles

Electric/electrified vehicles have been a part of the motorway system since the early days of automobile manufacturing, with the inclusion of electric lighting and a horn. Modern automobiles have now become almost totally dependent on the use of electric and electronic components, with software-driven microcontroller systems that monitor and control nearly every aspect of vehicle operation. However, despite the advances in electronic control and functionality, the internal combustion engine has been the vehicle's primary power plant.

Today's ever-increasing need for low- or zero-pollutant emission vehicles with improved fuel efficiency – especially in crowded metropolitan centers – has led to the development of a new class of electric vehicle that either supplements or replaces the internal combustion engine with an electric powerplant and drivetrain. Hybrid vehicles employ a battery bank to power a set of DC motors to drive the wheels and provide power to the electrical systems, as well as a small gasoline engine for supplementary drive power and to recharge the battery bank. Plug-in vehicles employ a high-capacity battery bank to power the all-electric DC drivetrain and electrical system. This battery bank must be periodically recharged at either a public or home-installed charging station.

Hybrid and plug-in vehicles offer significantly better fuel economy levels and emissions ratings in comparison with vehicles that are powered solely by a traditional internal combustion engine, and many governments offer incentives to encourage consumers to convert to EVs. In the USA, general acceptance of EVs will be determined by the consumer and not by government regulations.

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INQUIRY NO. 565

Advanced battery design, development and manufacturing

Johnson Matthey Battery Technologies is an independent provider of battery materials and system design, development, manufacturing and supply for use in demanding industry applications.

The company produces a wide variety of batteries, which are used in products from simple power tools to the most advanced automotive applications. In March 2015, the company reached a significant milestone by manufacturing its one-millionth e-bike battery pack in its Gliwice facility in Poland.

Johnson Matthey Battery Materials has recently completed the acquisition of the materials business of Clariant, a move which makes Johnson Matthey a key supplier of lithium iron phosphate (LFP) cathode materials to cell manufacturers worldwide.

The company continues to recruit staff in key functions in Dundee and Coventry in the UK, and Gliwice.

Coupled with ongoing investment in capital equipment, Johnson Matthey continues to develop its technical expertise and capability to meet the growing demand for high-performance battery systems across a wide range of applications and market sectors.

The company, along with 25 partners, has recently commenced work on the EcoChamps Project, which is part-funded under the Horizon 2020 framework and led by DAF Trucks. The objective of the coordinated project is to achieve efficient, compact, low-weight, robust and cost-effective hybrid powertrains for both passenger cars and commercial vehicles with increased functionality, improved performance, comfort, safety, and emissions below Euro 6, proven under real driving conditions. For its part, Johnson Matthey will design and supply five prototype battery systems for the demonstration vehicles. The aim is to have tested and validated vehicles that are ready for a market introduction between 2020 and 2022.

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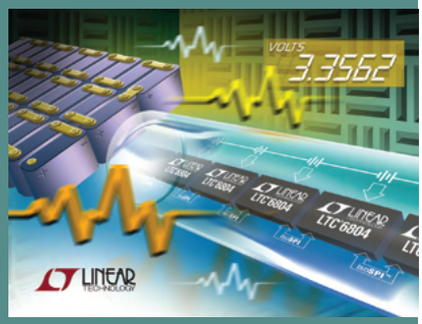
INQUIRY NO. 566

High-voltage battery stack monitoring



A single gallon of gasoline contains more than 36kWh of energy. A typical battery pack in an electric or hybrid electric automobile application contains between 16kWh and 60kWh. Clearly, for a battery system to be competitive against gasoline, it must be able to extract as much energy as possible from each and every cell. This requires careful battery management – the most difficult requirement of which is the precise measurement of every cell's voltage, as each is positioned at different points along a high-voltage string that can be subject to electrical spikes and the effects of electromagnetic interference.

Linear Technology's LTC6804 high-voltage battery stack monitor addresses this challenge with industry-leading measurement accuracy. An LTC6804 is capable of measuring up to 12 series connected battery cells with 16bit resolution and better than 0.04% accuracy. Each LTC6804 can be connected in a daisy chain, allowing many of them to be combined to measure all cells in a long, high-voltage battery pack. Very high measurement accuracy is guaranteed over time, temperature and operating conditions by the inclusion of a precision subsurface Zener voltage reference. Furthermore, the LTC6804 includes a built-in third-order noise filter to eliminate the electrical noise from inverters, actuators, switches and relays. As part of a battery management system, the accuracy and stability of the LTC6804 enables the maximum extraction of energy from an automobile's battery pack.

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INQUIRY NO. 567

Ultracapacitor use in automobile architectures

Evolving automotive architectures are, in turn, creating opportunities for a wide range of ultracapacitor applications, including regenerative braking, stop/start systems, active suspension, board net stabilization, electric turbochargers, and other higher power functions. Maxwell's ultracapacitors are optimized for the demanding automotive environment and are an established product in transportation applications such as hybrid diesel buses and railways.

Ultracapacitors can support batteries in emerging automotive applications, including stop/start systems. Ultracapacitors in stop/start systems provide faster start times and increased battery life. They eliminate voltage sags by enabling separation of the starter from the 12V board net and offer a compact solution with no additional stop/start battery. Navigant Research forecasts that total global sales for stop/start systems will exceed 55 million by 2022, accounting for 54.3% of total vehicle sales. Today, Maxwell ultracapacitors are installed in over one million vehicles with the Continental VSS systems, with further OEM evaluations underway.

Furthermore, ultracapacitors may emerge as a strong technology that is capable of handling the additional current and cycle loads of an electric turbocharger. A significant number of pre-development programs are underway where ultracapacitors and battery technologies such as lithium-ion are evaluated.

Ultracapacitors offer several benefits in active suspension, including outstanding power density and adequate energy density, a wide operating temperature range, long cycle life and calendar life.

The emerging electrification of vehicles, the development of different board net architectures, and increasing power demands will require a rethinking of automotive energy storage strategies, placing ultracapacitor technology in a position to fill the current power gap in automotive platforms.

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INQUIRY NO. 568

Magnetizing permanent magnets in electric motors

Within the architecture of a vehicle, the electric motor is the biggest device containing magnets, which must be magnetized.

Currently among the most commonly utilized technologies are IPM brushless synchronous motors, with magnets embedded deep in the rotor; synchronous reluctance motors, without magnets; and PM synchronous reluctance motors, with ferrite magnets inside the flux barriers, which saturate the iron in the direct axis.

In hybrid motor applications, rare earth magnets are inserted in the main rotor slots along the direct axis and the barriers still lie along the quadrature axis.

Magnetization of these motors is interesting, as the magnets are far from the magnetizing conductors, which are usually fed by a capacitor discharging unit.

Typically, the rule of thumb for an efficient magnetization is to keep the conductors close to the magnets.

Ferrite magnets saturate at 1T, which can be achieved by guiding the magnetic flux along the iron core. However, magnetizing the rotor using the stator windings is not really practical or safe, as the current is very high. Moreover, rare earth magnets require fields higher than 2T, a level unfeasible for the stator windings. A robust magnetization head should be used. Laboratorio Elettrofisico Engineering fixtures are an ideal choice, maximizing flux penetration and minimizing forces.

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LAST WORD

Automated vehicles, such as Google's self-driving car, will have a major impact on the automotive industry

"Autonomous vehicles are a technology revolution that will change everything. They will have a profound impact"

GREG **OFFER**

Dr Gregory Offer is a research fellow at Imperial College London, based in the department of earth science and engineering. His pioneering research focuses on sustainable transportation aspects such as fuel cell, battery and supercapacitor technologies

Google makes headlines quite often with its self-driving cars, but autonomous or automated vehicles are being developed by everyone. In 2012 Bob Lutz, a former vice president at General Motors, said that driverless cars could be ubiquitous in 20 years, and Nissan CEO Carlos Ghosn said they would be in showrooms by 2020. I can believe that, as many cars already have most of the technology required for semi-automation. Features such as cruise control, lane keeping, GPS and speed matching already make self-driving on controlled roads technically possible, so the transition could begin sooner than many think. The main barriers remaining are not related to technology, but rather to cost, legislation, liability and public acceptance.

I predict that as soon as customers experience the potential of automated vehicles, demand for more and better self-driving vehicles will massively exceed expectations, driving innovation and introduction of the technology faster than many anticipate. Why am I so sure? Quite simply because autonomous vehicles are a technology revolution that will change everything. They will have a profound impact not just on our industry, but on the way we live our lives, and are likely to trigger great social change and upheaval.

In a recent research paper, I demonstrated how autonomous vehicles will seriously destabilize the status quo. The ability to increase vehicle use could tip the balance in the EV's favor and mean that the ICE is deposed sooner. Vehicles will be designed to meet a business need rather than the whims of unpredictable individuals, so purchasers will be prepared to pay a higher price upfront and will value low running costs more – something electric vehicles can offer.

Owners who can aggregate vehicles into fleets to provide mobility services on demand will mean range anxiety won't be a factor, and multiple full discharges on a daily basis will maximize the return on the cost of batteries. This will mean fewer vehicles per person, and although demand from the developing world will probably offset this, some automotive companies could resist this transition. I would warn them not to. Is Kodak around to enjoy the growth in demand for photography since the advent of digital cameras and smartphones? Famously not – it failed to invest in new technology and paid the ultimate price.

Of course, automated vehicles are not reliant on EVs, and many of the benefits can be realized with existing powertrains, albeit at a higher cost. The increase in demand for mobility they will bring could reverse the trend for peak oil demand in developed countries, putting serious pressure on oil supply and damaging efforts to reduce greenhouse gas emissions from transportation. Therefore the society-wide benefits of autonomous vehicles, in my opinion, can only be fully realized if they are accompanied by a transition to electric vehicles. Autonomous vehicles could be one of the next major disruptive technology revolutions in our lifetime, with the potential for a huge positive impact on our lives. But only if we decide how we want them to change our lives, and don't leave it to chance.

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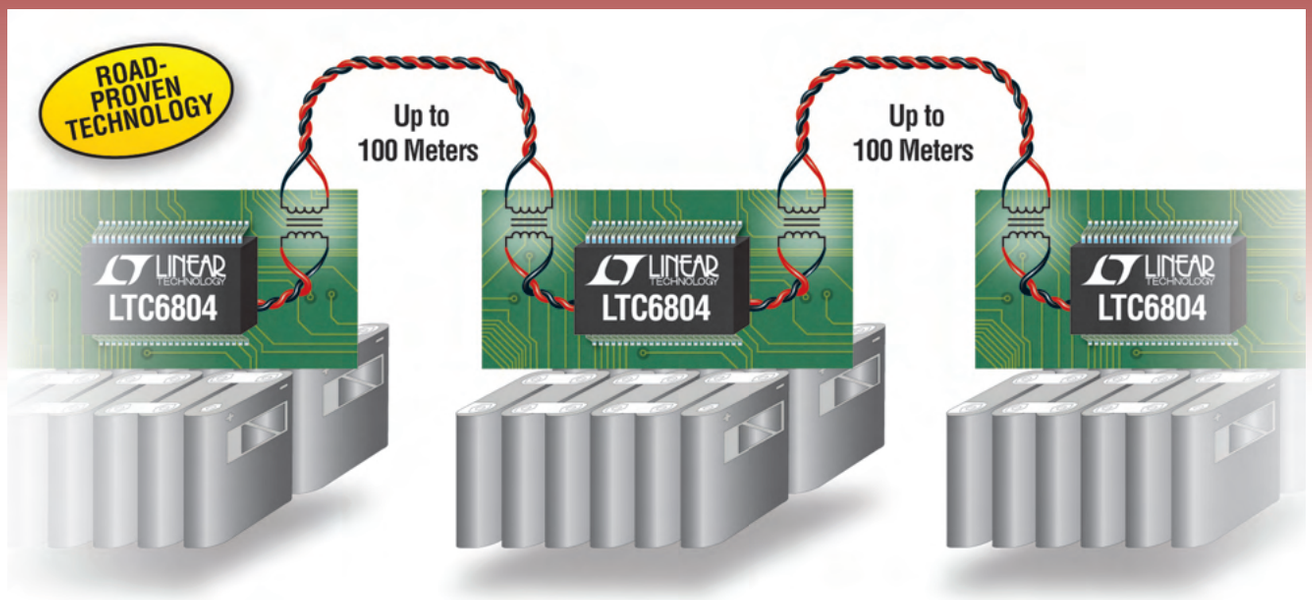

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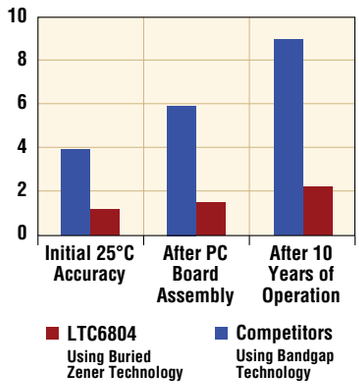
- 4µA Sleep Mode Supply Current
- AEC-Q100
- Engineered for ISO 26262 Compliance

Measurement Error (mV) when Measuring a 3.3V Cell



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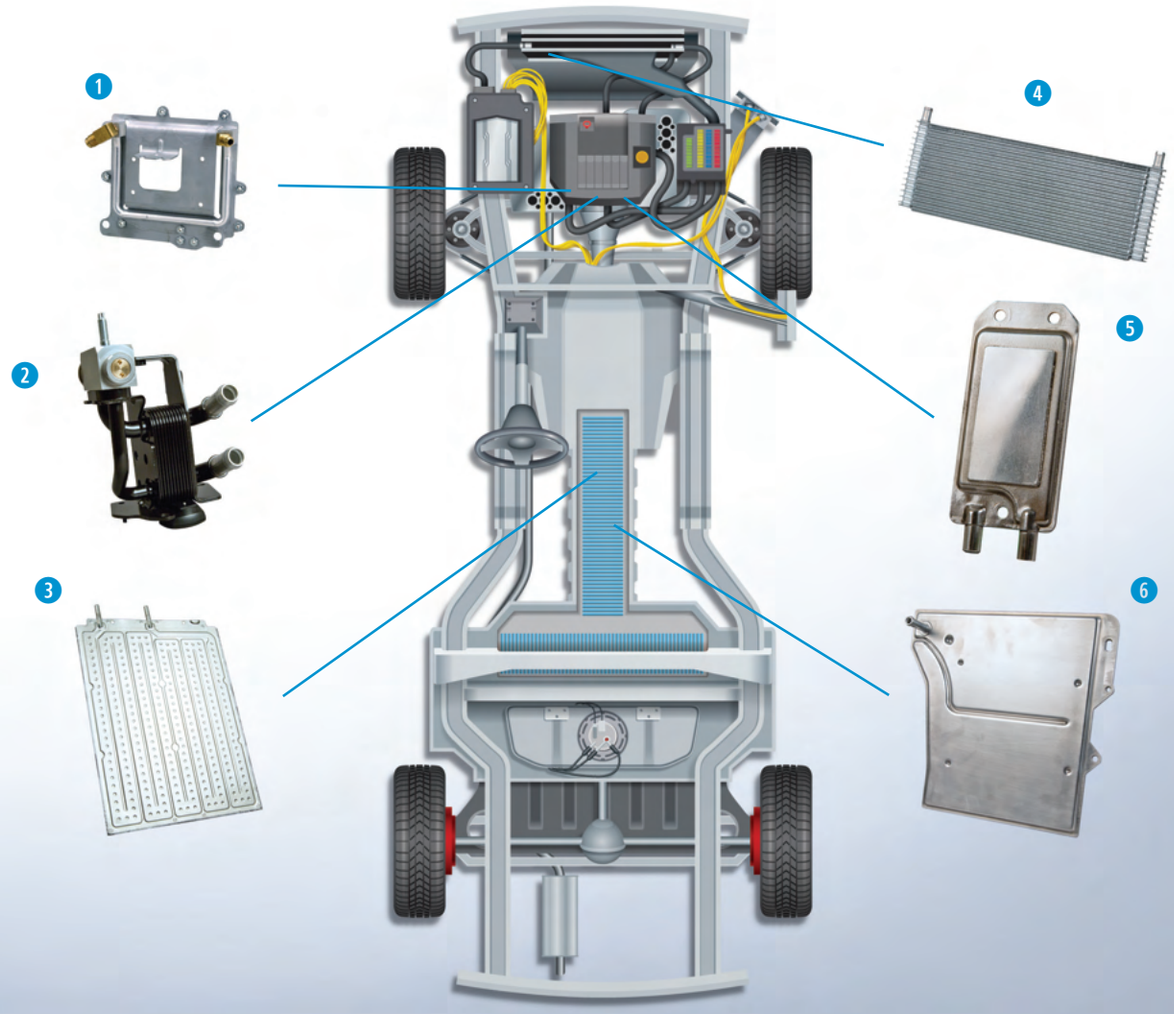

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