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Carlos Tavares, CEO of Groupe PSA

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RQ The task of RQ is to highlight the latest thinking in global engineering and technology in the transportation and clean energy sectors and related industries. We aim to achieve this by presenting an up-to-date mix of news, profiles and interviews with top business leaders, as well as in-depth features on programmes – both from within Ricardo and other leading companies.

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RQ INDUSTRY NEWS

The latest in technology, innovation and sustainability across world industries

Mainstream electrics arrive

Peugeot seized a double initiative at the Geneva show in March: not only did its new 208 steal the limelight from the launch of the latest generation of its arch-rival, the Renault Clio, but Peugeot has come straight out with a fully electric version. Customers for an equivalent battery-powered Renault will have to settle for the Zoe, a model that has been on the market for several years.

Groupe PSA is very much the company of the moment, having boosted sales and profits in 2018 and succeeded in turning around Opel Vauxhall, the perennially loss-making operation acquired from GM in 2017.

Peugeot's e-208 is the first of many pure electric versions of mainstream compact cars, heralding a new level of accessibility for battery power. The outgoing 208 diesel and gasoline featured regularly among Europe's five best-selling nameplates; with the new model, the all-electric e-208 version will complement the conventional powertrains right from launch.

Another announcement to cause some surprise was Porsche's decision to make the next-generation Macan, its best-selling model, exclusively electric. Other potentially market-shifting EVs are waiting in the wings, including the Polestar 2 from Volvo, Daimler's Mercedes EQC, BMW's electric Mini, and a rush of models from the Volkswagen Group and its many brands: notable at the Geneva show were SEAT's el-Born and the Q4 e-tron concept from Audi. VW's Golf-sized ID hatchback still promises to be the first big hitter on the market, reaching showrooms in the final quarter of this year; Audi's e-tron SUV will appear sooner.

Peugeot e-208: volume seller will offer full-electric powertrain right from launch

Declaring that by 2025 fully 100 percent of its European sales would be electrified, Honda presented its e-Prototype, the near-production version of its long-awaited urban electric car. Aimed at the city commuter market, the rear-wheel drive compact has a range of 200 km and a fast charge functionality to provide 80 percent of this in just 30 minutes. Its semi-retro style and sophisticated interior could also see it positioned as the fashionable must-have for green-minded city dwellers: already, Honda has received 15,000 registrations of interest for the new model.

Urban EVs square up

Two leading players hoping for a slice of the urban electric market have presented their visions of next-generation city-centre mobility services. The Minimó, from VW subsidiary SEAT, bears a striking resemblance to the Renault Twizy, and seats its two occupants in tandem on a narrow four-wheeled platform. Citroen's Ami One *(right)* **is more Smart-like in its side-by side seating and is being promoted as an on-demand vehicle "for 5 minutes or 5 years". The Ami One takes just two hours to charge, while the SEAT features a novel battery-swap solution taking just minutes. In addition, SEAT claims its Minimó is prepared for Level 4 autonomy, allowing the vehicle to deliver itself direct to the customer. "The industry is adapting to changes in the way customers view personal transport," said Luca de Meo, president of SEAT. "With the Minimó, the vision of our first product designed to purpose, SEAT is addressing those challenges, combining autonomous driving technologies with electric powertrain systems to create the future of urban mobility."**

All change in commercials sector

As Volvo and Daimler begin customer deliveries of electric trucks, and driverless electric trucks embark on public-road trials, the commercial vehicle sector is under unprecedented pressure from every quarter, especially in Europe.

In February the European authorities finalized the first CO_2 reductions to be applied to the commercial sector: the targets are a 15 percent cut by 2025 and a 30 percent drop by 2030. In addition, 2 percent of each manufacturer's sales must be zero-emission or hydrogen fuelled by 2025. The target for 2030 will be reviewed in 2022.

Environmental NGO Transport & Environment calculates that the 30 percent reduction in truck CO_2 will save transport operators more than €60,000 per vehicle over a five-year period.

Volvo has developed a range of battery-powered construction machines, and the company calculates that a typical electrified construction site will show a 98 percent reduction in carbon emissions over a diesel set-up.

One further pressure on truck makers is the need to implement safer cabs offering the driver direct vision of vulnerable road users such as pedestrians and cyclists.

Get your motor humming

Welcome to the new two-wheeled premium: electric motorcycles on which, to quote Harley-Davidson, the loudest sound you will hear is the racing of your heart. Harley, whose battery-powered LiveWire goes on sale later this year at just under $30,000, is the first premier-league bikemaker to market a serious performance electric model. The LiveWire faces competition from specialists such as Zero and ArcVector, and with a quoted range of just 170 km it may overlap with luxury electric city commuters.

Coal: the heat is on

With one of the world's leading coal producers bowing to investor pressure to accept the Paris Climate Accord and the warnings of the most recent report from the IPCC, a shift in the global energy balance is beginning to become clearer.

Glencore's promise to cap its world coal production follows the decision by fellow exporter Rio Tinto to exit the coal sector, and after much discussion Germany has agreed to phase out coal-fired power stations from its energy mix by 2038. Many countries are already well advanced in ending their reliance on coal for energy production.

A study by the University of Leeds recently calculated there would be a two-thirds chance of the world staying under the IPCC's 1.5 Celsius warming threshold if, at the end of their working lives, all fossil fuel infrastructures such as power plants, factories, vehicles, ships and aircraft were replaced by zero-carbon alternatives.

Global carbon emissions hit a record high in 2018, though investment in renewable energy appears to be falling.

NEWS **IN BRIEF**

Highlighting the latest thinking in automotive engineering and technology worldwide

Volvo to limit top speeds

True to its reputation as a world leader in safety, Volvo is to cap the top speeds of all of its cars to 180 km/h from 2020. Accident data from the National Highway and Traffic Safety Administration in the US shows that 25 per cent of all traffic fatalities in the US in 2017 were caused by speeding, said the company. Volvo will also begin to tackle two further safety hazards: driver distraction and intoxication.

IBM reveals quantum computer

One-time global computing superpower IBM has revealed the world's first quantum computer, though in prototype form only. Housed in a giant glass cube at January's Consumer Electronics Show in Las Vegas, the machine represents a long-held dream of the computer industry. Its quantum calculations promise to speed up processing by several orders of magnitude but require elaborate interference shielding and cryogenic helium tanks to keep its elements sufficiently cool.

Ford and VW join forces on vans

Germany's VW and Ford of the US are to collaborate on the development of commercial vans and medium-sized pickups for global markets from 2022. The alliance will drive significant scale and efficiencies, say the companies, and will also take in technologies for autonomous and electric vehicles. This is widely expected to open the door for Ford to use VW's high-volume electric architectures.

AIR Index clears emissions confusion

A new colour-coded rating system promises to make it easier for consumers to make an informed choice between competing models conforming to the same EU standard but delivering different results in on-the-road testing. The AIR Index has already rated over 200 vehicles on its six-colour scale, the assessments taking in all tailpipe emissions from CO_2 to NOx. The AIR Index database can also identify which vehicles are allowed to enter the 14 German cities that have imposed NO_x limits.

The vehicle that walks on all fours

Aiming to tackle not just the last-mile stage in emergency response but also the final metres too, the Hyundai-developed Elevate ultimate mobility vehicle concept is a new take on disaster relief equipment. With its wheels set on four robotic legs, each with five degrees of freedom, the vehicle can drive normally, raise itself to traverse rubble, or even walk over boulders on its legs. It can even walk up steps: this, says Hyundai, could make it a useful inner-city taxi.

Premium rivals pair up

Extending their already-announced partnership in urban mobility car-sharing schemes, BMW and Daimler will also embark on a long-term strategic co-operation to develop and scale future technology more profitably. The co-operation is initially expected to cover autonomous and self-driving vehicles and, say the two CEOs, will speed up innovation and the spread of new technologies.

Global passenger car sales level off

Under the combined pressures of uncertainty in Europe and a slowdown in the dominant Chinese market, world light vehicle sales in 2018 showed a slight fall over 2017, prompting speculation that the market for cars and light trucks may have passed its peak.

A breakdown of the 86 million sales spread across 54 markets shows a slight fall in the sales of cars and light commercials, offset by a small rise in the volume of SUVs. These now account for more than one third of all passenger car registrations, with compact SUVs the most popular sub category. Sales rose for pickups, too, fuelled by growth in Brazil and south-east Asia.

The segment showing the strongest growth of all, albeit off a very low base, was that for electric vehicles. Global BEV sales soared by 74 percent to 1.26 million units, with China, the US and Norway the top markets. Tesla was the top manufacturer, with its new Model 3 firmly in the number one spot. Nissan's Leaf came third.

In terms of markets, Europe and North America stagnated, allowing India to snatch fourth spot ahead of Germany. Brazil and Russia showed growth, too.

The data, compiled by JATO Dynamics, shows the VW Group, Toyota and the Renault-Nissan-Mitsubishi Alliance as the world's leading manufacturers, while among brand names Toyota, Volkswagen, Ford and Honda lead the field, with Nissan in fifth place. The world's best-selling individual model line in 2018 – and the only nameplate to top the million mark – was the Ford F-150 series. The US pickup was followed by the Toyota Corolla, the Honda Civic, the Toyota RAV4 and the Nissan X-Trail, confirming the Toyota RAV as the world's leading SUV nameplate. The highest-placed European-branded model was the Volkswagen Golf, down in seventh place with 732,000 sales - perhaps impacted by the diesel fallout and the expectation of the upcoming eighth-generation model this summer.

Ford F-150 series: global best seller in 2018 and the only model to break the 'one-million unit barrier

Auto show focus returns to EVs

Self-driving and autonomy took a back seat at this year's Geneva show, with electric cars firmly back in the limelight. Close-to-production battery-powered models included the Volvo Polestar 2 (set to do battle with the Tesla Model 3), Honda's cute e-Prototype, Audi's Q4 e-tron – third in line in Audi's electric assault – and SEAT's el-Born, further evidence of the versatility of the Volkswagen Group's MEB platform. Fiat's compact Centoventi EV concept *(left)* **previewed the next-generation Panda and marks the Italian firm's first foray into series-production battery power – and there was a surprise in the elegant shape of Alfa Romeo's Tonale midsize plug-in hybrid SUV. As ever, a lunatic fringe explored the outer limits of power and performance, made easier by the ability of electric powertrains to be simply turned up to the max. Champions, perhaps, were Pininfarina's 1900 hp Battista, along with Rimac's C2, now claiming to hit the 100 km/h mark in 1.97 seconds.**

EU turns the screws on CO_2

After much debate and in the face of dire warnings from the industry lobby, the EU has agreed on a 37.5 percent reduction in fleet average CO_2 emissions by 2030, compared with 2021 levels. The target represents a slight weakening of the 40 percent originally proposed by the European Parliament but is still much tougher than the 30 percent preferred by industry.

The target is made tougher still by the booming popularity of SUVs, which are taller and less aerodynamically efficient than traditional sedans and hatchbacks, and by the rapid move away from diesel. Automakers who fail to deliver the required sales-based corporate average CO_2 emissions will face substantial fines, potentially in the billion-euro range.

Bosch, a supplier of both electric and combustion engine equipment, has said that the new limits cannot be reached with conventional engines alone, and Volkswagen – already the most ambitious in its electrification programme – has conceded it will need to rethink its plans in order to bring in EVs faster and in greater numbers.

Shipping faces clean-up

Under a recent proposal, all ships docking at ports within the EU would have to publish their emissions data. The idea of the scheme, which could also be extended to non-EU shipping, is to make emissions data more transparent and to allow customers to identify the most efficient vessels.

Shipping contributes approximately 3 percent of global CO_2 emissions, with the EU accounting for around one-fifth of that figure. In a roadmap entitled *Decabonizing European Shipping* environmental study group Transport & Environment concludes that battery power, liquid hydrogen and liquified ammonia provide better solutions for reducing shipping emissions than switching to synthetic diesel and methane. Longer voyages could use the renewable hydrogen or ammonia options, each of which require 25 percent greater primary energy, while syndiesel and methane need 50 percent more. Batteries could come into play for shorter trips.

Scotland's Orkney archipelago is working on replacing its diesel ferries with vessels powered by renewable hydrogen. The world's first tidal energy powered hydrolyzer, on the island of Eday, is already splitting water into hydrogen and it is hoped that this fuel will be able to power re-engined ferries from 2021 onwards.

End date set for combustion engine

Volkswagen gave the auto industry cause for thought earlier this year when it stated that its last generation of combustion engines would debut in 2026. The announcement came as part of a massive €80 billion investment programme designed to re-orientate the whole VW Group away from diesel and gasoline to refocus on electric and electrified powertrains. The Group and its many brands now plan to be selling some 3 million EVs by 2025, flooding the market to gain maximum advantage from its heavy financial commitment, its wide spread of models, and tightening emissions standards.

At the core of the strategy lies the Group's dedicated MEB electric platform, easily adaptable for different vehicle lengths, widths and drive arrangements. Volkswagen is to license this architecture [that's been confirmed] to other OEMs, and announced a co-operation with e-mobility start-up e.Go for assembly of the low-volume Buggy, which was unveiled at the Geneva auto show. A likely deal with Ford would further boost scale economies for the MEB toolkit.

Nissan, for its part, has had success in Japan for its e-Power series hybrid engine package for the Note hatchback. The system is fitted to the company's IMQ crossover concept and will appear in Europe in 2022, said corporate vice president Roland de Vries.

VIEWPOINT

How electric power could democratize car design

Martin Tolliday – Ricardo passenger car & motorcycle market sector director

Hispano Suiza, Lagonda, Frazer-Nash, Pininfarina – all glorious and evocative names from the golden age of automotive history, and all suddenly back in the spotlight after decades lying dormant. So too are reimagined classic Minis, Jaguar E-Types and even the very latest Ford Mustang. The connection might appear tenuous, but there is indeed one: the common thread is electricity.

The arrival of electric power into the automotive mainstream has, paradoxically, come to embolden fringe players and total outsiders, too. Not in the sense of rousing them to challenge the major players head on, but because of the qualities inherent in electric power and the way battery vehicles are developed and engineered. No vehicle programme is ever simple, but if that vehicle is an EV it can leapfrog several of the most challenging steps that beset conventionally powered models.

With volts and amps in place of chemically complex hydrocarbon fuels, the EV advocate need never again worry about engine development or emission control systems. E-motors, batteries and control systems are largely commodity items and widely available off the shelf; fine-tuning their power characteristics is the task of a few software engineers rather than teams of engine specialists.

But it is in the realm of packaging that battery power stands to make the most startling difference, promising to democratize the whole process of vehicle creation. Electric motors are compact enough to be placed anywhere, even hidden in the wheels; power electronics can be dispersed, and batteries can be tailor-made to fit almost any spare space available. And aerodynamics receive a major boost, too, with air now flowing through the body as well as around it, and no drag-inducing cooling to worry about.

What this means to the designer is liberation – at last – from the cruel tyranny imposed by that big black lump of an engine, rigidly stuck in a fixed location and forcing the vehicle's external style to conform to those unforgiving hardpoints.

Escaping from those constraints has allowed the wildest imaginations of stylists and ambitious engineers to run riot – initially in the form of outrageous supercar concepts and even more outrageous performance claims. But now, the benefits of battery power are finding a focus in an altogether more serious segment, that of super-luxury sedans. And it is here that Aston Martin is reviving its Lagonda nameplate as a pure-electric luxury car maker; Italian design house Pininfarina promises a similar mix, as does Spain's Hispano Suiza. Most recently, Porsche surprised the establishment by announcing that the next generation of its best-selling model, the Macan SUV, will be electric only.

Electric power has allowed the wildest imaginations of stylists and ambitious engineers to run riot – initially in the form of outrageous supercar concepts and even more outrageous performance claims

Battery power is the perfect solution for this elevated sector. The smooth, silent torque of electric drive is unmatched, and for spectacular headline-grabbing performance the powertrain can simply be dialled up to deliver astonishing acceleration. Range and cost are rarely an issue, either, for large batteries can easily be specified within a top-premium budget.

Most of all, however, electric power is lowering the barriers to entry for smaller brands and start-ups: witness the success of Tesla, the high hopes surrounding E-SUV newcomer Rivian, and the profusion of new Asia-based hopefuls. More variety in automotive design is an enticing prospect, as is the advent of new volume-built e-platforms such as Volkswagen's MEB. Perhaps these electric chassis could pave the way for a renaissance of even more classic names, of personalized design and extravagant belle-époque coachbuilding style.

RQ INTERVIEW

Chasing growth in China and beyond

Groupe PSA CEO **Carlos Tavares** delivered good news to investors in 2018, with ex-GM subsidiary Opel Vauxhall at last turning a profit and worldwide sales up nearly 7 percent. Besides keeping the focus on Opel, Tavares has other tasks ahead of him – notably, managing the transition to low-emission drivetrains and rejuvenating PSA's struggling operations in China. Here, in an interview originally published in *Automotive News Europe*, Tavares explains how he plans to maintain the Group's winning streak

It has been more than a year since PSA bought Opel, and you already have reported profits in the first half of 2018. Are you still in the cost-cutting and restructuring phase?
We are still implementing the [PACE turnaround] plan. The first results are promising, which is a testimony to Opel CEO Michael Lohscheller and his executive team and the Opel employees. There are still a lot of things we need to do to get to the level of operational excellence that we are aiming for. When we deliver on the guidance for 2020, and a 6 percent operating margin, then you can consider that the plan is finished.

Are you at breakeven now in terms of annual production at Opel?
Breakeven is now a six-digit number and not a seven-digit number. That is very positive. The 5 percent profit margin that we announced in the first half was a good result, but we still need to make sure that we have a cost structure that will bring us to recurrent profits in an almost automatic way. We are also still working on improving our sales channel mix. We have gotten rid of the 'toxic' channels in some cases, but it's all about managing the sales mix to maximize the pot of profit, rather than to exclude this or that channel. In some cases, even the toxic channels such as rentals or fleet sales make money.

We have seen some headcount reduction at Opel in the past year. How big is the company now? It had 38,000 employees when PSA bought it. Will that number decline or stabilize?
Based on the decisions we have made, the number of employees is about 32,000 right now. There were reductions in Germany, the UK and some other parts of the world. But at the same time, we need to compare it with the 50,000 jobs that were shed at Opel over the past 20 years [under GM]. Before we took over, more than $19 billion in red ink had accumulated, 50,000 jobs were shed and 2.2 points of European market share were lost. One of the things that is clear is that we do not kick the can down the road – we try to face problems head-on and fix them. If you kick the can down the road, all of a sudden you have two cans, then three cans, and it overwhelms you.

Did you face any unanticipated obstacles during the integration of Opel?
One of the things that was surprising is all the legal packaging that came with the co-determination [union negotiation] process in Germany. That doesn't exist in France. I have done many deals with my French unions – the level of mutual trust is at the point where we don't need papers, we don't need signatures. We just need to agree on the problem to solve to make the company higher-performing and protect employees through the performance of the company. Co-determination works fine in Germany, but it's very technocratic. I don't think it's very helpful in the end, but this is how it is. We are learning.

PSA recently decided to leave Iran, where it has a long history, after the US pulled out of the nuclear accord and reimposed sanctions. Did this come at a financial cost?
Not significantly, because everything was already booked in the first half. In terms of governance and compliance, you can't be in the middle of the road, so we left.

PSA's electrification strategy through 2022 is very clear: plug-in hybrids on midsize and large cars and full-electric options on smaller cars. How will you convince people to buy plug-in hybrids when they have typically come with a very high cost penalty?
I have been repeating like a broken record that sustainable, clean mobility is like organic food: it's more expensive. And it is. But we think that plug-in hybrids bring the best of two worlds, which protects buyers' freedom of movement. The DS 7 Crossback E-Tense has 300 hp; it's outstanding in terms of acceleration and driveability. Then you have 50 km of electric-only range for when you go inside an urban ring road, for example, and want to drive downtown. It even has a blue light on the mirror so from the outside you can see that it's in full-electric mode. It's a really fantastic mobility device, but it will cost about 10,000 to 15,000 euros more than a conventional internal-combustion car. It's the price to pay for this comfort and convenience.

Taking into account plug-in hybrids and full-electric vehicles, will you have any problems meeting the EU's emissions standards that start to take effect in 2020?
We have a corporate CO_2 committee that meets monthly – we are monitoring it very closely. The big gorilla in the room is what is going to be the diesel mix in 2020, because the best tool to reduce emissions is still diesel. It's affordable, it's highly driveable, and it's efficient in terms of CO_2. But with news about forthcoming city bans on diesel, we don't know to what extent the market share will fall by 2020. We have a plan that will let us achieve the targets even if the diesel mix goes down to 10 percent and without using more than 7 percent of the sales mix on full-electric vehicles. You need to limit electric-vehicle sales. If you want to sell 50 percent EVs to meet the CO_2 targets, fine, but you may not have the profitability you are looking for. You also need a very low level of diesel sales to make sure you are not promoting a mix that is above the market level.

What is the status of PSA's recovery in China?
We are not there yet. Some of the improvements we are trying to make with our partners are being countered by the market's volatility, meaning the speed at which the market is evolving. We need to make our partners understand that we need to move faster. It's all about discipline and the way we manage sales and marketing. They are understanding step by step, but it has been difficult.

How so?
How to manage and incentivize a sales network to achieve objectives. Also, one thing that has been neglected has been the brand storytelling. It's not all about throwing money at the problems. It's about being relevant in the way you talk about the brand, and you can't do that if you don't love the brand. It won't work if you are just spreading around money to buy media advertising.

PSA spends less on R&D as a percentage than other European automakers. Are you doing enough to prepare for your future?
If you looked around the Paris auto show we had the DS 3 Crossback, a B-segment premium SUV with a full-electric variant. We had the Peugeot 508 fastback and wagon with plug-in hybrid options. We had the Citroën C5 Aircross, which also offers a plug-in hybrid variant. Then we had concept cars such as the Peugeot E-Legend. There is nothing missing. What is difficult to understand – and this is perhaps the sweet spot of the PSA Group – is that we are much more efficient than many of our competitors.

Why are you the only one getting these results?
We are gaining share and our profitability is above the premium carmakers because we are fighting to gain efficiency and effectiveness every day. Look at the Paris show, for example. In 2014 we spent twice the amount we are spending today. Do you have the feeling that our booth is cheap, that it is low-value and low-quality? No, it's just about being frugal and thoughtful in the way we spend each euro.

How did you reduce costs? Less carpeting, fewer lights?
Fewer press conferences, which are boring [laughs]. It's eight minutes for the ego of the auto executives. Fewer press conferences, more roundtables. We challenge every expense – the catering, the spaces, which are smaller, but we are using them in a better way. Our default position about auto shows is that we don't go. The brand CEOs have to explain why it makes sense to go and what the return on investment will be – then they have to report back and say whether they achieved their objectives.

Automotive alliances have come together and broken apart, such as DaimlerChrysler, and some have succeeded for many years, such as the Renault-Nissan alliance. Will we see more automotive industry consolidation, and is PSA open to another alliance or merger?
We are in a position where we are making significant money and our net debt position is very good, so of course we need to be mindful of any opportunity. Some of these opportunities will come in Europe from what the 2030 CO_2 objectives will be, especially if the target emissions reduction is really out of reach.

So if you are an automaker that doesn't have the technology to meet tougher emissions standards, could you be vulnerable?
Yes, sure, and that is why this is a problem for governments. If you want to fine a company that is not meeting the objectives in a way that brings them to their knees, then guess what happens? That will trigger investor activism, there will be a restructuring. And beyond that, you will have another player coming in that will do even more restructuring. It's about what kind of automotive industry you want to have.

Carlos Tavares, CEO, Groupe PSA
Portuguese-born Tavares joined Renault in 1981, and held a series of engineering roles until moving to Nissan in 2004 and taking responsibility for North American operations in 2009. In 2011 he was appointed COO of the Renault-Nissan Alliance; in 2014 he joined Groupe PSA, becoming CEO the same year.

This article originally appeared in Automotive News Europe. Reprinted with permission, from the December 2018 issue.

Towards a LIFE CYCLE economy

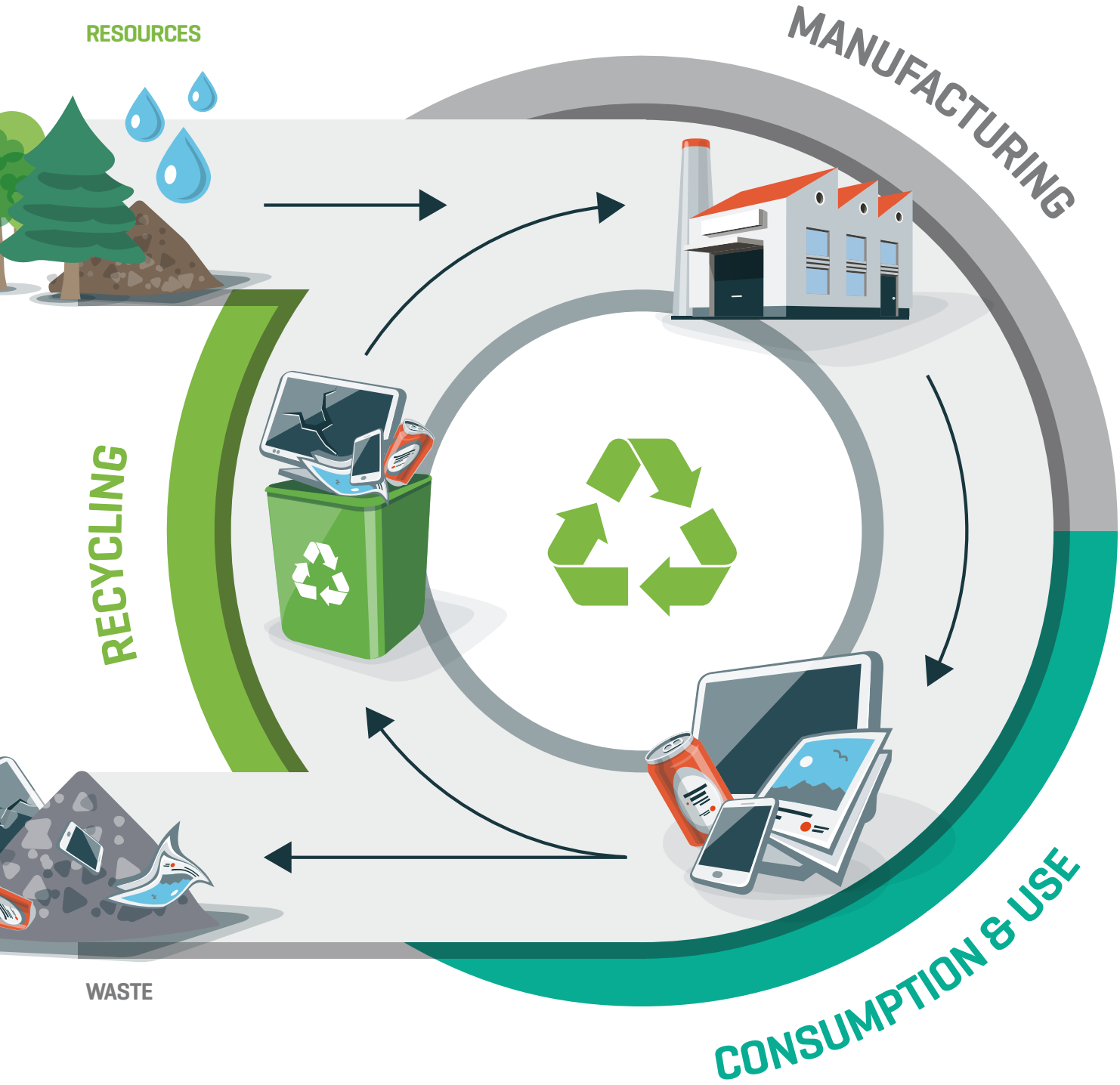
With tightening legislation forcing us to rethink our attitudes to resource consumption, energy use and harmful emissions, a long-established mindset is fast gaining new ground. Life Cycle Assessment (LCA) is a valuable instrument in the planner's toolbox for examining policies, projects and products to assess their environmental impact over their complete lifespan – and, as **Tony Lewin** reports, Ricardo is an important LCA player on the international stage

Should I buy organic vegetables or the ordinary varieties? Shop on the high street or online? Take the plane or the train? Choose a woollen sweater instead of one made of synthetic fibres? Or, raising the budget somewhat, should I replace my car with a standard gasoline model, a hybrid or an electric?

These are everyday dilemmas faced by environmentally conscious consumers in many parts of the world, and they touch on several sensitive issues – ethics, cost, health, convenience and personal politics. On a much broader level the consequences of decisions like these present a dilemma for planners, too. Take the car example: just as the rush to diesel in the past two decades has had air-quality knock-on effects in Europe, so a wholesale migration to electric vehicles might have other unforeseen consequences besides the obvious one of pressure on the electricity supply industry.

These are all areas where the technique of life cycle thinking can be useful in helping both individuals and public policy makers come to a balanced and level-headed decision – one that weighs up the positive and negative impacts of the various alternative policy choices. The assessment can be framed in many different ways: the most familiar of these metrics is money, central to life cycle cost analysis and the total cost of ownership (TCO) calculations that help operators of costly trucks, aircraft and other machinery to decide which vehicle packages will offer them the best return on their investment.

Increasingly, however, life cycle techniques are being employed to examine much broader aspects of issues than just the familiar question of cash. Life cycle assessment (LCA) looks to evaluate the environmental (and sometimes social) impacts of a product or service, across its entire life cycle. A good example is provided by the recent analysis conducted by Ricardo on behalf of the fuels industry



The circular economy model re-uses and upcycles waste materials to minimise the exploitation of primary resources. It contrasts with the conventional linear practice of extract, make, use, dispose

research body Concawe, and reported on in the Q4 issue of RQ last year. The study looked at two contrasting pathways to achieve net-zero greenhouse gas (GHG) emissions from Europe's vehicle fleet by 2050, comparing an all-electric approach with one in which low-carbon liquid fuels play a major part. The report took in a broad spectrum of parameters, from biofuel supply chains to rare-metal resource scarcity, and concluded that a halfway house position, with a more limited role for liquid fuels, could provide the optimum balance between cost, environmental impact and security.

On a more micro level, as we show below, LCA can also flag up important warnings when it comes to engineering choices – such as deciding on the optimum capacity for an electric vehicle's battery.

High-level planning tool

In recent years LCA has taken on a whole extra dimension as a valuable tool to inform governments and legislators and to aid them in key macroeconomic policy decisions, especially when it comes to weighing up the environmental consequences of alternative courses of action under consideration.

LCA is becoming increasingly important in the public sphere, says Simon Gandy, principal consultant in sustainability and LCA knowledge leader at Ricardo Energy & Environment. "If you look at what's going on at the European Commission, they are advocating for all their environmental policy that decisions be taken on a lifecycle basis," he reveals. "And initiatives like the circular economy and trying to make things last longer, a lot of that is predicated on LCA."

Ricardo Energy & Environment (REE) is working with Zero Waste Scotland, for instance, to reduce the nation's waste. "Life cycle thinking underpins a lot of what they do," says Gandy, "and the same is true of the UK Department for Food and

The circular economy

The Ellen MacArthur Foundation describes the concept of the circular economy as "looking beyond the current take-make-waste extractive industrial model, and aiming to redefine growth, focusing on positive society-wide benefits. It entails gradually decoupling economic activity from the consumption of finite resources, and designing waste out of the system. Underpinned by a transition to renewable energy sources, the circular model builds economic, natural, and social capital."

It is based on three principles:

- **Design out waste and pollution**
- **Keep products and materials in use**
- **Regenerate natural systems**

Ricardo is one of the lead participants in a European Commission Joint Research Centre study looking at options to develop a circular economy for EV batteries.

The committee's report, due to be finalized later this year, includes a look at life-cycle impacts of the various value and materials chains. Its interim recommendations state that while in some areas the costs of establishing standardized structures may outweigh the benefits, "the overall range of expected benefits outweighs the identified costs," delivering "positive impacts ranging from industrial growth, job creation and enhanced environmental protection."

Rural Affairs (Defra)."

Businesses in the transportation sector are becoming much more conscious of their public image, notes Nik Hill, also of Ricardo Energy & Environment. "They are already using LCA in a variety of ways, not just for costs but also for environmental impacts. They are very conscious of their corporate responsibilities to minimize the environmental impact of their activities."

While climate impact assessments are central to most of today's analyses, Simon Gandy also notes a broadening of LCA applications: "We're seeing a lot more interest in things other than global warming: companies come to us as they want to think about resource consumption – and I think that is going to be the biggest issue we face in the future."

LCA can also address other issues such as local air quality, pollution, acidification, and ozone depletion, says Gandy. "These are existing issues, but also very important looking into the future."

Life cycle assessment can be used to weigh up potential impacts for many different types of pollution, allowing policymakers to come up with informed decisions

A case in point: EV battery capacity

With almost every international automaker having now woken up to the reality of an electric vehicle future, there is much jockeying between rival brands to offer the longest possible driving range, thus allaying perhaps the greatest perceived concern of potential customers.

But is bigger necessarily better when it comes to car batteries? Does higher capacity equate with a lower overall environmental impact? And how do the various technology choices influence the holistic picture? These are among the many questions being examined in detail by Nik Hill and his team in two significant studies for the European Commission, the first entitled *Circular Economy Perspectives for the Management of Batteries used in Electric Vehicles*, and the second *Determining the Environmental Impacts of Conventional and Alternatively Fuelled Vehicles through Life Cycle Assessment*. Throughout the studies, LCA methodologies are employed to weigh up the multitude of choices available to engineers, policymakers and consumers.

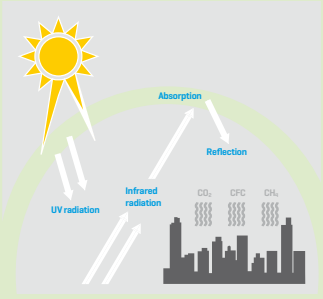
As is often the case in environmental matters, this picture is not as straightforward as it initially appears. Looking across the lifetime of an electric vehicle, and assuming the energy on which it runs is largely renewable, one of the biggest of its environmental impacts typically arises from the manufacture of its battery. The bigger the battery, the higher the vehicle's embedded GHG emissions, the greater its weight and the lower its efficiency – so on the face of it, for drivers who don't cover much daily mileage, a smaller battery might appear better. But, as ever, there are competing factors at work.

A smaller battery, recharged more frequently, could prove a false economy. Though cheaper and lighter and better for short-term economy, it has a higher likelihood of reaching its limit of charge-discharge cycles and, critically, it might need replacement sooner, thus increasing the vehicle's embedded emissions impacts. A larger battery might not need replacement within an average vehicle's lifetime as it would require fewer cycles.

Yet there could be further mitigating factors. What would be the influence of alternative battery chemistries better suited to frequent charge-discharge cycles? And what if the potential second lives (in domestic energy storage, for instance) of ex-automotive batteries are taken into account? Again, the range of factors in the equation is immense, but, as Hill reveals, there may be a sweet spot.

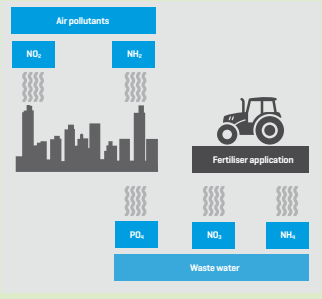
"How these things play out is really complicated," he says. "It's not like saying a smaller battery is better and a big one worse. It may be that if you have a bigger

Environmental impact categories

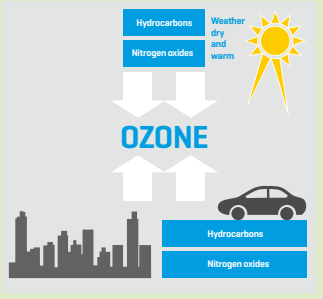


Global Warming Potential (GWP)

Acidification Potential (AP)



Eutrophication Potential (EP)



Photochemical Ozone Creation Potential (POCP)

battery you don't have to replace it. What this illustrates is that you have to be careful. LCA is a brilliant tool, but if you miss or over-simplify certain elements you can end up making the wrong decisions."

It all comes back to thinking more holistically about the issue, argues Jane Patterson, technology strategy consultant at Ricardo Strategic Consulting. "It's not necessarily bigger or smaller," she says. "What matters is to right-size the battery. It's not so much the vehicle segment, either: it comes back to who is the operator, and how they want to use the vehicle. The powertrain solution for someone who has a daily commute of 10 miles each way would be very different to that for the driver who's up and down the motorways all day."

In addition, she points out, other likely future EV applications such as on-demand mobility services will further tax the ingenuity of engineers when it comes to providing the best possible battery configuration for each purpose. And again, LCA can be a very useful tool in exploring the multitude of variables and identifying the more environmentally favourable solutions.

Auto industry perspective

Viewed through the eyes of automotive industry decision makers, the political and regulatory landscapes have become vastly more complex in the last decade. The once-narrow focus on CO_2 and greenhouse gas performance in the laboratory has broadened to take in emissions of a wide spectrum of other pollutants in real-world driving. Nitrogen oxides, hydrocarbons, particulate matter, sulfur, volatile compounds, even noise – so broad is the legislative matrix and so intricate the network of trade-offs and compromises that only a multi-dimensional analysis can make sense of the picture.

Again, says Patterson, LCA techniques

> **"The powertrain solution for someone who has a daily commute of 10 miles each way would be very different to that for the driver who's up and down the motorways all day"**
>
> **Jane Patterson, technology strategy consultant, Ricardo Strategic Consulting**

Whole-life emissions: vehicle types and life cycle stages

Relative contributions of each life cycle stage by vehicle type and powertrain technology

Vehicle Type	Conventional ICE Powertrain Technology				BEV Powertrain Technology			
	Vehicle Production	Well to Tank	Tank to Wheels	End of Life	Vehicle Production	Well to Tank	Tank to Wheels	End of Life
Motorcycle	c.10-30%	c.10-15%	c.60-75%	>5%	c.45-75%	c.25-55%	–	>5%
Passenger Car	c.15-30%	c.10-15%	c.60-70%	>3%	c.20-60%	c.40-60%	–	>3%
Heavy Duty Truck	c.1-3%	>95%		>1%				
Bus	c.15>95%%	>95%		>5%	c.30-40%	c.60-70%	–	>5%

The relative contribution of embedded emissions (from vehicle production and end-of-life to in-use (WTW) is highly dependent on the **vehicle type, lifetime mileage and duty cycle**

The contribution of end-of-life is difficult to quantity since most studies assume high recycle rates and some apply 'credits' for producing recycled material. However the general consensus that its portion of overall life cycle emissions is relatively low (<5%)

Carbon intensity for electricity could be nearly zero if renewable, sustainable electricity is used in the vehicle. This should shift all life cycle environmental burdens to vehicle production and end-of-life

Source: Understanding the life cycle GHG emissions for different vehicle types and powertrain technologies, Ricardo report for LowCVP (2018) (RD18-001581-2

Objective answers to everyday questions

As mentioned on page 10, Life Cycle Assessment (LCA) is a useful tool in making major strategic decisions – but it can be employed to resolve everyday dilemmas, too.

As regards organic or non-organic food, some studies have found that the greatest emissions occur in the growing of the food, not the shipping, while in the field of clothing the wool/synthetic dilemma impacts on many areas – agriculture, petrochemicals, the consumer society and the circular economy. One suggestion is that temperature at which the garment is washed could be another important factor.

Another earlier external study came up with some interesting answers. Tasked with deciding which hand-drying solution was best for public washrooms, LCA experts looked at all the issues involved in the supply of electricity for hot-air hand dryers, and the environmental balance of the alternative solution, the provision of paper towels.

The hand air dryer manufacturers wanted to make the point that their products are better for the environment than paper towels, even though most people think the opposite. However, the study found that the result depended critically on how many paper towels people use. If you pull out two and two fall on the floor, it is definitely better to use a hand air drier – but if you use two towels it is about the same.

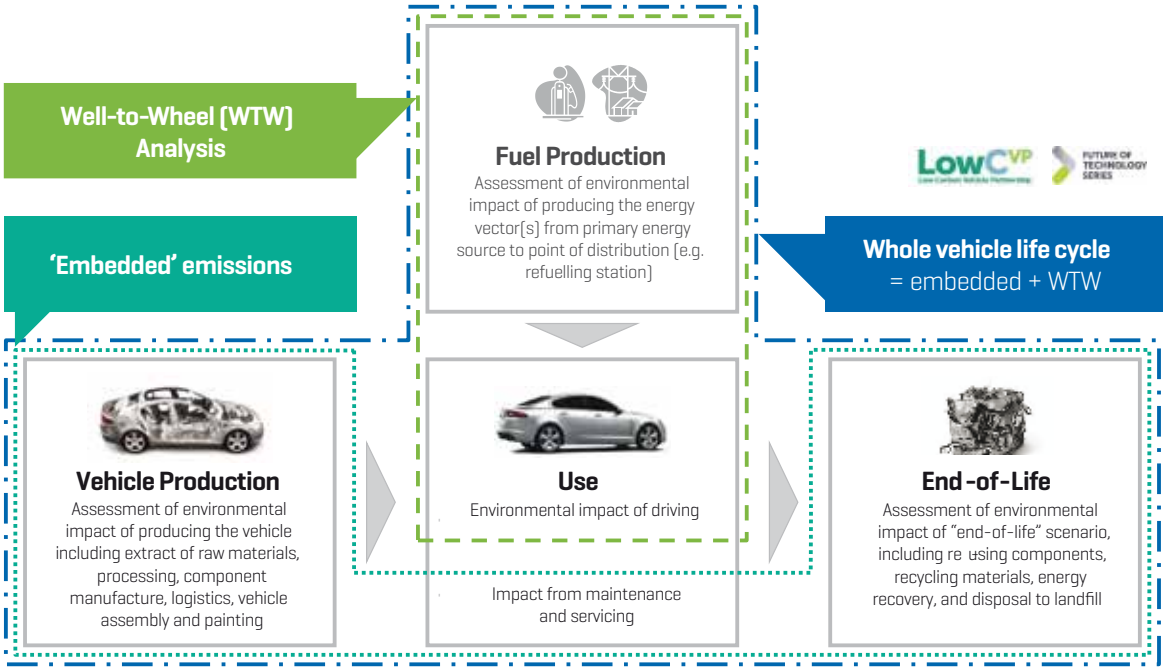
Keeping rail's eco footprint on track

As part of the tendering process for the UK's massive HS2 high-speed rail programme, all companies bidding for contracts have to calculate the climate change impacts per passenger kilometre for the entire life of the equipment on offer. Ricardo has been involved with one potential rolling stock supplier to evaluate the significance of their materials and construction techniques versus their operating performance, to identify the most preferable solution to put into the tender specification.

"This means we have to calculate the CO_2 that's embedded in the materials chosen, as well as the carbon consumed during the life of the components on the train," says Simon Gandy of Ricardo Energy & Environment. "In this case, HS2 is not concerned with the end-of-life of the components. Our client has sent us the bill of materials and the anticipated maintenance schedule, and we can use our software to calculate the associated carbon impacts."

In an earlier rail project Ricardo specialists looked at the relative carbon impacts of using steel versus aluminium versus a composite material. Steel is easiest to make and has the lowest manufacturing impact, aluminium is next and composite the highest. But steel is also the heaviest, and to operate the heavier train over however many years means higher overall emissions. Because of the long lifespan of a train it pays to go for the lightest solution possible, even if you have to use a more environmentally expensive material at the beginning. So, over the lifetime of the train the composite material is the best.

Life cycle assessment as applied to a vehicle



Source: Understanding the life cycle GHG emissions for different vehicle types and powertrain technologies, Ricardo report for LowCVP (2018) (RD18-001581-2

Calculating the life cycle impact of a vehicle is a complex business, taking in not only the emissions from manufacture and in-service fuelling, but also those generated in fuel production, routine maintenance and end-of-life disposal

can be employed to help plan a clearer way forward. "One of the things that has been coming out of Ricardo's recent LCA work is that we need to look at more than just GHG emissions."

To further compound the issue, shifts in many of the key parameters mean that decision-makers have to deal with a series of moving targets. Tailpipe CO_2 emissions, for so long the basis of European automotive regulation, will be significantly tightened in the next decade, something which will increase the relative embedded GHG in conventional vehicles but reduce their emissions in the key in-use phase. And with automakers using ever higher proportions of recycled materials in their new vehicles, new ways of evaluating the overall GHG impacts will have to be agreed.

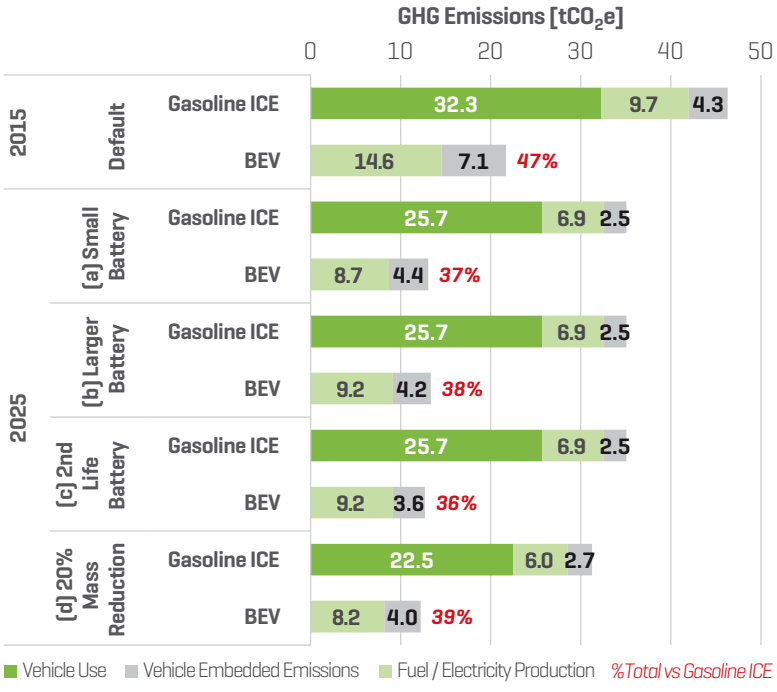
"At some point in our LCA work we may need to go to the next level of understanding," says Patterson. "If we are using these recycled materials, how much processing has to be done to make them to the right grade? And what will be the environmental burdens of that? And, further, for policymakers the concern might be that the use of that recycled material might be offsetting its use for a different purpose, which might then have to take more primary material."

> **"Our client has sent us the bill of materials and the anticipated maintenance schedule, and we can use our software to calculate the associated carbon impacts"**
> **Simon Gandy, Ricardo Energy & Environment**

Drawing the boundaries

As the examples above show, the results of any assessment can be heavily influenced by the assumptions built into the study and the boundaries that determine the scope of the study. But precisely where - and when - to

How design decisions affect life cycle emissions



Left: **Illustrative examples of how powertrain technology choices can affect the cumulative greenhouse gas emissions of a vehicle over a 210,000 km lifespan. Scores for large- and small-battery EVs are very close**

> **"It's not like saying a smaller battery is better and a big one worse. It may be that if you have a bigger battery you don't have to replace it"**
> **Nik Hill, Ricardo Energy & Environment**

draw the line is a tricky issue, as evidenced by several older electric car studies that incorporated the cost of setting up a charging structure but conveniently ignored the sunk costs and embedded emissions in the existing liquid fuel distribution network.

Deciding where that line should be drawn is "precisely the problem," agrees Nik Hill. "It can depend on a lot of things, including what environmental impacts you are looking at," he explains. "And it can depend on your resources, because the wider the net, the more work you have to do. But if you keep the line too close, you'll have to make more compromises and concessions."

Yet to have a good sense of where that line should be drawn in itself requires experience with the whole LCA process and a prior assessment of the likely significance of the different components and the likely consequences of going beyond the boundaries set.

Applying this thinking to the much broader landscape of possibilities that arise in an urban area if personal transportation is pitched against public transport and other intermediate modes, LCA can theoretically still cope, says Patterson. "But," she warns, "it still depends where you draw your boundary of analysis and what you're looking at, as well as what questions you are asking. If the goal of the scope is to work out what mode of transport is going to have the lowest environmental impact over a year's worth of commuting, you could build up a picture of what you want to model. You'd have to bring your assumptions into play, but basically, LCA could be used to answer that question."

Towards an environmental score?

Are LCA techniques robust enough to provide the basis for regulation and legislation, perhaps something like a lifecycle GHG footprint to underpin future vehicle taxation policies? It is a tempting proposition, especially in the transport sector, where it could at last provide a level playing field between the different primary energy sources in play, and it would also give a more accurate reflection of the actual life cycle environmental impact of each type of powertrain.

Yet, caution the Ricardo specialists, it is a complex subject and is already being discussed at a European level. The current frameworks, says Hill, provide rather too much flexibility and mean that outcomes of different studies may not be comparable with one another. The European Commission is now exploring the idea of a product environmental footprint, or PEF, which uses LCA in a much more standardized way – something that would make the assessments much more useful than those carried out under varying assumptions.

In the PEF pilot studies carried out so far, specific methodologies are applied to each category of item, meaning that like can be compared with like. Some 25 product categories have been assessed so far, ranging from photo-voltaic generation to T-shirts, beer and even pasta; the studies on coffee, stationery and marine fish were discontinued because they proved too problematic.

However, adds Gandy, Ricardo was recently commissioned to provide an environmental product declaration (EPD) for a company producing timber I-joists to take the place of the usual steel elements. "As there are already product category rules in place for construction materials, we were able to produce an EPD for the timber joists. So now if you go onto the International EPD System's website you can look at their EPD and compare it like-for-like with those of a Scandinavian company who also make timber joists."

The backers of PEFs, says Gandy, are trying to reduce the number of environmental criteria and, in a really ambitious initiative, distil them into a final environmental score. "This is controversial," adds Hill, "as each of these factors has to be given its own weighting in the determination of the final score. It's tricky, because you are dealing with climate change impacts, toxicity impacts, eutrophication impacts, and each has to be weighted in how much it contributes to the overall score."

Outlook

The type of objective, level-headed assessment that life cycle thinking can deliver is doubly important at a time when so many contrasting technologies are in the frame – not just for our future personal mobility but also for how we feed ourselves, power our homes and spend our leisure time.

And in many ways the example of battery-powered vehicles provides an excellent demonstration. Of course, with their heavily front-loaded environmental footprint because of their manufacturing emissions, BEVs start off on the wrong foot. But when BEVs are treated to the broader scope of a full LCA of everything from monetary and resource costs to their GHG emissions and other pollutant impacts, the comparison becomes clear enough to enable those key long-term decisions to be made.

Are we THERE YET?

Ricardo experts discover the causes of car sickness and help mitigate it in new vehicles

Safety has attracted the majority of investment in the development of connected and autonomous vehicles (CAVs), but there is also a widespread public expectation of comfort levels approaching those of a living room environment while in motion. **Farah Alkhalisi** talks to Ricardo engineers working on a solution for motion sickness in CAVs which can be applied in conventionally-driven vehicles as well

Kinetosis, or motion sickness, is not a new problem. But as new use-case scenarios for vehicles emerge, avoiding motion disturbance – as a minimum – and guarding against passenger nausea are becoming greater concerns. Autonomous driving and driverless vehicles bring particular issues, since people expect to be able to work, to read from a screen, watch a movie or hold a conversation in motion, perhaps while sitting in a swivelled, side- or rear-facing position. All these are factors known to contribute to kinetosis. Solving car sickness will therefore be crucial for consumer acceptance of CAVs.

Having a young daughter very prone to car sickness personally motivated Professor Jonathan Wheals, chief engineer, Ricardo Innovations, to research this topic. He recognized a general lack of knowledge around the effects of automotive motion on children and teenagers, as well as on rear-seat occupants. And, given the industry's concentration on safety, he believed that kinetosis has been neglected in CAV-related R&D thus far.

"About a year and a half ago, we started thinking about this in detail," he says. "Autonomous vehicles will be safe, or they will not be sold; the question now is what new activities are enabled by these vehicles? New is the ability to read, use a tablet and everything else while travelling. But if you no longer have a driver who has sympathy with the occupants, and an algorithm controlling the vehicle, it doesn't know who's in the car, or what their particular sensitivities are."

Wheals also contends that the application of these same techniques to non-CAVs would be beneficial to customers. Cars, he explains, tend to be engineered for 40-60-year-old males, of a certain weight and build, who have a certain response to things, sitting as a driver or passenger in the front. Second- and third-row seats have a very different ride quality, but they're not usually part of the product design criteria. So, the methods Ricardo has developed are pertinent to CAVs when they arrive, but also to the conventional products of today.

Trials and testing

As a first step, the Ricardo team constructed a modular vehicle dynamics model including parameters known or thought to contribute to kinetosis. These included vehicle suspension set-up, driver inputs, human physical factors (i.e. weight, height, sex, age, health), mental factors (personal sensitivity to kinetosis, previous experience, alcohol consumption) and also

seating position, seat type and cabin air quality. A simplified 'crash test dummy' style simulation shows the relative impacts of the vehicle's motion on the occupant as measured by accelerometers under the tested scenarios, taking into account the different parameters.

This bio-mechanical model was then correlated and refined against real-life data collected in a small-scale on-road trial based at Ricardo's Midlands Technical Centre near Leamington Spa in the UK. For this, participants were wired up with accelerometers, driven around three different routes, and observed on in-car video cameras.

Innovations engineer Michael Wheeldon explains: "There were two of us, each with a head-mounted camera, a head-mounted accelerometer, and an accelerometer on the seat. We were holding a phone, which we were sometimes looking at, sometimes not, and we tried this sitting as a front and rear passenger." Both Wheeldon and his co-participant – a much smaller woman – experienced higher accelerations in the rear seats, especially over speed bumps. As expected, there were also differences between their responses to the various motions, highlighting the need to understand the effects of motion on different body types and sizes.

"Sitting in the back, all accelerations were higher for both of us, in line with how we understood the car's design was focused around the front two passengers," he notes. This exercise was a useful proof of experiment, he says: "We can see on the recorded video that with different styles of driving, you can elicit very different responses very quickly, and that there are a lot of different factors involved."

The resulting kinetosis prediction model, says Wheals, can be applied by OEMs during a vehicle's attribute definition phase: "Within your simulation of the full vehicle, maybe four years before start of production when you can still make significant changes, this model can be applied: it could represent, say, an eight-year old European passenger, male or female, to see how they will respond to the passive spring damper settings, the ride height, the roll stiffness and everything else that you're defining.

"You can simulate a passenger with a validated and known propensity for kinetosis in different positions in the car, and try, for example, taking two roundabouts a bit quickly, or a cobbled road, which upsets children for all sorts of reasons.

"Our software modules can be built into the existing vehicle simulation," adds Wheals, "but rather than trying to get seconds off a Nürburgring time, you're thinking about how the ride can be softened or changed. The results could then be put in front of a panel of potential customers, to assess the relative importance of speed or sportiness against a comfortable, safe ride for their children." OEMs can also use the model to decide and calibrate seating position, seating design, and other issues of cabin packaging, layout and ergonomics.

Yet the software can further be applied to directly benefit the vehicle's end-user in continuous dynamic monitoring while driving, giving potential for a series of interventions to enhance comfort and prevent sickness. "The same algorithms could be used to avoid traditional compromises," says Wheals.

Real-time analysis and interventions

In a CAV, data can be accumulated over a series of manoeuvres or corners to help optimize its path; its trajectory or cornering line can be adapted or determined according to a motion sickness index. Wheeldon explains: "We have a set of personalized factors including a driver – autonomous or otherwise – which coupled with the vehicle's motion, go into the kinetosis quotient known as the 'misery factor'. It's a first foray into a vehicle model which translates vehicle design decisions into how people actually feel within the vehicle, rather than just how much they're accelerating.

Causes of car sickness

Motion sickness, in general, is believed to be the result of dissonance between senses: namely, a disconnect between the motion as experienced by the vestibular system (inner ear) and what the eyes are perceiving. The classic Treisman's hypothesis suggests that such a disconnect mimics the hallucinatory effects of severe food poisoning – hence the vomiting. Children and teenagers are thought to suffer the most since development of the central nervous system tends to lag behind physical growth, giving an even greater vestibular-visual mismatch. "It peaks at about 11 or 12 years old; all these things only stabilize when you're approaching your 20s," says chief engineer, Ricardo Innovations, Jonathan Wheals.

Frequency of the motion is a factor in the specific nature of carsickness. "You have to look at the frequency of pitch, heave, yaw, roll," says Wheals. "In coaches, trains, ferries and boats those motions are quite different. In a boat like a liner, the roll frequency is quite low, but a car on a road is more like a fast RIB inflatable clattering over waves."

Seating orientation adds a further dimension, he adds, as is any exterior scenery or background to a journey: "There are a multitude of different objects passing in your peripheral vision, like street furniture, trees, high walls, hedges, clouds, lights from oncoming vehicles; and all of these are quite dramatically different." This 'peripheral flicker' is a key contributing factor, especially when asymmetric, arising when detected mainly by one eye.

Seating in SUVs

High-riding SUVs and crossover-style vehicles are highly popular amongst families, but less-fashionable lower-riding station wagons may be a better option for those with children sensitive to carsickness. This is due to the height and positioning of rear seats: in an SUV they are often towards or even behind the rear axle, right at the roll axis – a crucial point which gives the counter-intuitive and unnatural effect of the head and upper body travelling in a different direction to the lower half of the body. This is amplified by the 'theatre' seating layouts of some larger SUVs (and MPVs) where the rearmost third-row seats are higher-set than the central and front rows, plus magnitude of sway and the often harsh ride quality.

"We analysed an overtake, running a particle swarm optimizer on Bezier curves to define a target driving path. The optimizer models different approaches; you see the peak motion sickness index achieved for a given path. Despite no training or guidance, the process results in a nice smooth line: an intuitively sensible result. This can be used in active control, as well as tuning vehicle control parameters, such as the driver preview distance, and you can find a sweet spot to minimise motion sickness for a given person."

Not only can the vehicle's path be optimized, the ride on that path can then be modified by adjusting parameters such as chassis stiffness and automated driver tuning to improve occupant wellbeing. "We can put our kinetosis model in the vehicle simulation and get an objective rating of how that corner was, or the overtaking manoeuvre," says Wheals. "While remaining within the safe manoeuvring envelope, you can calm everything down to the level of the person most likely to be susceptible to motion sickness."

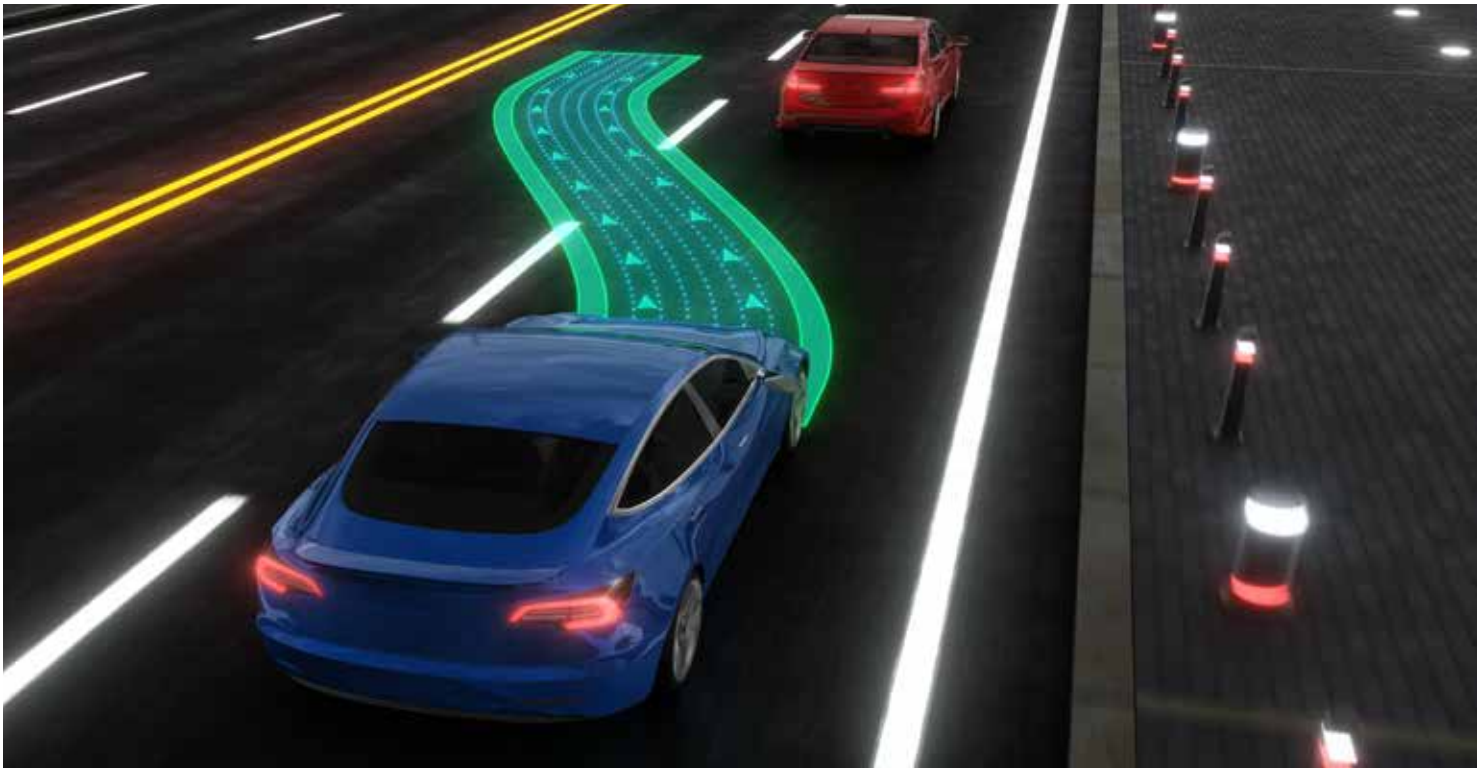
Potentially unwell people could be identified by sensors – according to biometric indications such as eye and bodily movements, breathing, sweating, and even facial expression. "And then rather than just saying 'we knew you were going to be sick!' our maths is cleverer: it could have provided the right amount of cool air, or adjusted the seating position, lowered the window blinds, or adjusted the car's line to prevent that sickness," Wheals notes.

Time, place and individual mood

A challenge, says Wheeldon, is that individuals have different propensities to kinetosis, and "the same person in a different position or orientation will have different inputs, based on the dynamics; or the same person on a different day or time of day. It's a very variable problem, because we humans are very variable. It's almost about building a personal propensity index, to say 'well, I'm alright with roll, as long as you don't pitch', and adjustment factors such as it being a late night, you're tired and all the lights are down."

Drivers could be 'nudged' to take measures to avoid their passengers becoming unwell, in the same way that gearshift indicators are currently used to prompt a more economical driving style. Nevertheless, predictive technologies play an even more important role in CAVs. "Anticipation is a big part of avoiding motion sickness," says Wheeldon. "Maybe the vehicle says 'roundabout coming up, I'm going to slow and let that vehicle pass'. Or it could be more subtle: when the car is about to turn left, the left-hand-side ambient lights in the interior increase their brightness by 20 percent, so you get a subconscious idea of what the vehicle's going to do – lighting will naturally draw people's gaze and attention, so that could dictate the direction they look. You can also do that with music, moving the balance a particular way."

In addition, Ricardo Innovations engineers are developing a specific biodynamic reading model, particularly pertinent to use-case scenarios for CAVs. Reading, whether from a book or on a screen, appears to bring a further



In an autonomous vehicle, data can be accumulated over a series of manoeuvres or corners to help optimize its path – helping to avoid motion sickness for passengers

moving reference point to conflict with body motion, supplementing the visual-vestibular mismatch. The position of a book, tablet or phone relative to a passenger's head, and the tilt or angle of the head, are thought to be important, as well as the fatigue that comes with continually having to refocus. "Changing the angle of the head has a big effect on the compound angles and accelerations that take place in the inner ear," says Wheeldon.

Importantly, a 'peripheral flicker' metric is incorporated. This measures feature changes per second within peripheral zones, such as objects entering into the field of vision, considering factors such as different perceptions by the left and right eyes; the obscuring of field of vision by vehicle pillars; and lighting, whether external, within the vehicle, or the lighting of a screen. "We're using Virtual Reality (VR) to simulate being in a car, and different flicker stimuli, whether objects passing or brightness increasing and decreasing," says Wheeldon of the ongoing research in this area. "VR gives us a way in which we can control the visual field completely, which helps us to separate the variables."

Future opportunities

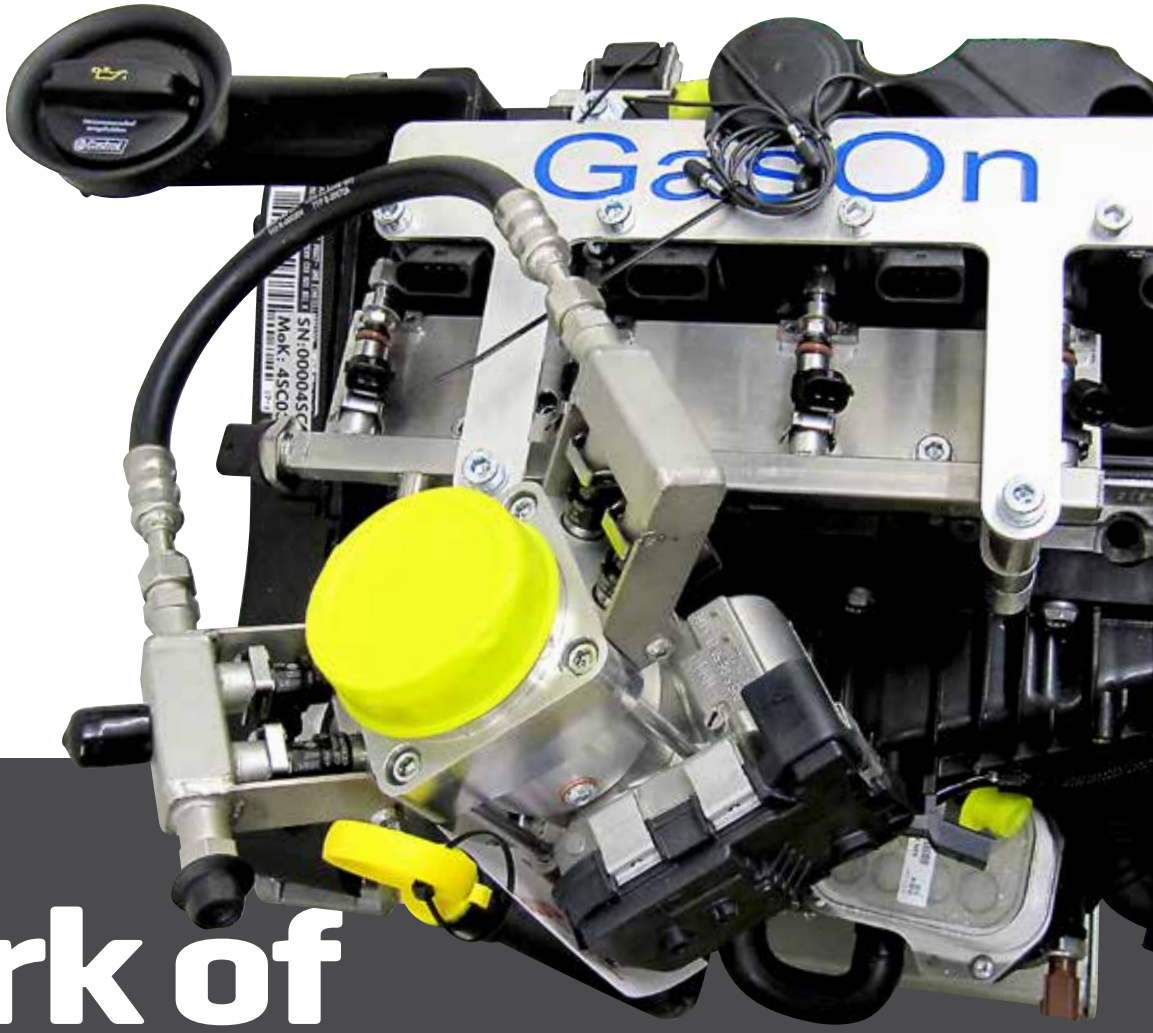
A large OEM launching an autonomous mobility service is already in discussion with Ricardo, seeing an obvious application of the model and its algorithms in shared-use and on-demand taxi-style operations, but some of the technology could be available as a consumer app too, perhaps on a subscription basis.

There are many longer-term opportunities and synergies for Ricardo's kinetosis prediction software technology with other in-vehicle systems and services too. These include an interest in integrating nausea prediction with 'e-nose' electronics to detect and control scents and odours in vehicle cabins, for example – smell being another sense highly implicated in kinetosis – and there are potential linkages with wellness data from smartwatches or other wearables, or with swarm data from other connected vehicles. Swarming of vehicles equipped with this technology could have a big impact in stop-start traffic, where many people suffer from motion sickness, allowing vehicles to travel at a low but continuous speed.

> **"We have a set of personalized factors including a driver – autonomous or otherwise – which coupled with the vehicle's motion, go into the kinetosis quotient known as the 'misery factor'"**
> **Jonathan Wheals, Ricardo chief engineer**

In the meantime, the Ricardo Innovations engineers are focused on increasing their dataset to calibrate the kinetosis algorithms, through a larger-scale research programme involving the participation of local schoolchildren – of course carefully monitored to all required ethical and safeguarding standards. This project will be tied to the science curriculum and has been met with enthusiasm by teachers. This work, being carried out in collaboration with and using the testing facilities of UK university partners, will be completed later in the year and will provide important additional data on the crucial 4 to 18 year-old cohort for susceptibility to kinetosis.

As such, for both the premium vehicles of today and the autonomous CAVs of tomorrow, Ricardo is developing software technology that could enable motion sickness in cars to be consigned to the realms of an unpleasant collective memory of the past. Applied from the design stage in the specification of suspension to provide the most desirable ride and handling characteristics, through to the real-time adaptation of multiple sensory aspects of the cabin environment and vehicle motion, this promising Ricardo technology offers the prospect of a more comfortable travelling experience for all passengers. It is perhaps unsurprising that it is attracting very serious attention from across the spectrum of existing vehicle manufacturers, new market entrants in the electric and CAV sectors, and mobility-as-a-service innovators. And no doubt in the future, the parents of sickness-prone children, not to mention taxi drivers, will grow to appreciate this innovative Ricardo technology too.



Spark of INSPIRATION

The auto industry is constantly striving to explore cleaner and more sustainable forms of combustion engine to support both conventional and hybrid electric powertrains – and in collaboration with Volkswagen, Empa, ETH Zurich and Poznan University of Technology, Ricardo's software engineers are creating tools that will enable the development of a new form of compact, lean-burn natural gas engine offering diesel-like power and performance and extremely low NO_X. **Anthony Smith** reports

Compressed natural gas (CNG) has long been recognized as an attractive alternative to gasoline or diesel as a transportation fuel. It is typically less expensive, exists in more abundant reserves, and provides lower overall greenhouse gas (GHG) emissions when burned. In addition to fossil resources, there are also significant supply chains being developed for biomethane, the renewable equivalent of CNG derived from agricultural operations, domestic refuse disposal, or water treatment works, and power-to-gas energy conversion. Coupled with a mature distribution infrastructure, including widespread existing filling station availability, it is understandable that CNG continues to attract significant interest.

As a road fuel for use in an internal combustion engine, CNG has some further very practical operational advantages. It is comparatively resistant to knock, making it ideal for boosting and downsizing, and it is amenable to the use of higher compression ratios to further improve efficiency and reduce CO_2 emissions.

Further efficiencies are possible when lean combustion is employed, as heat

losses are reduced. But lean operation also brings with it some inherent limitations. To date, most passenger-car CNG applications have been based on conversions of spark-ignited gasoline platforms relying on port injection and the use of a broadly homogenous charge. This approach places a restriction on the extent of lean operation possible if combustion stability is to be maintained, thus restricting the fuel-saving and emissions reduction potential of light-duty automotive CNG operation.

In heavy-duty gas engine applications for large commercial vehicles and power generation, this limitation can be overcome through the use of a pre-chamber: this enables combustion to be initiated in near-stoichiometric conditions in the vicinity of the spark plug through the use of a pilot injection process. The flame front emanating from the pre-chamber nozzles then provides the basis of a more stable ignition of the leaner, port-injected charge within the main cylinder.

The precise conditions close to the spark plug at ignition, such as the spatial distribution of turbulence intensity and fuel concentration, play a pivotal role on the flame development within a scavenged pre-chamber equipped gas engine. A successful pre-chamber therefore needs to be very carefully designed to ensure that it delivers the required level of combustion stability to the main cylinder. Firstly, scavenging needs to be effective to ensure that unburned hydrocarbons and exhaust products are expelled; the flow structure and injection characteristics and the timing need to be arranged in a manner that delivers the required conditions close to the spark plug electrode and, finally, the spark needs to initiate combustion in a stable manner.

As the flame front propagates, it needs to move in a manner that avoids excessive wall quenching, requiring the nozzles to deliver a reliable flame jet into the cylinder to initiate combustion of the main charge. In addition to the engineering challenges of achieving the above, the inherent constraints of packaging a miniaturized pre-chamber (including its spark plug and gas injector) within the space available in an automotive cylinder head have limited the use of this approach for passenger car applications.

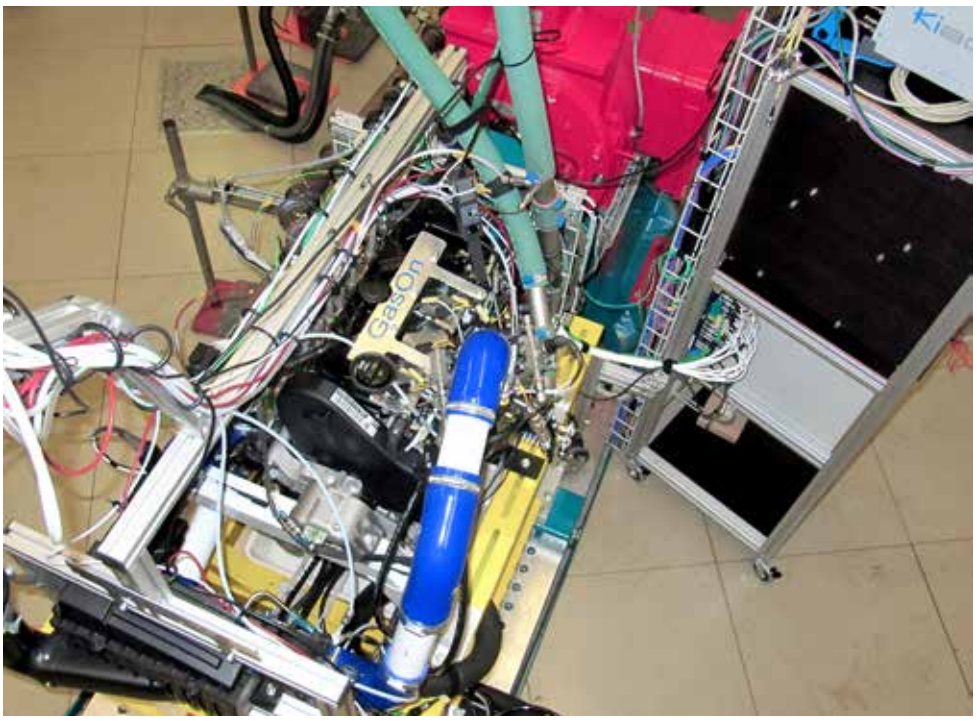
The GasOn project

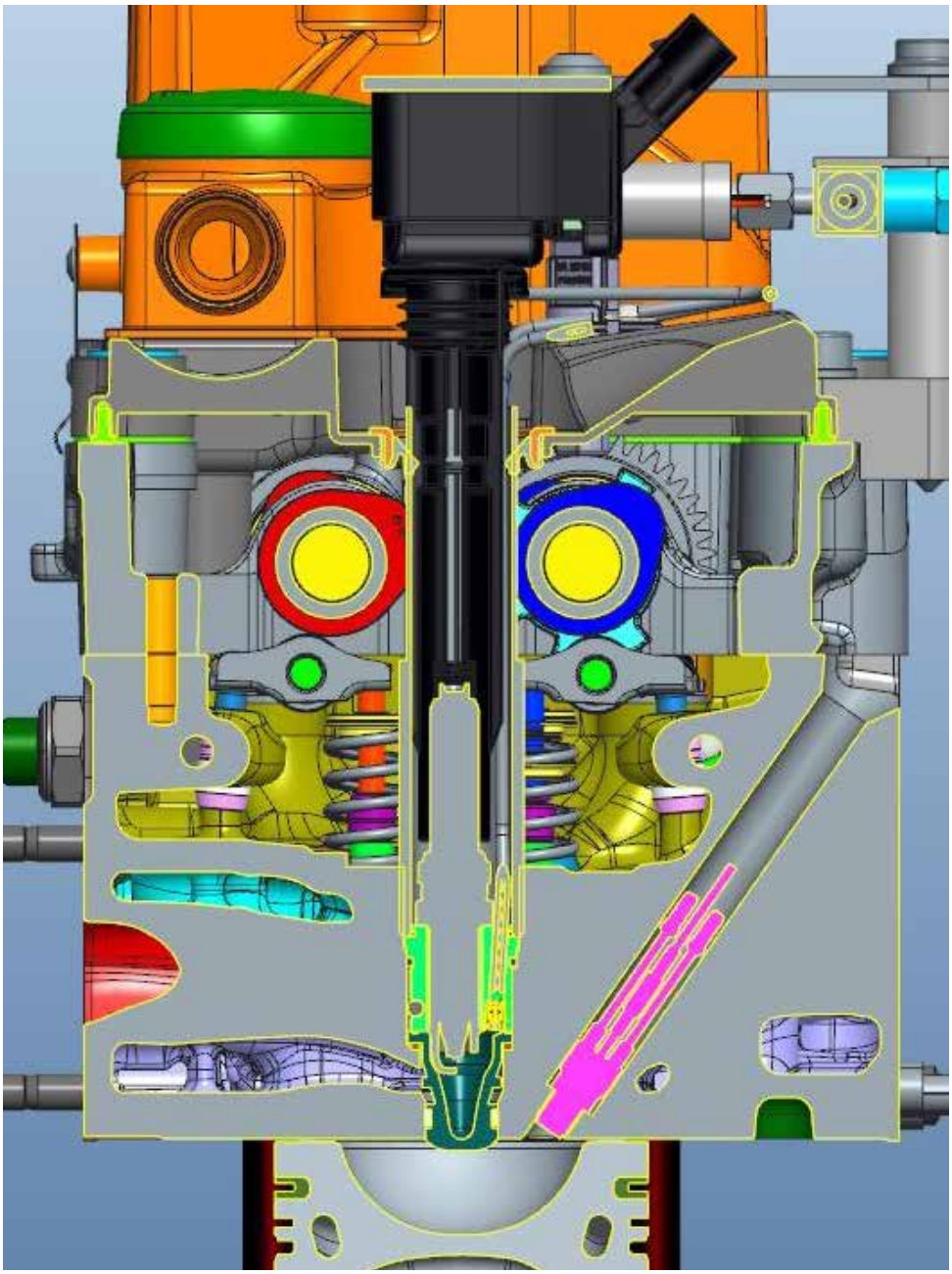
In order to help realize the full potential environmental and emissions benefits of CNG combustion in the passenger car sector, the multi-partner EU Horizon 2020 project GasOn has been aiming to develop advanced CNG mono-fuel engines which improve on the current state of the art based on converted gasoline platforms. Within the project, Ricardo is partnering with Volkswagen, Empa, ETH Zurich and Poznan University of Technology, on the development of a new form of pre-chamber ignition (PCI) system that is capable of extending the lean limit of automotive CNG operation, while also enabling the adoption of diesel-like compression ratios. The combustion system and corresponding hardware is developed by work package leader Volkswagen, with ETH Zurich providing fundamental experimental capability, advanced analysis models and engine control system, and Poznan University of Technology and Empa respectively conducting investigations of developed systems in a single cylinder research engine and full-scale engine. Ricardo's role within the project is focusing in particular on the development of the computational fluid dynamics (CFD) tools that would enable the future design of this type of engine.

"There has been an increasing interest in the potential of PCI CNG engines as a potential substitute for diesels in future automotive products," explains Evgeniy Shapiro, Ricardo Software development manager for the VECTIS CFD package. "If we are able to design PCI systems that deliver stable CNG combustion significantly beyond current lean limits, then with higher compression ratios it should be possible to offer performance broadly similar to diesel but with much lower NO_x emissions."

In order to enable PCI systems to be designed effectively within the time and resource constraints typical

"This form of engine operates in a very different realm to truck or power generation engines; the physics may be similar, but the pre-chamber is tiny, packaged within the same volume as the injector would be in a diesel engine"
Evgeniy Shapiro, Ricardo Software development manager





Section through the GasOn engine showing the packaging of the miniaturized pre-chamber, including the spark plug and pilot gas injector

of automotive product development, accurate and fast CFD modelling of the mixture formation and early flame kernel development in the pre-chamber are essential. "A review of the physical models currently available in commercial CFD codes highlighted a gap in the technology currently available," continues Shapiro. "This is not least because the initial stages of ignition in spark-ignited engines typically occur at time scales, temperatures and geometries falling outside of the scope of conventional CFD techniques."

Spark modelling

The spatial distribution of turbulence intensity and fuel concentration at spark time play a crucial role in flame development within this form of engine. So too does the development of the spark.

"The main focus of our contribution to the research was the development of a new spark model," continues Shapiro. "We were concerned that the traditional CFD treatment of spark modelling would not be sufficiently accurate to capture the relevant physics of the highly turbulent and space-constrained environment of a highly compact CPI pre-chamber. This form of engine operates in a very different realm to truck or power generation engines; the physics may be similar, but the pre-chamber is tiny, packaged within the same volume as the injector would be in a diesel engine."

In electrical terms, the spark event occurs over three phases: breakdown, arc discharge and glow discharge. The first, measured in nanoseconds, is where the voltage between the electrodes exceeds the breakdown voltage of the dielectric fuel-air mixture, causing plasma formation. This is followed over the ensuing micro-seconds by the arc discharge phase, in which the flame kernel begins to form. The third phase, representing the final milliseconds of the spark event, is that of the glow discharge where the maximum energy is delivered to the spark, causing the characteristic visible glow. This stage marks the growth of the flame kernel and subsequent flame propagation away from the spark plug and onwards through the combustion mixture.

"In simulation terms we need to be able to predict the initiation of the spark and how the kernel moves – how it breaks down from the initial discharge, and how this influences the propagation of the flame front," continues Shapiro. "Accurate modelling of the initial stages of spark ignition is therefore essential. To achieve this, we developed a Dynamic Discrete Particle Model (DDPIK) for incorporation into VECTIS, which captures all stages of the spark - from the point that power is supplied by the ignition coil, to the transition of the flame kernel supported by the spark discharge, to a fully developed turbulent flame."

The spark model comprises three parts, the first two being flame kernel initialization and flame kernel growth. The final stage is the transfer to the VECTIS turbulent combustion model, which is a well-established tool for the characterization of the combustion of natural gas and other fuels. In addition to the new spark model, a new and more highly resolved wall quenching model was created by the VECTIS development team. The avoidance of excessive wall quenching is a crucial consideration in the design of an automotive PCI CNG engine as it is essential for combustion stability that the flame is able to propagate through the nozzles and out into the combustion chamber without being extinguished.

Validation

As with any new predictive modelling capability, it was necessary to validate the approach in order to have confidence in its use as a CAE tool. This was achieved in several ways. Firstly, the model was used to simulate spark discharge in a combustion bomb for which academic benchmark experiments are readily available. Then, in work carried out by ETH Zurich, a rapid compression expansion machine (RCEM) experiment, was used to compare the predicted and

observed spark-initiated combustion. The RCEM operates in a single cycle mode (compression-expansion) and combines excellent optical access with high flexibility in independently changing parameters, such as mixture composition, start of ignition, and initial chamber conditions.

The spark and combustion modelling was also correlated with much higher fidelity models by ETH Zurich using approaches that would not be amenable to production CAE applications. Furthermore, the model was validated by VW within another project in an optically accessible spark-ignited CNG engine.

Engine development and testing

Using the enhanced physical models of the spark and wall quenching, VW engineers were able to evaluate different pre-chamber geometries, simulating their performance in terms of scavenging, spark and flame development, and the promotion of stable, lean combustion. A number of different nozzles were assessed – including different shapes as well as numbers of nozzles – to give different combustion effects. Finally, VW also investigated the use of optimized piston crown geometry. Promising configurations were accessed in single cylinder engine tests at Poznan University of Technology and full engine tests at Empa.

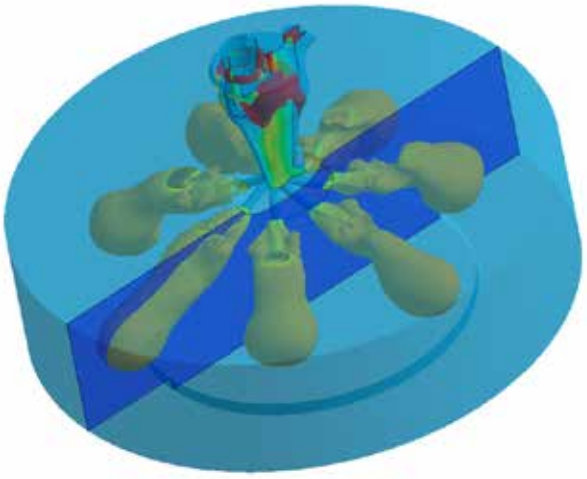
Testing revealed that stable combustion can be achieved for air–fuel equivalence ratios up to 1.5 in passive pre-chamber operation but with undesirably high NO_x levels. When injecting methane into the pre-chamber, the engine could be smoothly operated with overall air–fuel equivalence ratios above two and strongly decreased NO_x emissions. The best fuel efficiency was found to be at an overall air-fuel equivalence ratio of 1.7, while NO_x levels remained below 1 g/kWh. In such settings, the four-cylinder two-litre engine with a compression ratio of 14.5 achieved excellent peak brake thermal efficiency levels of around 45 percent. While known and well-proven deNO_x systems would be available for the application of this combustion concept on the road, the remaining challenge to be solved is the catalytic reduction of the unburned methane emissions, due to the comparatively low exhaust temperature.

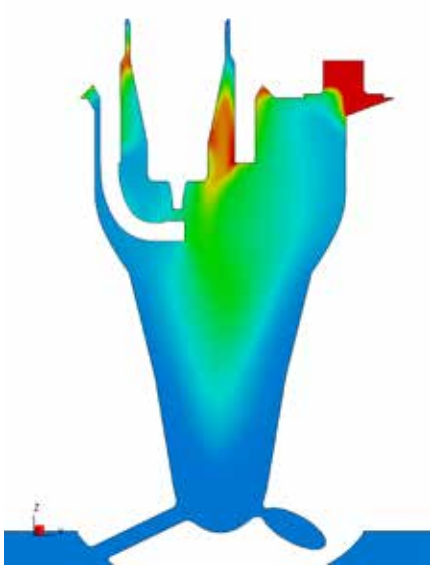
A positive automotive future for pre-chamber gas engines

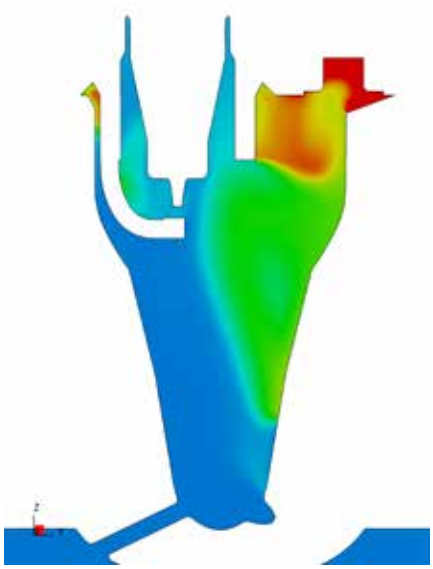
As a result of the collaboration between Ricardo, Volkswagen, Empa, ETH Zurich and Poznan University of Technology on the GasOn project, several very significant outcomes have been achieved. Firstly, engine-based testing has successfully demonstrated the concept of using PCI CNG combustion as a means of delivering a very practical extremely low emissions engine offering diesel-like performance and attractive fuel efficiency in an automotive-scale package.

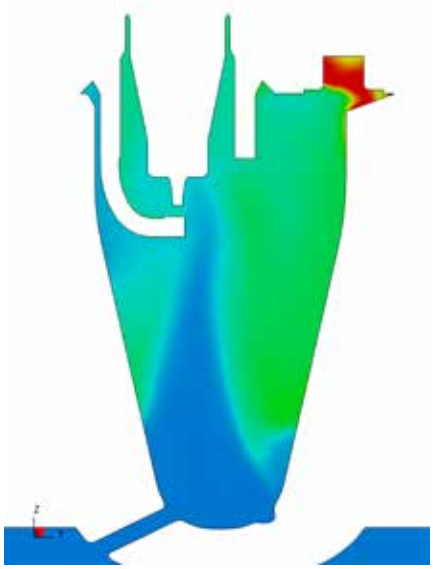
Secondly, CNG is already a very practical and environmentally attractive alternative to conventional liquid fossil fuels - and now the successful demonstration of a miniaturized pre-chamber concept is a significant enabler for this fuel to occupy a gap in the market for products that would traditionally have been diesel-powered. In addition, the innovation provides a highly fuel-efficient and flexible powerplant for hybrid electric powertrains.

Thirdly, from a Ricardo Software perspective, the new DDPIK spark and wall quenching models developed under the GasOn project are now incorporated into the commercial VECTIS package. These physical models are not limited just to CNG applications and can be used to enhance the accuracy for other combustion systems development including, for example, gasoline pre-chamber engines. As such, these sophisticated and state-of-the-art models will be of use both to Ricardo and its external VECTIS licensees in the creation of the next generation of a wide range of ultra-low emissions, low carbon and high fuel efficiency engines.









3D iso-surface of predicted flame temperature *(below top)* **- showing stoichiometric combustion in the pre-chamber with high temperature and lean cool combustion in the cylinder; the slice in the same plot shows equivalence ratio stoichiometric/ rich pre-chamber and lean cylinder**

Sections through different pre-chamber designs *(below)***, showing the VECTIS-predicted distribution just before spark ignition**

RICARDO NEWS

Latest developments from around the global Ricardo organization

Ricardo and McLaren renew engine supply agreement

Since 2011, Ricardo's purpose-built assembly facility at Shoreham, UK, has assured the entire engine production requirement for McLaren Automotive. In the past year, production levels under the existing Ricardo-McLaren agreement approached 5000 engines – with the total delivered since the partnership began now significantly exceeding 15,000.

Under the terms of the new agreement, Ricardo is nominated as the exclusive supplier for engines as McLaren Automotive embarks on its Track 25 business plan. Included in the plan are 18 new models or derivatives, many featuring hybrid technology. To support this diversification, Ricardo will invest in the production facility to accommodate additional product flexibility, new manufacturing capabilities, and further capacity. This third generation of supply agreement for the McLaren engine succeeds the previous contract with the company and is the largest in Ricardo's long and proud history.

"McLaren is pleased to be continuing our very strong relationship with Ricardo as our engine supplier," commented McLaren Automotive, CEO, Mike Flewitt. "Ricardo shares McLaren's passion for exceptional performance, product innovation and quality. It has also become a trustworthy and reliable partner to McLaren in engine manufacture. We look forward to working with Ricardo and to receiving its full support as we implement our Track 25 business plan."

New air pollution alert system

A new website and air quality notification service has been launched by 11 local authorities in the region just north of London. The 'Herts & Beds Air Pollution Alert System' is a free alert service, managed by Ricardo, and is designed to help those living and working in the area to understand their exposure to air pollution and to access advice on limiting risk. In instances where local air pollution increases to a moderate level or above, the free notification service provides a text or email alert straight to users' mobile phones.

The alerts are sent out when moderate, high, or very high levels of air pollution are forecast. Residents in the local area can sign up to the free service and specify their notification preferences via the Air Quality England website. The air pollution website complements the alert service, providing at-a-glance air-quality information for the area. Coloured markers on a regional map pinpoint areas with increased pollution levels, providing an easily accessible pollution summary to visitors to the site.

Integrated energy solutions for public sector facilities

Ricardo is to participate in a ground-breaking pilot project with the aim of assisting the deployment of smart, integrated energy solutions to cut energy costs and carbon emissions across the public sector estate.

Modern Energy Partners (MEP) is a collaborative project between Energy Systems Catapult and the UK Government's Cabinet Office and the Department for Business, Energy and Industrial Strategy (BEIS), working with Crown Commercial Service, SALIX and private-sector specialists including Ricardo.

The project aims to leverage private sector expertise in cutting-edge smart, integrated and optimized energy efficiency solutions that combine low-carbon generation, storage and energy demand management to benefit both the public sector estate and the wider energy system.

Ricardo is one of four leading private-sector suppliers taking part. The appointment follows a competitive tender to develop integrated energy solutions across four public sector sites; these include a university and military bases. Ricardo will lead a consortium that will focus on the estate of HMP Sheppey Cluster, a group of prison facilities located in the south-eastern county of Kent. The Ricardo consortium will evaluate potential strategies for innovative integrated energy solutions at the Sheppey estate, solutions which offer the potential to reduce carbon emissions and energy expenditure. The methodology used will ensure that the solutions recommended are repeatable and scalable, providing a future-proof site energy plan for the Sheppey Cluster as well as valuable lessons for future initiatives across multiple public-sector campus sites of all types.

International urban resilience report

The Urban Institute, with financial support from The Rockefeller Foundation, has released an independent midterm findings report in December 2018. The report shows that in the five years since they came together, the 100 Resilient Cities (100RC) are making important progress in helping urban areas around the world institutionalize and build resilience to a wide range of shocks and stresses.

The 100RC was created by the Rockefeller Foundation on the foundation's Centennial in 2013 and is dedicated to helping cities around the world become more resilient to the physical, social and economic challenges that are a growing part of the 21st century. The report is part of the ongoing independent assessment of 100RC by the Urban Institute and its global partners – C230 Consultores, Ricardo Energy & Environment, Oxfam UK, and Zerihun Associates. The objective is to measure the effectiveness of the organization in building a global practice of resilience through structural changes in city functions. The 100RC, which spans six continents and more than 40 countries, helps cities better understand their challenges and then develop and execute comprehensive and integrated solutions.

Strong demand for crisis management training

Ricardo's growing crisis management and business continuity consultancy has seen a significant increase in demand for its services, with contracts won across a range of industries including government agencies, major UK higher education institutes, and a European Commission agency.

Businesses throughout the world are increasingly recognizing the need for preparedness and resilience in the face of the unexpected, from major weather events and natural disasters to terrorism and cyber-crime. Ricardo's crisis management team has long provided incident and emergency response support to businesses throughout the world – including those in the sectors of air travel, hazardous materials handling, distribution and logistics and manufacturing. More recently, this branch of Ricardo's business has developed consultancy and training services, aimed at enabling clients to develop their own levels of preparedness and resilience in the face of an unpredictable and very broad range of potential threats and disruptions.

Examples of some of the recent training contracts awarded have included the development and delivery of bespoke incident management and crisis management training for the strategic, tactical and operational staff of a major UK public agency. This training will help the agency's key staff to improve understanding of their roles and responsibilities as well as their non-technical skills, such as leadership, situational awareness, stress, teamwork and mission-critical communications. One of the UK's largest higher education organizations has also contracted Ricardo to work with each of its major departments to deliver exercises – over 14 of which will be delivered in the next year – with the objective of significantly improving their organizational resilience across teams who are not often involved in crisis preparedness.

Outside the UK, a major European Commission multi-country agency will be supported by Ricardo in a range of different exercise and training programmes, from a full-scale crisis simulation exercise through to awareness training across the entire organization.

Braking system for all-electric sport utility trucks

Ricardo has been selected for production supply of the braking system for the world's first all-electric sport utility trucks, the Bollinger B1 and B2 models. The agreement includes Anti-lock Brake System Electronic Stability Control (ABS/ESC) systems too.

The award of this contract follows development of the Ricardo ABS/ESC system for the High Mobility Multipurpose Wheeled Vehicle (HMMWV), and a subsequent five-year prove-out of the system on a pilot project – in which a number of Michigan Army National Guard vehicles were fitted with ABS/ESC for evaluation testing. This earlier work enabled the operational testing of the system to produce a high-quality system for the domestic and international defence and commercial sectors.

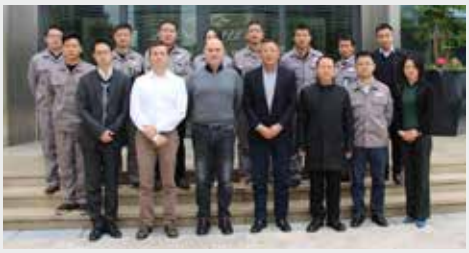
The Bollinger B1 and B2 models will now use the very same military-hardened Ricardo ABS/ESC braking system components already deployed with military units around the world, improving the safety, performance, and reliability of these new trucks.

Bollinger Motors has now received over 25,000 reservations, and production of the B1 Sport Utility Truck and B2 Pickup Truck is slated to start in 2020.

"We chose Ricardo," said Robert Bollinger, CEO of Bollinger Motors, "because the Ricardo braking system leverages best-in-class engineering and components and has proven itself in demanding military applications. Our relationship with Ricardo is a great example of the reason we relocated our business to Michigan and demonstrates our commitment to US-based products and suppliers."

Ricardo Defense engineers at the company's Detroit technical facility worked very closely with the local automotive industry to create the highly reliable brake and stability control system for use in the defence and automotive sectors. Production supply of the braking system will be from Ricardo's facility in Van Buren Township, Michigan, and will create additional jobs in the suburb close to Detroit's Metro Airport.

New 650 cc motorcycle for China's Zongshen



Based in the heart of China's motorcycle industry in the city of Chongqing, Zongshen Motorcycle is one of the country's leading two-wheeler manufacturers and produces around two million units per year. To support the company's ambitions for growth in product range and engineering capability, Zongshen has contracted Ricardo Motorcycle to assist with the development of a completely new platform to support a family of future large motorcycle products.

The new 650 cc platform will use a Zongshen powertrain but will form the basis of a completely new vehicle, fully developed as a clean-sheet design. Ricardo will support the project from the early styling phase, assisting Zongshen with market research, benchmarking and target setting. Ricardo will also provide the engineering concept and design solutions required to develop and validate the product, ensuring compatibility with the local supply chain.

Electrification 'requires a new approach' to taxation

Ricardo is one of nine leading organizations representing vehicle fleets, motorists, the automotive industry, energy providers and local government to have contributed to a new British Vehicle Rental & Leasing Association (BVRLA) report *Road to Zero: time to shift gear on tax*. The report is focused on the needs of the UK but has relevance to many nations with a similar vehicle fleet mix and system of motoring taxation. In publishing the report, the BVRLA aims to stimulate a dynamic discussion between drivers, the automotive supply chain and policymakers about creating a tax system fit for the future.

Together, the report's authors warn that the advent of increasingly connected, electric and shared road transport presents challenges and opportunities for future Government motoring tax policy. They point to the impending decline in revenues from the current CO_2 emissions-based regime and highlight the potential for a new tax system that could help tackle transport priorities including urban air quality and congestion.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