Ricardo Quarterly Review **Q3** 2019

RQ

A focus on the latest in technology, innovation and sustainability

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Interview
Jon Hunt, alternative fuels manager, Toyota GB

Air quality
The impact of post-Euro 6 regulations

E-mobility in India
Supporting the launch of India's largest-yet electric bus fleet

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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.

Client confidentiality is of the utmost importance to Ricardo, which means that we can only report on a small fraction of the work carried out by the company. So we are especially grateful to those Ricardo customers who have kindly agreed to co-operate with RQ and allow their programmes to be highlighted in print: without such help from customers it would not be possible to present such a fascinating insight into the development of new products, technologies and innovations.

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RQ INDUSTRY NEWS

The latest in technology, innovation and sustainability across world industries

Sparking the EV market

First deliveries of the Volkswagen ID.3 are scheduled for mid-2020

German industry has always prized its bi-annual Frankfurt auto show as a high-profile shop window for all that's new in power-hungry premium sedans, SUVs and sports cars. This year's event was – on the surface – quite different, with one of the most significant launches being Volkswagen's ID.3, a compact EV priced from under €30,000. The first production model on the MEB (modular electric drive) platform, the ID.3 is offered in three battery-size formats: basic 45kWh, giving a range of up to 330 km on the WLTP cycle; a 58 kWh upgrade good for 420 km; and 77 kWh, promising up to 550 km. The MEB will underpin 33 new VW Group models in the next three years, the company says; a glimpse was given of the ID.4 SUV, and over at the SEAT stand was a related concept, the sportier Cupra Tavascan.

The Mercedes-Benz Vision EQS previewed an electric luxury sedan, motors at front and rear axles delivering over 350 kW and torque of around 760 Nm; a range of up to 700 km was claimed for its batteries, supplied by Daimler subsidiary Accumotive.

BMW, meanwhile, was hedging its bets. Chairman Oliver Zipse confirmed 25 electrified models – including plug-in hybrids – on sale by 2023, but also announced the launch of a fuel cell fleet in 2022. "We expect to see an increase in demand for this technology in the second half of the next decade," he said, introducing the i Hydrogen NEXT development vehicle alongside the plug-in hybrid M NEXT sports car and all-electric Concept 4 coupé. And summing up how speed and performance stole much of the limelight after all, Porsche's volt-powered Taycan comes badged 'Turbo' (761 hp) or Turbo S (680 hp).

Of the foreign OEMs exhibiting, Hyundai's electric 45 Coupe concept debuted a minimalist design approach referencing the 1974 Pony. However, another vehicle with heritage took more headlines: the all-new Land Rover Defender, now with a monococque structure said to be three times stiffer than body-on-frame construction, plus a plug-in hybrid option.

Mercedes-Benz Vision EQS hints at the design of the next S-Class

Partnerships for EV platforms

Achieving economies of scale is an important aspect of electric vehicle manufacturing, and to that end, many firms are forming strategic collaborations. Prior to the Frankfurt show, Automobili Pininfarina announced a three-way partnership with Bosch Engineering and Benteler – not just to develop a platform for its own ultra-exclusive, high-performance cars, such as the Pura Vision previewed at the Monterey Design Week this summer, but for supply to other brands. This follows announcements earlier this year by firms including Daimler, to co-develop the next-generation electric Smart models with Geely, and by Toyota, collaborating with longtime partner Subaru on a C-sector SUV combining Toyota's electrification technologies and Subaru's all-wheel-drive knowhow. Toyota's own new GA-B platform, for compact cars, is also thought to have the potential to accommodate electrification.

Vans of all sizes go electric

A perfect storm of city-centre diesel bans, unstable fuel prices, and pressure to reduce corporate carbon footprints means that manufacturers are finding a ready market for low- and zero-emission vans for local and last-mile deliveries. Renault and Nissan are already well-established in the e-van segment, and others are seeking a foothold.

At the smallest end of the spectrum come e-bike-based designs like the tiny EAVan *[pictured]*, built by Oxfordshire's Electric Assisted Vehicles Ltd for the Norwegian postal service. This can carry 120 kg and supports Posten Norge's aim to be carbon-free by 2025.

Of larger offerings, pilot build of the ACE, a 500 kg payload e-van with a carbon chassis, is beginning at a former Mitsubishi plant near Adelaide, Australia.

Ford has a plug-in hybrid Transit already on trial, and an all-electric model for 2021; LEVC has launched a van spin-off of its London taxi, with range-extended powertrain giving a total range of 600 km; Toyota has announced battery-only versions of its Proace and Proace City, built by PSA; and illustrating projected global growth in this sector, Chery has signed an MoU with Deutsche Post subsidiary StreetScooter to develop and build up to 100,000 electric light utility trucks a year from 2021.

Biggest of the upcoming e-vans is Fiat's market-leading Ducato, soon available all-electric with ranges of up to 360 km and no sacrifice to its 1950 kg payload.

Electric aircraft taxi towards take-off

This summer's Paris Air Show brought an upsurge of interest in electric and hybrid aircraft, with Airbus reportedly considering jet/electric combinations; Rolls-Royce planning to fly hybrid test aircraft in 2021; and widespread talk of flying taxis, led by Uber.

Israeli start-up Eviation, acquired in early September by Clermont Aerospace of Singapore, attracted particular attention – and orders – for its eight-seater Alice *[pictured]*, despite the prototype having not yet made its maiden flight.

World energy outlook worsens

As global energy demand surges and CO_2 emissions are at an all-time high, political momentum for zero-carbon commitments is building, especially in Europe. Yet with investment in renewables flatlining and hydrocarbons still accounting for 80 percent of energy provision, fears are growing that measures announced so far will be insufficient to limit a temperature rise to 1.5 degrees, as agreed in the 2015 Paris Agreement on Climate Change.

Fewer than 75 of the world's top 500 companies are aligned to meet the Paris goals, according to the Financial Times, and the visible effects of climate change such as melting Arctic ice, hurricanes and other extreme weather events continue to escalate. Washington's Carnegie Institute maintains that achieving 1.5 degrees would require some existing power plants to be taken out of service, and for society "to stop building things with smokestacks and tailpipes that dump CO_2 pollution into the sky," its report authors said.

Some 18 EU nations have pledged to support a 2050 zero-carbon goal; Finland is aiming for 2035. In Germany, Bosch CEO Volkmar Denner is calling for a carbon tax, and the new president of Europe's power sector umbrella organization predicts that domestic rooftop solar arrays will become as common as fridges.

NEWS **IN BRIEF**

Highlighting the latest thinking in automotive engineering and technology worldwide

Quattro on demand and personalized

Audi showed its fourth 'AI' concept in Frankfurt, this time an extreme off-roader. AI:Trail had its (theoretical) autonomous capabilities played down in favour of showcasing the myAudi digital platform, allowing users to book a vehicle pre-configured to their personal preferences, from seating position to music library. Audi envisages a service providing specialist-interest models for short-term lease or specific use-cases.

Byton's big screen

Byton's high-tech M-Byte SUV, designed in Munich, is thought to have the largest-yet interior screen in a production car: a curved 48-inch wide display with three zones for digital content. This isn't touch-sensitive, though: instead, interactions are via a seven-inch 'tablet' in the centre of the steering wheel or a similar eight-inch device for passengers mounted between the front seats. Gesture, voice and facial recognition controls will also feature.

Li-ion to live on

The European Institute of Innovation and Technology (EIT, a body of the EU), is supporting a two-year, €4.7 million project to develop a closed-loop process for recycling lithium-ion batteries from electric vehicles. Partners in the ReLieVe programme include Eramet, Suez and BASF; they will look at industrial integration and scaling-up, from collection and dismantling of batteries to manufacturing new electrode materials.

Power direct to the wheels

The Japan Science and Technology Agency (JST) is leading a joint venture on wireless charging systems for in-wheel motors. Partners Bridgestone, NSK and the University of Tokyo have agreed to a system of open patents for technologies to reduce dependency on batteries in electric vehicles, thus enabling a cutting of vehicle weight as well as lessening pressures on battery production. Conductive road surfaces are under study.

An 800-volt blast

Delphi Technologies has announced an 800-volt inverter which could halve electric vehicle charging times. This silicon carbide (SIC) inverter is said to be lighter and more compact than competitors' products; to give faster power switching; and to operate at higher temperatures. Launch in 2022 is expected, and Delphi has signed a $2.7billion deal with "a premier global OEM" for volume production.

Start-up gets going

Global auto services company Cox Automotive is taking equity of $350 million and joining Amazon and Ford as major stakeholders in electric 'adventure vehicle' start-up Rivian, based in Plymouth, Michigan. Rivian aims to launch its R1T pick-up truck and R1S SUV in late 2020; both are based on a skateboard platform and are said to have battery ranges of up to 400 miles.

Connecting charging solutions

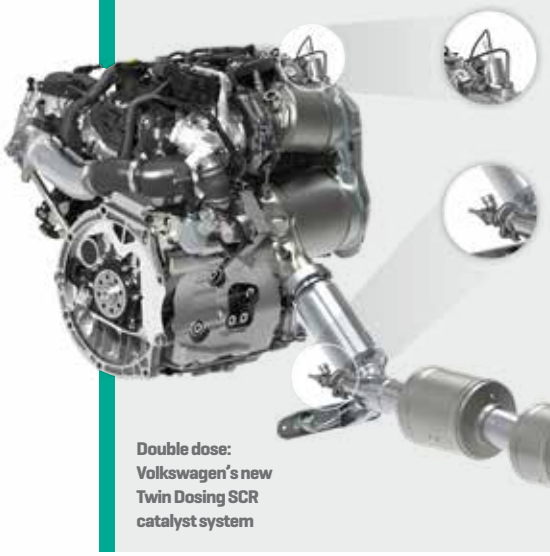
Alongside the electric vehicles unveiled in Frankfurt came equipment and solutions for charging them. Honda revealed its production-ready e city car plus options for both domestic and on-street charging, the latter being lamp post-integrated technology from partner Ubitricity; it also demonstrated vehicle-to-grid and power management technology, to go on trial with a local authority in London, and confirmed its intention to become a commercial energy service provider.

Volkswagen is applying a similar three-tier approach to its home charging solutions for the battery packs of the ID.3 itself: the basic ID. Charger wallbox (11-22 kW); the upgraded ID. Charger Connect with digital connectivity to a home network via W-LAN or LAN plus a further LTE option, giving control via an app, with remote maintenance and updates; and the range-topping ID. Charger Pro, with integrated meter for kilowatt-hour billing, i.e. for company car drivers. ID.3 buyers can sign up to Volkswagen subsidiary Elli for renewable electricity supply, and access around 100,000 public charging points in Europe via Volkswagen's WeCharge network, further illustrating how automotive OEMs are embracing the opportunities to provide services as well as products.

Hyundai Motor Group, meanwhile, has joined the IONITY high-power charging network as a partner and shareholder; founded by BMW, Ford, Daimler and Volkswagen, this currently provides around 140 HPC (350 kW) facilities to customers in 12 European countries, with a further 50 sites – all supplying renewable-source electricity – said to be under construction.

The Honda e is offered with 100 kW and 113 kW power outputs, and a compact battery giving a range of up to 220km

Combustion engines clean up



Double dose: Volkswagen's new Twin Dosing SCR catalyst system

Internal combustion engines are cleaning up their act in a rapidly tightening regulatory framework, and reporting on its second batch of test vehicles, Green NCAP, the new independent testing body for vehicle emissions, concludes: "new diesel-engined cars, with proper calibration and effective after-treatment, can deliver extremely low pollutant emissions."

Volkswagen claims an impressive 80 percent reduction in NOx from its new Twin Dosing SCR system for diesels *(pictured)*. This features twin SCR catalysts in series, the downstream unit being combined with the particulate filter and operating at a lower temperature than the close-coupled first converter to broaden the effective operating range. It is fitted to the 2020 Passat and will migrate to other VW Group models. VW also has new-generation gearboxes with low-friction bearings and wider ratio spreads, enabling a claimed 5 g/km CO_2 saving.

In gasoline engines, Hyundai-Kia's CVVD valve control system varies the duration as well as the timing of valve actuation, improving performance by 4 percent and economy by 5 percent and achieving a claimed 12 percent reduction in emissions. Mazda's innovative Skyactiv-X combustion system is the first to combine spark and compression ignition in a gasoline engine: in the new Mazda3, it gives 180 hp with 96 g/km CO_2 emissions.

Hydrogen hopes rise

Japan is emerging as a leading advocate of hydrogen to help speed up the decarbonizing of transport and industry. Its ambitious plan will see a variety of innovative vehicles showcased at next year's Tokyo Olympic Games, and calls for a 90 percent reduction in the production cost of the gas by 2050, along with a quartering of the price premium for FCEV vehicles; and a target of 200,000 on the road by 2025 and 800,000 by 2030.

In Germany, researchers from the Fraunhofer Institute for Solar Energy Systems have calculated that the climate impact of an FCEV's powertrain – including its fuel cell, hydrogen tank and other components – is similar to that of a 45-50 kWh battery for an EV capable of 250 km, with FCEVs winning out beyond that distance as longer-range EVs are hampered by the 'rucksack' of their larger battery.

The European Commission's Clean Planet for All strategy identifies hydrogen and fuel cell technologies as one of the new energy technologies needed to achieve significant greenhouse gas cuts by 2050. The main aim of its Fuel Cells and Hydrogen Joint Undertaking is to enable commercial deployment by 2020.

Sustainable economy

Prompted by the growing likelihood of zero-carbon targets in the coming decades, the world's engineers, inventors and researchers have been coming up with a wealth of imaginative ideas. California start-up Prometheus hopes to extract gasoline from atmospheric CO_2, while Tata will open a carbon capture plant in Cheshire, UK. Abundant water in disused British coal mines is already finding new value, as open-loop water-source heat pumps extract 6 kW of energy for every kilowatt input; the Coal Authority estimates there is enough geothermal energy to heat 180 million homes.

A new pallidum diselenide material co-developed in Siberia and Stockholm helps boost efficiency of photovoltaic systems, and scientists in Dresden have come up with a photovoltaic fabric that generates electric current, which could have applications in clothing and also on truck sides. South African and Belgian engineers, finally, have developed a clear glass which harvests the ultraviolet and infrared radiation invisible to the human eye to generate electricity. Automobile windows are a possible application.

Australia's first electric bike

Priced from AUD 9990 (€6200), the Australian Fonzarelli NKD electric mini-bike features belt drive and regenerative braking and can travel up to 120 km and reach 100 km/h.

In the US, Electrify America has done a deal with Harley Davidson to provide free charging to owners of its new LiveWire electric motorcycle.

Emission-free JCB

The silent building site comes a step closer with JCB's announcement of an all-electric excavator. The company claims the new 19C-IE is the construction industry's first ever battery-powered mini excavator and, perhaps less surprisingly, that it is a "staggering" five times quieter than its diesel counterpart.

Capable of running for a full typical working day on a fresh charge (which takes two hours), the digger's running costs and servicing requirements are between 50 and 70 percent lower than those of a conventional machine. The company says that the model, which is already in series production, is expected to be a big hit with operators working inside buildings and in emissions- and noise-sensitive inner-city areas.

VIEWPOINT

What is the true cost of different transport modes?

Ella Andrew – analyst consultant, policy strategy & economics, Ricardo Energy & Environment

We pay for transport through fares, fees and taxes. But do these charges accurately reflect the impact of each form of transport on society and the environment? A ground-breaking report compiled for the European Commission and co-authored by Ricardo looks at what would happen if the true externalities of each mode of transport were built into its pricing structure.

Transport brings many benefits to society, but it is something of a shock to realize that the broader societal and infrastructural costs of transport exceed the revenues generated by transport-related taxes. In fact, for the majority of vehicle categories, only 15 to 25 percent of these costs are covered by tax and charge revenues. More shockingly still, for motorcycles and diesel passenger trains the average costs significantly outstrip tax and charge revenues: this is primarily due to significant air pollution and noise, and infrastructure costs respectively.

This is perhaps unsurprising when confronted with the significant costs associated with the expansion of transport networks. New transportation projects and the expansion of mobility networks resulted in infrastructure costs of € 267 billion in 2016 in the EU28, with € 184 billion for road, € 81 billion for rail and €3 billion for inland waterway transport (IWT).

In parallel with infrastructure costs, the use of transport services engenders widespread external costs amounting to €987 billion in the EU28. External costs are defined as costs imposed on a third party not involved in the consumption of the service in question. These costs include air pollution, climate change, congestion and accidents, all of which contribute towards a negative impact on society.

By way of a footnote, the congestion figure only includes costs for road transport, as it was not possible to estimate those for other modes. In general, the most important cost category is accident costs, equating to 29 percent of the total costs, followed by congestion costs (27 percent). Overall, environmental costs (climate change, air pollution, noise, well-to-tank and habitat damage) make up the remaining 44 percent of the total costs.

Although the costs are significant, some transport modes prove more successful than others in covering their costs through tax and charge revenues. Owing to high fuel and vehicle tax levels in some EU member states, passenger cars cover 50 percent of external and infrastructure costs. However, for IWT and maritime transport, much lower cost coverage ratios were found (6 and 4 percent respectively), reflecting the limited tax and charge burden levied on these modes in the EU.

"Transport brings many benefits to society, but broader societal and infrastructural costs of transport exceed the revenues generated by transport-related taxes"

It is therefore clear that transport taxes and charges levied in the EU are, in general, insufficient to fully cover the external and infrastructure costs associated with transport. To improve internalization, Ricardo and our partners made a number of policy recommendations: these include applying graduated rail access charges according to noise levels generated, and wider use of distance-based road charges differentiated to vehicle characteristics.

Alongside measures for increasing revenues, it is also important to introduce measures which aim to reduce the average costs of transport modes such as rail, so as to increase the utilization rate of the infrastructure. In addition, subsidies and non-pricing regulatory policies can be applied to achieve cost coverage and more fairly reflect the true cost to society.

For more about cost coverage in the transport sector, and recommendations for policy and research which could help to guide policy-making with external and infrastructure costs in mind, download the summary report at: https://ec.europa.eu/transport/sites/transport/files/studies/internalisation-study-summary-isbn_978-92-76-03076-8.pdf

RQ INTERVIEW

Hydrogen society

Next year, at the Olympic Games in Japan, Toyota will roll out a broad array of new mobility solutions - solutions which it believes will form the basis of a future hydrogen society. In RQ's interview with Toyota GB alternative fuels manager **Jon Hunt**, **Tony Lewin** finds out just how the transition to this new clean energy vector will take place

The International Energy Association has declared 2019 to be the year of unprecedented momentum for hydrogen. To what extent does Toyota agree?
There has been a longstanding recognition of the role hydrogen can play in various sectors. We have seen a growth and then a drop-back for hydrogen over several cycles; the challenges before have been around some technical aspects, the price of oil, and how you integrate across sectors at different maturity levels. Despite this, the technologies have been developing in the background over decades and across sectors . Over the last four or five years, on top of the concern about CO_2 and climate change we have seen a recognition that air quality and pollution in general are having a fundamental impact on human health. And it is the health impact, more than anything else, that has now brought hydrogen – which is ready to scale – to public and international attention.

How is hydrogen gathering momentum internationally?
The Hydrogen Council was formed in 2015 and now has about 60 members. It is dedicated to delivering the broad hydrogen society across multiple sectors; it is commercial and CEO-led. What we are seeing now is that focus really bearing fruit: the technology of hydrogen - whether it's in heat and power, in transport, or in industry – is now at a level that can be scaled. Nothing needs to be created or invented. As a result, we can present a united front.

How does that work in the case of transport?
One of the challenges in transport is the silo view that you encounter. You need to appreciate the broader context and that there is no silver bullet. For example, you can't deal with transport issues until you deal with energy issues. And you can't deal with energy issues without understanding the global situations. You've got to think how you address the problems in sub-Saharan Africa, in central Europe, even in the Arctic. That alignment is starting to happen, and what you see, for example in the recent report from the IEA, is that clear pathways are now being mapped. Hydrogen is one of the pathways, and there is now a defined timeline and willing investment – because there's going to be a return on that investment.

How does Toyota fit into this?
In 2015 Toyota launched its sixth environmental plan, the Toyota Environmental Challenge 2050 – Tech 50 – which is an integrated programme of sustainable activities that include the resources we use, the energy in factories, the vehicles we put on the road, the recyclability of those vehicles, the energy they use in [their operational] life. One of the key components of that is introducing the best solutions for the situation. Hydrogen is what Toyota as a business identifies as the ultimate zero-emission energy vector. It will be used in many different creative ways alongside other suitable technologies. The business has always looked to improvements; for example at our Burnaston (UK) factory, the largest industrial solar array in Europe was installed and all our others around the world have very clear targets for sustainability. Integration of hydrogen will definitely happen within them and we already have a timeline through to 2050.

Some examples of what you are doing?
One challenge is to make best use of renewable energy. In certain conditions solar and wind, for instance, can become stranded assets when they are producing more power than the grid can accept. If these stranded assets can be brought together and that energy moved appropriately, then you've unlocked a global distribution network. In our Motomachi plant, which manufactures the Mirai, we have a solar unit which produces hydrogen, which is used in the forklifts; this could be replicated in all regions.

Why is it better to store that energy as hydrogen, rather than as electricity in a battery?
It depends on the conditions. In Japan there is a test programme being developed with [the convenience store chain] 7-Eleven. What we're doing there is using redundant hybrid batteries to store energy on site; some of the stores have forecourt stations so they will be able to produce hydrogen from solar arrays. That energy can be used to run fuel cells for the store itself, excess energy can be stored in batteries as a back-up, and it can be supplied to the refrigerated fuel cell trucks that are delivering the food. The interesting fact is that it can be run completely off grid: one of the issues in Japan is earthquakes, and the fuel cell trucks act as mobile generators to provide resilience in areas where grid electricity has been cut off.

How might hydrogen be used in industry? Can you, for instance, heat a blast furnace with it?
Yes. Hydrogen can produce a lot of heat. Back in the 1950s and 1960s, our gas network for residential and industrial use was based

on coal gas. Coal gas is around 60 percent hydrogen, and that's what we use to put through the pipes. If you concentrate that gas, make it purer and purer hydrogen, you can get greater heat and you will reduce the emissions. Already in production are fuel cells that produce electricity and heat from natural gas, CH_4, and they can run on anything between zero and 100 percent hydrogen. They can be implemented in any setting, whether it is commercial or residential.

One of the difficulties with hydrogen is that it can sometimes produce too much heat. How do you get round that?
Until recently that was the case. But Toyota has developed an injection process to pre-combust some of the hydrogen, which reduces the amount of oxygen available for the main burner to give a lower flame temperature and reduce emissions. This means it can be used domestically, and the process was developed using our experience of engines and fuel injection. Baxi has just started trials in the Netherlands with 100 percent hydrogen boilers; already, combined heat and power boilers are available globally, though in Europe we haven't really touched on using them.

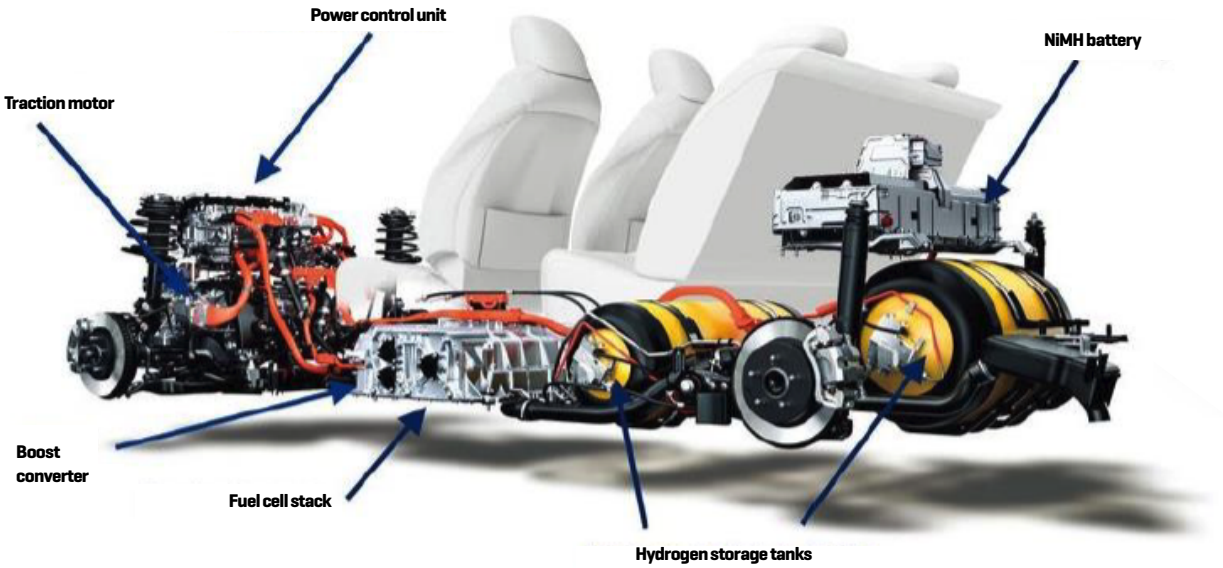
Honda is among the automakers to have developed a home energy station where people can use domestic gas to generate heat and hydrogen. Is home fuelling feasible for hydrogen-powered cars?
Doing this domestically and in different environments is probably quite challenging. The interesting thing about hydrogen as an energy store is that it is extremely efficient in terms of distribution and utilization because it has multiple uses. So what you can envisage is that in an area - such as a housing estate – all those homes with solar panels on their roofs can deliver that energy centrally. That energy can be used to generate hydrogen through electrolysis, so it is completely off grid; you get hydrogen for transport and to feed back into homes for heat and electricity. This would help cover the ups and downs of renewable generation.

So would this be a kind of community energy hub?
Effectively, yes. You are centralizing your energy and, rather than having your own personalized hydrogen refueller, you get a localized refueller which can satisfy everyone – not just locals but passing vehicles, too, and for passenger cars as well as commercial vehicles and public transport. These hubs can really act off grid: it is localization that increases overall resilience.

Toyota Mirai fuel cell sedan, first launched in Japan in December 2015

Turning now to the Mirai fuel cell sedan, how are you marketing it? It costs more than twice as much as an equivalent combustion-engined executive car.
Right from the start we realized that this is a new technology and we can't presume that customers will accept it. When introducing it in the US the decision was to focus on retail users; in Europe, the decision was to try and identify businesses that could use the vehicles. This would give us a balance of understanding. In the UK we have 137 on the road so far: the biggest fleet is the London-based Green Tomato taxi company, which has 50 .They use the London fuelling infrastructure and have big utilization rates with an average of 150 miles (250 km) a day; London's Metropolitan Police are big users too. The

"Hydrogen is one of the pathways, and there is now a defined timeline and willing investment – because there's going to be a return on that investment"



Toyota's fuel cell system (TFCS), as in the Mirai. The TFCS is also being supplied to Caetanobus SA in Portugal for trial in city buses

businesses we get are those who find it hard to decarbonize: the taxi operation, they sweat the assets, and the police always need to respond quickly – they have very few alternatives, and they have the most demanding conditions.

How does the Mirai compare in terms of TCO (total cost of ownership)?
Business customers have a good understanding of TCO, so whilst the cars' cost in terms of retail price is high relative to other vehicles you can buy, when you look at TCO they are very competitive. From the perspective of a taxi company they need absolute reliability, and the biggest factor in TCO is residual value: our maintenance costs are low and our fuel cells simply don't wear out. So when businesses lease the cars, they are as cheap as a normal vehicle.

Is filling station coverage in Europe adequate?
The Mirai has a 500 km range, so the UK would require 65 sites to cover everyone geographically; 1100 would be needed for full convenience. Today there are 11 stations for passenger cars, plus two for buses. Across Europe, Germany has strategic plans for 100 this year and 400 by 2025.

Have recent government announcements of zero carbon by 2050 resulted in a spike in interest?
We've been producing hybrid vehicles for over 20 years and more than 50 percent of our sales across Europe are hybrid. There hasn't been a kneejerk reaction, but what we have seen is that awareness of the technologies, whatever they might be, has increased greatly – and this, by the way, is a job that governments can [also] do. But we have seen more interest in plug-in hybrids and, of course, hydrogen. The big step change is that of actual air quality.

What do you see as the key steps in expanding the use of hydrogen?
Hydrogen vehicles will ramp up more quickly than hybrids did. What you have to bear in mind is that every fuel cell car is an electric car: so [in general] we need more electric powertrains to be developed, ready for mating with fuel cell power. But the real driver will be the development of some of the other areas of hydrogen use. Because hydrogen is a versatile energy vector as well as an industrial feedstock, what you will see is an inevitable growth of hydrogen utilization in other sectors. And as a consequence it will become cheaper and far easier to access for transport, for trains, buses and other commercial vehicle applications. This in turn will unlock new opportunities including small-scale localized and off-grid production of hydrogen. RQ

Jon Hunt, manager, alternative fuels, Toyota GB plc
Jon has worked in the automotive industry for almost 30 years, and has been with Toyota 26 years in a variety of sales and marketing roles in the UK and Europe for both the Toyota and Lexus brands. Since 2014, when Toyota decided to launch the world's first hydrogen fuel cell electric vehicle (FCEV) production car to the global market, he has been responsible for the commercialization of the Toyota hydrogen FCEV programme in the UK. He sold and delivered the first Mirai FCEVs outside Japan in September 2015 and is the Chair of the Society of Motor Manufacturers and Traders Hydrogen Fuel Cell Task Force.

Driving – and refuelling – the Mirai

The size of an Audi A6 rather than an A3 or VW Golf, Mirai is like a much bigger Prius hybrid on the road. It is silent and seamlessly smooth almost all the time, and its different drive modes can be used to balance driving range with extra responsiveness for, say, overtaking at motorway speeds. A buffer battery helps with kickdown-style acceleration, and a suite of driver aids ensures it is up with the very best in terms of safety. The refuelling process we tested at the Cobham Shell hydrogen station on the M25 motorway, outside London, appears complex at first but is soon mastered; the procedure is automated once the nozzle is properly connected, and only takes a couple of minutes for a full 300-mile refill.

Shaping a safer ATMOSPHERE for tomorrow

Fifty years of evolving legislation have helped reduce the damage vehicle emissions inflict on the world's atmosphere. Today, as we stand on the threshold of a new era of multiple fuel and powertrain choices, the challenge of establishing an all-encompassing set of rules is even greater. **Jesse Crosse** speaks to the Ricardo air-quality experts at the centre of discussions about the new holistic post-Euro 6 standards essential to keeping tomorrow's environment clean

It was back in 1966 that the state of California introduced the world's first legislation to curb tailpipe emissions. Ever since then, the debate over the extension of these exhaust standards has been intense and often bitter, confronting the global auto industry with some of the biggest conundrums in its long history.

So today, more than 50 years later, one of the most crucial questions facing the industry is what comes after Euro 6. Ricardo is a key player and part of a consortium set up to work with the EU Commission to come up with the answer. Other members include OEMs, oil companies and Tier 1 suppliers.

Jon Andersson, Ricardo's global technical expert on emissions measurements and standards, is a key member of the consortium known as CLOVE (Consortium for Ultra Low Emissions Vehicles). "At Ricardo, I'm responsible for identifying not only what emissions we might have to deal with," he explains, "but also how we physically measure it, and I bring that expertise to CLOVE."

Electrification, other pollutants, and avoiding Catch 22

While emphasizing Ricardo's belief in electrified vehicles generally, Andersson believes the growing enthusiasm for electrification in the public and political arenas is often driven by emotion rather than science. The European Commission agrees that electrification is not the single solution and that it may not necessarily be the panacea for the world's emissions woes that people think it is.

"It certainly won't be the pathway for heavy duty vehicles, and there's huge potential for light duty vehicles as well in terms of combustion-based technology," continues Andersson. "There will have to be other solutions too, and there is a great deal of effort being focused in the industry on parallel paths that will accompany electrification."

The likelihood is that more pollutants and greenhouse gases will be addressed in the next stage of regulations, but it will be vital to ensure that new regulations don't inadvertently make matters worse.

Emission standards

Emissions standards have become much tougher since Euro 1 was introduced almost 30 years ago, but they will soon become tougher still.

Euro 1: applied to all new vehicles from 31st December 1992
Gasoline
CO: 2.72g/km
HC + NOx: 0.97g/km
Diesel
CO: 2.72g/km
HC + NOx: 0.97g/km
PM: 0.14g/km

Euro 6: applied to most new vehicles from 1st September 2015
Gasoline
CO: 1.0g/km
THC: 0.10g/km
NMHC: 0.068g/km
NOx: 0.06g/km
PM: 0.005g/km [direct injection only]
PN [Number/km]: 6.0x10 ^11/km [direct injection only]
Diesel
CO: 0.50g/km
HC + NOx: 0.17g/km
NOx: 0.08g/km
PM: 0.005g/km
PN [Number/km]: 6.0x10 ^11/km

Dealing with the emission of one particular substance inevitably leads to a Catch 22 situation, where the steps taken to neutralize the effect of one pollutant can cause knock-on impacts on another. A prime example is the way the introduction of diesel particulate filters contributed to the urban NO_2 problem. In the same way, though electrification is without doubt a powerful environmental tool, its wider consequences beyond the EU could be profound if not carefully controlled, thanks to upstream factors such as the impact of mining on local air and water quality.

Creating the bigger picture

For that reason, Andersson is keen to emphasize the importance of the bigger picture. That means considering continental problems as well as local ones, or what he calls 'problems in the neighbourhood'.

In addition to tailpipe emissions, local problems can include non-exhaust emissions which also degrade air quality, he explains: "So let's not drive policies focused solely on exhaust emissions: that could damage the rest of the world just to solve local issues." On a continental level, he continues, we need to factor in trans-boundary pollution from countries getting their energy predominantly from coal, and also to include secondary aerosols (produced by the reaction of particles in the atmosphere) as well as the contribution of the familiar well-to-wheel emissions. Then, expanding the scope still further, there is a universal level where the whole world is contributing to emissions. These can derive from irresponsible raw material sourcing, and emissions of greenhouse gases that contribute to global warming, as well as other noxious pollutants.

If you take this holistic view, says Andersson, the generally accepted idea of what is environmentally sound, and what isn't, suddenly becomes less convincing.

If EVs are charged with electricity from grid networks that use predominantly coal-fired power stations (and there are many globally), then well-intentioned policies may later turn out to have unintended consequences. "While Ricardo is absolutely in favour of electrification deployed in the right way, let's not fall into the trap of creating an 'electric NO_2' problem," says Andersson, referring to the acknowledged unintended consequence of Euro 5 and the widespread retrofitting of diesel particulate filters (DPFs).

In contrast, he says, the latest super-clean diesels burning low carbon fuels could easily outperform an EV running on non-renewable grid energy. This underlines the importance of life cycle (or at least, well-to-wheels) analysis. "In these two cases," asks Andersson provocatively, "which one would be the angel and which the devil?"

All agree: the next stage will be the last

One thing the European Commission and the stakeholders all agree on unequivocally is that the next stage will be the last stage of emissions regulation. "It may be called Euro Ultimate or Euro Omega, or it may be called something other than "Euro" because we want buy-in from a much larger geographic region," explains Andersson.

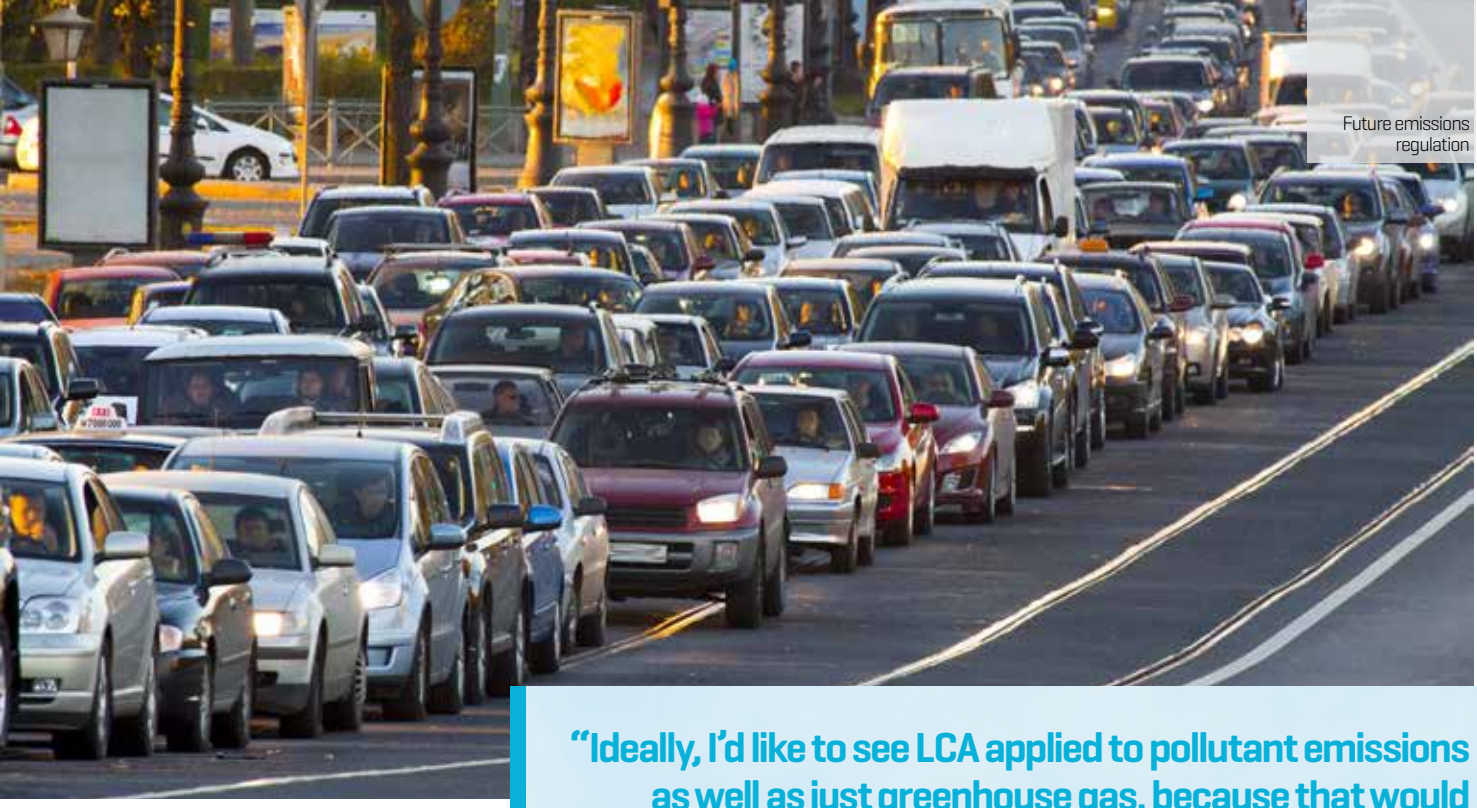
Looking ahead, there are several factors to take in account, which factors which go well beyond the current suite of emissions already legislated for. One is the possibility of a new fuels directive to enable the introduction of low-carbon fuels, something which would help to perpetuate internal combustion engines and put them on a fair footing with electric vehicles.

A 'zero emission' electric vehicle is not zero emission if you take into account its entire life cycle. Andersson believes there will be a new fuels directive, but at this stage no one can say how big its scope will be: "The complexity is that the specification for any new fuels has to be agreed between the fuel suppliers and OEMs, and it has to be rigorously understood so that vehicle warranties will stand with the new fuels. The liquid and gaseous road fuels of today have evolved slowly over a long period of time, so having a paradigm shift in fuel chemistry will be very demanding - yet the timeframe for the next legislative stage is relatively short."

Extending the scope: new species, more durability

A second factor is the extension of the range of pollutants the legislation will cover. It is expected that a number of new species of pollutants will be included in the regulations, and Andersson suspects these might even be applied in further steps of Euro 6 preceding this next major 'ultimate' step of a holistic standard.

The inclusion of these new pollutants is likely to go hand in hand with a strengthening of the durability criteria for new cars. "At the moment, full useful life



> **"Ideally, I'd like to see LCA applied to pollutant emissions as well as just greenhouse gas, because that would produce a genuinely level playing field, and truly realize the environmental benefit"**
>
> **Jon Andersson, Ricardo global technical expert on emissions measurements and standards**

in Europe is assumed to be 160,000 km; in the US it is 240,000 km and I wouldn't be surprised to see it go even further, to, say, 300,000km. In essence, that a vehicle will have to produce lower emissions even if you keep it for 15 years and drive it for 300,000 km."

Complex questions surrounding durability include things like who looks after the vehicle and who warranties an aftertreatment system for 15 years.

In-service compliance (ISC) will be a further consideration. This involves some means of monitoring the emissions control efficiency of vehicles in the real world. Measures may include the use of remote sensing, portable emissions measurement systems (PEMS) both for certification and for in-service compliance testing. "I think we will see the PEMS boundary conditions tighten," explains Andersson. For example, the scope will encompass higher altitudes and both higher and lower temperatures than currently legislated for, as well as more aggressive transients and the urban component becoming shorter. Whereas Real Driving Emissions (RDE) assessments currently represent 95 percent of normal driving, they could go much higher, to 99 percent, for example. Some non-governmental organizations (NGOs) are pushing for testing to include every possibility, something which is hardly realistic, but the scope of RDE testing will certainly be increased.

A fourth consideration will be in-use performance monitoring (IUPM), which is linked to new on-board sensors. Modern vehicles already include NOx sensors, and the Lambda sensors that enable three-way catalytic converter systems have been around for a long time. The proliferation of all types of new sensors for various uses makes it a fairly straightforward proposition to constantly monitor the health of the vehicle and send the data up to the cloud. If the vehicle's emissions systems go awry, the vehicle will be called in for an emissions test. This is already happening to some extent, and Fiat Chrysler Automobiles already monitors the fuel consumption of its vehicles in this way. The data has revealed a wide range of CO_2 emissions depending on driver styles and region – useful incremental information as RDE testing does not yet include CO_2 (fuel consumption) measurement.

Travelling more intelligently – and more cleanly

Intelligent transport systems and connectivity (ITS) will also be included. "It should be possible to make a car behave differently when it is in a city, and you can use geofencing to do that," says Andersson.

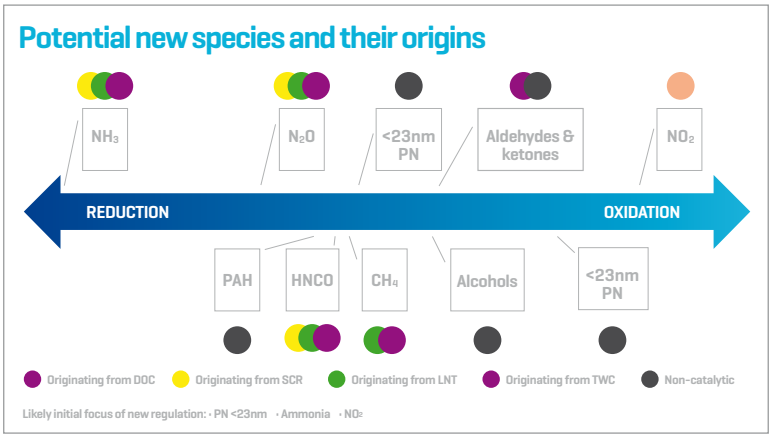
Geofencing monitors the position of a vehicle using GPS and triggers an alert should it cross a virtual 'fence' defined in software by map co-ordinates. Vehicle tracker systems are an example of geofencing already in widespread use today. "When the vehicle crosses the boundary it could be switched into a different mode, or the system could be used to prevent vehicles from leaving a certain area because they won't function outside," says Andersson. "Those possibilities are a little more remote but they are certainly being discussed."

Technological neutrality is under consideration too, where all technologies are subject to the same level of regulation. Whereas today, for example, gasoline and diesel vehicles are subject to different pollutant limits, in the future they would have to co-exist on an equal footing. "China is already heading in that direction following the US," says Andersson.

Technical neutrality for tailpipe emissions will help preserve the focus on local air quality – for instance, on what causes a nitrogen dioxide (NO_2) or carbon monoxide (CO) problem in a particular area. The legislation will address low carbon pathways for internal combustion engines, as touched on earlier. "Pathways should be compared on a well-to-wheel or life cycle analysis (LCA) basis to avoid unintentionally incentivizing those coal-powered EV scenarios," says Andersson. "We don't want to get in the situation where we rule out the internal combustion engine and then find we haven't got all the materials to make the EVs that we need, so we have to have the parallel paths. Ideally, I'd like to see LCA applied to pollutant emissions as well as just greenhouse gas because that would produce a genuinely level playing field, and truly realize the environmental benefit."

The importance of good science

Measurement of emissions and limits will need to be based on what Andersson



A range of new emissions species, originating in part from the aftertreatment system, are likely to be the focus of new regulation

describes as 'good science.' There is not enough time between now and the likely introduction of the final-stage legislation by the end of the next decade to conduct health studies that are comprehensive enough to reliably link those measures directly to obvious health effects. Instead, there will need to be a link to benefits and air quality targets.

The timeline for the final stage of emissions regulation is aggressive, with Andersson suggesting that, typically, Euro stages are spaced from five to seven years apart. Under normal circumstances that would point to around 2025 for the new rules to come into effect but, as there is so much to implement, Andersson sees that timeframe being stretched to 2028 or 2030.

The likelihood, however, is that to ease the burden of the transition some new measures will be introduced earlier as part of the Euro 6 emissions series. By happy coincidence, the expected timeframe for the transition to lower carbon fuels is possible in the 2025-2030 timeframe, making a convenient fit with the future regulations.

Nanoparticles – a health warning

One thing the European Commission is especially keen to see implemented as soon as possible is a way of dealing with nanoparticles – the tiny particles that are not just produced by diesels.

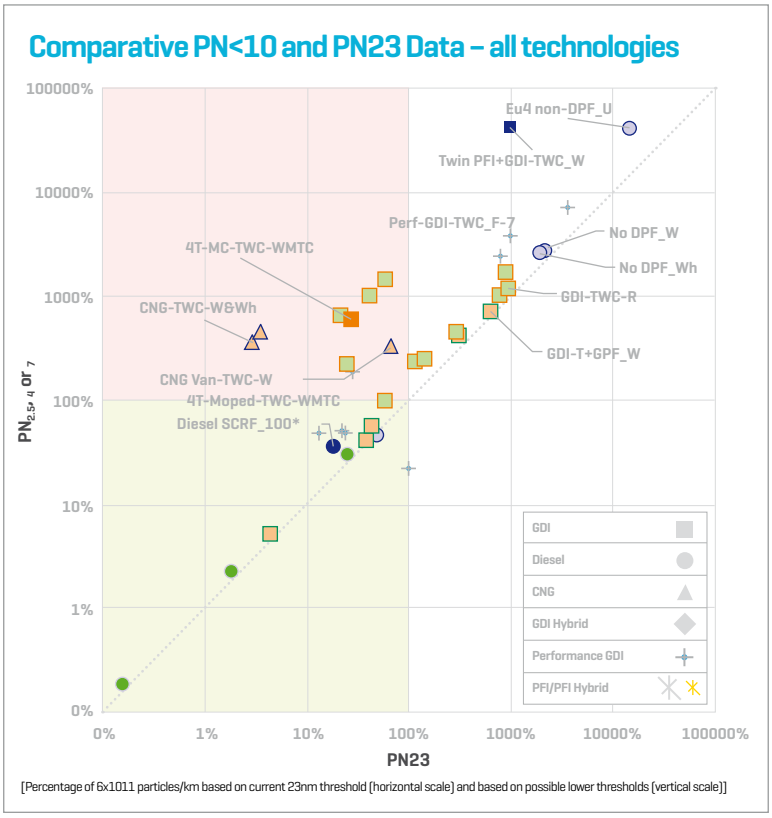
"The existing 23 nanometre (nm) lower particle size limit was established to force the use of soot-trapping DPFs, but below that size range (and independent of the soot) there are metal oxide particles and other sources of particles, at quite high levels," explains Andersson. Diesel DPFs already deal with these smaller nanoparticles, but mandating the use of particle filters on gasoline and even gaseous fuel engines would be the next step. Because filters have a near 100 percent clean-up rate, the problem of the smaller particles would be solved without lowering the emissions limit, instead simply extending the size range of particles for certification.

The future scope of regulation to include new pollutants extends to the 'nitrogenous' species. As well as NO_2 and nitric oxide (NO), the regulation will include the greenhouse gas nitrous oxide (N_2O – commonly known as 'laughing gas'). Ammonia, a pollutant which also transforms to PM2.5 in the atmosphere, will also be accounted for. This will be important because particulates pose a more serious health hazard than NO_2, despite the media focus on the latter.

Isocyanic acid (HNCO) is also of interest to the European Commission. "It's not something we've looked at yet," says Andersson, "but it is an intermediate in the process where the urea used in selective catalyst reduction (SCR) aftertreatment systems decomposes to ammonia; it can also be produced under rich-lean transitions by catalysts that have a reductive capability, such as three-way catalysts and lean NOx traps."

The carbon species of CO_2 and CO are already accounted for, yet in the forthcoming regulations sulfur dioxide (SO_2) and hydrogen sulfide (H_2S) will not be regulated at all. "This is because we have been so successful in pushing down the sulfur content in lubricants and fuels that there's not enough of either to be of concern in general operation," says Andersson.

The hydrocarbon methane should be classified as a greenhouse gas rather than a pollutant, he argues, and the expectation is that in the future methane and nitrous oxide will be grouped together as CO_2 equivalents (CO_2e). "What you don't want to do is have a separate limit value for these: instead, you just add them to the CO_2 targets," he continues. "Nitrous oxide is generated by nearly all types of aftertreatment system and if you set too stringent a limit for it the aftertreatment challenge increases without delivering a pollution benefit. Dealing with the nitrous oxide by classing it as CO_2 is the most effective way."



The current particle number emission limit is $6x10^{11}$ particles per kilometre based on a minimum measurement size threshold of 23nm. A likely area of focus for new regulation would be a reduced threshold to include sub-23nm particles, capturing particle emissions from powertrains that currently do not require fitment of a particle filter. Work by Ricardo shows the effect on compliance when different powertrain technologies are assessed at lower particle size limits

New suites of gases under the microscope

Other forms of hydrocarbon under consideration are the non-methane hydrocarbons (NMHC), non-methane

Future emissions regulation

> **"It is vital to take a holistic life cycle view of the impact of both greenhouse gases and pollutants to establish truly sustainable mobility for the future"**
> **Jon Andersson, Ricardo global technical expert on emissions measurements and standards**

organic gases (NMOG), aldehydes and acetaldehydes. An interesting question (and one which highlights the fact that it is easy for measurements to mislead if they are misunderstood) is the classification of NO together with NO_2 for emissions purposes, the two simply being referred to as 'NO_x'. This is done because, over time, NO oxidizes to NO_2 in the atmosphere anyway – yet in terms of local pollution it is only NO_2 which is a major health hazard and NO is much less harmful. Were they to be treated individually to reflect only the amount of the harmful gas NO_2 present in the air, another problem would arise. NO is lighter than NO_2, but in classifying them together, its weight is assumed as equal to NO_2. Were they separated, anyone adding the two individual quantities together would see an apparent reduction in the original NOx level. Such is the complexity of representing emissions in a meaningful way, especially as NO_2 is widely and regularly discussed in the media. "We're not even close to having the discussion as to how to deal with that yet, but when we do, it will be an interesting one," says Andersson.

Finding the best way forward

The intention is that this new wave of post Euro 6 regulations will be the last 'ultimate' stage of European emissions regulation. It will need to encompass a massively wider spectrum of new fuels and power sources, and to take a whole-life approach to all the elements involved.

Whatever shape the finished framework takes, it will be huge and multi-faceted. Its complexity means it will take longer than usual to complete, possibly until 2030. Before then, there may be more stages to go through to bridge the gap between now and the final stage.

New pollutants will come under scrutiny, something which may create new challenges in aftertreatment development. The first of these new pollutants to be considered could be sub-23nm PN (number of particles measured smaller than 23 nanometres). Limit values of various pollutants need to be carefully considered to avoid the setting of arbitrary limits which may, as we have seen, have an unfavourable impact elsewhere in the emissions suite; additionally, the way in which greenhouse gases and CO_2 equivalents are dealt with in the future will also need careful consideration.

Internal combustion and EV pathways will need to be developed in such a way that both the local and the global issues surrounding them are considered for the long term. 'Yet, and perhaps the most important of all as Andersson says, "it is vital to take a holistic life cycle view of the impact of both greenhouse gases and pollutants to establish truly sustainable mobility for the future."

Emission perception

Perception plays an important part in understanding the impact of emissions. NO_2 is the focus of attention regarding local air quality in cities based on quoted NOx figures. But broken down, the facts paint a different picture.

NOx is a blanket term for three gases: nitric oxide, nitrogen dioxide and nitrogen dioxide. All three are grouped together for the purpose of setting emissions limits and it is the last of these which is the cause for concern in terms of local air quality because of its harmful effects on health. But of NOx emitted from the latest diesel, only around 10 percent or less is nitrogen dioxide. Yet most air quality models assume that 30-50 percent of NO_x is NO_2, a huge departure from reality. Removing the old diesels from urban environments could solve the local nitrogen dioxide problem in cities, whereas pushing the introduction of EVs in place of new EU6 diesels can never do so.

Helping NASA navigate BIG DATA

Ricardo Defense is providing the United States' National Aeronautics and Space Administration (NASA) with advanced software for the analysis and optimization of large and complex data sets – data which will be used in the planning of future deep space missions. **Anthony Smith** reports

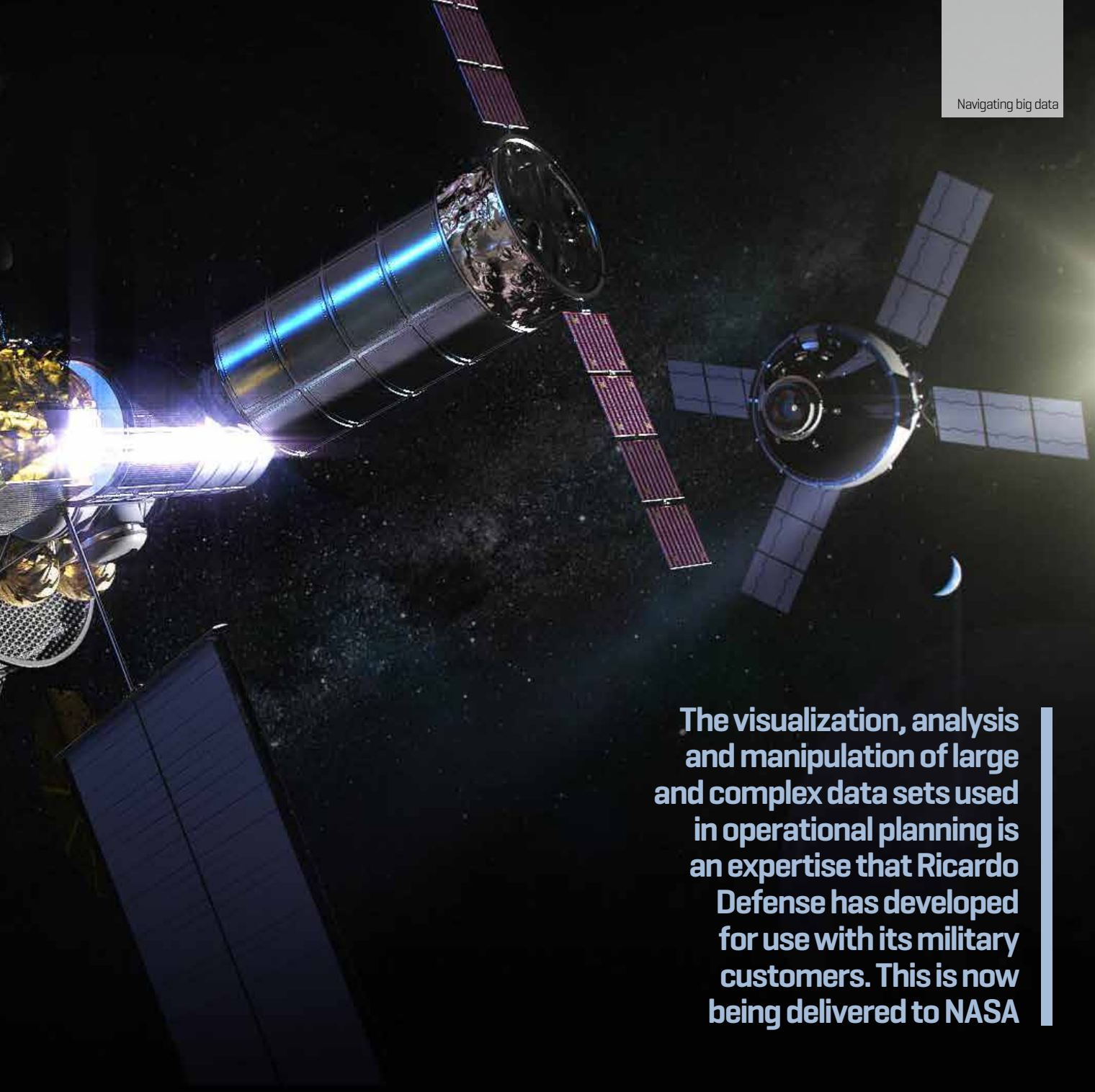
NASA has an enviable and well-deserved reputation for the planning and execution of the most challenging, safety-critical and complex of space missions. Fifty years since placing Neil Armstrong and Buzz Aldrin on the surface of the Moon and returning them safely to Earth, the agency continues to strive for new frontiers. Now NASA is actively pursuing plans that envisage a return of astronauts to the lunar surface in 2024, with ambitions to extend human exploration to Mars and beyond in the years that follow.

In parallel, NASA's unmanned missions are following in the footsteps of the pioneering Voyager spacecraft, the first human-made objects to enter interstellar space. The new missions include numerous probes exploring the planets of the solar system, and the investigation of the Martian surface by a series of rovers, most recently the Curiosity vehicle of the Mars Science Laboratory mission, which remains active since touching down on the red planet in 2012.

The planning of these long-duration, deep-space missions is an extremely complex and data-intensive process, requiring the close and effective collaboration of numerous specialist scientists and engineers, ranging from risk managers and experts in human factors and systems analysis to user interface developers. Standard modern tools and techniques such as spreadsheets and project scheduling systems would have been beyond the wildest dreams of the engineers who planned the Apollo programme in the 1960s, but even today they are inadequate for addressing large, diverse and dynamic data sets for the modern, high-criticality missions now envisaged by NASA. The planning of such operations that risk lives and property on this scale can have only very limited tolerance and scope for ignorance, deficiency, or accident.

Software for big data analysis

The visualization, analysis and manipulation of large and complex data sets used in operational planning is an expertise that Ricardo Defense has developed for use with its military customers. This is now being delivered to NASA in the form of advanced visual data analyze software that allows teams to quickly analyse extremely large datasets in order to isolate potential conflicts, risks,



The visualization, analysis and manipulation of large and complex data sets used in operational planning is an expertise that Ricardo Defense has developed for use with its military customers. This is now being delivered to NASA

human or system errors, or excessive workload. This enables operating plans to be optimized, including providing for resilient contingencies. The software also enables the investigation of opportunities to eliminate non-value add activities, thereby minimising cost, complexity, and susceptibility.

The process on which it is based is known as Hierarchical Task Analysis (HTA), which enables groups - ranging from a few individuals up to large multi-organizational engineering teams - to systematically assess essential functions, interdependencies and capabilities to an appropriate level of clarity. This hierarchal analysis approach enables the development of a highly granular incremental understanding of each aspect of the wider business processes, providing a capability for continuous analysis of the probability of success or inherent resilience.

The method enables collaboration between teams and collaborating partners, while at the same time protecting sensitive information and intellectual property. A piece-wise analysis of interrelated functions of a complex plan is followed, with each successive level of decomposition providing a budget of constraints for all lower levels to ensure that more detailed activities are compliant with requirements of the higher-level plans. The software automatically identifies conflicts and opportunities for improvement where they arise, so that task expectations and the over-arching plan can be developed and optimized with the highest probability of success.

Visualization is key

Pioneered by Ricardo, important aspects of the software provided to NASA are its extensive data visualization capabilities and drag-and-drop graphical tools that follow standard Business Process Modelling Notation. These address the challenges of the large, dynamic datasets associated with collaborative planning of sequential and concurrent activities, activities that may each contain many potentially conflicting attributes.

A creative workflow technique enables analysts to follow their own preferred approach. Some, for example, may be detail-oriented and choose to flush out the full set of characteristics for each task in turn. Others may be methodical in dissecting functions in a rigorous decomposition, while still others follow

NASA aims to land the first woman, and the next man, on the Moon by 2024, as part of its Artemis lunar exploration programme, marking the agency's first human deep space exploration since the Apollo missions of the late 1960s/early 1970s. First use of the Artemis logo was in August 2019 during a spacewalk at the International Space Station *(cover image)*. **The Lunar Gateway** *(above)* **will serve as home base for human and robotic missions to the Moon and, ultimately, to Mars.**

⇢

a train-of-thought workflow through the business activities. This creative workflow approach permits multiple users to follow any order through the planning data, exposing crucial insights in a truly collaborative manner.

Graphical tools include a TreeMap enabling a comparative interrogation of activity complexity, including risks, resources, and errors. Complexity analysis provides insight into the relative weighting of contributing factors that will reduce the probability of success, so that they may be eliminated, reduced, or mitigated. A Spider or Radar diagram quickly accentuates inconsistencies between the budgeted constraints for an activity and the aggregated constraints from all elaborated subtasks. A quick selection changes the analysis focus to human-machine screen mock-ups for usability and user experience evaluation of the proposed final system. Additionally, dependencies, conditions, and time constraints are readily visible for the activity under analysis.

The software also includes a chromoscopic indicator palette – a unique, Ricardo-developed feature – that facilitates 2D/3D diagnostic analysis and correction of potential obstacles to mission success. User-specific and team-defined criteria are presented as a unique background or font colour, using a slider to switch between a range of assessment filters. This might be used, for example, to quickly identify all activities that are allocated to a certain team or subcontractor or partner organisation, or to highlight all activities with a risk exceeding a pre-set threshold.

Pioneered by Ricardo, important aspects of the software provided to NASA are its extensive data visualization capabilities and drag-and-drop graphical tools that follow standard Business Process Modelling Notation

Multi-industry potential

The powerful and highly sophisticated software provided to NASA was originally conceived and developed for the requirements of Ricardo Defense's military customers. Despite this initial focus, the software has clear potential to support the planning of a wide range of mission-critical operations across many industrial sectors, from energy systems management, autonomous vehicle development, hazardous materials handling, disaster response planning, and transportation systems optimization.

In this space application, this innovative Ricardo big data analysis technology has been delivered and is in pilot use by the NASA Human Factors engineering teams. It is thus helping the team that went to the Moon fifty years ago to plan effectively for a successful return to the lunar surface, and a bold onward programme of human deep space exploration. RQ

A previous era of human deep space exploration: Gene Cernan - the last man on the Moon - drives the Apollo 17 Lunar Rover in December 1972

Photos and illustrations in this article and cover courtesy of the NASA image library

Powering smart e-mobility in India

In a collaborative programme with Tata Power Delhi Distribution Limited, Ricardo engineers are assessing solutions to support the launch and deployment of India's largest-yet fleet of electric buses. Their work will also inform planning to ensure that the electricity distribution network can meet the demands of future electric vehicle uptake. **Farah Alkhalisi** finds out more

"It's the sheer scale of the population," says John Snow, senior consultant, power engineering, Ricardo Energy & Environment, when asked about the most immediately striking challenges that the programme needs to consider. "Tata Power is one of three network utilities in Delhi itself and they have about eight million people connected in the region; there's a massive population, it's increasing – and you don't quite know what the growth is going to be in the next five to ten years, because it's so rapid."

Alongside Delhi's surging population come the Indian government's ambitious plans to electrify transportation *[see p20]*, which include the deployment of electric buses in the city and its surrounding metropolitan area: a thousand are coming into operation through 2019-20, with a target of 10,000 in the next five years. The pressures this large fleet will bring on power generation and distribution must therefore be assessed, and appropriate smart management strategies identified and developed.

Under the terms of a collaboration agreement signed in July 2019 *[see p22]*, Ricardo has embarked upon a three-phase programme with Tata Power Delhi Distribution Limited (Tata Power DD-L). In the first phase, this aims to assess the network capacity in the vicinity of the bus depots in terms of load profile and projected vehicle charging scenarios; outline the design

Accelerating EV take-up in India – on a large scale

In 2015, the Indian government introduced a 1.4 billion dollar funding and incentives scheme termed FAME: Faster Adoption and Manufacturing of Electric vehicles. Initially supporting hybrid models as well, it subsidized vehicle-buyers including authorities, utilities, businesses and public transport providers to procure or purchase Indian-made electric vehicles, from two-wheeled motorcycles and rickshaws to cars, taxis, trucks and buses. In spring 2019, the three-year, Rs 10,000 crore (100 billion rupees) FAME II phase was launched, alongside ambitious targets and support for the installation of public recharging infrastructure in the country's largest metropolitan areas.

"The individual federal states are also providing incentives," explains Arbaaz Nayeem, associate director, Energy Practice, Ricardo Energy & Environment. "The Delhi government said it will have, in addition to FAME, about $30 million dollars to support electric vehicle uptake in the state of Delhi in the current fiscal year (FY2019-2020), probably the most generous in terms of incentives across the states in India. That's why we've seen a lot of activity in Delhi."

"And we need to put the numbers in context, because they dwarf anything we're doing here in Europe," Nayeem adds, with reference to supporting transport and energy demands. "If you look at Delhi, it has a resident population of about 15 million, just in the city, and then we're talking about the state of Delhi and the broader NCR (National Capital Region), which includes about 12 cities and townships and a couple of other states. So we'll be looking at about 30 million people, and maybe a couple of thousand square miles of area where the Delhi government's initiative is focused."

and evaluation of proposed technical solutions; carry out an initial cost-benefit analysis; and identify solutions suitable for implementation.

John Snow is leading the programme, with a team of five engineers based at Ricardo Energy & Environment's office in Guildford, UK, plus two team members based in Delhi and other Ricardo knowledge resources he can draw upon. "We have worked with lots of the leading utilities in Europe in the network innovation sphere, and we've got our experience in the automotive industry – and the EV sector in particular – as well," he says. "We're offering our experience of working in an innovative environment, of bringing forward new solutions, and working to develop and deploy these. We have a similarly forward-thinking state of mind to Tata Power themselves."

Work is now underway, he says. "We are in the early stages of assessing the technical aspects, asking some questions about the current infrastructure and finding out the situation from our point of view, because it's the first time we've worked in that region. So we're doing a process of network evaluation to understand what solutions we think might be suitable; and understanding the network assets they have at the moment, their level, and the differences from some of the other projects we've worked on."

Space, speed and state-of-the-art monitoring

"One of the most significant things we've found so far is that space is a real challenge in most urban environments in India," Snow says. "In Europe, we have cities like London, but the rest of a country is not so densely populated; and we also have loads of long-existing underground tunnels and ducts, so we're able to put a lot of the system underground." Physical constraints are more of an issue than technical limitations in the existing infrastructure, he explains. "In the UK, a lot of the focus has been looking at monitoring and getting greater network visibility, to understand how a network's behaving, whereas Tata Power actually has quite a lot of monitoring already and very good visibility: they've got smart meters and advanced metering throughout the network. They've got state-of-the-art technology, the latest systems, a lot of development; and some of their assets are more advanced than those in the UK."

Given that city space is already at a premium, Snow says, the country's urban power networks are challenged in terms of the number and size of its substations in densely-populated areas. "It's not as simple as saying we'll install a new substation, or we'll make that substation have more capacity, because

Power lines and pylons: India's network is said to be technically advanced and well-monitored

the capacity of a substation is linked with its footprint; and the footprint of the existing substations needs to grow to meet the future capacity."

Alongside space comes a further issue: speed. "India has historically done really rapid infrastructure update programmes, from the late 1990s with the national highway development programme when they were planning to build 20km of highway a day; now every state is connected, a massive initiative given the size of India," says Mohammad Arbaaz Nayeem, associate director, Energy Practice, Ricardo Energy & Environment. "That was followed by the Ultra-Megawatt Power Programme, which aimed to boost power generation capacity by 100GW by 2022; and since then, the renewable energy programme in which 170 GW of renewables will be deployed by 2025. The automotive and electric vehicle sector will be no different in terms of the expected speed of implementation."

This Ricardo-Tata Power DD-L collaboration therefore demands relatively well-proven solutions which can be quickly implemented, rather than technologies which may need to go through successive iterations or extensive field-testing. "We haven't got a single one-stop solution or product in mind," says Snow. "We will look at a range of solutions or options to see if they are suitable, whether they bring maximum benefit, and whether they align with the solutions Tata Power already has." As their monitoring is much greater than we've seen in other parts of the world, we'll look at how we can use that; and then at how the solutions we've explored elsewhere can be adopted in the Indian market."

Assessing solutions

Solutions under consideration and assessment include active network management; demand-side response; AC/DC power electronic devices; flexible voltage management; energy storage; DC microgrids; flexible connections; dynamic network reconfiguration; time of use tariffs for consumers; smart charging; and integrating the network and transport planning. Not all of these will be appropriate for deployment in Delhi, given their different technical readiness levels and the degree of development needed for longer-term upscaling, but the Ricardo team will draw upon their experience on applying such technologies in earlier projects in making their recommendations.

The Active Response programme with UK Power Networks *[see p23]*, focusing on the impact of electric vehicle uptake in London, has given the Ricardo engineers particular insight into how to manage growth in electricity demand. "That particular project's about using power electronic devices, new technologies which are being deployed on the distribution network," says Snow. "This is the latest thinking on managing growth. We're working with UKPN to develop and

"Tata Power is one of three network utilities in Delhi itself and they have about eight million people connected in the region; there's a massive population and it's increasing"

John Snow, senior consultant, power engineering, Ricardo Energy & Environment

Buses lined up by the Gate of India, New Delhi: the Indian government intends a significant number of buses to be electric in coming years

demonstrate, and uncover the challenges and benefits that these technologies bring. Although there are differences between London and large cities in India and there will be different solutions, it's the same problem statement."

Before making recommendations, however, the team must learn more about India's urban specific context. "What we are doing at the moment is really looking at the existing network capacity and how the seasonality of their network changes this," says Snow – "to understand the difference between European networks where ambient temperature is much lower most of the time. We want to understand when the networks in India are overloaded or at maximum capacity, and how that changes throughout the day, what the base load is – because air conditioning is probably one of their largest consumer device demands.

"We are going to look into that, and see whether any of the solutions we have to maximize the existing capacity might be applicable, but in order to do that, we have to look at how their network operates, how the demand goes throughout the day, and the month, and the year. That will help us make decisions on certain solutions which can help with the buses: for example, do you have peak demand during the evening, or the afternoon, but much lower with spare capacity at night-time? Or no peaks or troughs during the day? We will then think how this might change in the future with all this new electric vehicle demand, which is a new challenge – a new type of load."

The electric bus fleet is expected to initially add around 10 MW of load, Snow adds. "The grid has to consider: if we have to charge 1000 buses, or 250 connect into this bus depot, what's the impact for the local network around that depot, and what solutions can we deploy to manage that? It's likely that there will be fast-chargers within the depots, and it might be that we deploy other chargers by the roadside, other charging techniques which might be regular top-ups, or smart-charging options. We're not planning urban charging infrastructure ourselves, but there are a number of options for whoever is building it."

These options must reinforce stability across the whole network, Snow stresses. "The other issue is to keep the lights on: Tata Power has targets with fault-finding and fault restoration, so we're also looking at increasing or maximizing the reliability of the network, and how our solutions could support the network management – so if a fault happens, it's restored as quickly as possible with a minimum outage for consumers."

"One of the most significant things we've found so far is that space is a real challenge in most urban environments in India"

John Snow, senior consultant, power engineering, Ricardo Energy & Environment

Beyond the buses

Beyond the impending introduction of the bus fleet, the Ricardo team has been discussing further issues with Tata Power, says Arbaaz Nayeem. "There are

An agreement to collaborate

Tata Power DD-L (Delhi Distribution Limited) is a joint venture between Tata Power and the government of the New Capital Territory (NCT) of Delhi, India, and a publicly-regulated utility body; Tata Power Company holds a majority 51 percent stake. Tata Power DD-L has been the first Indian utility to join the Global Intelligent Utility Network Coalition (GIUC), a worldwide initiative working to accelerate common standards, technology solutions and processes for intelligent networks. It signed an agreement with Ricardo in July 2019 covering collaboration on topics including smart energy management technologies and process improvements; network resilience; integration of renewable energy technologies; and managing the growth in energy demand due to electric vehicle charging.

The agreement was signed by SanJay Banga, CEO of Tata Power-DDL; Timothy Skelton, director of advanced systems architecture – energy networks and associate director, Ricardo Energy & Environment; and Arbaaz Nayeem, technical director and associate director, energy practice, Ricardo Energy & Environment. Skelton said: "The extensive experience of both Tata Power-DDL and Ricardo experts will enable us to add significant value in tackling the energy challenges and recognizing the substantial opportunities in Delhi's fast-changing energy industry. We're very proud to be collaborating with Tata Power-DDL and look forward to seeing the positive impact our companies can have by working together."

"Tata Power and Ricardo offer complementary world-class knowledge and breadth of experience and expertise," Banga added. "Through this collaboration we aim to deliver strategic-level support and insight to help the energy distribution infrastructure of the Delhi region make more effective use of its resources, while exploiting the opportunities arising from innovations in areas including the integration of renewable energy generation and the electrification of road transport."

UK Power Networks: moving spare capacity to meet EV demand

Ricardo Energy & Environment's Active Response project for UK Power Networks (UKPN) has focused on automatic, dynamic reconfiguration of the electricity network to meet the changing energy demands from electric vehicle charging. Both high- and low-voltage power electronics in combination have been trialled to shift electricity demand from heavily-loaded substations to nearby substations with spare capacity, and to control the power transfer. Remote control switches and Soft Open Points (SOPs), giving active power flow control and monitoring, are deployed for advanced network optimization; and the power transfers between the primary high voltage substations are controlled using a Soft Power Bridge (SPB) to share loads and optimize capacity. In this ongoing programme, Ricardo has delivered a requirement capture for hardware and software; site selection; management of research packages; trial data analysis, modelling and inputs to the business case, and reporting of findings.

In another Active Network Management (ANM) project with UKPN, Ricardo has focused on flexible urban networks, trialling SOPs on low-voltage networks to quickly release and share spare capacity; it has also worked in partnership with Capula on a further project to explore the visualization of data for enhanced monitoring and asset management of UKPN's distribution network.

other challenges they are facing with the utilities, so it could be multiple different solutions that we will be looking at over the next couple of months. We could be looking at the wider uptake of electric vehicles, and also improving the network performance throughout the city and in other territories." This could involve supporting the expected near-term growth in renewable electricity, currently accounting for nearly a quarter of the country's entire generation with an ongoing large-scale roll-out of solar and wind farms. "A key point of electric vehicle uptake as well is that it helps renewable integration," Nayeem says.

An electric bus on the streets of Mumbai

In the next phase of the collaboration programme, meanwhile, the implementation sites and solutions will be determined, and technical specifications and operational processes developed; the Ricardo engineers will work on testing strategy, fail-safe and fall-back requirements, as well as data reporting and performance metrics, and support procurement and commissioning of the new network assets. In the final phase, they will provide operational support plus monitoring, reporting of performance, and validation.

"There's no specific time-frame on the collaboration, but we are working towards timed deliverables," says Nayeem, explaining that while the initial concept and proposals for the first phase of the roll-out are to be presented by the end of September, these must then be approved by the electricity regulators. However, says Snow, "it's safe to say that within the next couple of months we hope to have designed or identified a route we plan to follow – and within the next 12 months or so, we will start implementing and connecting these solutions onto the grid."

RQ RICARDO NEWS

Latest developments from around the global Ricardo organization

Solar power takes to the rails

A solar array located near Aldershot, Hampshire, UK, has become the first in the world to supply electricity directly to an adjacent railway line, thanks to the innovative 'First Light' project delivered by Riding Sunbeams Ltd and supported by Ricardo.

Comprising around 100 solar panels, the 30kWp solar test unit is connected to an ancillary transformer on Network Rail's Wessex Route's traction system, with energy from the array set to power signalling and lights. Electricity demand data is also being gathered from six potential community solar sites in the south of England. Putting all this real-world data together will enable analysis of how to plug in much larger solar arrays to power trains. By the end of 2020, Riding Sunbeams hopes to build and connect the world's first ever full-scale community- and commuter-owned solar farm to the UK rail network.

Photo: Andy Aitchison / 1010 Climate Action

Ricardo's energy experts supported Riding Sunbeams through their experience in power generation research and in connecting renewable energy technologies to existing infrastructure – and monitoring the results. The Ricardo team is managing monitoring equipment at multiple sites, working with Birmingham University to commission and review the energy model simulating this system. The work carried out by Ricardo will enable an in-depth understanding of the energy production and use from the solar array, which will be used to assess the success of the Aldershot-based test unit and forecast the opportunities for application on other parts of the rail network.

Funded by the Department for Transport through a competition delivered by InnovateUK, the 'First Light' project was born out of an earlier study by 10:10 Climate Action and Imperial College London's Energy Futures Lab, which showed that connecting solar panels directly to rail, tube and tram networks could meet a significant share of their electricity needs. Crucially, the research also found that this clean, renewable power could be supplied at a lower cost than electricity supplied via the grid today – without the need for public subsidy.

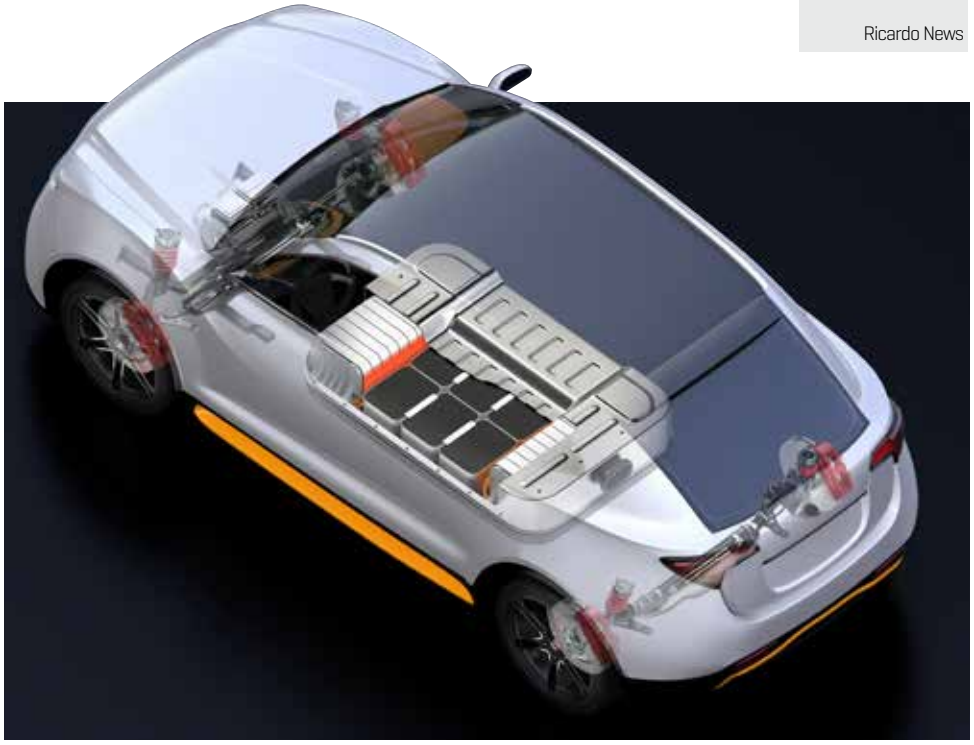
The project for Riding Sunbeams Ltd complements Ricardo's work on integrating renewable technologies into transport – and specifically the rail sector – through a number of projects across the UK, in locations including London, Sussex, Hampshire and across South Wales.

JCB sets tractor speed record

A JCB Fastrac stormed to a new British tractor speed record, powered by a variant of the 7.2 litre, 6-cylinder Dieselmax engine co-developed by JCB with Ricardo. The aerodynamically enhanced Fastrac tractor notched up 103.6 mph in June at Elvington Airfield, near York, with TV presenter and engineering guru Guy Martin behind the wheel – smashing the previous 87.27 mph record set in March 2018 by Top Gear's Track-Tor. The team of engineers that has been working on the project over the past few months was praised by JCB chairman Lord Bamford for their "amazing achievement."

The special variant of the DieselMax engine developed by Ricardo is capable of delivering up to 1,000 hp and 2,500 Nm of torque. JCB and Ricardo engineers were able to apply knowhow gained from their involvement in the previous Dieselmax streamliner, along with new technologies such as electric supercharging, to achieve these high performance levels. Ricardo also used its state-of-the-art VR CFD visualization techniques to help JCB enhance the Fastrac aerodynamics.

Project aims for immersion cooled EV batteries



i-CoBat project: visualization of battery cell layout

A new form of EV battery cooling technology, based on cell immersion cooling using dielectric fluid, is to be developed and demonstrated by the i-CoBat research project – a collaboration between M&I Materials, Warwick Manufacturing Group and Ricardo. It's an innovation that promises improved power output and cell longevity, faster charging rates and lower costs, significantly addressing the key consumer issue of range anxiety – and the need for such a new technology is urgent, as the automotive industry seeks to electrify its product ranges.

The thermal management of high capacity batteries used for electric vehicles (EVs) is proving a significant challenge. The performance and efficiency of battery cells can deteriorate – and their ageing can be accelerated – if operating temperatures exceed the upper or lower limits of a comparatively narrow range. In extreme cases, exceeding upper operating limits can risk thermal runaway of cells, leading to catastrophic failure and, potentially, fire.

For market acceptability – and in particular, to persuade owners of liquid-fuelled vehicles to switch to an EV – charging time is a significant challenge in terms of alleviating range anxiety. Consumers seek fast recharging times, good performance and range, and competitive prices; during fast charging, however, battery cells can produce up to three times more heat energy than in normal driving and charging operations, and heating of the cells is a dominant factor in battery ageing and performance degradation. Using current battery cell technology, therefore, thermal optimization of pack design and operation is a vitally important requirement.

Current EV battery packs tend to use air cooling or cold plate cooling using water/ethylene glycol or a refrigerant. The limitations of such thermal management systems act to restrict charging rates or the number of fast charge cycles that can be carried out each day. One possible answer to range anxiety could be to increase pack size, but this would significantly increase costs.

Led by M&I Materials, the i-CoBat project is part of the government's Faraday Battery Challenge and will test an immersion cooled battery pack concept using M&I Materials' biodegradable dielectric cooling fluid, MIVOLT. M&I Materials has been working in advanced materials and electrical insulation for over 100 years, with a core specialism in dielectric fluids for more than 40.

Supporting Bermuda's first integrated energy plan

Bermuda's first Integrated Resource Plan, outlining the approach to meeting the North Atlantic island's energy requirements over the next 20 years, has been launched this summer – with the assistance of Ricardo.

Ricardo's energy experts supported the Regulatory Authority of Bermuda in the development of the plan. The team collated the underpinning data, including feedback from over 800 people during a public consultation; benchmarked suitable technologies; and modelled the cost of future energy scenarios, including carbon emissions. This enabled the Regulatory Authority to select the mix that would best meet Bermuda's ambitious, consumer and climate-focused energy needs over the next two decades.

With the Integrated Resource Plan, Bermuda is demonstrating leadership among island nations in aiming to reduce carbon emissions without compromising on the reliability and affordability of electricity for its citizens. The Integrated Resource Plan seeks to achieve this by enabling investment in high levels of renewable energy resources. By 2026, the island is due to add 21 megawatts (MW) of utility-scale solar photovoltaic, 60 MW of offshore wind power, and significant amounts of distributed generation (e.g. residential and small-scale solar), while generation dependent on fossil fuels will be phased out or used as back-up to support renewable generation. Biomass generation is another source of renewable energy that could be deployed from 2028 onwards.

The Integrated Resource Plan for Bermuda builds on Ricardo's international energy expertise, which includes supporting island nations around the world – such as Saint Lucia, Samoa, Tonga, São Tomé and Príncipe – in the increased integration of renewable technologies into their energy mix.

Mind does matter

Participants in the 'R-Tour', a 900-mile charity cycle ride between each of Ricardo's UK sites, raised an impressive total of £50,000 for mental health charity MIND.

The tour, which took place in early July, was the brainchild of Ricardo Energy & Environment's Ian Behling, who is based at the Harwell site. As someone who had previously suffered from depression and had received support from MIND, Ian wanted to give something back. His idea for the R-Tour was supported by many of his colleagues – as well as by Ricardo and external sponsors Ceratizit and Cycle2Work – and even generated a spin-off tour by Ricardo employees in Detroit.

The tour involved a total of 63 riders – three of whom cycled the entire route – and 11 support drivers, drawn from five Ricardo divisions and 13 offices. Over the ten days of the event a total distance of 900 miles was covered by R-Tour, comprising a total climb of 45,000 feet.

In preparation for the event, Ian encouraged colleagues participating to include cycling in their regular daily commute as a part of their training schedule. He regularly led training sessions at the end of the working day, inspiring others to get on their bikes too, rather than commuting by car.

In recognition of Ian's achievement in arranging the R-Tour, encouraging people to consider cycling as an alternative to commuting by car, and raising such a significant sum for MIND, Ricardo has nominated Ian as 'Cyclist of the Year ' in this year's Cycle2Work awards.

R-Tour team members take a break outside Buckingham Palace on their way through London - on their way to raising £50,000 for MIND

Ricardo joins recycling label scheme

In order to support its clients more effectively in developing sustainable packaging solutions, Ricardo has signed up to the On-Pack Recycling Label (OPRL) scheme, which seeks to deliver a simple, consistent and UK-wide recycling message on consumer packaging.

As the not-for-profit labelling scheme's compliance auditors for the last five years, Ricardo understands the ever-increasing pressures facing brands and retailers to make the right packaging design and labelling choices. OPRL members are increasingly seeking a fully aligned service on the recyclability and labelling of their packaging as part of their OPRL membership.

"Over the last two years we've been working to strengthen the end-to-end service that members receive," explains Jane Bevis, chair of OPRL Ltd. "We are clear that our remit is to run a lean and efficient, evidence-based labelling scheme, supported by world-class online tools such as PREP, our recyclability claims evaluation tool. But we know many members want more detailed advice on their packaging and the sustainability commitments they have made."

Ricardo helps develop biomethane-powered tractor

The diesel tractor is the backbone of many farming operations worldwide. Given a tractor's requirements for high power and torque, as well as for versatility, it is understandable that diesel is currently the fuel of choice for this ubiquitous agricultural workhorse.

Biomethane, however, is a fuel source that is increasingly being harnessed by many medium- to large-scale farming operations, through the process of anaerobic biodigestion of waste vegetation. While much of the biomethane produced by such units is used in renewable energy generation schemes, a clear potential pathway exists to produce sustainable fuel for tractors and other powered agricultural equipment, thus displacing at source the mineral diesel that would otherwise be used.

In the APC UK funded Low Carbon Tractor (LoCT) project, CNH Industrial – one of the world's leading capital goods companies – is partnering with exhaust aftertreatment technology specialist Eminox and thermal management and ceramic coating specialist Zircotec. The project aims to design and demonstrate a commercially viable tractor capable of operation on biomethane while conforming to the latest European and US emissions standards.

CNH Industrial has contracted Ricardo to support its contribution to the LoCT project, specifically for some of the design and development of the vehicle, working alongside CNH Industrial's in-house team as the vehicle approaches readiness for commercial production. Key challenges include managing the heat rejection and tuning of the engine to be able to operate successfully in an agricultural environment, and the optimization of vehicle-based compressed natural gas storage to fulfil operational needs, while also meeting all necessary safety and visibility requirements.

The first examples of the pre-development LoCT project tractors were shown publicly for the first time at the UK Low Carbon Vehicles event in early September 2019.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