

Ricardo Quarterly Review

Q3 2020

RQ

A focus on the latest in technology,
innovation and sustainability



Interview

Covestro's Markus Steilemann
on closing the carbon circle

Carbon markets

Counting the cost of emissions:
Ricardo experts on the frontline
of helping nations reduce their CO₂

Going carbon negative

How biochar holds the secret to
taking carbon out of the air

An end to EV range anxiety

Making every kWh go further, and
range predictions more accurate

ALL ABOUT CARBON

Keeping it in check, sequestering it from
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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

Green or black: oil majors face a stark choice



already prompted European producers such as BP, Shell and Total to commit to carbon reduction programmes. The EU's upcoming sustainable finance package will compel firms to make much clearer declarations of their economic, social and governance (ESG) policies in their communications, putting further market pressure on those behind the curve.

Outside the Green Deal bubble of Europe, Australian giant BHP, the world's largest mining conglomerate, has announced its exit from coal and retreat from some older oil assets, while in the US the once fast-growing shale industry has stalled. Exploration and drilling projects have been put on hold, but while there is some acceptance that peak oil has passed, there is still a reluctance at boardroom level to embrace a clear pathway towards renewables.

Even so, the International Renewable Energy Association has reported that global investment in renewables has for the first time exceeded that in oil and gas.

With fuel prices in free fall, billions wiped off their assets and their long-term value uncertain, the major fossil fuel producers are facing a stark choice: adjust to the reality of climate change, or gamble their

corporate future by continuing to do business as usual.

Pressure from shareholders and asset managers, allied to plunging oil prices and a collapse in demand, has

Oil refinery installations: carbon footprints are under scrutiny

Innovation for the elite

It goes without saying that each new generation of Mercedes-Benz S-Class will be the most technically advanced ever produced – and the 2021 model, pictured below alongside its many predecessor generations, is no exception.

Built in Daimler's new eco-friendly Factory 56, the new line-up includes a plug-in hybrid with an electric range of 100 km, though no diesel hybrid. Two different rear-wheel steering systems are optional, as are three levels of autonomous driving and remote parking controlled by smartphone. The digital headlights can project messages and warning signs onto the road as well as superimposing navigation symbols onto turns, while 3D instrumentation and an enlarged head-up display make life easier for the driver.

The new Rolls-Royce Ghost, launched at the same time, claims to be pioneering a new spirit of 'post opulence' or a simplification of the luxury environment. With 4WD and all-wheel steering as standard, it has a new Planar suspension system that includes special mass dampers on the front wishbones and a stereo camera to read the road ahead and prepare the springs accordingly. Some 100 kg of insulation ensure silence on the

move – but not absolute silence, as Rolls owners find that too disconcerting. Instead, says the company, all components are tuned in to a special 'whisper' frequency so that occupants have some sense of speed.

The promise of all this innovation is that it will eventually trickle down into more affordable models in years to come. In today's real world, one of the most significant introductions for 2021 will be the Nissan Ariya, an advanced all-electric crossover set to do battle with VW's ID.4 and Tesla's Model Y.





Urban e-commercials arrive

Automakers and start-ups are hurrying to release zero-emission vans and light commercials in response to the growing number of zero- and ultra-low emission zones in city centres around the globe.

Renault, Peugeot, Citroen, Opel-Vauxhall, Fiat, Ford and Mercedes-Benz are among the European brands marketing battery or plug-in hybrid versions of their existing medium and large panel vans. Mercedes, for instance, recently announced a major order from Amazon Europe for 1800 eVito and eSprinter models to ensure eco-friendly last-mile deliveries for online customers.

Those vans, which are essentially battery-electric adaptations of existing combustion-engine platforms, will soon

be facing serious competition from a growing array of potentially more efficient clean-sheet EV designs from start-up firms in Europe and North America.

Bollinger Motors is one example, which already builds the electric B1 SUV and B2 pick-up; its new Deliver-E is a dedicated urban delivery van with a choice of batteries between 70 and 210 kWh.

The Volta Zero (pictured) promises to be one of the more credible newcomers. The UK-built vehicle is claimed by its Swedish parent company to be the world's first purpose-designed electric light truck, with a payload of 16 tonnes and a range of 150 to 200 km. It will go into a pilot trial with DPD in London in 2021.

Automation reaches motorcycle sector

BMW will soon offer car-type automation systems and other high-technology components to its premium two-wheeler customers. Newly developed Active Cruise Control uses radar to keep a constant distance from the vehicle in front, and can also cope with motorcycles banking in turns; the rider can adjust the follow distance to his or her preference.

Serious riders of BMW's sports bikes such as the S1000RR can select the optional M Performance carbon wheels for €3990, saving 1.7 kg and improving acceleration, braking and handling.

Seasoned motorcyclists, meanwhile, will welcome the maintenance-free drive chain which uses industry-grade diamond coating on its rollers to eliminate this messy lube chore.



Covid: helps air, not climate

The near-global lockdown triggered by the Covid-19 pandemic this year has helped provide a short breathing space of improved air quality, but the slowdown has not had any parallel effect of benefiting the world's climate.

Average concentrations of CO₂ in the atmosphere peaked at a record 417 ppm in May; the world first breached the 400 barrier in 2015 and 350 ppm is considered the maximum safe level. Nevertheless, the IEA expects fossil-fuel GHG emissions to be 8 percent lower than in 2019, thanks to

growing use of renewable energies. Europe, for instance, hit a 55 percent renewables share in May.

Nor has the Covid slowdown led to the hoped-for let-up in climate-damaging deforestation, which WWF Germany's satellite surveillance reports as up 50 percent during the pandemic, especially in Asia, Africa and Latin America. Fires are again ravaging Siberia, which reached an unprecedented 38 Celsius in July, and the north and south poles are experiencing much faster temperature rises.

NEWS IN BRIEF

Highlighting the latest thinking in automotive engineering and technology worldwide

EV tipping point

Why don't more people buy EVs? A study by Castrol, quoted in Green Car Reports, pinpoints the key metrics that will help swing the decision for the 61 percent of buyers who still want to 'wait and see'. What is needed for a breakthrough, reports Castrol, is a minimum range of 470 km, charging in less than 31 minutes, and a sticker price below \$36,000.

Uber to go electric

Following a widespread campaign by leading NGOs, mobility provider Uber has agreed to begin cleaning up its act by ensuring that at least half its rides in European capitals are emission free by 2025. Longer term, the target will be 100 percent electric. A parallel programme will see Uber rides in North America go fully electric by 2030. The decision comes in the wake of Uber's first-ever environmental report, which analyzed over 4 billion rides since 2017 and showed that the organization's emissions per passenger kilometre were worse than those of private passenger cars.

Leaf hits half million

Nissan's pioneering Leaf hatchback, the world's first mass-market electric car, hit 500,000 sales in September, nine years after its launch. In that time, says Nissan, Leaf drivers around the world have covered 14.8 billion zero-emission kilometres, saving 2.4 billion kg of CO₂ in the process.

Taxis to trial wireless charging

Jaguar is to test the real-life effectiveness of wireless EV charging on a fleet of I-Pace taxis in Oslo, reports the FT. The 25-car trial in the Norwegian capital will see induction pads installed in taxi ranks outside the central station and other hubs, so that the vehicles can top up their batteries while waiting for customers. Similar schemes are in prospect for buses and vans in Norway's push to go all-electric. Jaguar CEO Ralf Speth describes wireless EV charging as more effective than refuelling a conventional vehicle.

Toyota: destination moon

Toyota and JAXA, Japan's aerospace exploration agency, have been developing a novel crewed rover vehicle for possible future exploration missions. With a pressurized hull and a fuel cell driveline powering its six wheels, the Lunar Cruiser is designed to support continuous activities on the moon's surface and is expected to be deployed in the latter half of the decade.



Airlines grounded on emissions

Airline operators have been among the organizations hit hardest by Covid-19. However, a measure of relief came with the announcement that the industry's UN-backed CORSIA emissions agreement will use 2019 as the base year for its timetable of GHG reductions. Given the dramatic slump in travel this year, and the consequent fall in GHG emissions, the originally agreed 2020 base year would have given airlines a much tougher set of reductions to achieve.

European political leaders have acted cautiously in helping their countries' airlines, seeking to avoid a rush back to business as usual and a return to the steeply climbing path aviation emissions were on. France, for instance, has insisted that aid to its aircraft sector is contingent on the industry developing a carbon-neutral passenger plane by 2035, using either e-fuels or hydrogen power; also in the mix are a smaller regional plane and a helicopter, which could be battery powered.

Hydrogen received something of a boost in the EU's fuels strategy, published in July. Nevertheless, important decisions still need to be made when it comes to promoting more sustainable fuels and perhaps taxing conventional aviation kerosene - and over integrating the airlines' international CORSIA agreement into the European Emissions Trading System.

In the meantime, it has been left to smaller aircraft to fly the flag for carbon-neutral aviation. In June the European air

safety regulator awarded the world's first certification for an electric aircraft: Slovenia's Pipistrel Electro Velis, a two-seater trainer capable of an 80-minute flight time. California-based ZeroAvia has already test-flown a commercial-scale six-seater under electric power from a base in the UK, and longer term it is planning a medium-range passenger plane incorporating fuel cell power and, for 2040, a 200-seater with a range of 5500 km.

Thousands of aircraft remained grounded during the lockdown months



Electric aspirations

The constant tightening of CO₂ emission regulations and city-centre access rules is prompting luxury-car makers to fall into line with volume manufacturers and offer electrified models - or at least enough promise of them to keep customers loyal.

Bentley, for one, showed a battery-powered sports car concept some years ago and has now announced its participation in the Octopus programme to develop advanced e-axles for electrified vehicles. This unit, says the company, will appear on the first all-electric Bentley in 2026, with the first hybrid Bentayga coming in 2023.

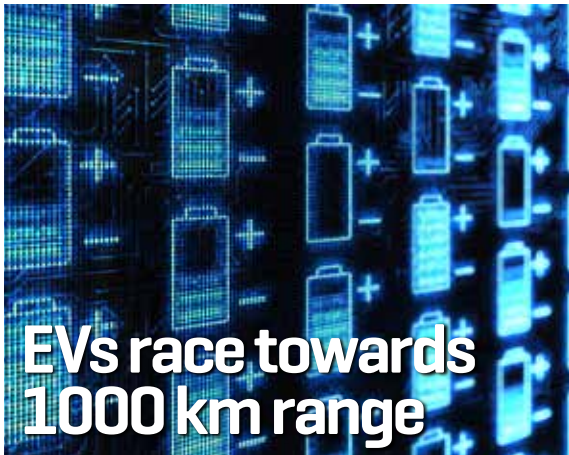
Cadillac, meanwhile, is promoting its Lyriq show car as an ambassador for a whole portfolio of "transformative" EVs which, says Steve Carlisle, executive vice president and president, GM North America, "will deliver experiences that engage the senses, anticipate

desires and enable our customers to go on extraordinary journeys". The production Lyriq SUV will debut in 2022 and features GM's Ultium propulsion system that delivers ranges of over 500 km from its 100 kWh capacity, and which can accept DC charging rates of up to 150 kW. In contrast to previous designs, the Lyriq will use an all-new modular platform purpose - designed for battery power.

Even supercar maker McLaren is in on the act: its newly revealed lightweight carbon architecture will underpin new models from 2021 and enable a transition to 100 percent electric sports cars by 2035.

But for environment-conscious customers who find the McLaren or the Cadillac a shade too modern, there is always the alternative of an electrified classic Rolls-Royce from Lunaz [pictured] - starting at £350,000 before taxes.





EVs race towards 1000 km range

A bidding war is in full swing among automakers and battery manufacturers to be the first to offer a range of more than 1000 kilometres.

Next year's luxury Mercedes-Benz EQS, the all-electric companion to the new S-Class, is expected to claim a range of 700 km on a full charge, while China's Lucid Air sedan, also due next year, will go one better with a claimed range of 833 km on the US EPA test cycle, which is regarded as tougher than Europe's new WLTP.

While CATL, a supplier to Mercedes-Benz, BMW, Tesla and VW, is one of the major players in the battery sector, Chinese automakers BYD and GAC are backing slightly different technologies. BYD's lithium iron phosphate is claimed to offer better fire protection than lithium ion, and will give 600 km in the new Han sedan, and GAC's silicon anode chemistry has better energy density (at a reported 275 Wh/kg) and the potential for a 1000 km range.

In addition, Bloomberg reports that CATL is ready to market a powerpack that has a lifespan of 18 years and 2 million km, opening up important opportunities for second-life applications and an improvement in its lifetime carbon impact. This autumn, the European Commission will publish its proposals for sustainable batteries and a circular value chain for all batteries.

Sustainability gains ground in auto plans

BMW CEO Oliver Zipse declared himself "cautiously optimistic" about the group's Covid-hit 2020 performance but, more significantly, he signalled a raft of measures aimed at cutting, by 2030, one-third of CO₂ emissions across the complete product cycle from manufacture, through use, to end-of-life dismantling.

Seven million electrified BMWs would be on the roads by 2030, he added; two-thirds will be fully electric models, of which there will be 12 or 13 by 2023. BMW's 'Power of Choice' would give buyers the option of diesel, gasoline, plug-in hybrid or fully electric propulsion in most of the firm's model lines.

Honda, which is one of the five automaker groups to have sided with California in its legal battle over preserving environmental standards, is targeting a 50 percent reduction in its CO₂ footprint by 2050 and has signed a memorandum of understanding with GM covering the sharing of platforms, powertrains and technologies. The two groups already have an agreement on EVs and fuel cell systems.

VIEWPOINT



DC interconnection could help speed EV rollout

Michael Feasey, DC Share project manager, Ricardo Energy & Environment

The UK is just one of the governments around the world setting increasingly ambitious targets to achieve net-zero carbon emissions, and attention is naturally turning to decarbonizing the electricity grid and using the new greener energy for applications traditionally consuming fossil fuels. Road transport remains a significant contributor to the nation's greenhouse gas (GHG) emissions, with the UK Office for National Statistics estimating that it contributes around one-fifth of the country's emissions. Yet data suggests that a mere 0.5 percent of the vehicles in service are zero emission electric vehicles (EVs).

Apart from the general public's fear that they will be unable to charge their EVs while on long journeys, another reason for the continued low uptake of EVs remains the fact that large sectors of the population do not have off-street parking and so are unable to charge their vehicle at home overnight via a standard 7kW domestic charging point. Instead they would be required to drive somewhere for extended periods of time just to charge their EV.

To encourage more of the general population to purchase EVs, a more efficient and widely available charging regime must therefore be introduced providing hub facilities more akin to a petrol station 'quick fill-up' environment, giving EV users complete confidence that they can connect their car and receive a full recharge in a matter of minutes via rapid chargers typically providing 100kW+ of power.

To provide this confidence, rapid EV charging points should ideally be deployed in hubs located near population concentrations and also in locations which attract a significant throughput of visitors, such as within our town and city centres. However, given that each hub will comprise many rapid EV chargers, the total load will be considerable when all rapid chargers are in use at the same time. This may, simply not be possible to provide from a single substation, given the capacity restrictions prevalent within our already congested urban power networks.

In an effort to avoid the cost of

significant power network reinforcement and/or new substation builds, the DC Share project aims to trial the interconnection of several distribution substations with differing load profiles. This will enable available spare capacity to be extracted at any point in time and, after being efficiently converted from AC to DC, be transported around a DC cabled ring

"Rapid EV charging points should ideally be deployed in hubs located near population concentrations"

to provide network reinforcement should any interconnected substation become heavily loaded and/or to provide power for the rapid EV charging points. For example, if four distribution substations were interconnected with an average spare capacity between them of 1MW, then up to ten rapid [100kW] EV chargers could be connected without the need for costly asset replacements.

The DC Share project's aspiration is, therefore, to demonstrate that significant power that might otherwise remain unused can be extracted from the existing power distribution assets to provide large numbers of rapid EV charging points, and also assist in network equalization should certain substations become heavily loaded at any time. Such a local DC ring would also permit the future connection of Distributed Energy Resources (DERs) such as solar and wind generation, or battery storage systems, all of which may assist in providing and storing power where it is needed in congested urban environments.

In July 2020 DC Share announced that the trial installation will be located in Taunton, Somerset. It will be commissioned during 2022, followed by a 12-month period of evaluation before being handed over for longer term commercial use – and ideally will provide a template for urban public charging that will boost EV take-up.



Closing the carbon circle

Everyone is familiar with those Blue Planet images of marine life being devastated by waste plastic, eight million tonnes of which is tipped into the oceans each year; overall, failing to recycle plastic costs global industries \$120 bn a year. But, as Dr Markus Steilemann, CEO of leading polymers producer Covestro, tells **Ian Adcock**, the concept of the circular economy can reduce this waste and close the carbon cycle



When will Covestro become a fully circular producer, and what does this entail?

Over the next decade we are planning to broaden our alternative [range of] raw materials and, together with our customers, we will develop joint solutions for circularity. Becoming fully circular means more than recycling end-of-life materials: we aim to fully close the carbon cycle, preventing CO₂ escaping from the cycle, and depending purely on alternative, renewable feedstock. In the long run we will avoid sourcing virgin fossil raw materials, either in production or as feedstock for energy generation to run our operations.

How long will this take?

It will take time, and it will also depend on how quickly the external infrastructure develops to support a circular economy. It will also be influenced by the appetite and demand for circular solutions both in the value cycle and from the end consumer, as well as by how quickly the market and regulations move in the same direction.

How will you demonstrate this progress?

To make sure that circularity is implemented throughout the whole company we will underpin our ambition with tangible targets, allowing us to measure our progress and apply key performance indicators to steer Covestro on all levels towards circularity. To achieve full circularity we foresee significant investments in circular economy [CE] related activities over the next decade and beyond.

Can you detail the steps involved in this strategy?

By the end of 2020 we will have more than 25 R&D projects on recycling pathways in the pipeline. We are currently investigating the option to build a semi-industrial pilot plant to recycle polyurethane foam, concentrating on soft foam - but rigid foam is another potential area for these recycling efforts.

Renewable energy is a strategic pillar of our CE approach and

in the long run we will power our operations purely by renewable energy. Covestro has taken the first decisive steps to build a renewable energy supply in addition to an alternative raw materials portfolio. By purchasing renewable power and through our investments in self-generated renewable energy we will lower our Scope 2 emissions towards a climate-neutral power supply. In addition, alternative raw materials and joint solutions are already part of Covestro's daily business.

You have said that plastics are 'far too valuable to be thrown away'. Can you put a value on that annual global wastage figure?

This is a challenging question, and the answer depends on whether we are talking about [plastic] having a monetary value like other forms of raw materials. It will depend on market demand, on regulations like carbon taxes and on other external framework conditions. However, these are not the only value-defining criteria, as plastic that isn't thrown away but finds its way back into the economy can replace virgin fossil materials.

You talk about innovative raw materials in addition to CO₂. What are they?

Theoretically, many alternatives to crude oil are conceivable. There are more waste gases than CO₂: carbon monoxide [CO] or methane [CH₄], for example. Beside waste gases, end-of-life materials and sustainable biomass are very promising feedstocks. Covestro is also looking into using hydrogen as a raw material for production. We are convinced that alternative raw materials are needed to fully unlock the circular economy potential of the chemical sector.

Won't these new materials be more expensive? And won't this be a deterrent to their use?

More expensive in this case is not equivalent to a single monetary value. The range of chemical products is far too wide to give a concrete figure for every one. In general, more modern techniques

are more expensive in the early stages of development, as R&D requires large sums of money.

Can you give more detail on the pan-European collaboration?

We are collaborating with several partners from industry and science in EU-wide projects to drive the circular economy, and some, like Carbon4PUR and PReSmart, are publicly funded. Our aim is to establish new, value-creating co-operations with our customers and partners. As part of the EU Circular Plastics Alliance founded in 2019, Covestro collaborates with numerous organizations that help push plastic recycling forward throughout Europe. The Alliance, which was created by the European Commission, brings together 100 partners from across the value chain. These include plastic manufacturers and processors like Covestro, large retailers, and waste management and recycling companies.

Is there not a conflict of interest with food production when you use biomass for coating processes?

We use a holistic approach as outlined in the German and European bio economy strategies, for example. These aim to ensure food and resource security for a growing population, in parallel with economic and ecological sustainability. Unquestionably, the reliable production and supply of food has the highest priority. When discussing the use of biomass as a renewable feedstock for industrial purposes, the crucial issue is the availability of arable land – but not at the expense of food crops. We believe that it's important to use the world's arable land with maximum efficiency, at the same time as ensuring sustainable cultivation. In parallel with the efficient use of first-generation biomass, we are also evaluating the use of waste biomass as an alternative feedstock. According to the European Bioplastics Association, in 2019 only 0.02 percent of the globally available agricultural land was used for bio-based plastics.

What are the pros and cons for mechanical recycling versus chemical recycling?

Today recycling is still a challenge because plastics are inseparably mixed. So far, mechanical recycling is the only available industrialized and commercialized recycling solution. It is proven to be a profitable technology with much lower investment costs compared to other recycling methods. Chemical recycling is still at an early stage of development, but we regard positive results as quite achievable.

Will Covestro develop into a plastic recycler for others? And if so, when?

On the one hand, we are primarily focusing on finding solutions for the recyclability of our own materials and polymers. On the other hand, we want to continue to build an alternative raw material base for our production, therefore becoming independent from virgin fossil raw materials. This could also mean developing recycling technologies for other materials through which we could derive the building blocks of our own raw materials. In the long run we will become a 'reducer', recycling end-of-life materials in order to continue as a producer of high-performance materials. →

“The transition to a truly global circular economy requires commitment from all parties: governments, business and society, all participants in the value cycle and, of course, the end consumer”

Toyota's LQ concept car, revealed at the 2019 Tokyo motor show, was developed in conjunction with Covestro's innovation centre in Japan





Toyota LQ concept interior [above] uses new Covestro polyurethane composite materials incorporating Kenaf fibres, while the transparent polycarbonate for Mercedes' new E-Class headlamp [right] is a Covestro-Neste co-operation to promote the use of raw materials from sustainable sources

How long before all Covestro products will be sustainable?

In the long run we want our production to be a fully circular stream, based on alternative and renewable raw materials. When this will be achieved depends on strategic decisions that ensure that the company continues to steer fully in the direction of circularity. It also depends on how quickly the external framework develops towards a circular economy and how quickly the market and regulations move in the same direction. As a marker, we have set ourselves the goal of demonstrating a track record by 2030.

How can Covestro encourage other industries to follow its lead? Are others coming to you for advice and help to circularize their business or industry?

We exchange ideas with customers about our innovations and always strive to develop new solutions in collaboration with those



clients. In addition, we are represented in various R&D projects such as Carbon4PUR and PURESmart, working with partners on the best CE solutions as well as initiatives like the Circular Plastics Alliance, the Alliance to End Plastics Waste, and the World Economic Forum.

Is the circular economy concept applicable to all manufacturing sectors or principally to the materials industry?

The transition to a truly global circular economy requires commitment from all parties: governments, business and society, all participants in the value cycle and, of course, the end consumer. In a fully circular system many aspects have heightened priorities: these could be the durability of products in use, the efficiency of the system with regard to greenhouse gas emissions, and the avoidance of waste wherever possible. But the chemical and plastics industries play a crucial role in bringing circularity into the value cycle. A truly circular economy should deliver on the shared goal of climate neutrality. That is why the energy sector is very important for a sustainable and circular world.

At the end of the day isn't the circular economy just a fancy name tag for recycling and sustainability?

A fully circular economy is one that is more than simply sustainable and, in particular, it is more than just recycling. It is a new way of thinking about production and products. It is no longer acceptable to do business, whether that business is sustainable or not, in linear value chains that depend on fossil raw materials with massive negative influences on the environment and society. A truly circular economy doesn't let valuable raw materials like gas and end-of-life-products leave the circle. That's how we will replace the critical fossil raw materials. Our vision - to become fully circular - is the only plan bold enough to properly address the challenges we are facing. [👉](#)

Cardyon: the sustainable polymer that's made from CO₂

What links a pair of socks, the sub-strata of an artificial hockey pitch, and a mattress? On the face of it, they have little in common - except that they formed part of Covestro's display at last year's K 2019, the world's largest plastic and rubber exhibition, held in Düsseldorf, Germany.

The common ingredient is a new polyol called Cardyon. This is partly based on the use of CO₂ as a raw material, a process that has been under development with Aachen's Fraunhofer Institute for the past eight years.

The CO₂ is captured from coal-gas flue stacks using conventional scrubbing technology before undergoing chemical transformation into the plastic polymer. How this is achieved is something that Covestro and its partner are keeping a closely guarded secret, admitting only that it is done using a relatively small amount of energy - despite the fact that CO₂ has previously been described as a "sluggish" gas that needs "quite a lot of energy to get it reacted".

However, Covestro's Dr Marc Schütze conceded that any emitter of CO₂, such as a cement works, could equally be a source of raw material.

Currently the CO₂ is replacing 20 percent of the traditional oil-based feedstock in the new material, but this could be doubled to 40 percent, said Schütze: "It's the difference in viscosity between milk and honey, and this sets a challenge for the manufacturing process. But there's no reason why that shouldn't be overcome in time with further developments."

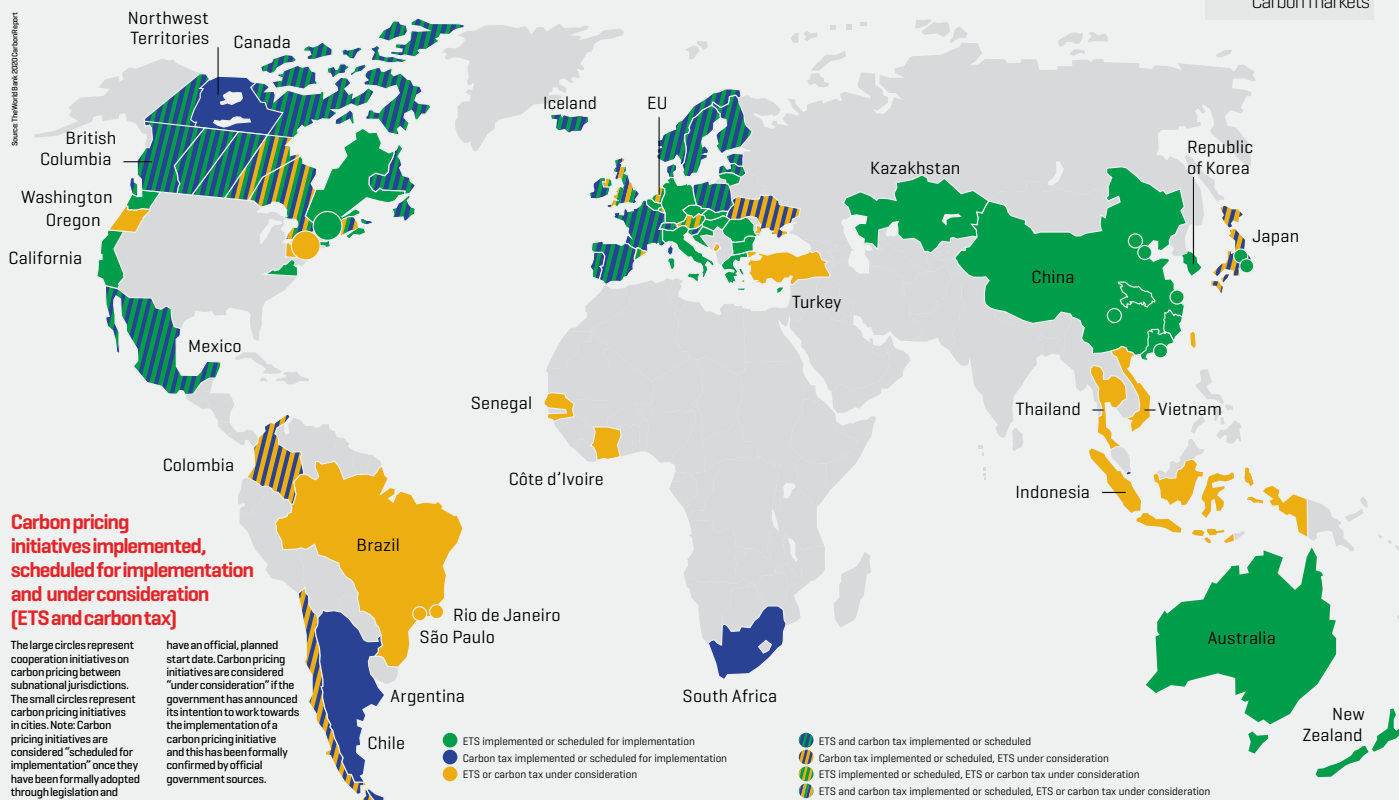
According to Schütze, there are enquiries coming in from other sectors, including the automotive supply chain - even though producing seating, for instance, using this new material could prove challenging given that production times and sequences are faster and more complex than those for mattresses.

Currently, 5000 tonnes of Cardyon is being produced annually at Covestro's Dormagen plant, but the company predicts this will increase as demand grows globally.

At the end of its working life, Cardyon is simply recycled and the process starts again.

Biography:

Dr Markus Steilemann has been chief executive officer of Covestro since June 2018. His area of responsibility covers strategy, sustainability, personnel and communications. After graduating with a PhD in chemistry from RWTH Aachen University, Steilemann began his career with the Bayer Group in 1999. From 2008 he held various management positions in the polycarbonates business unit at Bayer MaterialScience, the predecessor company of Covestro. Between 2013 and 2015, he headed the business unit headquartered in China. Returning to Germany in 2015, Steilemann joined the Covestro board of management, with responsibility for innovation. In addition to this role, he became head of the polyurethanes business unit in the following year. In 2017, he became chief commercial officer before being named CEO in 2018.



Counting the cost of Carbon

Advances in technology are not the only means of reducing the emissions of greenhouse gases and slowing the pace of dangerous global heating: legal, financial and trading structures are equally vital in the battle to keep carbon emissions in check. **Tony Lewin** speaks to Ricardo experts on the frontline of bringing nations together in international mechanisms aiming to rebalance the global climate



Carbon is everywhere – quite literally. Not just at the top of every news bulletin or all over our newspaper front pages, but in plants, trees, animals, in the soil, the seas and oceans and, most critically for our climate, in the air. And it is the fast-accelerating concentration of carbon in the atmosphere that is the central cause of climate change – which many believe is the biggest existential challenge ever to confront humanity.

Many years of political and diplomatic negotiations, including the Kyoto and Copenhagen agreements, culminated in the 2015 Paris Agreement on Climate Change, which finally achieved consensus within the international community. Drastic and sustained cuts in carbon emissions would need to be made if the doomsday scenario of runaway global heating was to be averted, and all nations needed to play their part.

"Being able to meet the Paris warming target of 1.5 degrees requires a steep downward trajectory in carbon emissions," says Mark Johnson, carbon markets business manager at Ricardo Energy & Environment. "What the Agreement did was to create the framework and the international political commitment to be achieving that goal, through a process where each government makes its own nationally determined contribution, or NDC."

Carbon pricing in numbers



61 carbon pricing initiatives implemented/scheduled



31 ETS and 30 carbon taxes



46 national, 32 subnational jurisdictions



Covering 12 GtCO₂e [22% of global GHG emissions]



US\$45 billion raised in carbon pricing revenues in 2019



More than 14,500 registered crediting projects to date, generating almost 4 billion tCO₂e of cumulative carbon credits



Forestry sector credits make up 42% of all credits issued in last five years



“Being able to meet the Paris warming target of 1.5 degrees requires a steep downward trajectory in carbon emissions”

Mark Johnson, carbon markets business manager, Ricardo Energy & Environment

→ For the first phase, to 2030, this is based on the country’s economic circumstances and its capacity to make reductions.”

Despite the severe blow of President Trump withdrawing the US from the accord, the vast majority of the Paris Agreement’s 197 signatory nations are on board and carbon reduction has become the keynote issue of our times. But while the necessary carbon-descent trajectory is plain for all to see, how the burden will be shared is still an intensely political question, laden with economic, societal and individual consequences that will affect millions, if not billions, of people and the lifestyles they lead.

Yet, as Johnson readily concedes, even with the first round of promised national reductions aggregated together, the combined total was never going to be enough to achieve the 1.5-degree target. The expectation has always been that the pace of those reductions will need to be stepped up substantially to keep carbon in check: already eight countries have

submitted updated NDC targets and two more are at the proposal stage.

Instruments for carbon control

Many of the lower-level measures for driving down carbon emissions are already in operation: consumer product labelling and standards that encourage energy efficiency; taxation on fuels and congestion charges for inner-city zones and state support for low-carbon innovation. The net-zero carbon targets announced by many governments and businesses have brought added focus to the issue, and in several countries products are now taxed on their notional carbon content.

Less obvious are the behind-the-scenes mechanisms that are contributing to greenhouse gas (GHG) reductions and the targets set out in the Paris Agreement. Many countries, regions and economic blocs are determining their own targets, establishing policies, incentives and timetables for individual industries to

Turkey

Ricardo is leading a project to develop a climate change law and legislation to pilot an emissions trading system in Turkey. This World Bank-funded work will be important to help Turkey take forward its climate change mitigation and adaptation plans, even though Turkey has not ratified the Paris Agreement.

We have studied successful approaches in other countries and carried out a gap analysis in Turkey, so that we develop an approach to the legislation that is comprehensive and fits well with existing energy and environmental laws in the country. We have defined the roles of government institutions to implement and oversee each aspect of the carbon market as well as establishing how an independent committee can provide expert high-level advice to the government on climate change matters.

Stakeholder engagement is a key part of the project and we have held many workshops in Ankara and lately via Zoom to gather the wider views of private and public sector practitioners.

Florianne de Boer, senior consultant, is leading this work, drawing on carbon market and legal experts within Ricardo.



Lowering carbon emissions by boosting renewables: Rolls-Royce MTU is supplying battery storage for a microgrid on the Pacific island of Rarotonga. The EnergyPacks will serve as power reserves and grid support



cut their emissions, and monitoring and verifying the reductions actually taking place. And at the core of enabling these mechanisms to function smoothly and transparently is the concept of putting a value on every tonne of carbon emitted, saved or captured.

“Carbon pricing is one of the most important mechanisms we have,” says Johnson. “It works by sending out an economic signal and it provides the incentive for emissions to be reduced wherever it is cheapest to do so.”

The common currency of a carbon price is already allowing trading in carbon, most notably in the EU’s Emission Trading Scheme (ETS), but elsewhere too. Emitting industries must purchase allowances (EUAs) to enable them to emit carbon; the cost of these allowances is passed on to the end customer in the form of higher prices. Taking the example of the electricity generation sector, the higher consumer prices then make it even more advantageous for zero-carbon energy suppliers – who will not need to buy allowances – to invest in additional and improved generation capacity.

By capping the number of allowances issued, authorities have a tool to effectively limit the total amount of carbon emitted in any given period. In some variations of the trading mechanism, low-carbon producers can be allocated credits which they can then sell to higher-emitting businesses. In addition, further markets are evolving in

carbon futures and carbon derivatives.

Already, around half of Europe’s GHG emissions are covered by the ETS scheme. It encompasses the most carbon-intensive heavy industries, such as power generation, steel and cement, glass and even some aspects of transport such as internal EU aviation. Trading systems in general can also provide credits for removing carbon from the atmosphere through schemes such as forestry or carbon capture and storage (CCS); the proportion of removals is still small, but is set to grow as technologies improve. Globally, according to the World Bank, some 22 percent of GHG emissions are covered by ETS or carbon trading schemes.

The Paris Agreement also makes provision for the trading of allowances between nation states, so countries such as Suriname and Bhutan, which are both net absorbers of carbon rather than emitters, have the opportunity to be rewarded for their favourable GHG performance.

Carbon leakage and the limitations of markets

Carbon cap-and-trade systems have been shown to work well when it comes to heavy industries in fixed locations: across Europe, GHG emissions from these sectors have fallen by more than 16 percent since the ETS started in 2005. But for obvious reasons the system is less effective when an industry straddles the borders of many jurisdictions, as in the case of aviation. How, for instance, should international carrier Air France register its transatlantic flight emissions?

Though airline emissions are still relatively small at 2 percent of global GHG output, the steeply rising trajectory of air travel has raised alarm and has led to the establishment of another form of carbon control – CORSIA, or the Carbon Offsetting and Reduction Scheme for International Aviation. This is the first sector-specific global agreement and is designed to allow the industry to continue to grow, but only on a carbon-neutral basis – see panel [right]. Work on an entirely different parallel scheme for the shipping industry is at an earlier stage.

A potentially bigger limitation of regional or even continent-wide carbon trading schemes is the problem of carbon leakage, as Mark Johnson explains:

“Take the example of the EU’s steel sector, which needs to improve its carbon performance in order to be part of the EU’s reduction trajectory. Overall system emissions are capped, so this imposes extra cost and makes European firms less competitive compared with producers in other countries – China, for instance –

Keeping control of airline emissions

CORSIA, or the Carbon Offsetting and Reduction Scheme for International Aviation, is a plan developed by the International Civil Aviation Organization to stem the rapid rise in airline emissions since business and leisure air travel took off in the 1990s. It is the world’s first international sectoral carbon stabilization commitment and is set to enter its pilot phase in 2021 and become mandatory from 2027 onwards.

However, because of the Covid-19 pandemic and the slump in air travel this year, 2020 may no longer be taken as the baseline year, and the implementation timetable may change as a result.

Airline operators are already required to monitor, report and verify (MRV) the CO₂ emissions from their aircraft; these values can take account of any sustainable fuels used. As the scheme gets under way, airlines will be required to purchase approved CO₂ offsets to cancel out their own GHG emissions for each particular year. An elaborate growth factor formula will allow for airline mileage to increase, as long as this increase is matched by greater efficiency or the inclusion of sustainable fuels to keep overall GHG emissions at baseline year levels.

Several nations, such as Jordan, Argentina and Columbia, are engaging with Ricardo to evaluate the potential provision of carbon offsets suitable for the CORSIA scheme.

South America and Jordan

The Paris Climate Change Agreement envisages cooperation between countries as they reduce their emissions. In particular, Article 6 of the Agreement allows for the trading of mitigation action (ie emissions reductions) between countries, so that those with high potential could make greater reductions and receive payments from other countries for doing so.

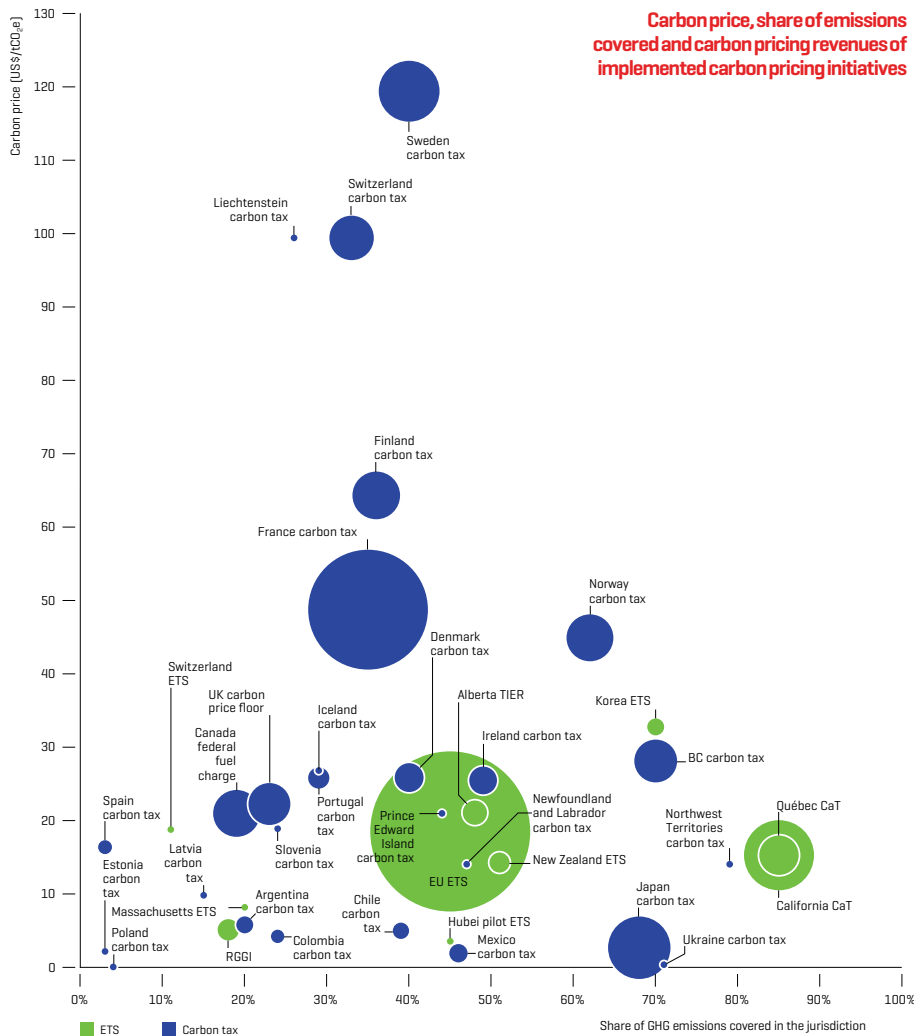
This opportunity is interesting for many governments, but they must be careful as the emissions savings they trade will be attributed to the buyer, so they need to make sure they meet their own commitments for emission reductions first, and only trade the extra savings.

Ricardo is helping many governments to understand how to implement Article 6 including the processes they need to put in place to account for and trade the emissions savings. We are also helping them understand how the savings they make could be sold under the CORSIA system for aviation. We have supported Argentina, Colombia and Jordan in these areas.

Marianna Budaragina, senior consultant, has led these projects.



Source: The World Bank (2020) Carbon Report



Note: Government revenues from carbon taxes, auctioned allowances and direct payments to meet compliance obligations. The size of the circles is proportional to the amount of government revenues except for initiatives with government revenues below US\$100 million in 2019; the circles of these initiatives have an equal size. For illustrative purposes only, the nominal prices on April 1, 2020 and the coverages in 2020 are shown. The carbon tax rate applied in Argentina, Finland, Ireland, Mexico and Norway varies with the fossil fuel type and use. The carbon tax rate applied in Denmark and Iceland varies with the GHG type. The graph shows the average carbon tax rate weighted by the amount of emissions covered at the different tax rates in those jurisdictions. The middle point of each circle corresponds to the price and coverage of that initiative.

Carbon price, share of emissions covered and carbon pricing revenues of implemented carbon pricing initiatives

says, “they reflect low levels of government ambition. If it’s a carbon tax, then it’s a treasury decision - what that government sees as the price necessary to drive the emissions reduction outcome that it wants; this is also coupled with the political and economic willingness to pay. If it’s on a trading system, then the price emerges from the cost of meeting the particular carbon budget.”

The marked difference between countries is explained by the level of climate ambition displayed by each nation, suggests Johnson. With a carbon price pegged at almost \$120, Sweden places a very high value on reducing GHG emissions, and its citizens are prepared to accept the cost; countries with heavy GHG emissions from legacy industries hardly value carbon at all. Local and regional trading schemes evolve their own prices, and many are clustered around the \$15 band, with the EU’s ETS rising steeply past \$19 as of April 2020.

A possible inflection point was noted by the Financial Times in June this year. “Although at the current levels the benchmark EU [carbon] Allowances contract is still below its all-time high of €30, in another sense EUAs have in the past two weeks traded higher than ever before,” the paper reported. “This is because for the first time in their 15-year history, EUAs are now trading above the upper end of the so-called fuel-switching range — the range in which EUA prices incentivize less carbon-intensive gas plants to displace more carbon-intensive coal plants.”

Strong commitments needed

The significance of the EUAs’ recent upward trend is clear. Even a widespread switch from coal to gas will not be enough to keep emissions on track to the EU’s declared net-zero target by 2050: carbon-reduction investment must shift into other technologies and other sectors.

But the EU is an exception: it is a highly organized and regulated market, and one with a clear Green Deal pathway towards net-zero GHG. The EU’s strong commitment to carbon reduction is supporting the ETS and its derivative markets, and most of the mechanisms can be seen to be working effectively.

Regrettably, however, that is not yet the case everywhere in the world. For global decarbonization to gather the necessary momentum, what is now needed is for governments to engage with the international co-operation mechanisms already in place, most of them defined by the Paris Agreement. And it is here that Ricardo specialists are most active, assisting governments as far afield as South America, South Africa, Turkey and

The World Bank’s 2020 review of carbon trading and pricing schemes (above) clearly shows Sweden with a high price and medium revenues, and California and Quebec with lower prices covering more GHG sectors. France is medium price but high in revenue

where carbon emissions are cheaper.” It could then follow that less steel is made in the EU and more in China. And if Chinese steel plants are less efficient, warns Johnson, this will actually push global emissions up, “which isn’t what we want”. These global disparities in carbon pricing also risk distorting the siting of international investment: in the absence of an agreed international price for carbon, the closer alignment of the various jurisdictions would be a positive step.

Why is the price of carbon so low?

Given that emitting carbon to the atmosphere is the root cause of dangerous climate change, it is legitimate to ask why the price of carbon is so low. In principle, the carbon price in any jurisdiction will be determined by how expensive it is for the local industries to meet their carbon targets – so the looser rules in, say, China

would lead to a lower price per tonne in that market. The problems come, as we saw above, when the differentials are so large that they influence decisions on procurement and investment.

The IMF has estimated the average carbon price around the world at just \$2 per tonne of CO₂ equivalent [tCO₂e]. This is somewhat concerning in the light of the independent High-Level Commission on Carbon Pricing’s calculation that carbon prices of at least \$40–80 per tCO₂e by 2020 and \$50–100 by 2030 are required to cost-effectively reduce emissions in line with the temperature goals of the Paris Agreement. As of today, reports the World Bank, less than 5 percent of GHG emissions currently covered by a carbon price are within this range, with about half of covered emissions pegged at less than \$10.

These low prices, notes Johnson, have little to do with the carbon pricing mechanisms themselves: “Instead,” he

“What will be interesting to see is how the markets evolve over a five-year timescale as a result of the present pandemic”

Mark Johnson, carbon markets business manager, Ricardo Energy & Environment

Jordan in developing climate-change law, strategies for transport, for carbon markets, and for taxation and offsetting.

The key to all these initiatives, as is clear from the accounts in the boxes on pages 12, 13 and 15, is to enable governments to participate more fully in both internal and international carbon-reduction protocols; nevertheless, many emerging economies have conflicting priorities such as the alleviation of poverty, and their embracing of the Paris processes may be slower than that of richer nations with greater capacity to make the necessary reductions.

Parallels with financial accounting

After many years of holding back, the business community is now beginning to accept the need to reduce its impact on the global environment, acknowledging that this requires monitoring and disclosure as well as low-carbon investments and even divestment away from fossil fuels. In 2015 the Task Force on Climate-Related Disclosure drew up its guidelines for corporate reporting of future risks related to climate change [see RQ Q1 2020], and Ricardo has worked actively since 2012 with the World Bank's Partnership for Market Readiness, which seeks to bring together innovation and funding to support capacity building and the scaling up of climate change mitigation actions.

Also founded in 2015 is the originally Dutch-based Partnership for Carbon Accounting Financials, which is expanding globally and will launch harmonized and transparent global carbon accounting standards in January 2021. Pointedly, on its website it observes that since the Paris Climate Agreement the largest banks have still invested nearly \$2 trillion into the fossil fuel sector. This, said the PCAF last year, is equivalent to \$2.4 billion for every working day since the end of 2015, with no downward trend and no assessment of the carbon impact of that finance.

However, recent fossil-fuel divestment decisions by some financial institutions may begin to reverse that trend, as may the net-zero pathways announced by some of the major oil companies.

What next?

The direction of travel for carbon markets is clearly towards a much greater prevalence,

where they will draw in fresh sectors and increase the scale of their ambitions. It is likely, says Johnson, that carbon instruments will become more substantial over time as countries need to deliver more change and carbon prices rise.

“For a while now,” he explains, “there has been a trend away from the economically pure vision of carbon markets only as a price signal, and towards a more nuanced view where governments have a bigger role in protecting industries and supporting research and innovation in a way that is pragmatic but not necessarily so free-market ideal.

“We have already seen this in the responses to the financial crash of 2008, when the carbon market didn't work so well and had to be reformed,” he continues. “What will be interesting to see is how the markets evolve over a five-year timescale as a result of the present pandemic.”

As the more advanced economies make progress towards their net-zero GHG targets there will clearly be a much greater role for carbon markets in creating

South Africa

South Africa has implemented an ambitious carbon tax programme covering all sectors of the economy. To help encourage low-carbon investment within industrial sectors and protect them from carbon leakage, businesses that meet carbon performance benchmarks will receive a reduction in their tax liabilities.

Ricardo has carried out many studies concerning industry benchmarks and has recently been commissioned to carry out a critical review of the benchmarks in South Africa to ensure they are realistic and robust measures of good carbon performance. We will be gathering and assessing industry data and helping the National Treasury with a plan to make any improvements to the benchmarks that will be needed over the next year.

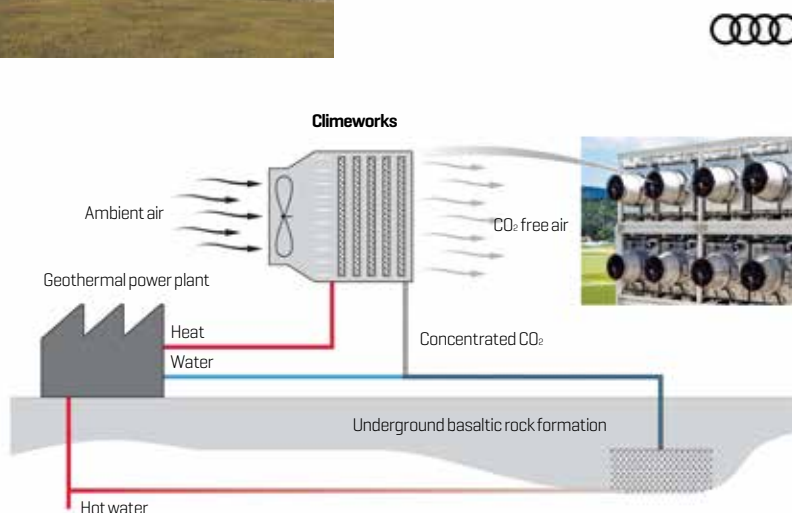
Chris Green, associate director, is leading a team to deliver this work.



incentives for carbon removals. Carbon pricing provides enormous potential for contributing to international efforts to meet the Paris Agreement goals to limit global heating – but, equally, there is a huge amount of work to do this in a way that is equitable, that recognizes each country's own circumstances and which avoids challenges like the risk of carbon leakage. And it is in these areas that Ricardo is especially active in helping to shape that all-important political agenda. 📌



Negative emissions: Audi is working with Switzerland's Climeworks to build the world's largest direct air capture and storage facility for converting atmospheric CO₂ into rock. The facility, in Iceland, will sequester 4000 tonnes of carbon dioxide from the air each year



CO₂ Capturing
Facility for converting atmospheric CO₂ to rock

From net zero to CARBON

Parts of the modern economy such as aviation and agriculture are extremely challenging in terms of emissions reduction, so to achieve overall net zero will require other sectors to adopt technologies that are capable of removing carbon from the atmosphere. **Anthony Smith** speaks to experts at Ricardo who are collaborating with Bluebox Energy on a highly innovative combined heat and power concept that sequesters carbon in the form of biochar

Combined heat and power (CHP) systems have long been recognized as having the potential to deliver considerable improvements in efficiency compared with the separate production of conventional electricity and thermal energy. According to the United States Environmental Protection Agency (EPA), the average efficiency of the country's fossil-fueled power plants is just 33 percent, meaning that a full two-thirds of the energy used to produce electricity is wasted in the form of heat discharged to the atmosphere.

CHP plants act as a combined production system for both electricity and thermal energy, for example for district heating schemes or for industrial processes requiring heat; this allows them to achieve total system efficiencies, according to EPA figures, of between 60 and 80 percent for producing electricity and useful thermal energy. Some systems achieve efficiencies approaching 90 percent. Moreover, as CHP systems are typically developed at a scale appropriate to the immediate demands of an industrial facility or local community, they can also avoid the transmission and distribution losses and capital costs that would otherwise be incurred through centralized power generation.

The use of biomass as feedstock for CHP systems is particularly attractive as a potential low-carbon option, especially if the material is either derived from waste timber or from resources which will be replaced with the cultivation of further forested crops. "Biomass is being widely recognized as a major contributor to the national grid power mix," explains Djapak Mistry, director for infrastructure & utilities at Ricardo Energy & Environment.

Yet, continues Mistry, biomass also has a major role to play in the more localized CHP sector. "In the UK, major multi-gigawatt power plants show that alongside nuclear energy and renewables such as wind and solar, biomass can play an extremely valuable role in reducing the carbon intensity of grid power supplies. But we also need to focus on smaller-scale co-generation technologies, for in many industrialized societies the greater imperative is the challenge of achieving net zero through decarbonizing heat."

While conventional large-scale power and CHP plants use the conventional steam Rankine cycle, current small-scale CHP installations are often based upon the Organic Rankine Cycle (ORC). Rather than using water as the working

fluid, these systems have a closed circuit filled with an organic compound with a much lower boiling point: liquids such as toluene, isobutene, isopentane or silicon fluid can be employed. The lower boiling point allows power to be generated from much lower grade heat sources across a wide range of potential biomass feedstocks. A major drawback of ORC-based small-scale CHP systems is their complexity, which attracts a comparatively significant capital cost.

Pyrolysis and FLOX combustion

Based near Portsmouth on England's south coast, Bluebox Energy is a specialist in hot air turbomachinery. The company has developed a CHP concept that promises improved efficiency and lower installed costs than current ORC systems. But that's not all: the concept also sequesters approximately 50 percent of the carbon content absorbed by the timber during its growth, and delivers it in the form of a potentially valuable by-product: biochar. In the Bluebox concept, the biomass fuel is pyrolyzed rather than combusted. This

NEGATIVE

The use of sustainably grown or waste biomass as an energy source provides an opportunity for negative carbon emissions if carbon is sequestered in the form of biochar, separated from the flue gas



is done by heating it to a temperature at which it decomposes to form a combustible synthesis gas, together with residual carbon biochar as a by-product. The syngas produced through pyrolysis is then fed to a flameless oxidation (FLOX) combustor. A small proportion of the heat released is used to feed the pyrolysis process, while the remainder is used, via a heat exchanger, to feed a turbo-compressor and power turbine to provide clean hot air and electrical power respectively. Some of the clean hot air

is used to dry the feedstock, while the remainder is used for direct air heating and industrial drying processes, or to produce hot water or steam supplies. The flue gas produced by the FLOX combustor is already very low-NOx by virtue of the lower temperature of the combustion. It is then passed through electrostatic filters to eliminate particulate matter before being exhausted to the atmosphere. Key advantages of the Bluebox CHP concept also include its competitive cost:

the turbomachinery system is based on the use of commercially available off-the-shelf components from the truck, shipping and power generation sectors. In addition to their competitive cost and easy availability, such components are also well proven in terms of robustness and reliability. This pragmatic use of available components is a major factor in Bluebox Energy's claim that its concept is between 20 and 40 percent cheaper to build than competing CHP systems based on established technologies.

Valuable biochar

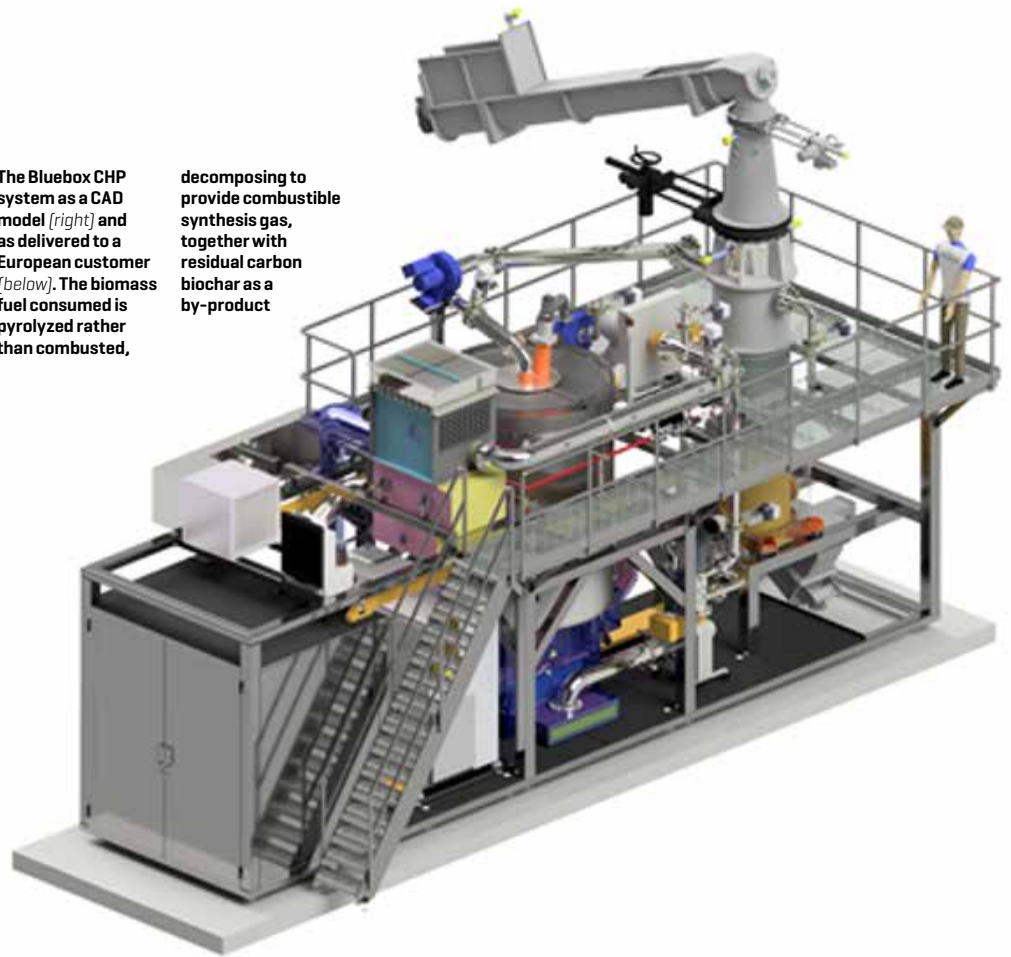
In the wider context of efforts to move towards net zero, however, one of the most decisive advantages of the pyrolysis and FLOX CHP concept is its ability to sequester fully 50 percent of the CO₂ contained in the biomass fuelling the process in the form of biochar. Biochar is a product that the Intergovernmental Panel on Climate Change (IPCC), as well as the Royal Society and Royal Academy of Engineering have since 2018 recognized as one of the key available solutions for CO₂ capture in a chemically stable form.

But biochar is much more than just an attractive carbon store and effective carbon dioxide removal (CDR) technology, and has many potential valuable downstream uses. According to the European Biochar Industry Consortium, such applications even include improving the quality of construction materials such as concrete or asphalt. Biochar is also being actively investigated as a soil conditioner for horticulture and agriculture, and positive effects already reported include improving plant health through neutralizing acidity, providing better water and nutrient retention – especially in sandy soils – and improved drainage and aeration. Due to its highly porous structure, each biochar fragment also provides a habitat for beneficial soil microbes.

Biochar is also widely used as an animal feed additive, particularly for ruminants where it has been used with the aim of reducing enteric methane emissions, thus providing a potential further greenhouse gas reducing benefit. Despite its chemical stability and its high elemental carbon content of up to 90 percent, not all biochar is identical. Care has to be exercised in the selection of a pyrolysis feedstock appropriate to

The Bluebox CHP system as a CAD model (right) and as delivered to a European customer (below). The biomass fuel consumed is pyrolyzed rather than combusted,

decomposing to provide combustible synthesis gas, together with residual carbon biochar as a by-product



the intended use of the biochar – for example in the case of its use as a soil conditioner, where it is vital to ensure that the pH is acceptable. However, if the inputs and outputs of the CHP system can be balanced according to availability of the feedstock, the electrical and heat energy requirements and the intended application of the resulting biochar, the Bluebox pyrolysis/FLOX system offers considerable potential for net-negative carbon emissions.

Collaboration with Ricardo

In June 2020 Ricardo and Bluebox Energy announced that they had drawn up a memorandum of understanding that

will see the two companies collaborate on innovation in heat and energy technologies. The agreement follows an initial period of less formal collaboration which, as Bluebox Energy CEO Jonathan McGuire explains, has proven to be very promising: “Even in the short time we’ve been working together, we’ve already seen a number of opportunities for us to develop innovative technology-based solutions that can drastically reduce carbon. The combined expertise of both companies will enable us to make the ambitious carbon reduction targets achievable. We’re now looking forward to making a real difference together.”

Post-combustion carbon capture

The initial focus of the collaboration with Ricardo is on the potential integration of additional technologies to the Bluebox CHP system. These technologies would have the potential to extract a significant proportion of the carbon content of the flue gas.

“The system as it stands already captures a full 50 percent of the carbon content of the biomass feedstock and delivers this in the form of a saleable by-product,” explains Ricardo’s Dipak Mistry. “Our next aim is to provide additional technologies capable of capturing the bulk of the carbon dioxide from FLOX combustor exhaust.”

This, Ricardo contends, will provide the opportunity to develop a fourth product



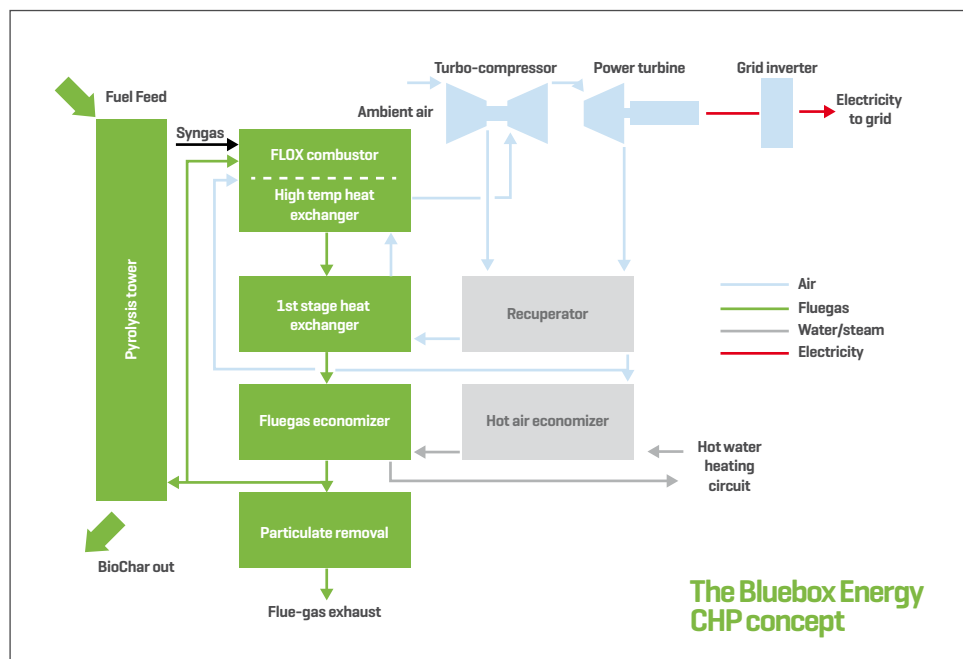
stream – commercial grade bottled CO₂ that can be used in sectors ranging from food and beverages to construction. This could be sold through a well established supply chain in other market sectors, and would complement the CHP system's primary products of electrical power and heat energy, and the existing by-product of biochar.

A number of established technologies are available for carbon dioxide capture from flue gas, each having different efficiencies and capital costs. These include separation methods such as absorption, adsorption and membrane technologies, as well as a proprietary Ricardo concept based on cryogenic liquefaction and fractional condensation. However, as Mistry explains, Ricardo is keeping an open mind on the most appropriate concept for this innovation: "We are currently exploring a range of candidate solutions that we believe could increase the carbon capture from 50 to around 90 percent. To achieve this, we are evaluating a range of possible technical solutions, including due consideration of issues of IP protection and potential commercial exploitation in other sectors."

Beyond zero carbon

The clear overarching theme of Ricardo's collaboration with Bluebox Energy is to go beyond zero-carbon processes to develop expertise in carbon-negative technology.

Where biomass is sustainably forested and harvested, there is already the potential for extremely low-carbon emission production of electricity. Through the pyrolysis and FLOX combustion CHP process that Bluebox Energy has developed, over 50 percent of the carbon absorbed from the atmosphere as the timber



"As there will clearly be many aspects of modern life that are not amenable to a fully sustainable future, achieving net-zero carbon at a national or regional scale means that we will also need technologies that are capable of negative carbon emissions"

Dipak Mistry, Ricardo Energy & Environment


is grown remains sequestered in the form of stable biochar. If successful, the collaboration with Ricardo will see this proportion increase to about 90 percent.

In addition to the immediate carbon-negative CHP process, further indirect greenhouse gas savings may well accrue from the uses to which the biochar is

Sequestered carbon dioxide can be separated and sold as a by-product, as in the case of this US bioethanol production plant

put. These could be in agriculture and horticulture, or in the offsetting of the energy that would otherwise have been required to produce bottled CO₂ for the food and beverage industries.

"As there will clearly be many aspects of modern life that are not amenable to a fully sustainable future, achieving net-zero carbon at a national or regional scale means that we will also need technologies that are capable of negative carbon emissions," concludes Mistry. "In our collaboration with Bluebox Energy we are committed to taking this challenge forward, and demonstrating new and innovative approaches to CDR technology that can remove carbon from the atmosphere while delivering improved CHP performance.

"By applying truly multidisciplinary technologies and working across the boundaries of established market sectors and product lines," he continues, "I believe that we can make significant inroads into decarbonizing the production of electricity and heat and, by doing so, help to deliver a truly net-zero future for society." 





An end to **RANGE ANXIE**

Maximum range is the top priority for attracting customers to electric vehicles, and for engineers this translates into achieving the best possible efficiency of the whole drivetrain from battery to wheels. Ricardo's innovative Integrated Model-Based Development framework is ideally suited to the highly complex subject of electrified vehicle thermal management, as **Jesse Crosse** reports



With electric vehicle buyers becoming more money conscious, the recipe for greater range is no longer just to add bigger, heavier and costlier battery packs. Instead, EVs can help meet end-user demands by maximizing the efficiency of their powertrains, helping make the most of every kilowatt-hour in the battery.

A key factor here is the efficient thermal management of the whole suite of xEV systems, 'x' standing for all types

of electrified vehicle, from pure battery electric vehicles to plug-in hybrids and range extended EVs. As well as boosting range, good thermal management can significantly improve passenger comfort, charging performance, battery durability and the predictability of that range. This last point is important because range anxiety and the difficulty of predicting available driving distance over different routes and in different weather conditions still remains a

big concern for many potential EV buyers.

Ricardo's Integrated Thermal Management approach to the design of xEV systems focuses not just on the drivetrain, but on the whole vehicle system including the cabin. The key to this is the Ricardo Integrated Model-based Development Framework (IMBD) which takes into account all onboard systems and the impact they have as a whole on the vehicle's total energy resources.



“We have an increased level of complexity in powertrain and heating and cooling systems because we have components that operate at different temperature levels,” explains Dr Cedric Rouaud, Ricardo global technical expert, thermal systems. “The battery operates at a temperature close to that which humans find comfortable, so it’s almost like having another passenger in the car. But the power electronics and drive motor operate at higher temperatures, so we see complexity in hardware and control growing tremendously.

“We have to work out how to couple or separate cooling and heating circuits, reuse waste heat and how to control them depending on ambient temperatures and driving conditions,” he continues. “We are also looking at ways of exploiting the satellite navigation system to reduce energy consumption by onboard ancillaries by knowing what might happen next on the road.”

By taking data such as road type, curvature and gradient from the satnav system and combining it with cloud-based dynamic data [such as real-time traffic speed, variable speed limits and weather], it is possible to see the future route in greater detail, a so-called electronic horizon, and use this to estimate and minimize energy consumption.

How the process works

Under the IMBD umbrella and using a number of tools including Ricardo’s IGNITE software, the powertrain (motor, power electronics and battery), and HVAC (cabin and heating and cooling systems) are first defined as a model sub-system and their parameters established.

The next step is to create a 1D base model of the thermal system model

including the powertrain and vehicle. Known as a plant model, it includes the cooling circuits, HVAC and cabin, and the battery and electrical system. Stage three is to generate a manageable Reduced Order Model (ROM) for the simulation and analysis of driving scenarios.

Finally, the ROM is optimized to make it capable of running in, or faster than, real time when integrated into a physical control unit.

Evaluating different alternatives quickly

This approach makes it possible to evaluate the many different technical alternatives that might be used for a particular task. For example, battery cooling can be accomplished in a number of different ways. Air cooling is one, liquid cooling with cold plates is another, and further options are refrigerant cooling or immersion cooling where electronic components – battery cells/bus bars, MOSFETs, IGBTs, electric motor end windings or stator slots – come into direct contact with a dielectric coolant.

“In a quarter of the time it would normally take, we can evaluate the best cooling methods for a particular scenario based on all the criteria like cost, packaging cooling and heating requirements required for a particular application,” says Rouaud.

And with the introduction of super-fast chargers now bringing rates of up to 350 kW, the thermal management of batteries is becoming increasingly demanding. “In the next three to five years we will see cars that can charge in less than ten minutes,” he continues. “To do that we have to develop new cooling methods such as immersion cooling.”

With side plate [as used by Tesla] or

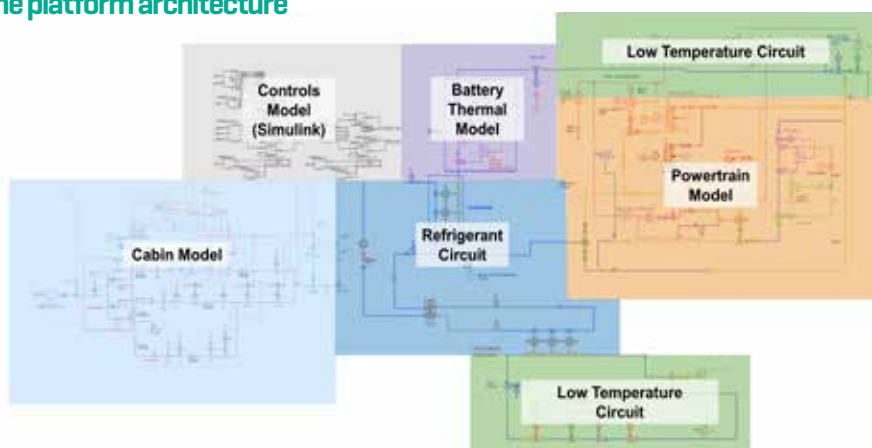
→ Ricardo’s modular approach to powertrain thermal optimization extends to the complete vehicle, which is critical for complex hybrid vehicles - thermal systems controls models are developed to maximize efficiency

Electronic horizon reduces anxiety

The EV market is reaching a critical point where range has begun to catch up with affordability and long-range EVs are no longer the preserve of wealthy premium buyers. EVs costing ~£35,000 are now capable of around 450 km range on the WLTP cycle and, as the cost of batteries continues to fall, the price gap has been closing between EVs and their internal combustion engine (ICE) counterparts.

It is clear, therefore, that one of today’s top engineering imperatives is to make better use not only of the energy stored in an EV battery, but also to address and exploit any latent thermal energy lingering in drivetrain components and power electronics. And this in turn poses some real challenges for automakers.

A modular approach allows complex system interactions to be modelled within the platform architecture



“In a quarter of the time it would normally take, we can evaluate the best cooling methods for a particular scenario based on all the criteria like cost, packaging cooling and heating requirements required for a particular application” Dr Cedric Rouaud, Ricardo global technical expert, thermal systems

→ bottom cooling (as used by the Chevrolet Volt and Porsche Taycan) the charging rate is limited to 3-3.5C (the C-rate is a measure of charge rate relative to a battery's capacity). Depending on the size of the battery pack, that limits charge to around 20-30 minutes.

“By using a non-electrically conductive fluid, the coolant can be in direct contact with cell connection tabs and bus bars, massively improving the cooling capacity and making it possible to charge at a rate of 4.5-6C for 8-10 minutes,” explains Rouaud.

Typical fluids used for this purpose are gearbox transmission oils or cooling oils used in transformers. Although the thermal conductivity of these fluids is lower than that of water-based cooling fluids, the overall cooling benefit is much greater than a conventional cold plates approach with ethylene-glycol water.

Latest to the market are synthetic cooling fluids; although they are safer on account of their non-flammability, they have a lower heat transfer coefficient than that of transmission or transformer oils. However, their viscosity is also less, giving the advantage of higher flow rates, so accurate modelling of the

relative performances is vital. Ricardo is collaborating with the manufacturer MGI on the development of these new fluids as part of an Innovate UK-funded project called I-CoBAT (Immersion-cooled Battery), which started in June 2019 and will finish at the end of 2020.

Prepare to charge

For high-power fast charging to be feasible, the temperature of the battery needs to be optimized en route, before the car arrives at a fast charging station. This is where the electronic horizon concept has a major role to play.

The battery temperature needs to be in the range of 25° to 30° Celsius for fast charging to begin at the moment the car is plugged in. If the battery temperature is outside that range, the charge speed will be de-rated to protect the battery cells and the temperature then has to be optimized during charging – something which significantly slows the charging process and increases the charge time.

If the battery is charged too quickly when cold, cell damage will be permanent. If the cells are too hot, they may not be damaged but their life expectancy will be reduced. What is more, a 20-minute

charging time could be doubled to 40 minutes if the battery temperature is not fully optimized when charging begins.

Energy management – in the cabin

Another key factor not so obviously associated with energy management and EV range is cabin comfort. This is an area where it is particularly useful to use Model Predictive Control to project a system's future behaviour. “We can also link energy consumption to CO₂ levels in the cabin,” explains Rouaud. “If the heating system is set to recirculate, cabin heat-up can be faster – but it's important to monitor cabin air quality for the wellbeing of the passengers.”

Overall energy consumption can be reduced using methods other than blowing hot or cooled air through vents to heat or cool the cabin. Traditionally, vents are positioned to direct air to the feet, face, upper body and the windscreen, but even with dual or multi-zone heating systems, the energy required to maintain passenger comfort is high. It is also the case that multi-zone climate control systems do not always work to everyone's satisfaction, so the answer is to introduce local heating and cooling methods for individual passengers and focus on the thermal energy to reach local comfort and not only the total energy for the whole cabin

In cold conditions, local heating solutions such as radiant panels, heated seats and heated steering wheels are more efficient than ducted air. “These still use electrical energy but consume a tiny amount of current compared to turning a conventional heating system up full blast,” explains Rouaud.

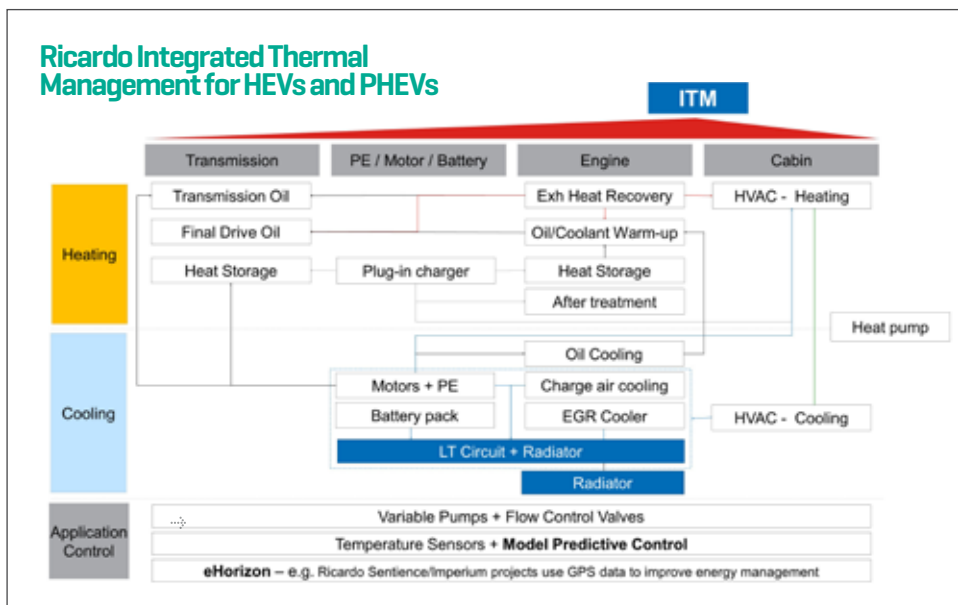
If heat from the drivetrain and battery is also used to supplement this electric heating, energy consumption can drop from several kilowatts to a few hundred watts. Similarly, local cooling could be extended from the fan-cooled seats or Peltier-cooled modules (using thermoelectric materials) already available in some cars to other areas of the cabin.

To facilitate this, the human body can be modelled in 1D following the same procedure as for the vehicle systems, and the output combined with 3D models of the complex airflow around it.

Accounting for the human factor

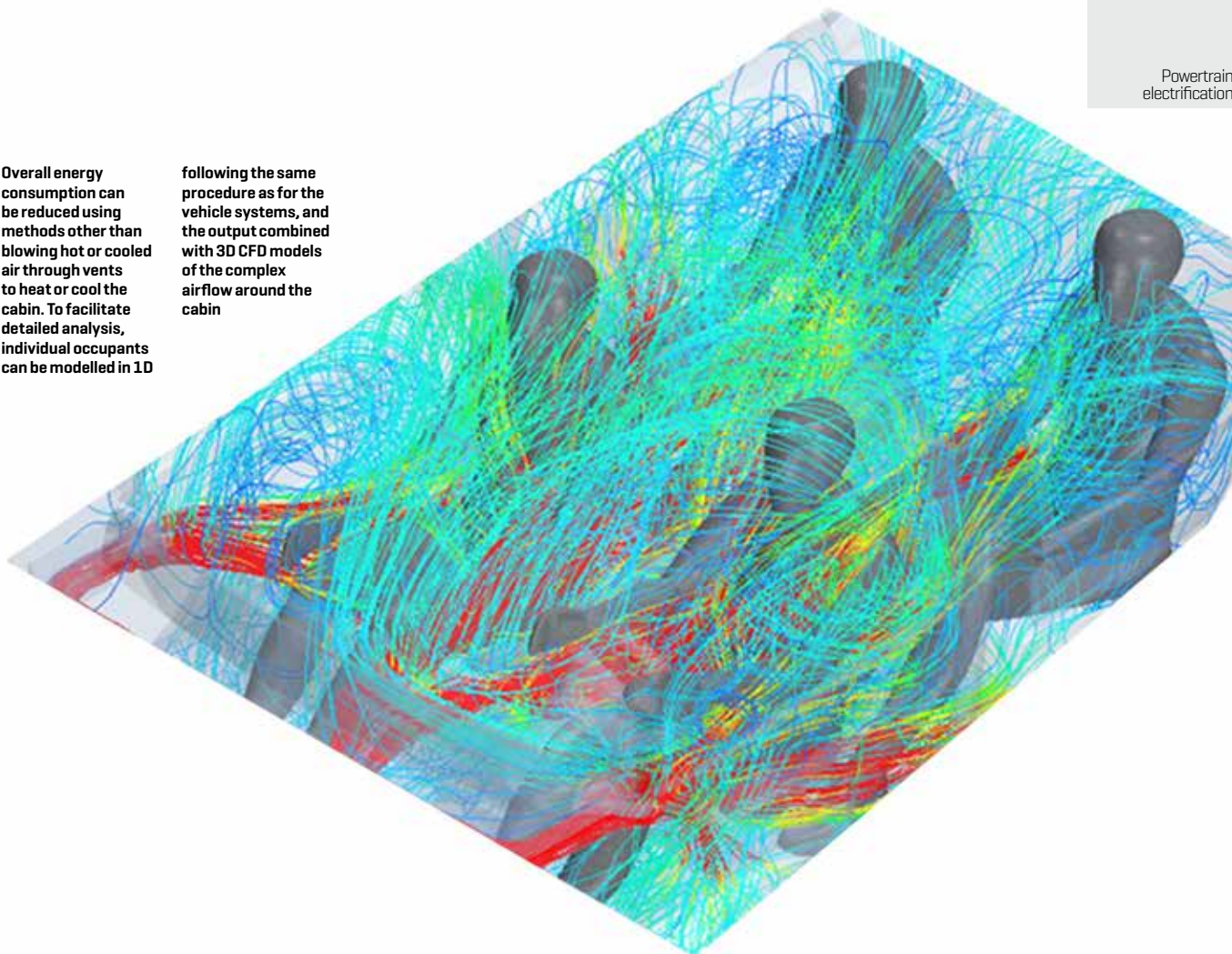
Modelling of humans can take into account complex details such as the kind of clothing being worn, the age and gender of the occupants and the level of activity they were engaged in before entering the car. Navigation data can also be used to establish the position of the sun, and local

Powertrain electrification adds thermal management requirements but also provides opportunities for more cost-effective Integrated Thermal Management (ITM) solutions



Overall energy consumption can be reduced using methods other than blowing hot or cooled air through vents to heat or cool the cabin. To facilitate detailed analysis, individual occupants can be modelled in 1D

following the same procedure as for the vehicle systems, and the output combined with 3D CFD models of the complex airflow around the cabin



infrastructure, trees and so on which can have a bearing on the ambient temperature of the surroundings and solar load impacting the cabin. This approach to cabin comfort and passenger wellbeing could become even more significant with the projected introduction of level four or five autonomy, where passengers of driverless cars will have the option of moving seats into different positions unrelated to the position of HVAC air vents.

Heat pumps, now popular in buildings for extracting heat from the ground, are also appearing in production EVs. Heat pumps essentially act like a refrigeration system in reverse, absorbing heat from cooler areas and then releasing it into warmer ones. An electric heater will produce around 1 kW of heat from 1 kW of electricity, whereas a heat pump can improve on that by a factor of two or more, producing over 2 kW of heat for every 1 kW of energy used to drive it. But the control required is sophisticated, meaning that IMBD and advanced control methods are ideal for integrating the heat pump with the other complex thermal systems in an EV or HEV/PHEV.

“A powerful approach to develop control algorithms for a complex thermal system is to break down the thermal system into the core control problem, then solve using optimal control theory, a mathematical minimization approach, over the route of interest to establish what could be the best possible results in a virtual environment,”

explains Professor Peter Fussey, technical authority, propulsion control, for Ricardo. “Then from that point, we can produce a controller capable of being run using the relatively limited computing resources in a car.

“The thermal systems consist of heat sinks and heat sources, with a number of cooling circuits to move the heat around the vehicle,” continues Fussey. “The objective is to move the heat around the vehicle as efficiently as possible, reusing the waste heat and minimizing the energy taken out of the battery just for thermal management.”

The art of modelling

The development starts by building detailed component models for system design and orientation of the requirements. From these complex models, the control engineer extracts control-orientated models using a variety of Model Reduction techniques. “These are the simplified models which can run very quickly but have less resolution,” explains Fussey. “It’s quite an art to pick the type of model for a controller that can capture the elements we want to find out about in our system, while avoiding unnecessary detail.”

With a suitable control orientated model, the model can be coded into the vehicle control system and used to optimize the thermal systems in real time, using techniques such as Model Predictive


Control. This can reduce calibration time and improve performance over conventional controllers.

Outlook

Ricardo’s IMBD methodology is already a well proven process, and its use in the context of EV thermal systems development makes it possible to assess many more alternatives than would be possible using less sophisticated methods. It takes the guesswork out of which system design might yield the best results.

Combining optimization approaches with advances in vehicle connectivity to feed the future route details, or electronic horizon, to the controller can open new opportunities to allow the car to manage its systems and energy budgets to reduce the range anxiety of the end user.

In terms of extracting the maximum performance from a traction battery, the results of such detailed modelling and optimization of thermal systems yield a significant margin of improvement rather than just a cautious advance of a few points.

Taking into account all improvements to the powertrain and cabin heating and cooling systems, Ricardo estimates IMBD can deliver a startling 10 to 15 percent improvement in the overall energy efficiency of the vehicle. What is more, work in this area is already moving beyond the automotive sector and expanding into marine, rail and aviation applications. 

RQ RICARDO NEWS

Latest developments from around the global Ricardo organization

Double success for Ricardo Defense



The U.S. Army has announced that GM Defense, together with Ricardo as its strategic partner, has been awarded a \$214.3 million production contract to build, field, and sustain the Army's new Infantry Squad Vehicle [ISV].

The ISV is designed to provide rapid

ground mobility transportation in the form of a highly flexible, light, all-terrain, air-droppable vehicle intended for use by a nine-soldier infantry squad moving within 'close battle areas'. The GM Defense ISV is founded on the award-winning 2020 Chevrolet Colorado ZR2 platform and

**GM Defense's ISV
Chevrolet Colorado
ZR2 based Infantry
Squad Vehicle**

leverages 90 percent commercial off-the-shelf parts, resulting in high manufacturing efficiencies, ease of maintenance, and a low-risk global supply chain.

Following on from this success, the United States National Defense Authorization Act [NDAA] for fiscal year 2021 included authorization for the procurement of 5421 Antilock Brake System/Electronic Stability Control [ABS/ESC] kits to help prevent vehicle rollovers in the world-famous High Mobility Multipurpose Wheeled Vehicle [HMMWV or 'Humvee'] fleet. This paves the way for orders to be placed with Ricardo for the retrofit safety kits.

The ABS/ESC retrofit kit for the HMMWV was developed by Detroit-based Ricardo Defense. The complete package includes antilock braking, electronic stability control, active rollover protection, traction control, and improved brake calipers, pads and rotors. The entire system leverages low-cost, proven components engineered by Ricardo specifically for the arduous requirements of application in the military environment; the system was specifically designed for ease of upgrade to the existing fleet. The Ricardo ABS/ESC Retrofit Kit is the system currently being installed in HMMWVs across a number of initiatives and is designed specifically for this iconic vehicle.

Optimizing railway pantograph and catenary systems

Overhead electrification systems rely on a smooth and uninterrupted connection between the rolling stock and overhead electrified wires. To help in the effective engineering of this crucial interface between rolling stock and infrastructure, Ricardo Rail has launched a new service to simulate the dynamic interaction between pantograph units and catenary systems. The new service aims to help optimize the design of future electrification equipment while also reducing development costs.

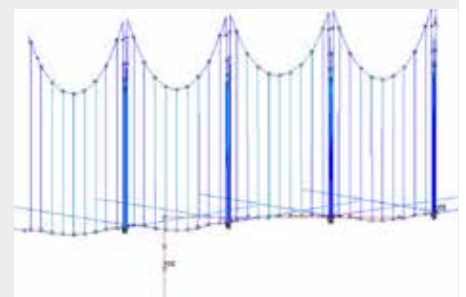
The Ricardo pantograph and catenary modelling and simulation package, RiPAC, has been developed to offer track and rolling stock engineers the opportunity to simulate the full motion behaviour of their designs at a much earlier stage of the product development process.

The simulations, which are performed in line with the applicable standard for current collection systems [EN50318], are overseen by Ricardo's vehicle-track engineering teams, who process the data to provide a detailed report of the measurements captured by the in-house software. The data can then provide the focus for the physical testing programme, subsequently reducing the time and cost of achieving the necessary certification.

RiPAC can also be used to monitor the performance of systems on existing routes across networks, or to inform major refurbishment and upgrade programmes. For example, RiPAC was recently applied by the Netherlands rail infrastructure operator, ProRail, and also the Rotterdam Port Authority, who used it to check the catenary standards compliance of a new 3.8 km line

serving the Rotterdam area.

RiPAC is part of a growing simulation and virtual testing portfolio available from Ricardo's vehicle-track interface team, alongside studies, analyses and advisory services related to vehicle dynamics, multi-body simulation and optimization of wheel/rail interaction.



Ricardo software in NASA technology transfer portfolio



The Technology Transfer Office of NASA's Johnson Space Center (JSC) aims to ensure that innovations developed for space exploration are made available for wider commercial use. Having proven its value in the planning of future NASA missions, Ricardo's advanced Five-Dimensional Task Analysis Visualization (5D-TAV) software has now been selected for inclusion in JSC's technology transfer portfolio.

NASA has an enviable and well-deserved reputation for the planning and execution of the most challenging, safety-critical and complex of space missions. The planning, in particular of long-duration, crewed deep-space missions is an extremely complex and data-intensive process. The visualization, analysis and manipulation of

large, complex and dynamic datasets to optimize operational planning required new methods, for which NASA turned to Ricardo Defense's research expertise in workflow-driven user experience.

Model-driven analysis refined for mission-critical military applications resulted in new visualization techniques and a rapidly developed software application for NASA in the form of the Ricardo 5D-TAV mission-critical planning software, which allows teams to quickly analyze extremely large datasets to isolate potential conflicts, risks, 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 activities that do not add value, thereby minimizing cost, complexity, and susceptibility.

The announcement of the selection by the JSC New Technology Evaluation Board of Ricardo's 5D-TAV software for publication in the official NASA Software Catalog opens the path for possible wider industrial applications of this sophisticated planning technology. In accordance with the commercialization objective of the Small Business Innovation Research programme (SBIR), Ricardo Defense is also advancing the software for Mission-Critical Planning (MCP) available to any business worldwide that needs a high confidence in long-range planning strategy.

Towards the net-zero Scotch

The Scotch Whisky Association (SWA) has published a report, produced with the support of Ricardo, exploring the practical ways in which the industry can collectively achieve net-zero carbon emissions.

The ambition to define a net-zero roadmap arose out of the desire of SWA member companies to proactively and positively reduce the impacts of climate change in line with the Scottish government's 2045 net-zero target.

Ricardo has supported the SWA in the development of the report, bringing in sustainability and energy experts to analyze data from over 120 Scotch whisky sites across Scotland.

Through the robust analysis of energy data from these 120 distilleries, and through engagement with industry stakeholders, Ricardo worked with the SWA to model potential pathways for the industry to achieve net-zero emissions status. Recommendations included decarbonizing current fossil-fuelled distillation processes (with an emphasis on anaerobic digestion), as well as energy efficiency improvements and the adoption of cutting-edge hydrogen technology.



Championship Formula E transmissions

The DS Techeetah team retained both the drivers' and constructors' titles following the completion of the interrupted 2019-20 Formula E season 6 – using a transmission designed and manufactured by Ricardo as a part of multi-year partnership.

The engineering challenges of Formula E are as extreme as anything in liquid-fuelled motorsport formulae, requiring a laser-like focus on driveline performance and efficiency. Ricardo has been supporting DS Performance in Formula E for a number of years, including supply of the transmission deployed in the earlier double championship winning DS E-Tense FE19 car used in the 2018-19 season.

With typical 0-100 km/h acceleration of 2.8 seconds and very high motor speeds, gearbox weight and durability optimization are crucially important. To meet such requirements, Ricardo used its cutting-edge design and analysis methods, its testing facilities, and its world-class advanced manufacturing technology to deliver to DS Performance an extreme performance and high efficiency transmission for the successful DS Techeetah 2019-20 season campaign.



Great Western assurance roles near completion



The £7.5 billion Great Western modernization programme is providing faster, more frequent and more reliable services, using new fleets of electric and bi-mode rolling stock. Some 380 km of routes from London's Paddington station to Wales and the west of England have now been electrified

The launch of passenger services running entirely under electrical wires between London and the Welsh capital city of Cardiff marked one of the last remaining milestones in a decade-long programme to modernize the famous Great Western railway route – a project for which Ricardo Certification played a key role.

The Great Western is one of the UK's busiest mainline routes and supports express passenger and freight services from London's Paddington station to the south west of England and south Wales. In 2010, Network Rail embarked on a £7.5 billion modernization programme to revamp the route to support faster, more frequent and more reliable services. In addition to new fleets of electric and bi-mode rolling stock, track upgrades and station improvements, a cornerstone of the scheme was the 380 km electrification of routes between London, Newbury, Bristol and Cardiff.

Ricardo Certification was appointed by Network Rail as the Notified Body/Designated Body (NoBo/DeBo) for the assessment of compliance with the Railways (Interoperability) Regulations 2011 (as amended) (RIR). The scope of the contract encompassed the mainline between Maidenhead and Cardiff, and also included assessment of compliance with the current Technical Specifications for Interoperability (TSI) for the Energy, Infrastructure and Persons of Reduced Mobility Sub-Systems, for the 25 kV electrification

programme and related infrastructure projects.

Separately, Ricardo Certification served as the Notified Body for the Maidenhead to London Paddington section of Network Rail's Crossrail and is currently performing the same role on the Stratford to Shenfield section. Ricardo also subsequently took on the role of Assessment Body (AsBo) for the assessment of application of the Common Safety Method for Risk Evaluation and Assessment (CSM RA) regulations. This included early design work for the rail link to Heathrow via a proposed twin-bore tunnel.

Over the seven years of the contract Ricardo teams logged, processed and, where appropriate, assessed in excess of 10,000 reports, drawings, certificates or compliance arguments. During the process, Ricardo produced 10 Intermediate Statements of Verification (ISVs), leading to 20 NoBo-Files as the NoBo/DeBo, and a further 164 Assessment Records, culminating in 30 Safety Assessment Reports (SARs) as the AsBo.

Ricardo pre-authorization deliverables included AsBo Safety Assessment Reports, NoBo/DeBo Files, and various addendums were supplied in June 2020 to support the electrification of Severn Tunnel. Final post-commissioning activities are ongoing to ensure that compliance statements are fully captured, enabling the completion of the project before the end of the year.

Remote working brings life quality – and air quality

The Business Clean Air Taskforce (BCAT), which includes Ricardo, Uber, Phillips and ENGIE, has presented the results of a new survey demonstrating that, in addition to bringing clear benefits to urban air quality, continued remote working is both achievable and welcomed by the public.

On the basis of the results of the nationally-representative survey of 2000 UK respondents, the charity Global Action Plan is urging the continuation of remote working as an option post lockdown to prevent a second spike of Covid-19, to keep the streets free for key workers, and to keep air pollution down.

Of the journeys analyzed, almost one in five trips by car could be avoided if employees continue to work remotely as we emerge from lockdown. The

BCAT survey also identified that 87 percent of those currently working from home would like to continue to do so to some degree – which implies that, post-lockdown, the UK could have 17 million regular remote workers versus just 10.8 million pre-lockdown. In addition, of the 19.5 million who have been working from home during lockdown, 41 percent were previously not permitted to do so.

While remote working is not suitable for all professions and is not welcomed by everyone, allowing employees the option to work from home when it suits them can improve wellbeing, with 54 percent of lockdown homeworkers saying they are less stressed. Some 65 percent say they are happier not to have to deal with a rush-hour commute.



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