

Ricardo Quarterly Review

Q4 2020

RQ

A focus on the latest in technology,
innovation and sustainability



Interview

**Isobel Sheldon,
CSO of Britishvolt**

Why customized low-CO₂
battery production is best

Persistent plastics

Undesirable substances that
linger too long – and how to
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Hydrogen

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Ricardo experts decide

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reporting on Ricardo's activities in
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tool to help policymakers shape strategies for a low-carbon future

Creating a world
fit for the future



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It has been billed as the wonder fuel for the future, but can hydrogen really step up to save our planet? **Tony Lewin** speaks to seven Ricardo experts to find out



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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

European automakers race to hit CO₂ targets



Environmental groups, climate scientists and green energy providers around the world are breathing a collective sigh of relief following Joe Biden's victory in November's US presidential election.

The US is the world's second-largest emitter of CO₂ after China, and one of Biden's campaign pledges was to take the US back into the Paris climate accord on the first day of his presidency, which

begins on January 20th. But just how much of his \$2 trillion climate agenda Biden will be able to implement will depend on the Democrats gaining control of Congress, which is not yet assured.

A report by Climate Transparency two weeks after the election revealed that the G20 group of industrialized nations are set to miss the 1.5-degree end-of-century temperature-rise

President-elect Joe Biden and vice president-elect Kamala Harris: ambitious pro-climate policies will require Congressional approval

target by a wide margin. On the basis of current trends, warming is likely to be 2.7 degrees, though recent pledges by China, Japan, South Korea and the EU could bring this down to 2.3 or 2.4 degrees. A further reduction of 0.1 degrees could be expected if the US becomes carbon neutral by 2050, says the report. Even the EU is not on track to meet its targets.

The FT cites the results of a survey of 6000 business groups worldwide by Swiss bank J Safra Sarasin, suggesting that businesses are on course for a 4-degree rise, despite many corporate net zero pledges and pressure from shareholder groups. Companies and asset managers are being accused by investors of complacency and "total greenwash" when it comes to the risks associated with global warming.

The dissension among the ranks of fund managers comes against the background of a renewed acceleration in global temperature rise and the risk of further feedback loops being triggered as frozen methane deposits off the east Siberian coast begin to be released. Methane has 80 times the warming effect of CO₂ over a 20-year period.

The Paris-based International Energy Agency has modelled several future scenarios and expects no recovery in coal demand, oil demand to peak before 2030, and natural gas to rise until 2040. To get back on track to hit net zero by 2050 requires a 40 percent cut in GHG emissions by 2030, says the IEA, meaning 75 percent of global energy demand must come from low-emission sources by that date, with half of all worldwide passenger car sales being electric models.

Combustion phase-out quickens

UK prime minister Boris Johnson's November announcement of a 10-point package of Green Industrial Revolution measures has been given guarded praise from green groups. The plan, designed to put the country on course for net zero carbon by 2050, includes a quadrupling of offshore wind power to 40 GW by 2030 and a ban on the sale of new diesel and gasoline engines cars and vans by the same date. Plug-in hybrids will be allowed until 2035, though their minimum battery range requirement has not yet been specified.

The move puts the UK ahead of several EU nations, most of which are set to phase out combustion models by 2040. Norway, however, is well

ahead of the field with a 2025 ban: some 60 percent of its new-car sales are already electric. Denmark, the Netherlands, Sweden and Ireland are all discussing 2030 phase-outs too, while Spain and France have earmarked 2040. Many local and city-centre zero-emissions zones are already in force.

Further afield, staged phase-outs will see California and its partner US states banning combustion car sales completely by 2035, though it is too early to say whether the new administration in Washington will extend this to other parts of the country.



Battery makers turn up the voltage

The upsurge expected in electric car sales as Europe phases out combustion powertrains is prompting significant investment by battery makers, both in terms of technologies and manufacturing capacity. In particular, new European ventures are seeking to pre-empt the advance of dominant Asian producers such as LG Chem, CATL and Panasonic, all of which are planning to add capacity in the region.

Peter Carlsson, CEO of start-up Northvolt, expects that Europe will need 600 GWh of automotive battery capacity by 2030. His new plant, in Sweden's Arctic region, will supply 34 GWh of batteries per year to customers such as Volkswagen and BMW by 2024, with the potential to rise to 40 GWh. Automaker PSA and oil major Total have joined forces for two

plants – in northern France and western Germany – totalling 48 GWh by 2030, while in the UK, Britishvolt – see page 8 – plans some 20 GWh by 2025.

Now SVolt Energy Technology of China is planning a 24 GWh facility in Germany to power 300,000 to 500,000 EVs annually by late 2023, EV global leader Tesla is in a strategic partnership with Panasonic, and Norway's Equinor and Hydro are to explore possibilities for a large battery plant to serve Europe. The latter, reports the FT, could be as big as Tesla's 38 GWh Gigafactory 1 in Nevada, where Panasonic already co-operates with Tesla.

There is still uncertainty whether Tesla's European carmaking site, already under construction near Berlin, will include the manufacture of batteries.

EVs redraw the manufacturing map

The anticipated rapid acceleration in electric vehicle (EV) demand is reshaping the auto manufacturing supply chain in both Europe and North America.

Volkswagen Group has already spent massive sums on its EV push, directed at establishing global leadership ahead of Tesla; it has a clutch of plants building a growing array of largely higher priced battery-powered models and has surged past Renault-Nissan to become Europe's EV market leader.

BMW has announced that by 2024 it will have removed all combustion-engine production from its core Munich plant to make way for flexible electric vehicle assembly. Gasoline and diesel units will in future be made in the UK and Austria. For a company with 'Motor' as its middle name, and which builds its appeal on powerful and sporty engines, this is an immensely symbolic move. By the end of 2022, says the company, each of its German plants will be producing at least one pure-battery EV.

In an unconnected announcement, General Motors' CEO Mary Barra has outlined the US organization's plans to launch 30 new EVs "at all price points" by 2025, including the fruits of two speeded-up programmes for the Hummer EV (see page 7) and the electric-only Cadillac Lyriq, due in early 2022.

Describing GM's "transition to an all-electric portfolio", Barra highlighted the role of the company's second-generation Ultium battery technology: the new packs, due by "mid-decade", would be 60 percent cheaper and carry double the energy density of the current batteries, she said. Today's units already claim a range of 725 km on a full charge.

Even superluxury car builder Bentley is set to go electric by 2030. Under its Beyond100 strategy it will sell only electrified models from 2025, and after 2030 these will be pure battery to allow the brand to claim "end-to-end carbon neutrality" for its entire operation.

NEWS IN BRIEF

Highlighting the latest thinking in automotive engineering and technology worldwide

The engine whisperer

In a hi-tech rethink of the age-old long-screwdriver engine diagnostic tool used by mechanics, software engineers at Skoda have developed an algorithm which compares a sound map of the engine against a stored pattern. Any divergences in the sound profiles would indicate an issue with the engine, and Skoda Sound Analyser trials to date have confirmed a 90 percent success rate. The software, claims Skoda, can already recognize ten patterns, including faults in the steering, the air conditioning compressor and the DCT transmission's clutches.

Time traveller

It has a normally aspirated 6.4 litre V8, 470 horsepower, four-wheel drive, a separate chassis and live axles front and rear – but this is not a muscle car from the late 1960s. Instead, it is the very latest Jeep Wrangler: the Rubicon 392, the first 'classic' Jeep for 40 years to employ an eight-cylinder engine, albeit now with variable valve timing and cylinder deactivation.



Designer wallbox for the fortunate few

For owners of the \$2.5 million Pininfarina Battista electric hyper GT, the famous Italian design house has developed an equally stylish and exclusive bespoke wallbox for recharging at home. Rated at 22 kW, the unit can provide the car's 120 kWh lithium-ion battery with a 500 km range overnight.

Aluminium comes full circle

As more and more aluminium is used in automobile production it becomes more viable to establish the use of recycled aluminium on a large scale. In its analysis of the recycling and manufacturing process, Jaguar Land Rover's REALITY project has revealed the potential to reduce CO₂ emissions from aluminium production by up to 26 percent compared with current automotive grades, helping the company further close the loop on its manufacturing and use of raw materials.

Tyre footprints go carbon neutral

France-based tyre manufacturer Michelin says it has developed the first tyre in the world to be carbon neutral at the point of purchase. As well as helping reduce CO₂ emissions on the vehicle through lowered rolling resistance, the e.Primacy tyre uses lower-emission raw material extraction, manufacturing and delivery. Overall, says Michelin, each e.Primacy saves 174 kg of CO₂ over its lifetime and increases the range of an EV by up to 7 percent.

European automakers race to hit CO₂ targets

Carbon dioxide emissions of passenger cars sold in Europe are tumbling fast as automakers rush to meet their fleet-average CO₂ targets by the end of the year. Those who fail to meet those targets, which are based on vehicle mass and are therefore different for each manufacturer, face large fines, potentially in the multi-billion euro region for a big-volume producer with a substantial discrepancy.

Some analysts expect that battery-electric (BEV) and plug-in hybrid (PHEV) models will triple their sales as brands hastily promote them in order to bring their brand average CO₂ down. By November, BEVs had accounted for almost 10 percent of overall sales, and PHEVs 12.4 percent. Gasoline and diesel models saw substantial reductions. Collectively, the industry was at 101.5 gCO₂/km – just 6.5 grammes above its 95 g/km target – by the end of October. This compares with an industry-wide average of 122.4 g in 2019, itself an increase over 2018's figure.

Of the major automaker groups, Geely, which includes Volvo, Polestar and Lotus, has been the star performer, beating its 110.3 g target by late summer; BMW is well placed, too, and Volkswagen CEO Herbert Diess said in November that his group of brands was only "about a gramme" short of its target.

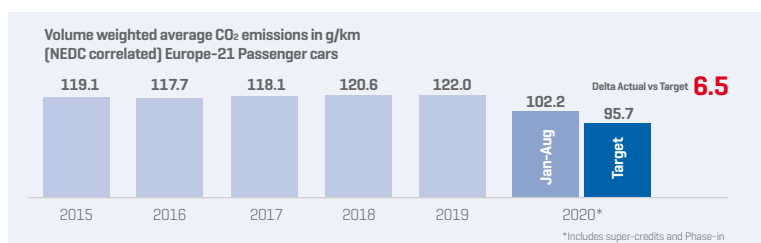
Under the EU's rules, manufacturers in a strong CO₂ position are free to trade credits and pool with poorer performers so as to avoid

or reduce fines. Tesla was quickly enlisted by Fiat-Chrysler, while Ford – which was hit by a big recall on a key new hybrid – sought help from Volvo. Even Volkswagen was prompted to pool figures with MG Motor, a move it described as an insurance policy.

From 2021 onwards, standards will get tougher still. BEVs will no longer be counted twice, and each brand's total European sales will be included, not just the most economical 95 percent. The 95 gCO₂/km limit will be tightened by 15 percent for 2025 and by 37.5 percent by the end of the decade.

The likely outcome is the swift disappearance from European showrooms of high-powered models which rely on large conventional engines rather than plug-in hybrid or battery powertrains for their performance.

Figures from Jato Dynamics show how fleet-average CO₂ emissions rose from 2016 but are dropping sharply in 2020



VW's zero-carbon island

Volkswagen Group will further step up its investment in electrification over the next five years, doubling its outlay on software capability. Some 70 all-electric models will be launched by 2030: of these, only 20 are already on the market.

One of the highest-profile elements in the plan will take place in Greece. Under a memorandum of understanding between VW and the Greek government, the small Aegean island of Astypalea will play host to an ambitious project to create a completely climate-neutral transport and energy system using vehicle- and ride-sharing to optimize traffic on the island's relatively few roads.

Astypalea has a population of just 1300, swollen in the tourist season by some 72,000; just two buses provide very limited mobility. VW's plan will see the island's 1500 combustion-engined vehicles replaced by 1000 electric models, with even emergency vehicles and police cars becoming battery powered. Also included are electric scooters

and e-bikes, aimed at tourist rentals. Some 230 charging points will be installed, to be fed by what VW describes as "green power generation", without giving specifics.

Renault's evolving portfolio of infrastructure projects now includes two eWays programmes aimed at establishing an intelligent electric ecosystem. Douai, in northern France, will host an Advanced Battery Storage facility rated at 4.7 MWh, using a mixture of new batteries and second-life units taken from used cars. Douai will become part of a 50 MWh network across France.

Across the Channel in southern England, Renault's SmartHubs project, a joint venture with Connected Energy, will operate second-life batteries from Renault vehicles alongside other technologies as part of a local energy system to help provide cleaner, lower-cost energy for use in social housing, transport, infrastructure, private homes and local businesses.

Astypalea in Greece: VW's Mediterranean island zero-carbon project





Hyperloop comes closer

Richard Branson's Virgin Hyperloop project is claiming a significant step forward after its first successful speed trials with passengers aboard. Two senior executives from the company rode in the prototype passenger pod at up to 170 km/h on its short 500 m test track in Nevada. With cargo and passenger pods travelling in a near vacuum in the Hyperloop tube and supported by frictionless magnetic levitation, the system has the potential for travel at up to 1000 km/h, says the company.

Hummer returns – as an electric supertruck

It is massive, heavy and hugely powerful – but it won't use a drop of fuel. The Hummer is reborn as an EV 'supertruck' with 1000 horsepower, nearly 16,000 Nm torque and three-motor AWD capable of scaling half-metre verticals and wading through water 600 mm deep. A 24-module Ultium battery pack provides a claimed range of 560 km, and production begins in late 2021.



Sail away sustainably – with 7000 cars

Could a new generation of sailing ships be in prospect as maritime emissions come under pressure? The Oceanbird concept from Sweden's Wallenius Marine is 200 metres long and 40 metres wide, and its five computer-controlled telescopic sails stand 105 metres above the waterline. It is expected to carry 7000 cars across the Atlantic in 12 days at an average of 10 knots, with a 90 percent reduction in emissions compared with today's oil-burning vessels, which take eight days. The first Oceanbird will be delivered in late 2024, says Wallenius.



VIEWPOINT

It's time to commit to net zero carbon

Dave Shemmans, CEO, Ricardo plc



There can be no doubt that the year 2020 will go down in history as one of the more challenging periods, world wars aside, that the global economy has faced. At a human level, we have been saddened by the suffering and loss of life experienced by so many people both directly as a result of the Covid-19 pandemic, and also in terms of indirect physical and mental health effects, the disruption of daily family and working life, and the damage to businesses and livelihoods.

Governments, industries and research universities around the world are charting a pathway to commercial and economic recovery from the Covid-19 crisis by developing effective treatments and vaccines. It will take time, but all the signs are that this is an achievable goal. However, what is perhaps an even greater imperative on a global basis is the issue of addressing climate change.

Over a longer perspective, climate change is in my view potentially a far deeper challenge – and one that is even more threatening to our way of life than the current pandemic. And this is a view that is clearly shared very widely: in September 2020, for example, the United Nations Framework Convention on Climate Change reported that the number of commitments to reach net zero carbon emissions from local governments and businesses has roughly doubled in less than a year.

Many governments, international organizations and commercial companies rely on the advice and guidance of Ricardo's climate specialists in establishing climate action goals, setting up initiatives and monitoring progress. So it seemed entirely appropriate that Ricardo should set its own highly ambitious but achievable net zero target. On 7 September 2020 I was extremely proud to announce that Ricardo has made a very public commitment to its shareholders, to its customers and to its workforce that it will achieve net zero carbon emissions from its operations by the end of calendar year 2030.

Specific and verifiable pledges

In order to demonstrate the concrete and solemn nature of this commitment,

we moved quickly to start setting out a series of environmental pledges against which our progress towards our goal of net zero could be measured. The first of these was in the area of moving to renewable energy. Ricardo has already increased its use of renewable electricity from 67 percent in financial year 2017/18 to 74 percent in 2019/20 – an impressive record over such a timespan. However, we intend to go much further, by raising this proportion to 90 percent renewable by the end of 2025.

What is more, these environmental performance pledges even go beyond the scope of those activities purely associated with net zero. As an example, in the area of air quality Ricardo has joined with seven other major businesses in another major initiative. Together with Philips, Uber, Engie, BP Chargemaster, the UK Department for Environment, Food and Rural Affairs (Defra) and air pollution campaigners Global Action Plan, Ricardo has formed the Business Clean Air Taskforce (B-CAT). The aim of B-CAT is to help organizations achieve the targets in the government's 2019 Clean Air Strategy, not least by setting standards for business action on air pollution.

More than just words

There can be no doubt that actions speak louder than words when it comes to corporate environmental commitments. Having set out our strategy to achieve an ambitious net zero target for our operations by the end of the year 2030, we at Ricardo are beginning to detail how we intend to achieve this as well as helping with other wider environmental targets.

By spelling out publicly how we intend to achieve our environmental goals in the form of a range of meaningful pledges against which our progress can be measured, the truth of our intent cannot be underestimated: our performance will be transparent for all to see.

In doing so, my aim as Ricardo's CEO is for our company to be a global organization that leads from the front in setting clear and measurable environmental targets – not just for our own business but, perhaps even more importantly, to help our many customers and worldwide partners to achieve the same.



Batteries: Why customized local low- CO₂ production is best

Britain needs to develop its own GigaPlant battery-making capability if the country's automotive industry is to avoid long-term decline. That is the stark warning from **Isobel Sheldon**, chief strategy officer of the new Britishvolt venture. In an interview with RQ she tells **Ian Adcock** how the company plans to revolutionize battery manufacturing in the UK



From the beginning of next year, the UK will no longer be part of the EU. What impact will that have on your business model?

It has certainly been a major consideration in our choice of site. Clearly Brexit is an opportunity as well as a threat. The automotive industry is importing the majority of its cells, sometimes from the Far East and not from Europe, and there are local content requirements that have to go into UK-manufactured electric vehicles [EVs]. So, clearly, Brexit represents an opportunity because we will be the first in the UK to set up a scalable facility for battery production. We would like to aim for a spade-in-the-ground date of April-May 2021, and that's working backwards from mid-2023 when we would like to be in production: this is because some British customers have a need for us to supply batteries as soon as possible.

You looked at 40 sites before confirming Bro Tathan in south Wales. Did you also look at locations outside the UK with attractive subsidies? And what finally persuaded you to locate in the UK?

We find the UK more of a challenge than in [continental] Europe, where there are potential locations. At the moment we have a memorandum of understanding with the Welsh government but we are in advanced discussions with another site in the north of the UK as well. Either could become the site of our first GigaPlant. These UK GigaPlants are strategically crucial to the UK automotive industry and the British economy. The EU is currently encouraging European gigafactories with huge financial incentives, so it would be good to see parity from the UK government.

With the likes of PSA and Total joining forces to create the Automotive Cells Company and Northvolt announcing deals with Volkswagen and BMW, where will Britishvolt's customers

come from? Do you envisage they will be principally UK-based OEMs, or will you also be targeting overseas manufacturers?

This is a really interesting question. What you generally get in the battery industry [is this]: a cell manufacturer will design a cell and say, *here you go, this is what we can make. If it suits your application, buy it from us - and this is the price. If it doesn't suit you, we will go and sell it to someone else.* Tesla has been extremely successful in this marketplace for one very good reason: they've had their arms round the cell technology and the upstream tech that goes into that, and they've been able to tailor the cells to the vehicles they're developing.

So how will Britishvolt's approach be different?

Our approach will be very different: we will be tailoring and customizing technology to the particular applications and requirements [of each customer]. In the UK that's really important for one reason: brand differentiation. Imagine if I open the bonnet of my £150,000 electric Range Rover and then look under the bonnet of a Fiat 500 EV and find the same cell technology. Why are car buyers spending a lot of money on one product and not so much on another? In the UK we have predominantly premium-sector brands and they need to differentiate themselves because all these vehicles have different application requirements and there's not a single cell that will do everything: you have to have tailored performance characteristics. Our Britishvolt approach, especially in the UK, goes like this: *I'm not going to tell you what I've [already] got and am selling to everyone else: I want to work with you to develop the cell technology that helps you differentiate your products in the market place. Your customers will get the brand experience they're expecting from the cars they buy from you.* Tailoring the technology is very much the core of our business, and that's landed very well with the OEMs we have spoken to. Even the higher-volume OEMs have bought into it and told

us they want to work together with us to develop that cell systems they need.

Is it effectively the same as having different states of tune within a model portfolio, perhaps ranging from an eco model to a GT?

Exactly – and don't forget in the UK we make 2.5 million [conventional] powertrains a year, of which 80 percent are exported. The reason why they're built here is because we're extremely good at premium-sector and performance powertrains. So we're extending that theme of differentiation [into the arena of electric vehicles]. I am quite content for one of the Asian producers to take the volume market; I am more focused on the high-performance models. Other [battery] manufacturers struggle to do that as they are trying to build as much scale as possible by producing a single type of cell and specification: we, on the other hand, are building both scale and flexibility into our production process, yet we are also able to take care of production costs for very specific application requirements. For some of our UK customers, if they have a vehicle that weighs 2.5 tonnes before you add batteries, that's a very different scenario to a VW ID.3, for example.

How adaptable will your manufacturing process be for other advanced battery technologies?

With Britishvolt we're adding [capacity] in 10 GWh phases. So our first 10 GWh is [already] better than current state-of-the-art technology – that's set for 2023. In 2025 the second 10 GWh will come on stream, and that's targeted at technology that has been proved out and which is going through commercialization over the next couple of years: we want to take advantage of that. Some of that is happening in the UK in the Faraday Battery Challenge and the Faraday Institution right now.

Are there any game-changing chemistries in the pipeline?

We're keeping an open mind on the third phase and, as the strategy person driving this, I am prepared to wait and see what happens with solid state. If it looks as though it's going to make a move towards the middle of this decade, then we can reserve that 10 GWh to produce solid state, but we won't make any decisions about manufacturing processes just yet. New chemistries have a habit of not materializing. A lot of what you hear about is actually laboratory-based work that shows promise, and scaling up to commercial levels takes quite a long time. That's the dichotomy of the technology, but the UK is leading the way in trying to solve those problems. Even so, the earliest estimations for solid state coming out of the laboratory and scaling up to production put it five to seven years away – and then when you add on the commercialization you're looking at the early 2030s before you have a really good chance of solving all the issues. Any game-changer technology is likely require new production processes and would have to provide an economic case for ditching the hundreds of billions of dollars spent in lithium-ion technology. I haven't seen anything so far that makes me think it will be the only game in town and that we need to invest in it right away.

How environmentally friendly will the manufacturing process be?

We aim to be the best in the world. We have a few ideas and patent applications that will lead to a significant emissions reduction in cell manufacturing and the material production as well. If we do a carbon audit on our process we will emerge head and shoulders above our rivals – and that will be a significant advantage for us. I would be looking to make massive inroads into that six-tonne CO₂ average quoted for battery production.

“I would be looking to make massive inroads into that six-tonne CO₂ average quoted for battery production”

Northvolt aims to secure 50 percent of its raw materials from recycled batteries by 2030. Do you have similar aims, and what are they?

We have very similar aspirations: the more recycled material we can return into the front end of our process, the more circular we can make the whole process. I do question their [Northvolt's] ambitions for 2030: if you do the numbers, there's not enough feedstock coming back by 2030 to get half your materials from recycling into the front end of your process.

There is growing concern over the ethics of mining the raw materials and about the regimes in the regions from where some are sourced. What's Britishvolt's position?

We take corporate responsibility extremely seriously in order to ensure our materials don't come from unethical sources. There's a technical element, too: we need to reduce the amount of cobalt, and that's going to be a challenge because it's the anchor for stability in the cathode material. There's ongoing work to eliminate cobalt completely: we've been able to increase the proportion of nickel in the cathode from 30 to 50 percent, which gives us a corresponding reduction in cobalt. Although the amount of cobalt in the pie is shrinking, the overall pie is getting bigger quite quickly. We stand a chance of keeping our noses clean when it comes to cobalt: it's a challenge and we need to invest to make sure we have the right structures in place. In five years I will put my hand on my heart and say our batteries are the lowest CO₂ products in the world, with no Chinese materials. We don't want to be held hostage by China and that's a lesson yet to be learned by European rivals.

Is there potential for Britishvolt to partner with Cornish Lithium, thereby avoiding supply issues and helping form a virtuous circle of supply?

Could they go and find some nickel as well, please? We're lucky in the UK because we're finding more lithium than we thought was there: those reserves are increasing. We have nickel refining in South Wales, we also have the best source of green needle coke in the world from North Sea oil refineries. Rather than shipping the nickel to China for refining, which is awful for logistics and CO₂, we should be able to process it in the UK with new methods we're filing patents for. We would then be creating a domestic supply chain for half the battery materials – and the EU doesn't have that. [🔗](#)

Isobel Sheldon, chief strategy officer, Britishvolt

Before joining Britishvolt in June 2020 as chief strategy officer, Isobel Sheldon was director of business development at the UK government-backed Battery Industrialization Centre [UKBIC]. Prior to that 2019 appointment she held senior leadership positions within global companies, recently serving as engineering and technology director at Johnson Matthey Battery Systems, where she led the technical strategy and execution function within the battery systems business. She also served as a director at Cummins. Earlier, she spent ten years as managing director of Amberjack Ltd before joining Ricardo UK as business manager responsible for development of Ricardo's battery design, development and manufacturing strategy, and as commercial lead for battery business development.

PERSISTENT, MOBILE AND TOXIC:

plastics and chemicals that last too long

The environmental persistence of undesirable chemicals and plastics is something that requires urgent action to protect human health, biodiversity and the natural environment. **Anthony Smith** speaks to the experts at Ricardo's National Chemical Emergency Centre (NCEC) who are helping prepare the world's chemical industries for a more sustainable future – a future in which potentially harmful and bio-accumulative 'forever' chemicals and plastics are entirely eliminated

The time taken for potentially harmful pollutants such as chemical and plastic wastes to degrade within the environment is becoming a major concern. Known as environmental persistence, the issue is increasingly the focus of both public anxiety and regulatory action.

Persistence is crucially important as it reflects how long a substance will exist within the environment – for example in water courses, in the soil or in the atmosphere – before it breaks down into less harmful constituents such as carbon dioxide and water. The time that a chemical resides in the environment indicates the levels to which humans and flora and fauna risk being exposed to it either directly or through its entrainment within the food chain. Persistence is also problematic in that chemicals that resist degradation processes tend to reach higher environmental concentrations than shorter-lived substances that are emitted at the same or even a higher rate.

The Attenborough effect

In popular culture, a key turning point in influencing international public opinion on environmental persistence came with the 2017 BBC documentary *Blue Planet II*,

narrated by Sir David Attenborough and, in particular, an episode focusing on plastic and microplastic pollution of the world's oceans.

The programme highlighted the environmental damage caused by the estimated eight million tonnes of plastics and microplastics that find their way into the world's oceans annually: animals become entrapped by debris or face starvation having ingested volumes of nutritionally useless plastic waste. The influence of the documentary has proven instrumental in spurring direct action ranging from beach cleans to campaigning pressure for tighter regulation and improved environmental product standards on the part of consumer-facing brands.

The chemicals industry also came under public scrutiny in the 2019 movie *Dark Waters*. This depicted the true events of a legal battle against the chemical manufacturer DuPont for the sustained release over many years of perfluorooctanoic acid (PFOA) into the environment near Parkersburg, West Virginia, polluting the local water supply. This chemical is part of a group known as per- and polyfluoroalkyl substances (PFAS) that feature in everyday household items such as non-stick cookware, waterproof

and stainproof clothing, and food packaging, as well as in commercial and industrial products such as fire-fighting foams.

PFAS are also known as 'forever chemicals' as they are highly persistent and can take up to a thousand years to break down. Robert Bilott, the lawyer depicted in *Dark Waters* and the author of the book 'Exposure: Poisoned Water, Corporate Greed, and One Lawyer's Twenty-Year Battle Against DuPont' on which the film was based, wrote a guest column in the May 2020 issue of the European Chemicals Agency newsletter in which he highlighted the pervasive and damaging nature of these chemicals: "PFAS are present in the blood of almost every living being on the planet. Independent world-class scientific studies have confirmed links between PFOA and several serious diseases in humans, including cancer. PFAS are a global disaster, and the true extent of the damage done to us and our environment will only be known and felt by people living beyond our lifetimes."

A new perspective on an old problem

The recent public concern over the problem of environmentally persistent chemical pollution is not an entirely new



→ phenomenon. Around 60 years ago, two very significant and then-new forms of pollution spurred similar public concern – and resulted in policy action. The first of these was triggered by the occurrence of foaming events in water courses and shorelines in the 1950s, episodes which were found to be traceable to the use of recently developed detergents.

Foam forms when air motion interacts with water that has a reduced surface tension due to the presence of molecules known as surface active agents or surfactants. While there are many naturally occurring organic surfactants, such as those that can be released by decaying algae or vegetation, synthetic surfactants were particularly pronounced in the early non-biodegradable detergents developed after the second world war.

In parallel with the escalating public concerns over this form of water pollution, the unintended negative effects of the use of chlorinated pesticides such as DDT were highlighted by Rachel Carson in her seminal 1962 work, *Silent Spring*, the title of which evokes an environment in which DDT had already damaged wildlife, birds, bees and agricultural livestock to the extent that the sounds of spring are no longer present.

As Ricardo NCEC's principal regulatory

consultant Chris Hughes explains, these early publicly expressed concerns about the issue of environmental persistence went further than just triggering the rise of the environmental movement. "The groundswell of public opinion on environmental matters in the 1960s and beyond clearly led to significant pressure for the policymakers of the day to act," Hughes says. "The result was the development of standardized methods for testing chemical biodegradability and also the creation of frameworks to identify and regulate substances that have persistent, bio-accumulative and toxic (PBT) properties.

"In many respects we are observing a modern-day parallel of that early popular pressure for environmental protection and its policy response, with initiatives such as those under the European Green Deal that embody the stated strategy of creating what is described as a zero-pollution ambition for a toxic-free environment," adds Hughes.

Strengthened regulation

One of the key international frameworks controlling the application of chemicals is Europe's Registration, Evaluation and Authorization of Chemicals (REACH) regulation. First rolled out across the EU in 2007, REACH aims to protect human

health and the environment from the risks that can be posed by chemicals, whilst still maintaining the competitiveness of the EU chemicals industry. It also promotes alternative methods for the hazard assessment of substances in order to reduce the number of tests on animals. Ricardo NCEC provides support to the chemicals industry to address the continuously evolving requirements of REACH, allowing them to place chemical products on the EU market.

"The environmental impact of PFAS is a primary driver of the recent focus on establishing regulatory criteria for so-called persistent, mobile and toxic (PMT) chemicals," explains Hughes. This has been championed by the German authorities and many scientists, and forms part of the proposed updates to REACH that were announced by the European Commission in its Chemicals Strategy for Sustainability (CSS), published in mid-October this year."

In addition to the extreme environmental persistence of PFAS, there is a growing body of evidence about their adverse effects on humans. PFAS are also extremely mobile in water due to their highly polar nature which complements the intrinsic electrical charge polarity of water molecules. This mobility allows PFAS to pass through natural barriers such as riverbanks and artificial sorption-based filtration systems of water treatment works.

In a landmark regulatory decision in June 2019, EU member state government experts voted unanimously in favour of adding 'GenX', a small group of fluorinated chemicals, to the official list of substances of very high concern (SVHC). This is a first step in increasing regulatory controls over these substances and classifies them as being at an 'equivalent level of concern' to substances that are very persistent, very bio-accumulative and toxic (PBT) or carcinogenic, mutagenic or toxic to reproduction (CMR). This represents an important tightening of regulations as the so-called GenX family had been previously promoted commercially as more environmentally friendly PFAS alternatives. The CSS has promised to give "special attention" to PFAS, with a comprehensive set of actions to ensure that the use of PFAS is phased out in the EU, except where it is proven essential for society.

Malign marine microplastics

Further measures under the REACH regulation have aimed to address the issue of microplastic pollution of the world's oceans. In addition to the widely recognized problem of plastic pollution at and below the surface level, a study published in early October 2020 by Australia's government science agency, CSIRO, indicated that at



"The groundswell of public opinion on environmental matters in the 1960s and beyond clearly led to significant pressure for the policymakers of the day to act. In many respects we are observing a modern-day parallel of that early popular pressure for environmental protection and its policy response" Chris Hughes, Ricardo NCEC principal regulatory consultant





least 14 million tonnes of plastic pieces less than 5 mm wide are thought to be sitting in the sediments at the bottom of the world's oceans. This pollution comprises both fragments of larger objects that have been broken up by the action of the water, as well as deliberately added microplastics that are used in products ranging from cosmetics to household cleaners.

"The unambiguous visual evidence of the damaging impact that plastic pollution can have on the ocean environment has been a catalyst for the public interest in microplastics, which are less visible but equally resistant to degradation," continues Hughes. "One of the new measures introduced in REACH has been to place a restriction on the use of intentionally added microplastics, but subject to a derogation allowing biodegradable materials. In this way, future REACH-compliant products will degrade without further adding to the problem of oceanic plastic pollution."

Why persistence assessments are difficult

Although chemical persistence assessment frameworks and criteria have been in operation for decades, there remain challenges that affect the robustness and consistency of those assessments. Foremost among these is the sheer variety of environmental conditions under which chemicals reach the environment, and the extent to which this affects their degradation.

Typically, persistence is assessed by comparing degradation half-lives in water, sediments and soil to set criteria. However, degradation half-lives for a chemical can often vary by several orders of magnitude depending on factors such as bioavailability and the presence of oxygen, nutrients and degrading organisms.

This means that the persistence of substances cannot be measured directly as it results from the inherent properties of a substance in combination with the environmental conditions where it is present. Persistence assessment thus requires the use of various types of data,

even though guidance on how to address key sources of variability in these data is limited. Existing approaches can be overly simplistic and not representative of dynamic processes in the environment. Also, many chemicals are unsuitable for standard tests, such as substances of unknown or variable composition, complex reaction products or of biological materials, together known as UVCB substances.

To address the need to improve methods of assessment of persistence in chemicals, NCEC is collaborating with the European Chemical Industry Council (Cefic) as part of that organization's long-range research initiative (LRI) programme. In a project entitled 'EC052: Expanding the conceptual principles and applicability domain of persistence screening and prioritization frameworks, including single constituents, polymers, and UVCBs', the work aims to assess and improve the guidance on persistence assessment of these substances.

"This project presents a significant opportunity to improve the consistency, predictability and robustness of persistence assessments at a time of growing interest in this important area," explains Hughes. "Our experience with complex and difficult test substances, along with broader research into persistence assessment, will be essential for this project – and this is something that we intend to build on."

Proactively protecting brands

The heightened public and industry focus on environmental persistence means that the importance of product biodegradability has increased in the mind of the consumer. And, as Hughes points out, brand owners are already responding proactively to this new reality: "Addressing the issue of chemical persistence is now an essential part of running a sustainable business – but it makes good commercial sense too. Product biodegradability is now a significantly increased priority in the mind of the consumer, and some major brands are responding not only by complying with

new regulations, but also in their public positioning and brand reinforcement."

A particularly notable development cited by Hughes is the announcement in July 2020 by Unilever, the international manufacturer of cleaning and laundry products, that it will make all 70,000 of its product formulations biodegradable by 2030 – something that will require the substitution of ingredients using technologies that are not yet available. A further example is that of energy company Shell, which is ensuring that all of its new gas-to-liquid (GTL) products provide a readily biodegradable alternative to conventional fossil derived fuels, lubricants and solvents.

Expertise from Ricardo

Chemical persistence is an increasingly important issue, both in terms of top-down regulation and bottom-up consumer preference for greater environmental sustainability in the products people purchase. For responsible companies it is clearly essential to have access to specialist expertise in the selection, testing, simulation and approval of biodegradable ingredients.

"Ricardo NCEC has many years of first-hand experience in supporting clients to properly assess the biodegradability and persistence of their chemical products," notes Hughes. "We can help our customers achieve optimal and scientifically robust regulatory outcomes, irrespective of whether they are conducting proactive biodegradability testing to improve marketability and risk-proof their product portfolio, or responding to a regulatory evaluation of an ingredient or product."

Over and above this, research work such as that on the EC052 project with the European Chemical Industry Council shows how NCEC is also contributing to help frame the next generation of persistence testing. In these ways Ricardo is helping to make the future of the international chemicals and consumer products industries more truly sustainable – and, by so doing, ensuring that 'forever' chemicals become a problem of the past. 

Chemical pollution of water courses has been a concern for many years, resulting from foaming episodes to the extremely toxic and persistent pollution from 'forever chemicals' such as polyfluoroalkyl substances [above left and opposite]. A key turning point in public opinion regarding marine plastic pollution [above] resulted from the screening of the 2017 BBC documentary Blue Planet II

Carbon calculus

Manufacturing, operating, maintaining and end-of-life recycling and disposal: vehicles impact the environment at every stage, not just in their use phase. Life cycle assessment, as **Jesse Crosse** finds out, has become a vital planning tool to enable policymakers to see the complete picture when making major strategic decisions



As long as it is well executed, life cycle assessment (LCA) takes into account every aspect of a human-made object's impact on the environment. These impacts can stretch all the way from those first team planning meetings right through to end-of-life and the object's reuse, recycling or disposal.

Whilst LCA has been in active use for decades, it has always been an evolving process. Although it has become a recognized element within automotive product development – and in other sectors too – historically a very diverse set of assumptions and scope have been applied, and some of the common assumptions on vehicle operation have not reflected the real-

world situation sufficiently well. In addition, there has been less focus on formulating LCA methodologies that are well-aligned for policymaking purposes in the wider sense and on developing and applying these across the wide range of vehicle types, energy production chains and environmental impact categories. Nor have temporal aspects been widely considered, even though they are particularly important for forward planning.

A new study led by Ricardo Energy & Environment, carried out in collaboration with consultancy E4tech and the Institute for Energy and Environmental Research (ifeu) Heidelberg, is the first of its kind to do just that. It has been heralded as the first



powertrain combinations; it also analyses the production of 60 different liquid and gaseous fuel chains, and 14 different forms of electricity generation, as well as region-specific generation mixes.

Beyond this, the study additionally encompasses the impact of vehicle and battery manufacturing, vehicle use including operation and maintenance, and end-of-life scenarios including recycling, energy recovery, disposal to landfill, and opportunities for battery second-life. As well as greenhouse gas emissions, the study assesses 13 other impact categories such as use of resources, cumulative energy consumption, mineral and metal depletion, scarcity of water and various impacts from air quality pollutants, including emissions of particulate matter and oxides of nitrogen.

Fact-finding mission

Nikolas Hill was the project manager for the work, and is an associate director and knowledge leader in transport technology and fuels in Ricardo's sustainable transport team. Developing such a significant and huge study – resulting in a report of over 450 pages – is no spur-of-the-moment task, and he explains how the project started with a fact-finding mission with the European Commission, as well as consultation with external stakeholder experts. “An important early part of the work were discussions about which were the key factors that impact sustainable transport policy, and what parameters and impacts were most important to compare powertrains and fuels on a balanced

holistic basis,” says Hill.

Ultimately, he explains, “the study would be used to assess such things as whether existing policies were likely to lead to the optimal outcome, if plans needed to change, whether negative impacts needed mitigating, should a policy framework be changed, are existing regulations delivering the desired results, and what are the best options from different environmental perspectives.”

The point of the study is not to suggest policy, but provide a tool which can help planners form policy by giving them access a massive amount of objective evidence-based information. And for that to be possible, the information has to be easily accessible.

“We had to strike a balance with the huge breadth, complexity and detail, to focus on the most important aspects and messages so that practitioners can understand what we’ve done and how we got to our answers, but at the same time providing meaningful results,” Hill continues. “The policymaker isn’t always interested in the detail and sometimes just wants to know what the results and conclusions are. In that case they can, for example, dip into data on greenhouse gas emissions and regulated pollutant emissions and ask what it tells them about the potential holistic impacts of achieving vehicle emissions standards.”

Moving the game on - significantly

Not only is the study the first of its kind, but it significantly moves the game on, making

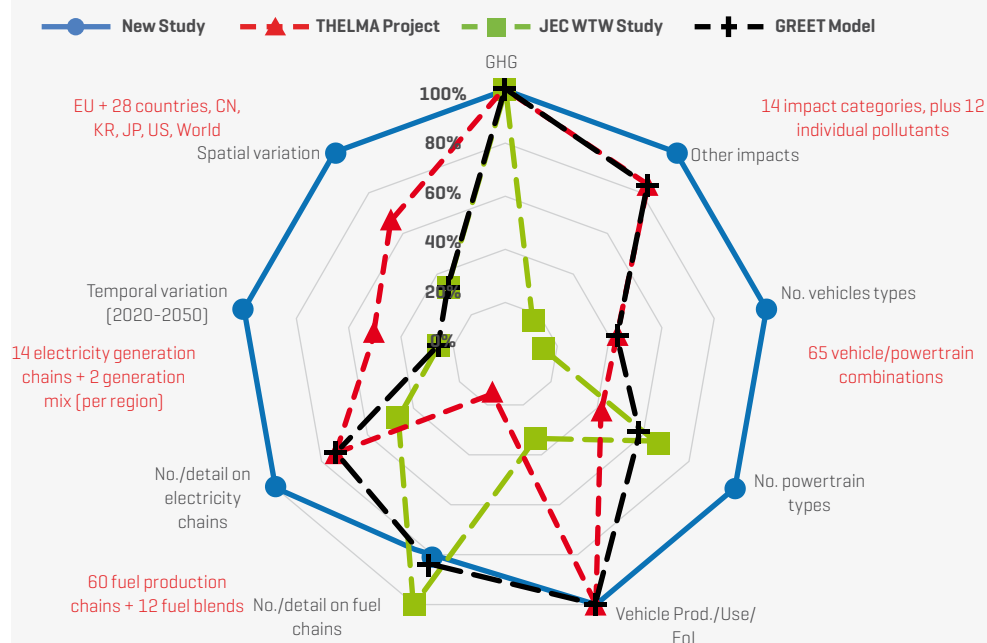
In almost every dimension, the new study equals or exceeds the scope of previous projects carried out by other organizations in Europe and the US

LCA study that comprehensively covers such a wide range of dimensions in such depth, exceeding or equalling the scope of previous projects including those of the Technology-centered Electric Mobility Assessment (THEMLA) project, the GREET life cycle analysis model of the Argonne National Laboratory in the United States, and the well-to-wheels report of the JEC consortium – Joint Research Centre of the European Commission (JRC), EUCAR and CONCAWE. See chart on right.

Commissioned by the European Commission's DG Climate Action, the new report will enable the European Commission to better understand the potential evolution of the environmental impacts of road vehicles between now and 2050. Crucially, though, it also provides a means to develop and apply LCA methodology across a range of road vehicle types, powertrains and energy chains.

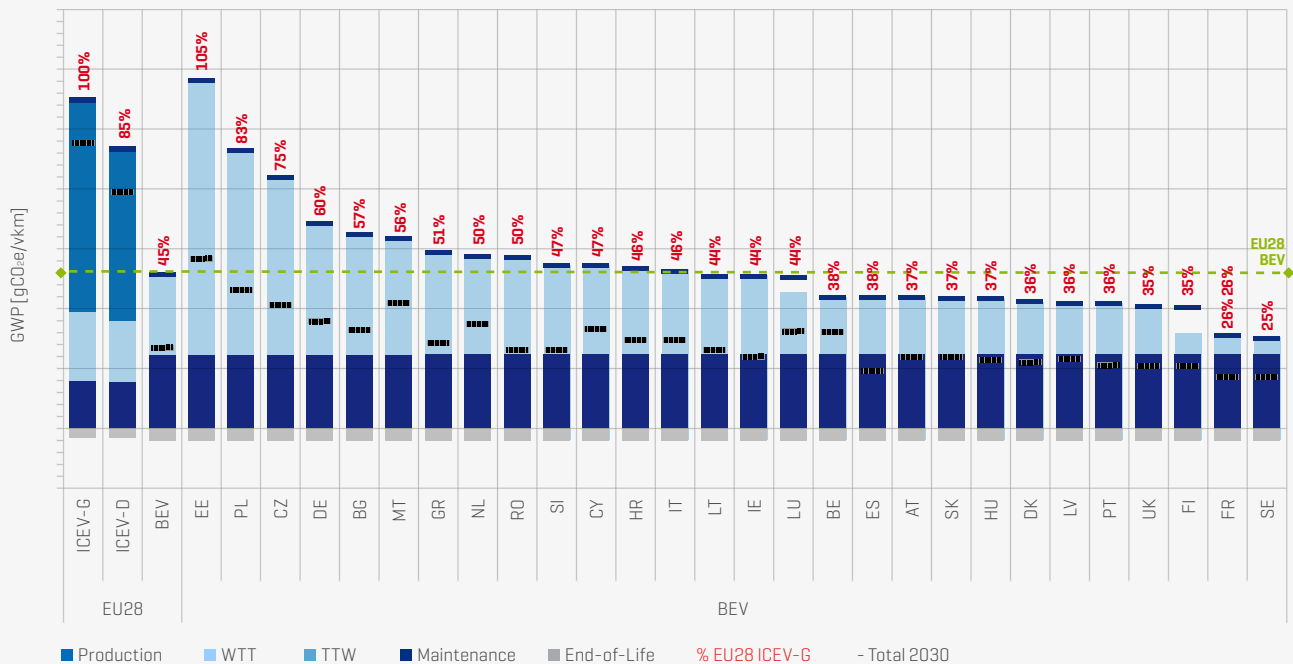
The scope of the study is highly ambitious. Rather than focusing on individual vehicles or brands, it assesses the lifecycle impact of a broad spectrum of generic European vehicle types including light and heavy duty vehicles such as cars, vans, trucks, buses and coaches. In doing so, it covers 65 different vehicle type and

Illustration of the comprehensive scope of this vehicle LCA study



Sources: The THEMLA project (PSI/EMPA/ETHZ, 2016), JEC Well - To-Wheels study (JEC - Joint Research Centre-EUCAR-CONCAWE, 2014b); the Argonne National Laboratory's GREET lifecycle model (ANL, 2018).

Comparison of lower medium car life cycle global warming potential (GWP) impacts



Notes: Results shown for the lower medium car in the baseline scenario. Production = production of raw materials, manufacturing of components and vehicle assembly. WTT = fuel/electricity production cycle; TTW impacts due to emissions from the vehicle during operational use. Maintenance = impacts from replacement parts and consumables; End-of-Life = impacts/credits from collection, recycling, energy recovery and disposal of vehicles and batteries. Additional information on key input assumptions and derived intermediate data include the following: a lifetime activity of 225,000 km over 15 years. 2020 BEV battery of 58 kWh, with 300 km WLTP range [and with 64 kWh and 460 km WLTP electric range for 2030]; an average lifetime EU28 fuel/electricity mix [age-dependant mileage weighted]. No battery replacement is needed for BEVs.

→ it possible to formulate a framework of policies confident in the knowledge that those policies will have the desired effect. "By helping policymakers to understand the critical issues and what the environmental hotspots are, they can better understand the kind of policies they can put in place," explains Hill. "The benefit of this study lies in the huge range of the analysis we've undertaken, as well as sensitivities around the most critical elements. Nothing with this kind of breadth and depth has been done before. We've tried to address what we see as deficiencies in previous LCAs as well as try and expand the boundaries a bit further into new areas. It helps debunk a lot of the myths surrounding the subject, particularly for electric vehicles, and the consistent approach has helped to cement that."

First steps included an exhaustive and essential literature review to thoroughly research what work has already been done in this field, to also help prioritize the most important elements. "Most of the studies are focused only on greenhouse gas emissions or passenger cars," explains Ricardo senior consultant Sofia Amaral. "With this study, the European Commission wanted to explore more impact categories - so in the end we've looked at 14 of those, plus 12 individual pollutants. The greenhouse gas emissions were included of course, but we also looked at other impact categories like water consumption, energy consumption, toxicity and so on."

The full list of impact areas analyzed in

Regional variation impacts of comparison of ICEVs vs BEVs show that in the vast majority of EU countries, pure battery electric vehicles already show significant GHG benefits



"The benefit of this study lies in the huge range of the analysis we've undertaken, as well as sensitivities around the most critical elements" Nikolas Hill, associate director, Ricardo sustainable transport

the study includes global warming potential (GWP), various impacts from air quality pollutant emissions, energy, toxicity and aquatic impacts, land-use change, water consumption, and resource depletion.

Taking the first steps

More planning was needed before work could start. "We had to set the milestones we needed to hit, and it also helped to look at the methodologies and approaches taken by others," says Amaral.

"We talked to other LCA experts in associations and academia and did a two-stage survey to establish whether there was a consensus on different approaches to tackling similar studies. The big first step was establishing the methods we would use to produce the study, and then this stage culminated with a workshop with experts and the European Commission in Brussels."

Some elements were quite different

from other studies, especially in terms of the vehicles included. The Ricardo study covers seven vehicle types, from passenger cars to heavy vehicles, all representative of the European market but without focusing on specific brands. It's an important consideration, because there can be significant differences between vehicles within the same segment, something that has not previously been covered in any depth. "When you see how many different combinations of vehicle types and powertrains there are, and the variation of impact they have, it's staggering," Amaral continues. "There's just so much data and so many results."

To be specific, the study covers passenger cars, small trucks, vans, rigid trucks, articulated trucks, buses and coaches. It also covers conventional internal combustion engine (ICE) powertrains, plus hybrids, plug-in hybrids, battery electric and fuel cell electric

vehicles (HEVs, PHEVs, BEVs and FCEVs). The range of fuels considered is even more extensive: as well as gasoline and diesel, the study includes biofuels, natural gas, bio-methane, and hydrogen and e-fuels. In all, the study analyses 60 fuel production chains and 12 fuel blends.

Electricity is included in the list of energy carriers covered, too, and is clearly very important as Europe begins making the transition from combustion engines to electrified powertrains. Traditionally, the main impact of vehicles with conventional powertrains has been during the use phase. With an electric vehicle, the impact during use is far less, but much higher during the manufacturing phase and disposal at end of life – although the latter can be mitigated significantly by recycling and second-life battery use – hence the importance of gaining a full understanding of the entire life cycle. The source of the electricity matters too, because the carbon intensity of the power generation mix varies widely across different countries and regions, affecting the effective carbon emissions of the electric vehicle during use. The electricity generation mix also impacts on the vehicle manufacturing and end-of-life stages, particularly for energy intensive battery manufacturing.

The study covers a whole range of sensitivities and uncertainties that could affect the outcome. Examples of these include regional variations, the way operating plug-in hybrid vehicles on electricity is shared across the board depending on charging behaviour, the impact of ambient temperatures on a powertrain energy consumption, and assumptions on future changes in battery technology. Some are more influential than others, but the impact of different sensitivities can be modelled by changing parameters in the data to see how they affect the overall picture.

Perhaps not surprisingly, electricity emerges as the lowest impact form of energy for powering all vehicles, but it is also the factor that most significantly affects the overall comparison. Furthermore, battery electric vehicles, including those also operating via a catenary, perform best across the entire product life cycle. That even includes 40-tonne articulated trucks, although this is based purely on the environmental aspect and discounts the significant practical limitations of today's technology such as the size and weight of the battery pack for a particular vehicle range.

Identifying the best options

"That's the point of a study like this," says Hill. "Whilst there are clearly many layers to consider, this work helps to tell us what we should be aiming for from an environmental perspective, subject to being able to overcome existing technical, practical or cost constraints. Whilst our future projections do consider the potential technical potential based also on consultation with Ricardo's technical experts, there is clearly uncertainty there. We cannot of course guarantee whether we can get there technically or, for example, at what point in time the battery technology improves to a degree that those considerations become less of an issue. However, it's less relevant whether something works in all applications today or not, rather the important thing is to assess what the potential could be for different options and to identify the best option if this technical potential can be achieved."

Even given the significant interest in hydrogen fuel cell vehicles, particularly for longer distance heavy-duty applications, that maxim still holds true. "If you have to transform renewable energy multiple times, for example electricity into hydrogen, then back into electricity on-board the

vehicle, then it's not as efficient as using electricity from renewables directly with a battery," adds Hill.

The study also moves on from most other LCA studies in relation to electricity consumption, which is usually based on a single value and applied to the lifetime of the vehicle. Over the last 10 years the greenhouse gas emissions from electricity production across Europe have fallen dramatically, and are projected to continue to decline in the future to meet decarbonization objectives. The study uses outputs from European Commission modelling work on the European energy system for all sectors of the economy. These include future scenarios for different energy chains that factor in changes to the electricity mix, so there is an annual change in the carbon intensity of the electricity that has been factored into models within the vehicle LCA study.

Results and conclusions

The study arrives at conclusions and provides robust information on different options particularly for powertrain comparisons, electricity chains and conventional fuels. It also provides a clear, evidence-based indication of the relative environmental impacts of different life cycle stages and how future developments in technology (or electricity supply, for example) are likely to affect these powertrain comparisons.

The results confirm that the environmental impacts during the overall life cycle of conventional ICE-powered vehicles and HEVs across all vehicle categories is mainly due to energy consumption during use rather than manufacture. The use phase equates to 82 percent of greenhouse gas emissions for passenger cars and vans and significantly higher percentages for high-mileage heavy duty vehicles. For other types of powertrain, the manufacturing stage is generally responsible for a greater impact, affecting many more environmental areas than just greenhouse gas emissions.

The main impacts of manufacturing result from the materials used in the vehicle – except in the case of battery manufacturing, where energy consumption also plays a significant role. The impact of BEVs and PHEVs is highly dependent on the energy mix across the EU and, in the case of PHEVs, the share of energy use between ICE and electric propulsion modes depends to a large extent on the driving and charging habits of individual users.

In general, the report makes clear the potential for electrification, with BEVs (both light duty and heavy duty vehicles) having a significantly lower impact on greenhouse gas emissions than any other

Hydrogen fuel cells have gained significant interest for zero emissions heavy-duty powertrain applications such as long distance trucks and buses, with cities such as London operating demonstration fleets in passenger service since the early 2000s



→ type of vehicle. Those benefits are greatest among large SUVs in the light duty category because they tend to cover higher lifetime mileages, while in heavy duty vehicles the benefits of a battery-electric powertrain are greatest for buses because of their urban duty cycle.

Greenhouse gases are not the only consideration

There are caveats to those findings, however, and the study highlights other non-greenhouse gas considerations relating to electrified vehicles. Whilst electrified vehicles also perform better than conventional vehicles across many non-greenhouse gas impact categories, there are also some hotspots.

Examples are human toxicity potential (HTP) and depletion of non-living resources such as minerals and fossil fuels (abiotic resource depletion). The cumulative energy demand is much higher for FCEVs than BEVs due to the former's less efficient energy chain, which involves converting electricity to hydrogen for use in the fuel cell, and back again.

End-of-life methodologies in the study illustrate the value of a circular economy of extended use followed by recovery and recycling of materials; second-life applications of batteries also emerge as beneficial.

Overall, the study provides a bespoke and, most importantly, a flexible LCA framework. It provides a consistent comparison of the environmental performance of vehicles that was lacking previously, and which covers all stages of a vehicle's life cycle. As well as confirming the significant potential benefits of electrified vehicles, it demonstrates how those benefits increase over time and with the degree of electrification - with BEVs at the top. Results also show that natural gas, bio-gas and synthetic gas-fuelled vehicles can provide significant benefits over their conventional counterparts.



“When you see how many different combinations of vehicle types and powertrains there are, and the variation of impact they have, it’s staggering”
Sofia Amaral, Ricardo senior consultant

As might be expected, the study concludes that the benefits of BEVs, PHEVs and FCEVs increase significantly with decarbonized electricity and hydrogen production as well as with improvements to batteries and EU manufacturing techniques.

Improved process efficiency clearly increases benefits, and of course the generation mix used in the production of raw materials influences the outcomes, as do improved recycling recovery rates and a shift to lower carbon electricity to drive the recycling process.

Next steps

There are still challenges in the field of life cycle assessment, and work continues at

Road based overhead electrification systems such as Siemens' eHighway (above), demonstrate the efficiency of electrified railways with the flexibility of trucks on dedicated routes

LCA results for lower-medium size passenger cars based on current and projected 2050 scenario (below)

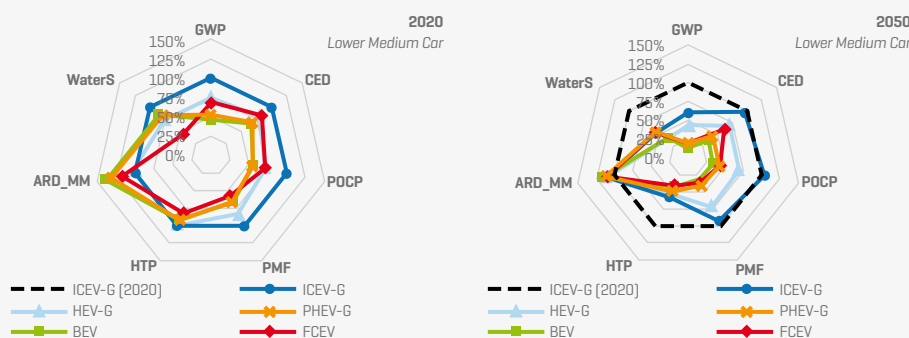
Ricardo to make further improvements, building on the considerable experience gained in the field over a number of years and culminating in this major project for the European Commission.

A specific example is the uncertainty surrounding future battery recycling, the recovery levels of materials and the impact those factors might have. Another issue is that key resources such as lithium, cobalt and nickel are not always well covered by current LCA impact categories and can better benefit from a system-wide resource modelling analysis. And again, the lack of clear policies, legal definitions and measures regarding second-life batteries makes it much more difficult to establish methodologies to assess them.

That said, however, the EC Vehicle Policy LCA project has already been a huge success. It is implemented using a modular Excel-based modelling framework developed by Ricardo, and incorporates a results viewer for easier access to its findings. The expectation is that this extraordinarily in-depth study will have a significant role to play in helping the EU to achieve its ambitious environmental targets over the next 30 years and beyond. 

The report **Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA** and its associated documents are available for download from the European Commission DG Climate Action's web pages: https://ec.europa.eu/clima/policies/transport/vehicles_en#tab-0-1

Summary of the relative impacts for lower medium cars



Notes: Total emissions are presented relative to a 2020 conventional gasoline ICEV = 100%.

Powertrain types: G = Gasoline; ICEV = conventional Internal Combustion Engine Vehicle; HEV = Hybrid Electric Vehicle; PHEV = Plug-in Hybrid Electric Vehicle; BEV = Battery Electric Vehicle; FCEV = Fuel Cell Electric Vehicle. **LCA impacts:** GWP = Global Warming Potential, CED = Cumulative Energy Demand, POCP = Photochemical Ozone Creation Potential, PMF = Particulate Matter Formation, HTP = Human Toxicity Potential, ARD_MM = Abiotic Resource Depletion, minerals and metals, WaterS = Water Scarcity.



Twenty years of RQ



RQ

The first twenty years

It is two decades since we produced the first pilot issue of RQ in late 2000; with a few small adjustments, this went on to become the first published issue early in 2001. Here, as the original launch team now prepares to hand over the controls of this prestigious quarterly technology and news magazine, we reflect on the many highlights for Ricardo and the changing industry landscape in which it operates

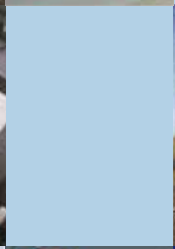
It was early in 2000 when the Ricardo Board decided that the company needed a high-profile in-house magazine. The challenge of finding the right format was significant, and for one very simple reason. Traditionally, Ricardo's project work for its then largely automotive client base was shrouded in near-total secrecy – even though the products benefiting from the company's engineering expertise were

ubiquitous and featured in almost every international motor show and on highways the length and breadth of Europe, America and Asia.

The brief the Board directors finally set was this: to communicate news of Ricardo's work and the technologies it developed to three key stakeholder audiences: the company's client base, its shareholders and its employees.

"Emulate the best, not the competition"

In order to communicate clearly and effectively to all of these groups, a radically different approach would be required. Firmly rejected was the idea of a conventional customer magazine or in-house workforce newsletter. RQ co-founder Anthony Smith, at that time the group marketing manager of Ricardo, →





→ recalls the challenge:

"We needed RQ to be able to capture attention and entertain across an extremely broad, technically astute but non-expert readership. So it was essential that the design was attractive, and that the style and voice of writing were accessible, authoritative and objective. Conventional company magazines of that time rarely achieved this. They could often be inwardly focused and, at worst, patronizing and preachy. For this reason, rather than looking at what our competitors were doing, we focused instead on the benchmarks of the best of mainstream engineering and business news magazines. My argument was that to be really successful, Ricardo's magazine needed to aim to compete for attention alongside the likes of The Economist, New Scientist, or SAE Automotive Engineering. If a Ricardo customer is going on a business trip, I used to say, I want RQ to be one of the magazines they take to read on the plane."

To achieve this, it became clear that we needed a never-before seen combination of two elements: an insight into the communications needs of Ricardo, paired with the journalistic and editorial flair

of someone from a news or technical magazine background. Smith prepared a list of the best-produced automotive engineering and business titles of the day and ranked them in terms of similarity to the desired style for RQ.

The first on the list was FT Automotive World, which had been launched by Financial Times publisher Pearson in 1999 under the editorship of Tony Lewin. "I was intrigued when I took the initial call from Anthony in the autumn of 2000," explains Lewin. "While I wouldn't previously have considered contract publishing, we discussed the idea of producing a magazine for Ricardo and it seemed a compelling proposition. With access to a worldwide network of freelance journalists as well as layout artists and other specialists, we could create a rich mix of bespoke material - and include FT material too. Not only would we document the work of Ricardo, we could add in independent external content such as high-level interviews with industry leaders."

It was a bold decision for Ricardo to back a radical approach such as this, and it has stood the test of time. To build confidence, the team prepared a pilot issue late in 2000 for review at an internal management

conference. Matters were helped considerably by the company's then head of business development, Dave Shemmans, who was a keen enthusiast for the concept of RQ. His budget would ultimately fund the project and today, as CEO, he continues to take a close interest in every aspect of the publication.

Widening editorial profile reflects Ricardo diversification

The first issues of RQ were an immediate hit with customers and investors, and a glance through the back issues shows the very rapid transformation of Ricardo over the two decades that followed. As a company firmly rooted within the automotive sector at the turn of the millennium but expanding its global footprint, the 2001 issues included features on the significant expansion of Ricardo's Detroit and Prague operations, as well as forward-thinking industry themes that we would return to with updates over the years, such as fuel cell technology and end-of-life product recycling.

The first few years of RQ cover stories reflect a broad and exciting mix of projects, including major engine programmes for the





Twenty years of RQ



Detroit Big Three, motorsports drivelines, supercar transmissions featuring the first DCT applications, off-highway engines and vehicles, and the 2006 smashing of the diesel world land speed record by Andy Green at the Bonneville Salt Flats, Utah, driving the JCB Dieselmex streamliner powered by two Ricardo-developed high performance engines.

But as a new decade approached, Ricardo's strategy broadened out from its automotive base. In Q1 2008, running under the somewhat prescient headline 'Winds of Change', the first truly non-automotive RQ cover story focused on the subject of wind energy, heralding one of the first fruits of this strategy of diversification.

"Ricardo's orientation was developing and expanding at around this time," continues Smith. "The company was still very much focused on automotive as a part of its portfolio of activities, but these were framed within the much wider strategic context of transportation and environmental sustainability."

The development of new sectors of business activity, in some cases through organic growth but in others through acquisition, are increasingly reflected in RQ articles from this point onwards. Perhaps the most significant developments for Ricardo recorded in RQ through this period arose from two strategic acquisitions – that of AEA in 2012, which was to become Ricardo Energy & Environment, and of LR Rail in 2015, which went on to become Ricardo Rail and Ricardo Certification. Beyond these, further tactical acquisitions

strengthened the business in areas including the water and power sectors, as well as further geographical expansions within existing market sectors, most notably in Australia.

In more recent years, cover stories have highlighted work in the areas of climate change mitigation, water resources, air quality, agriculture, renewable power industries, and innovation in the rail, maritime and defence vehicle sectors. Automotive coverage continues, of course, but these articles now tend to reflect the more up-to-date challenges of powertrain electrification, including electric machine and battery systems development. The expansion of Ricardo's motorcycle business is also reflected in the cover stories of many issues over the past ten years, most notably describing the assistance provided to BMW Motorrad.

A change of team

As RQ approaches the start of its third decade, however, there will be a change of editorial team. With their retirement approaching at the end of the year, this Q4 2020 issue of RQ is the last one that Anthony Smith and Tony Lewin will produce

for Ricardo. "We've really enjoyed seeing RQ through from a pilot twenty years ago to the stage where it reflects the full breadth of today's Ricardo," explains Lewin. "We've worked together on a number of print and online communications channels for customers in the US and Europe, but RQ will always be the project closest to our hearts."

A new future for RQ

"We've been working with the new editorial team over the past weeks to ensure that they are able to make a good start to their first RQ in 2021," adds Smith. "With a company as innovative and dynamic as Ricardo, I'm sure they'll have an interesting time and will produce even more informative and enjoyable coverage over the months and years to come. In so many respects I envy them for taking over perhaps the most interesting, most varied and most enjoyable project that it has been my pleasure to work on throughout my career. But it really is time to pass on the baton and we wish them – and all of our colleagues, RQ subscribers and the entire Ricardo organization – the very best for the future." 





HYDROGEN

Behind each historic advance in our society lies a major shift in our primary energy. Now, with our pressing need for deep decarbonization, can hydrogen step forward to break our fossil fuel addiction and take us into a sustainable zero-carbon future? **Tony Lewin** questions leading Ricardo experts to find out if this wonder fuel is up to the task of saving our planet



Hydrogen is the most abundant element in the universe. It is also a useful energy vector which is used to convert, store and release energy, and which, when used, does not release greenhouse gases (GHGs). These three facts alone should mark it out as the perfect solution to help halt the accelerating spiral of climate-heating emissions in a world hungry for energy.

"Of course hydrogen is a very attractive energy vector," affirms Mike Bell, group strategy and transformation director at Ricardo, "but like every major step forward

it is not always quite so simple. And like any fundamental shift it will require significant changes to national infrastructures and how we go about our business."

What gives the experts such confidence in hydrogen as an energy vector is the fact that it can be generated in several different ways, some greener than others. If it is produced using renewable electricity it offers the potential for a zero-carbon footprint – and BP's recently-announced green hydrogen tie-up with Danish wind power group Ørsted shows that even the oil majors

are beginning to take it seriously. Other hydrogen production methods also promise near-zero or potentially even negative GHG emissions.

The European Union, the first major economic bloc to target net zero GHG by 2050, sees hydrogen as a central plank in its new Green Deal strategy for deep decarbonization. "Hydrogen is a vital missing piece of the puzzle to help us reach this deeper decarbonization," said Kadri Simson, the EU's energy commissioner, when presenting the strategy in July this year.



will not achieve the Paris targets across all forms of industry," adds Bell. "People are getting very excited about hydrogen and it can really help – but it is by no means a panacea. For some industries with high temperature requirements, such as aluminium, steel, paper and cement, hydrogen would make sense; for others, [direct] electric forms of heat would be sufficient."

In a similar vein, Bell refers to the results of a recent comprehensive life cycle assessment (LCA) study carried out by Ricardo for the European Commission [see page 14]. Because of the energy losses involved in converting electricity into hydrogen, fuel cell electric light vehicles will always be less efficient overall than those storing their electricity directly in batteries. "All of that makes our point," he says, "and the reality of it all is that both electricity and hydrogen will be competing applications. Where things go will be driven partly by economics and partly by technology and regulations: the other problem right now is that we haven't got huge volumes of untapped hydrogen, so we have to create it."

The many colours of hydrogen

Hydrogen may be a uniform and chemically simple gas, but the different ways it can be generated make a profound difference to the GHG impacts it produces. There is a distinct hierarchy here, as Colin McNaught, technical director at Ricardo Energy & Environment, explains:

"For us, the focus is on both green and blue hydrogen as they're both zero carbon, or pretty close to it. How they compare depends on when and where you're talking about. Green hydrogen is produced using fully renewable energy, so there's no argument about that; with blue hydrogen, which is produced from natural gas via steam methane reforming (SMR) with carbon capture and storage, I guess some people may still question how long

Yet, as Bell points out, the production of hydrogen should not release GHGs into the atmosphere. The end goal must target the production of green hydrogen, for example, via electrolysis using renewable electricity. At present, 96 percent of hydrogen comes from fossil sources, so there's a long way to go. Some argue that a useful interim measure could be so-called 'blue' hydrogen – see below – which is made from natural gas but, with carbon capture and storage (CCS), which largely eliminates the release of GHGs. Natural gas is still cheap and available at scale, so a big advantage of this route is that it enables much of the hydrogen infrastructure to be built up while we wait for fully green hydrogen to ramp up to large-scale production – though others point to the dangers of prolonging the reliance on fossil gas.

Priority uses for renewable energy

The tapering off of fossil fuel dependence throws the focus back onto the renewables industry and the twin issues of available capacity and how to use that capacity to best overall advantage. The UK is a global leader in offshore wind power, with Ricardo involved at a high level in several programmes; nevertheless, Sujith Kollamthodi, strategy & innovation director at Ricardo Energy & Environment (REE), notes that, as the key element in

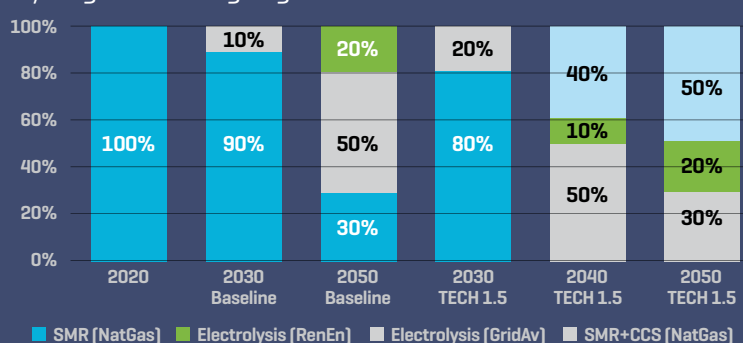
the bigger picture, renewable electricity must be used as efficiently as possible. As a general rule, he reminds us, converting energy into another form results in losses, so for many applications – especially in certain industries and in the home – the electricity is best applied directly.

"So when converting electricity into hydrogen," he explains, "we would want to target it at those specific areas where other [low-carbon] options are difficult to apply. So we would be looking at the heavier forms of transport, such as shipping and road freight, where the other options such as electrification aren't so effective, and where alternatives such as biofuels are in limited supply."

"Where the regulations currently sit, we

Airbus is actively exploring hydrogen-fuelled concepts to allow carbon-free air travel

Hydrogen's evolving origins



Source: European Union DG Climate Action, LCA viewer

Today's hydrogen is almost exclusively derived from fossil natural gas (left hand column) and in the baseline case becomes 70 percent renewable by 2050. In the more ambitious TECH1.5 scenario it is fully carbon-neutral by 2050 thanks to renewable electricity and CCS on the natural gas SMR process



Daimler Trucks [above] has joined forces with Sweden's Volvo to develop long-haul fuel cell powered heavy trucks such as this Gen H2 concept, presented this autumn. Series production is planned for the second half of this decade

the carbon will stay in the geological store – even though the IPCC report suggests 10,000 to 100,000 years.”

Also critical here, of course, is the issue of how much of the CO₂ from the SMR process is actually captured by the CCS system. Naser Odeh, Ricardo Energy & Environment knowledge leader in CCS, points to the world's first major industrial-scale CCS installation, on the coal-fired

power station at Boundary Dam in Canada. “It started at well below the planned 90 percent capture rate but now it has improved to 85 or 90 percent,” he says.

Naser Odeh, for his part, is keen to highlight the potential of biomass- and biomethane-derived hydrogen. “Steam reforming to produce blue hydrogen using biomethane rather than natural gas, followed by CCS, offers the potential of

giving you negative emissions, and that would be a big benefit. The same also applies to hydrogen produced by biomass gasification combined with CCS.”

The thinking behind this technology is that the plants that grow to form the biomass will absorb CO₂ from the atmosphere. With CCS making the SMR process very nearly carbon neutral, the net result is carbon-negative overall,

Transitioning to hydrogen

Industry

Hydrogen is well placed to replace coal and fossil gas in many industries requiring intense heat. Examples include aluminium and steel processing, paper manufacture and cement production. However for some applications the direct use of electricity may be more efficient, as it avoids the losses associated with conversion into hydrogen.

Shipping

With a wide variety of vessel types, sizes and roles, the shipping industry has always been difficult to regulate and is one of the world's biggest polluters and CO₂ emitters. The likelihood is that for the zero-emission future short-haul craft such as ferries could be battery powered, and medium-range ships could rely on fuel cells fed by compressed or cryogenic hydrogen. For long-distance shipping the fuel could be ammonia derived from green hydrogen: this is easier to store than hydrogen, packs more energy into a given space, and can be used in retrofitted diesel engines as well as in fuel cell systems. A Ricardo case study in 2019 looked at a site on the Moroccan coast as a potential location for a carbon-neutral plant for green ammonia, with lots of shipping traffic and abundant solar irradiation for its hydrogen plant and ammonia conversion processes.

Aviation

The need for high power, long range and light weight means that aircraft have always been difficult to electrify. But recent developments, such as the battery-powered ZeroAvia light plane and Airbus's stated

commitment to develop a zero-emission airliner in the 2030s have focused attention on the potential of hydrogen as an aero fuel. From today's perspective the expectation is for short-haul aircraft to rely on batteries, medium-range regional passenger planes to use fuel cell engines fed with liquid hydrogen, and for intercontinental flights to retain gas-turbine jet engines, reconfigured for the very different continuous combustion characteristics of hydrogen fuel or for newly developed e-fuels, also derived from hydrogen.

Introducing Airbus ZEROe		
Turboprop	<100 Passengers Hydrogen Hybrid Turboprop Engines (x2)	1,000+nm Range Liquid Hydrogen Storage & Distribution System
Blended-Wing Body	<200 Passengers Hydrogen Hybrid Turboprop Engines (x2)	2,000+nm Range Liquid Hydrogen Storage & Distribution System
Turbofan	<200 Passengers Hydrogen Hybrid Turboprop Engines (x2)	2,000+nm Range Liquid Hydrogen Storage & Distribution System

AIRBUS

Airbus expects liquid hydrogen to be the main aviation fuel for the future, with short- and medium-haul planes using hybrid turboprop engines and long-haul relying on turbofan motors

The many colours of hydrogen

Hydrogen is a uniform colourless gas but industry has devised these informal colour categories to distinguish the different origins of the gas and thus its environmental performance

Colour	Source
Green	Electrolysis using renewable electricity
Blue	Steam methane reforming (SMR) of natural gas, with carbon capture and storage (CCS) to ensure no GHG emissions
Grey	SMR of natural gas, no CCS
Yellow	Nuclear-generated electricity
Black	Any other sources, including coal and high-carbon electricity

drawing CO₂ out of the air at the same time as providing hydrogen fuel. Technology readiness levels (TRL) are low, however, at 5 or 6, and Odeh estimates it could be a decade away. One more candidate technology is the production of hydrogen through the pyrolysis of natural gas, leaving the carbon content as solid graphitic carbon which can be used as a construction material. The promises are of much cheaper hydrogen but, again, this process is at an early stage of research & development.

Colin McNaught sees the current interest in the many options for generating hydrogen as a sign of its

growing importance. Nevertheless, he observes that “the core issues are the GHG credentials and the cost: standards to define low-carbon hydrogen are being developed and the costs are falling, and this addresses two of the key challenges.”

And hydrogen is of course an important building block for a whole spectrum of other green fuels – all the way from ammonia for shipping to sophisticated ‘designer’ fuels for aircraft.

The hydrogen value chain

Though there are many different ways of generating electricity, there is only one method for turning that electricity into

hydrogen – the electrolysis process, which splits water into its constituent elements of hydrogen and oxygen.

Several different types of electrolyser are available, using a variety of technologies each with its own level of efficiency. Costs have fallen by 40 percent since 2015, according to Bloomberg New Energy Finance, and typical efficiencies are now in the 80 percent region. In effect, the electrolyser works like a fuel cell in reverse but, unlike fuel cells, electrolyser technology is not yet suitable for mass production in the same way as, say, solar panels. As a result, most of today’s available electrolyser units are modular systems about the size of a shipping container and with a rating of 1 MW.

Iberdrola in Spain will soon install 20 MW of electrolyser capacity for its Puertollano green hydrogen plant, which is set to come on stream in 2021. The facility comes as part of Spain’s commitment to provide 4 GW of green hydrogen by 2030, representing 10 percent of the 40 GW pan-European target set out in the EU’s hydrogen roadmap.

Once the hydrogen has been produced, it must then be prepared for delivery to the end user. Today’s distribution networks rely on compressing or liquefying the gas for storage in special transportation containers, and the modular nature

Rail

Significant percentages of regional and international rail networks remain unelectrified, forcing trains to run on hybrid or diesel power. Ricardo is already involved in the innovative HydroFLEX project to develop a hydrogen-powered train for mainline testing. The concept may in the future enable electric multiple units to operate by drawing energy from an overhead catenary or conductor rail, and to transition seamlessly to zero-emission self-powered operation when beyond the reach of existing electrification. The vehicle could thus serve many routes currently operated using diesel power, while also providing better utilization of existing power infrastructure on routes that traverse both electrified and non-electrified sections. Retrofitting existing trains is very feasible, notes Ricardo’s Mike Bell.

Heavy goods vehicles

While high-profile manufacturers such as Tesla are investing heavily in battery-powered trucks for long-distance goods transport, the consensus in the auto industry is that batteries are still too bulky, too heavy and too slow to recharge to allow such trucks a profitable payload. Rival start-up Nikola will offer combinations of pure battery and hydrogen fuel cell trucks, and has linked up with Europe’s IVECO and GM in the US. While fuel cell hydrogen power is expected to be the preferred option for large and heavy vehicles, Ricardo and some truckmakers are looking closely at using hydrogen fuel in adapted diesel engines, perhaps as an interim measure. For lighter local truck and van operations, pure-electric power again offers the most efficient

zero-emission solution, though the batteries’ weight still means a lower payload than in legacy diesel-powered vehicles.

Passenger cars

The LCA life cycle analysis carried out by Ricardo for the European Commission (see page 14) has demonstrated that the direct application of electricity is always the most efficient on a holistic well-to-wheels basis. This means that in most cases pure-battery electric light vehicles (BEVs) will be marginally more efficient than their fuel cell hydrogen counterparts, whose fuel is derived from electricity at less than 100 percent efficiency. But where extended ranges are required, batteries become disproportionately heavier and hydrogen fuel cell models could find themselves much closer to the overall efficiency of a BEV. Significantly, while BMW and its partner, Toyota, as well as Hyundai and Honda, are continuing to pursue fuel cell passenger car development, Volkswagen and Daimler have very publicly abandoned hydrogen cars to concentrate on the use of the fuel in commercial vehicles.

Domestic and residential

The UK is among several nations seeking to reduce the enormous GHG footprint of their housing stock and is outlawing new domestic gas boilers from 2023. The intention is to phase out the supply of the natural gas in today’s grid and migrate to piped hydrogen, though – especially in the UK – many details remain to be clarified both on the supply side and on the technical aspects of the future appliances.

Europe's roadmap to hydrogen

Phase	When?	Hydrogen electrolyser capacity	Renewable hydrogen production
1	2020-2025	6 GW	1m tonnes
2	2025-2030	40 GW	10m tonnes
3	2030-2050	Large-scale deployment of renewable hydrogen to reach all sectors; one-quarter of all renewable electricity used for hydrogen and hydrogen-derived synthetic fuels	

Source: European Commission



"Hydrogen is a very attractive energy vector, but like every major step forward it is not always quite so simple. And like any fundamental shift it will require significant changes to national infrastructures and how we go about our business"

Mike Bell, group strategy and transformation director, Ricardo

of hydrogen generation presents the potential for much smaller localized systems which avoid the extra costs and emissions of long-distance distribution. It is quite possible, for instance, to envisage a neighbourhood filling station which uses local solar and wind generation to power electrolyzers and provide the hydrogen for local cars and trucks, perhaps feeding any surplus into a future hydrogen grid.

Storage and distribution

What surprises many people is that the natural gas grid infrastructures in most countries can be used for hydrogen, too, albeit with some small upgrades: indeed, some hydrogen is often blended into the supply. It is currently only a limited percentage – perhaps 2 to 10 percent

by volume. Not all end-user appliances are yet compatible with stronger concentrations of hydrogen; under current UK regulations, for instance, all appliances sold after 1996 must be able to sustain 23 percent hydrogen. Some components in the gas pipelines will need to be upgraded from steel to plastic for the higher concentrations of hydrogen. Pressures may need to be raised, too, for hydrogen needs three times the flow area to deliver the same energy content as today's natural gas. But in principle it is perfectly possible.

Until piped hydrogen grids are more established, hydrogen will continue to reach its end applications in compressed or liquefied form. For mobile applications, both the mass and the package size of the hydrogen container are of critical importance, as Cedric Rouaud, Ricardo global technical expert for thermal systems and fuel cell R&D leader, explains: "For a heavy truck, for instance, we would need tens of kilogrammes of hydrogen. With compressed gas it is still a heavy solution: for 60 kg of hydrogen, to give a range of 500 to 700 km, the tank would weigh two tonnes."

The alternative solution of liquefied hydrogen helps reduce the weight to 1.2 tonnes for the same 60 kg of hydrogen, he continues. "But for the same space as the

conventional compressed gas tank we can store more hydrogen when it is liquid, so we can extend the range from 600 to 1000 km." Also being investigated, says Rouaud, are combinations of compression and cryogenic storage, known as cryo-compressed. Another promising avenue, which will soon be demonstrated in a London bus field trial, is solid-state storage using a metal hydride. This solution, developed by London South Bank University with Ricardo's assistance, is lighter than compressed gas for the 60 kg of stored hydrogen, reveals Rouaud. What is more, he says, it has the key advantages of operating at normal temperatures and pressures, and it is cheaper than a complex carbon fibre pressure tank.

One way or another, however, it is clear that heavy, bulky and costly storage is still a significant brake on the potential of hydrogen, especially where aircraft and lighter applications such as passenger cars are concerned.

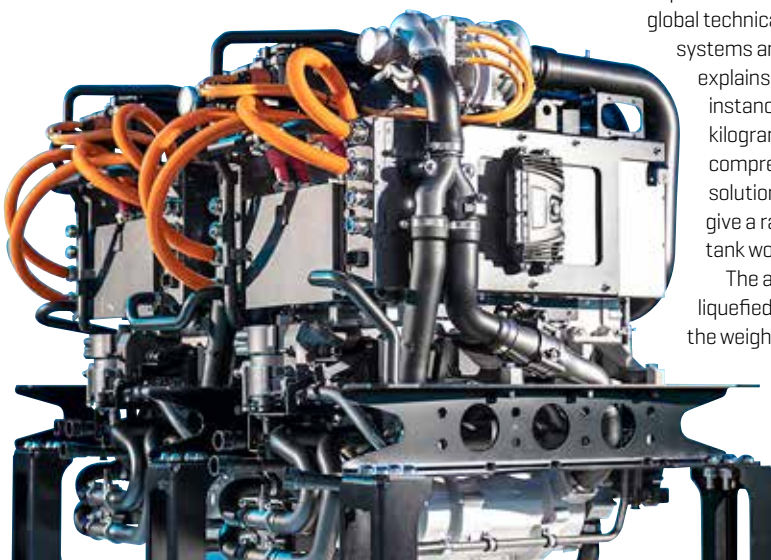
National and international strategies

Many nations have already launched their own hydrogen strategies, most notably Japan, whose economy depends almost exclusively on imported energy. Public and private hydrogen programmes had been in existence since the 1970s, but in 2017 Japan's energy security programme set up supply chains for liquefied hydrogen from other countries such as Australia and established ambitious targets for fuel cell powered cars, trucks and buses, and for co-generation schemes in industry. Indeed, the postponed 2020 Tokyo Olympics had been planned as an international showcase for hydrogen powered vehicles. Some hydrogen imports will soon be in the form of ammonia as a hydrogen carrier.

Australia, in a rapid about-turn from its earlier and much-criticized coal-centric energy policy, is reinventing itself as a major international hub for green hydrogen and is aiming to meet 3.5 percent of global demand. Norway's green hydrogen will come from hydro and wind power, linked to high-temperature electrolysis.

But probably the most ambitious of all is the European Union's Green Deal roadmap for clean energy, intrinsic to the Union's commitment to achieve net zero GHG emissions by 2050. The priority, states the EU plan, is to deliver 40 GW of green hydrogen electrolyzers by 2030, using mainly wind and solar energy: the roadmap [top left] details targets for the large-scale rollout of those renewable energy installations and electrolyzers. The

Fuel cell power pack technology (below) is being shared by Daimler Trucks and Volvo





UK's just-announced 10-point plan for a 'green industrial revolution' also includes important roles for hydrogen in its many bold undertakings. But, as with all of these ambitious strategies, what is equally critical is the political will and the budget to make them a reality.

Outlook

For many decades hydrogen has been idealized as a dream fuel, the fuel of the future. But now, with many indicators signalling we are close to an environmental tipping point, the need to decarbonize every sector, especially transport, has become doubly important. Fortunately, hydrogen is in a good position to help.

Hydrogen is likely to take off for a combination of reasons, says Ricardo's Mike Bell. "It can help decarbonize difficult sectors like land and sea transport, which account for 27 percent of all GHG emissions, and regulations and incentives are at last aligning to favour this type of sustainable solution."

But most of all, says Bell, it is the greater deployment of renewable energy to decarbonize the electricity grid that will be key. So does that mean there will be a time when electricity and hydrogen are our only energy sources?

"Probably not, or at least not in the next 30 years," says Sujith Kollamthodi. "It comes down to all the different use cases and resource availability - and biomass and sustainable biofuels will also play a role. These fuels can help decarbonize the existing vehicle parc."

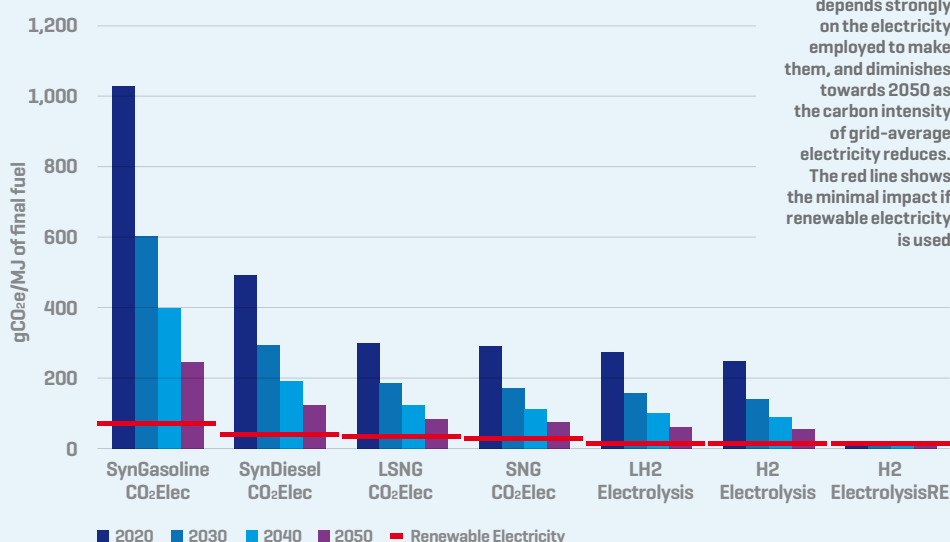
So, is hydrogen still the fuel of the future? The consensus among, engineers, climate specialists, legislators and Ricardo experts is that it is no longer simply the fuel of the future - it's the fuel of now. 

Ricardo is involved in the innovative HydroFLEX project to develop a hydrogen-powered train for mainline testing *(above)*; retrofitting of existing rolling stock would be relatively straightforward

Toyota *(below)* and BMW are partners in the development of hydrogen fuel cell powered passenger cars, but other automakers are focusing on pure battery EVs



Determining the environmental impacts of conventional and alternatively fuelled vehicles



The climate impact of producing the different e-fuels depends strongly on the electricity employed to make them, and diminishes towards 2050 as the carbon intensity of grid-average electricity reduces. The red line shows the minimal impact if renewable electricity is used

Notes: the fossil fuel comparator is 94gCO₂e/MJ in FQD and RED2 (European Union, 2018)
Source: Ricardo LCA report Key: LSNG: liquefied synthetic natural gas; LH2: liquefied hydrogen; H2: hydrogen; RE: renewable energy

RQ RICARDO NEWS

Latest developments from around the global Ricardo organization



New squad vehicle for U.S. Army

The first delivery of the new Infantry Squad Vehicle (ISV) to the U.S. Army was made in October – part of a \$214.3 million contract awarded to GM Defense LLC, a subsidiary

of General Motors, which has a teaming agreement with Ricardo Defense.

For the ISV – a light and agile all-terrain troop carrier intended to transport a nine-

soldier infantry squad and their equipment – Ricardo Defense is leading on integrated product support, including technical manual development, new equipment training, provisioning, total package fielding and field service support.

GM Defense will manufacture 649 ISVs and will support the production of up to 2,065 vehicles with additional authorization over eight years. The ISV is based on the award-winning Chevrolet Colorado ZR2 midsize truck architecture and uses 90 percent proven commercial-off-the-shelf (COTS) parts, including Chevrolet Performance race components, but is uniquely engineered to fulfill military requirements and designed to provide rapid ground mobility. The expeditionary ISV is light enough to be sling loaded from a UH-60 Blackhawk helicopter and compact enough to fit inside a CH-47 Chinook helicopter.

“The success of the ISV program within 120 days is a true testament to the hard work and determination of a great partnership between GM Defense and Ricardo Defense,” said Chet Gryczan, president of Ricardo Defense. “Ricardo is proud to be leading the creation and integration of critical ISV logistics products to ensure a successful transition of the ISV to the Army’s inventory.”

COP26: meeting climate change targets



Ricardo is supporting six countries in their preparations for the COP26 climate summit being hosted in the UK next year, providing assistance with formulating,

implementing and tracking their climate change mitigation plans.

Since the run up to COP21 in 2015, which launched the Paris Agreement, Ricardo has been supporting governments around the world in developing their Nationally Determined Contributions (NDCs) towards overall emissions reduction, and has continued to work at the national level to enable implementation of the legally-binding and critical climate change commitments.

Ricardo experts are helping countries to track

progress towards their NDC targets, and have assessed climate vulnerabilities and prioritised adaptation options in countries such as India. The team also ran the initial Climate Finance Accelerator that was key in supporting private sector investment into NDC projects.

For next year’s COP26 summit in Glasgow Ricardo is assisting the governments of Colombia, Jordan, Namibia, Nigeria, Palestine and Uganda in formulating and implementing climate change mitigation plans through their NDCs and emissions reductions and long-term low emission development strategies (LT-LEDS). Ricardo has also recently delivered workshops on meeting these standards for small island developing states, and is working with the German international development agency, GIZ, to prepare guidance on structuring updated NDCs.

Information security accreditation achieved

The UK technical centres and facilities of Ricardo’s Automotive & Industrial division have achieved Trusted Information Security Assessment Exchange (TISAX) Level 2 accreditation for information security. TISAX is a programme, defined by the International Standard ISO/IEC 27001:2013 and developed by the German Association of the Automotive Industry (VDA), for assessing the information security systems of companies in the automotive sector.

Information security has always been central to Ricardo’s operations, as the company interacts with clients worldwide, and often needs to exchange commercially sensitive and confidential information.

More V2I co-operation needed, says report



A report on V2I (vehicle-to-infrastructure) communication technologies – co-authored by Ricardo – has identified improved stakeholder communication as a key enabler for their wider deployment.

The report – commissioned by 5GAA, a global cross-industry consortium working to develop end-to-end solutions for future mobility and transportation services – saw Ricardo transport and mobility experts and their colleagues at Roke Manor Research analyze a range of V2I options, including the use of a pure cellular network system, or a combination of the cellular network with direct communication interfaces via the radio spectrum.

The study weighs up strengths, weaknesses and complementarity of the different communications technologies in terms of their technical performance and costs under a range of use cases. One

eye-catching finding was that, in Europe and the US, a pure cellular deployment comes in at 40-45 percent cheaper than arrangements including direct communication roadside units.

The report recommends increased co-operation and communication of technology strategy between vehicle manufacturers, central government, road operators and cellular technology providers, with particular reference to the interoperability of technology solutions. Central government is also identified as having a key role via the effective implementation of financial instruments to help leverage private sector investment in support of the wider deployment of this technology.

A full copy of the Ricardo report **Cost analysis of V2I deployment** is available for download from the 5GAA web site: <https://5gaa.org/news/cost-analysis-of-v2i-deployment/>

New battery technology in running for award

High power battery packs and ultra-fast charging solutions for electric vehicles, developed collaboratively by Ricardo with M&I Materials Ltd and Warwick Manufacturing Group at the University of Warwick, have been nominated for The Engineer magazine's 2020 Collaborate to Innovate award for the automotive sector.

The technology – known as i-CoBat, which stands for Immersion Cooled Battery Packs – uses immersion cooling to provide high heat transfer and the efficient management of temperature spikes. A significant benefit of this thermal management is to extend battery pack life by approximately 8 percent, reducing both environmental impact and cost.

The battery pack has a lightweight design which offers overall weight and cost savings thanks to partial immersion cooling of the cells, and bus bar cooling. It has been designed specifically for volume manufacture, enabling products to be brought to market sooner.

i-Co-Bat also offers a notable safety benefit: the unique design, incorporating the use of dielectric fluid, reduces the possibility of thermal runaway – one of the biggest safety issues for electric and hybrid vehicles.

The winners of The Engineer 2020 Collaborate to Innovate awards will be announced in early 2021.



Ricardo among 'UK Business Heroes'

Ricardo is one of just a 100 businesses across the UK to be named as a UK Business Hero – in a national recognition campaign led by the British Chambers of Commerce to recognise UK businesses who have gone the extra mile to help the local community during the Covid-19 pandemic.

This was in recognition of the company's work earlier this year in designing, manufacturing and assembling personal protective equipment (PPE) for frontline NHS staff and other healthcare workers.

Ricardo used its experience of high value, rapid response assembly and supply chain management to design and produce a face shield intended for prolonged use in medical settings. Local NHS doctors helped to optimise prototypes for wearability, and the fast-track approval of the face shield for NHS emergency use was secured via industry-leading test provider SATRA.

The face shield frames were manufactured by longstanding supply chain partner Stephens Plastic Mouldings, using tooling co-funded jointly with Ricardo. Facilities at Ricardo's Technical Centres at Shoreham-by-Sea in West Sussex and Leamington Spa in the Midlands were repurposed as assembly lines and logistics centres to ensure the rapid deployment of this PPE, which was much needed.



Supporting Siemens on new ICE trains



Ricardo Certification has been selected by Siemens Mobility to ensure the regulatory compliance of 30 new high speed intercity express [ICE] trains for the German national railway operator, Deutsche Bahn [DB].

The new trains, based on the Velaro MS design and due to be come into service from 2022, are part of a one billion euro investment by Deutsche Bahn to expand its mainline fleet. Initially they will run on routes between the state of North Rhine-Westphalia and Munich via the high-speed Cologne-Rhine-Main line, increasing daily passenger capacity on these routes

by 13,000 seats. The new ICE trains will be manufactured at Siemens facilities in North Rhine-Westphalia, Bavaria and Austria.

Ricardo Certification is accredited by the EU Agency for Railways as a Notified Body [NoBo]. In this role, the company is accredited to provide conformity assessments of trains and subsystems against the relevant requirements of the European Interoperability Directives 2008/57/EC and 2016/797/EC. Ricardo will verify the new ICE trains in terms of compliance with the current European Technical Specifications for Interoperability [TSI] regulations, including the quality management system of the production process.

Helping industries aim for net zero

In addition to making its own pledge to achieve net zero carbon emissions in its operations by the year 2030, Ricardo is assisting a wide range of industries and organizations with the development of robust plans to meet their own environmental targets.

Healthcare and climate change

The NHS and healthcare community has long recognised a climate emergency. Reports in 2009 by the World Health Organization and the Lancet Commission on Managing the Health Effects of Climate Change identified climate change as “the biggest global health threat of the 21st century” and cited air pollution as the cause of an estimated seven million premature deaths every year.

Ricardo is assisting NHS Services Scotland to develop a net zero strategy that aligns with the Climate Change [Scotland] Act; this outlines a requirement for the public sector to achieve net zero emissions by 2045 at the latest.

Zero carbon shipping

In September 2020, as a part of New York Climate Week, environmental group Ocean Conservancy released a Ricardo-prepared report presenting a compelling case for the widespread adoption of electrofuels, in order to move the international shipping industry from being one of the largest producers of greenhouse gas emissions to a

zero-carbon future. Electrofuels are a drop-in replacement for fossil fuels, being synthetically derived from hydrogen or ammonia and produced using renewable energy.

The report, Zero-Carbon for Shipping, presents case studies from South and Central America, which has an extensive shipping industry, with total imports and exports totalling around \$1 trillion. The studies demonstrate how existing technologies, such as electrofuels and renewable energy, will do much to help transition the shipping industry to a zero-carbon future – and could have wider benefits too. In the case of Porto do Pecém, Brazil, for example, the report found that the adoption of electrofuels would not only decarbonize the local shipping industry, but could also provide a carbon-free source of fuel for local steel and chemical manufacturing.

A routemap for UK water

Water industry experts from Ricardo and consultancy Mott MacDonald have collaborated to create a pioneering strategy that will guide the UK water industry to achieve net zero carbon emissions by 2030.

The strategic routemap was produced on behalf of industry body Water UK, and drew on many months of analysis, in-depth conversation and innovative thinking by specialists at the

two global consultancies.

The document is unprecedented: the UK water industry is the first such industrial sector within the country to commit to the achievement of net zero carbon emissions by 2030, a full 20 years ahead of the UK government’s stated goal.

The routemap was developed with the support of all the UK’s water companies. It has been designed to offer different pathways to suit the requirements of each organization, but with the same end goal of achieving net zero by 2030.

To achieve this, the industry will need to reduce its current greenhouse gas emissions through the use of efficiency interventions and alternative technologies; renewable energy generation; and removing residual emissions by contributing to the UK’s natural sequestration efforts. The sector has already started working towards its goal, with a number of programmes and initiatives already in place. Progress towards net zero carbon will be independently assessed each year, with key milestones reported publicly.





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