Ricardo Quarterly Review **Spring** 2022

RQ

A focus on the latest in innovation, sustainability and technology

RICARDO

From waste to energy
Capitalising on carbon capture, utilisation and storage

Battery power
Looking beyond lithium-ion chemistry

Raising a glass
Creating a sustainable future for the whisky industry

Food for thought

How climate-smart agriculture can produce more with less

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THAT MOVES US

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RQ is produced by LookUp Communications and published by Ricardo plc.

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RQ is Ricardo plc's quarterly magazine focusing on innovation, sustainability and technology. Each issue offers insight from within Ricardo and other leading organisations in the transportation and clean energy sectors and related industries.

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RQ NEWS

Latest developments from around the global Ricardo organisation

Innovation funding for rail projects

Ricardo has won support from the Strategic Innovation Fund (SIF) for two studies in the transport innovation challenges category.

Both projects focus on the rail sector and will be delivered in partnership with Scottish Power, Network Rail and the University of Leeds:

» **A holistic hydrogen approach to heavy duty transport (H2H)** will examine the energy used by trains in Scotland, where the rail sector aims to remove diesel-fuelled trains by 2035. Full electrification is the main solution but there is associated high cost and high emissions for the concrete, steel and copper used. Disruption to passenger services during construction is another factor to be considered. H2H will examine hydrogen and battery trains and compare these with full electrification. Ricardo is leading this study.

» **Resilient and flexible railway multi-energy hub networks for integrated green mobility** will look at railway stations and the feasibility of linking vehicles in station car parks, the energy used by the station and the electricity grid and rail traction systems. This project will accelerate the journey to railway decarbonisation by developing multi-energy hubs for, potentially, around 2,500 stations across the UK.

The SIF is expected to invest £450 million in energy network innovation until 2026. Initially, projects will receive money for a two-month 'Discovery' stage, with a selection going on to a more detailed 'Alpha' feasibility study. At the 'Beta' stage, the successful projects will go into full-scale demonstration.

Ricardo's work will support UK rail's ambitious targets for decarbonisation

» **Ricardo has also been tasked with developing a new action plan to support UK rail industry decarbonisation efforts.** Leading a partnership with international engineering and management consultancy Mott MacDonald, Ricardo's experts will consult stakeholders from across the sector to assess existing carbon reduction plans and develop a new unified response.

The Action Plan has been commissioned by the Rail Safety and Standards Board, the industry-funded body that strives to improve the network's health and safety performance and forms a key part of its work to deliver a net-zero railway.

Ricardo acquires Australian consultancy

The acquisition of Inside Infrastructure, an independent consulting company based in Adelaide, will expand Ricardo's environmental capabilities across Australia.

Founded in 2010, Inside Infrastructure provides environmental and technical advisory services through its team of 25 specialists, supporting the water, utility, mining, resources, healthcare, infrastructure and government sectors in developing, delivering and managing their projects and assets.

Inside Infrastructure's customer base complements Ricardo's existing presence in water and utilities as well as offering the chance to expand into adjacencies through a strong customer base in mining and Australian government sectors. Ricardo's existing Australian business has a broad expertise in upstream policy and consultancy services.

"Inside Infrastructure fits well within all the characteristics of our investment strategy," says Graham Ritchie, Ricardo CEO. "It's environmentally led and strengthens our current market position as well as opening into new growth sectors."

Supporting the UK's first zero emission zone

Scheme could pave the way for more cities to tackle air quality issues

A pilot zero emission zone (ZEZ) in Oxford covers nine streets in the city centre with vehicles not qualifying as zero emission facing daily costs of up to £10.

Ricardo conducted an initial feasibility assessment to help define the practicalities of the scheme and outline its air quality benefits and economic impacts.

"The effect of emissions from vehicles on public health is well documented," says Guy Hitchcock, Technical Director at Ricardo. "We have worked with various local authorities to find ways to reduce the negative impacts of air pollution and Oxfordshire County and Oxford City Councils have shown their ambition to move towards zero emission transportation by using our analysis for this pioneering scheme."

London already has its Ultra Low Emission Zone (ULEZ) while Bath and Birmingham have active Clean Air Zones (CAZ). Ricardo's air quality specialists supported London in the assessment of its ULEZ and have been working with local authorities in Bradford, Southampton and Cardiff to complete CAZ feasibility studies.

With Ricardo's support, Bradford secured £43 million of UK Government funding to implement measures later this year that are expected to reduce pollutant concentrations in the city to below legislative levels and improve public health five years earlier than would be the case without the CAZ.

"While Oxford is the first city to consider going beyond a CAZ with their ZEZ," adds Hitchcock, "other local authorities may choose to follow suit. The implementation of zones that charge drivers of vehicles with high emissions may persuade more motorists to switch to electric vehicles."

In Oxford, Ricardo used its innovative RapidAir© model to generate pollutant concentration results, looking at the benefits of a ZEZ in terms of annual and hourly mean nitrogen dioxide concentrations and population exposure.

Oxford's ZEZ covers nine streets in the city centre

Simulation towards a sustainable future

Virtual event to support the journey to zero tailpipe emissions

Registration is open for a unique and innovative event organised by Ricardo. To be held on 26 and 27 May, the free event will be staged entirely in a virtual environment and will showcase how leading-edge tools and solutions are being used to solve engineering challenges towards a net-zero and sustainable future.

Delegates will watch live presentations, have access to on-demand webinar and training content and meet other participants and Ricardo experts as if they were in the same physical location – without having to leave their own office.

"Ricardo is at the forefront of developing global, low-carbon solutions," says Nick Tiney, Product Management Director for Ricardo Software. "Our most recent software release, which came out at the beginning of April, focuses on using High Performance Computing ultimately to reduce tailpipe emissions. We look forward to welcoming customers from around the world to showcase this new capability."

The two-day event is entirely free to attend and will feature presentations from leading transport original equipment manufacturers, Tier 1 suppliers and Ricardo experts across two concurrent technical sessions: electrification, hybridisation and fuel cell technology; and internal combustion engine solutions using new fuels for net zero and a sustainable future.

On day two, Ricardo experts will host a series of workshops demonstrating how the company's products, for low-carbon solutions, can quickly reduce time to market.

To register, email: rs_events@ricardo.com

Recognition for sustainability consultancy

Ricardo's expertise has been recognised in the *Financial Times*'s fifth annual rating of the UK's leading management consultants. The company's experience and knowledge in providing trusted advice to clients in sustainability has featured in the rating every year since the awards began.

The rating is based on two surveys by data company Statista – one giving feedback from clients and the other of consultants evaluating their peers.

"Being recognised is a testament to the trust placed in us by our clients and the quality of the work that we have undertaken on high profile, nationally important projects addressing net zero and climate change," says Tim Curtis, Managing Director of Ricardo Energy & Environment.

Ricardo's experts have been helping a wide range of multinational companies to develop robust and science-based pathways to transition to net-zero carbon emissions.

Moving forward with sustainable motors

Ricardo's expertise in motor research, development and manufacturing has helped win two UK Government-backed innovation competitions to develop a dedicated electric motor for battery electric light commercial vehicles.

The company has been developing a rare-earth magnet-free sustainable electric motor concept with aluminium stator windings, which retains the key attributes of magnet-rich motors. The goal has been to create technology that is robust, costs less than current products and reduces lifecycle impact by eliminating the use of scarce resources – including up to 12 kg of rare earth metals and also high acidification materials such as copper – without impacting motor function or quality.

Funding provided by the Driving the Electric Revolution Challenge at UK Research and Innovation to the UK-ALUMOTOR consortium, which Ricardo leads, will get the light commercial vehicle motor concept to a much higher level of manufacturing readiness.

The consortium will deliver a tested and validated pre-production, highly sustainable motor, with a major reduction in rare earth metals used per machine. This will enable the UK to scale motor production and accelerate the transition to electrified transport, as well as build and secure its national capability and domestic supply chain.

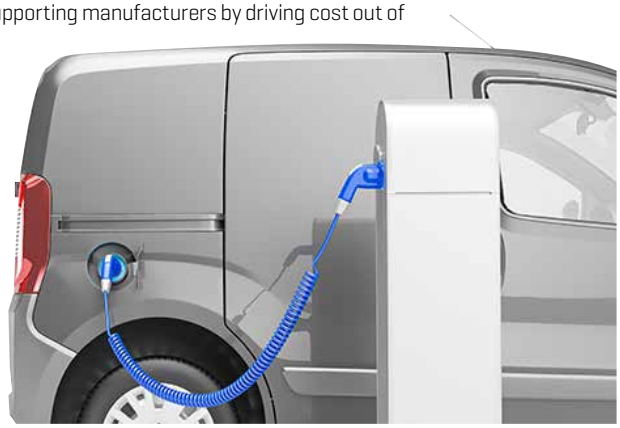
Funding has also been awarded from the Office for Zero Emission Vehicles in partnership with Innovate UK to help Ricardo develop the motor concept to a prototype level specifically for battery electric light commercial vehicles. This will assist the take-up of such vehicles by making them more efficient, cost-effective and sustainable.

The European battery electric light commercial vehicle 2.5-3.5 tonne market is currently 63,000 vehicles annually. This is forecast to grow to 282,000 vehicles in 2026 and rise to 345,000 vehicles in 2028.

"The cost of electrification is widely recognised as being the biggest barrier to wide-scale adoption of electric commercial vehicles," says Teri Hawksworth, President of Ricardo Automotive and Industrial EMEA. "Manufacturers are also concerned about supply security and the volatile costs of the rare earth metals used in most zero-emission vehicles. We are committed to supporting manufacturers by driving cost out of electrification."

In September 2021, Ricardo received UK Government funding for research to reduce the cost of future electric trucks and improve their efficiency and performance.

The cost of electrification is the biggest barrier to wide-scale adoption of electric commercial vehicles



Identifying ways to decarbonise shipping

Report finds large-scale deployment of new technologies and low-carbon fuels needed

A new evidence-based study outlines how the sector can reduce greenhouse gas emissions by at least 50 per cent by 2050 compared to 2008 levels, in order to achieve the target set by the International Maritime Organization (IMO).

The study, produced by Ricardo for the Oil and Gas Climate Initiative and Concawe, a division of the European Petroleum Refiners Association whose members operate refineries in the European Economic Area, identifies three possible pathways:

1. The early pursuit of green ammonia and hydrogen
2. Replacing fossil fuels with drop-in liquid and gaseous biofuels
3. Maximum uptake of energy efficiency technologies, carbon capture onboard vessels and the gradual increase of green ammonia and methanol.

All three pathways are reckoned to meet the IMO's decarbonisation goals when calculating greenhouse gas emissions from well-to-wake. However, when considering total costs through to 2050, the study estimated that pathway 2, while facing fewer barriers to deployment, would be more expensive than the fuel switches of pathways 1 and 3 that would require new vessel engine investments.

"This analysis shows that research investment in the short term to demonstrate the deployment of zero- and low-carbon fuels will pay off in the long term," says Tim Scarbrough, Ricardo Associate Director and one of the report's authors.

"Unlocking these zero-carbon fuel pathways will avoid higher emission pathways becoming locked in. At the same time, the deployment of energy efficiency technologies and operational measures is also vital in the short term to reduce the consumption of fossil fuels prior to that transition."

Ricardo is currently involved in two Scottish Islands projects centred on decarbonising maritime activities. The company is part of a consortium undertaking the ambitious Hydrogen in an Integrated Maritime Energy Transition project focused on ferry services in Orkney; and the £500,000 NEPTUNE project, funded by the Department for Transport, to support the transition to zero-carbon fuels for the Shetland Islands' marine sector.

A VIEW FROM

Why urban mobility must focus on more than connectivity and speed

Jenny Roe, Director, Centre for Design & Health, University of Virginia

Jenny Roe and Layla McCay are the authors of 'Restorative Cities: Urban Design for Mental Health and Wellbeing' (published by Bloomsbury Visual Arts, 2021). Jenny and Andrew Mondschein are the authors of the forthcoming 'Restorative Streets: A Conceptual Framework for Capturing – and Measuring – the Impact of Urban Streetscapes on Walkability and Mental Health', in *Mobility Design*.

Our travel choices are motivated not just by the convenience, speed or affordability of getting from A to B, but by the experience and the associated impact on our mental wellbeing.

Alongside the practical attributes of urban environments, the affective dimensions of space – how relaxing or stressful or safe a place feels, how curious (or fascinating) it is in engaging our senses, together with the associated issues of air quality and noise – have a direct impact on our travel behaviours. Our emotional connection to space can shape our health outcomes just as much as, if not more than, the distance (or number of steps) travelled.

Transportation policy in recent years has moved towards a focus on active living and enhanced walkability and cyclability in cities. As a result, the dominant urban design approach favours increasing walking and cycling opportunities through traffic calming measures and 'comfortable' street design – multi-modal streets with safe, attractive and convenient travel by foot, bike and public transit alongside motorised vehicles.

> **THE TRULY RESTORATIVE CITY MUST ADVOCATE FOR TRANSPORTATION SYSTEMS THAT ENABLE ACCESSIBILITY, CONNECTION AND PHYSICAL ACTIVITY**

Success is typically measured using metrics that quantify distance travelled, frequency of trips and before-and-after pedestrian and cyclist volumes. But the experience of travel – how daily life shapes mobility – goes beyond these metrics. The experiential component of travel – the role of street aesthetics, engagement with one's surroundings, sensory stimuli or mood of the street, the ad-hoc social interactions we have – has been neglected. These factors are all associated with psychological wellbeing, a reduction in perceived levels of stress and depression, and increased social wellbeing of a community.

Imagining the city of 2050 means learning how to address the challenges of mass urbanisation. Given mass transit is an essential feature of all cities, a key requirement is to engage with urban communities in developing an understanding of their mobility needs alongside their mental and social health requirements.

In the book 'Restorative Cities', we offer seven pillars that we believe are fundamental to what we term 'restorative urbanism': the green city, blue city (exposure to urban water settings), sensory city, neighbourly city, active city, playable city and inclusive city. Mobility is pivotal to all these pillars.

As we emerge from the trauma of COVID-19 and face, as a society, a tsunami of mental health issues, I'm not claiming that the design of our urban environment can take away the impact of the pandemic on people's mental health. However, many cities saw the benefits of temporary measures, such as setting out restaurant tables and bringing humanity back into previously traffic-clogged highways. There is growing public demand for these measures to be retained and made permanent.

The truly restorative city must advocate for transportation systems that enable accessibility, connection and physical activity. Public transit must not only be affordable, frequent, safe and comfortable, it must also be equitable and consider the needs of the whole population rather than prioritising a target group, such as those who work 'standard' hours. The changes to working patterns due to the pandemic may help to accelerate this approach.

Crucially, a restorative city needs to be built on public engagement. A forward-thinking example is the mobility hub created by design and engineering consultancy CALLUM as part of the West Midlands' Future Transport Zone programme [see *RQ* Winter 2021-22 issue]. Such hubs give communities a kit of micro-mobility solutions to construct according to local need, with each component adding a sense of presence, importance and purpose.

Overcrowding, air and noise pollution, long commutes and lack of daylight all take their toll on the daily lives of city dwellers. Alternative-fuel buses, traffic calming measures, low-emission zones and cycle lanes are, of course, important tools for change – but only if they are contextualised by an approach to urban design that places mental health and wellbeing at its heart.

THE BIG PICTURE

Tomatin, Scotland

Raising a glass

The calendar now seems to be full of international celebratory days for everything from doughnuts to hippos. However, there is one such day we are always happy to raise a glass to: World Whisky Day.

A wee dram in front of a roaring fire is one of life's little pleasures. You can enjoy it while celebrating the tenth anniversary of World Whisky Day on 21 May.

What will make the drink renowned as 'liquid gold' taste even better is knowing that the Scotch Whisky industry is making great strides to becoming a net-zero sector.

It is almost two years since the Scotch Whisky Association (SWA), the trade organisation that promotes and protects the industry, published a report by Ricardo exploring the practical ways that the industry can achieve net zero carbon emissions.

Drawing on data from more than 120 sites across Scotland, Ricardo's recommendations included decarbonising current fossil-fuelled distillation processes, with an emphasis on improving energy efficiency and the adoption of cutting-edge hydrogen technology.

> "THE LONG-TERM GOAL IS TO CREATE A PLAN OF ACTION THAT WILL HELP TOMATIN MOVE CLOSER TO NET ZERO"

Figures released by the SWA last year showed its producers have collectively reduced their greenhouse gas emissions by 53 per cent since the 2008 base year, putting it well on course to hit its 2040 net-zero goal.

Ricardo is continuing to help in that ambition by working with the 125-year-old Tomatin Distillery, which produces multi-award-winning single malt Highland whisky in a village about 40 kilometres south of Inverness.

Specialist consultants are calculating the business's carbon footprint to help it understand the emissions created by everyday operations. The long-term goal is to use this carbon footprint to create a plan of action that will help Tomatin move closer to net zero.

"With our commitment to net-zero carbon being vitally important to us," says Graham Eunson, Tomatin Distillery Operations Director, "we were aware that we required some external resource to help us in achieving this aim. The Scotch Whisky industry has a strong history of collaboration and having been part of the work carried out at association level along with Ricardo, it made perfect sense for us to utilise their expertise at company level too.

"There will undoubtedly be challenges ahead but we're confident that with Ricardo's assistance we will make large inroads towards meeting our final targets."

Reflecting on the industry's long history, Sam Williams, Ricardo Business Development Manager, adds: "The beginnings of Scotch Whisky can be traced back more than 500 years and it has an exciting history of smuggling, illicit stills and tax evasion.

"Now it is writing a new chapter with its ambition to become a net-zero industry. It's an ambition that deserves to be celebrated." *Sláinte!*

The prom

Agriculture, forestry and land use accounts for 18 per cent of global greenhouse gas emissions. It's an irony that a sector striving to feed the world more effectively is, by doing so, contributing to its environmental challenges. However, agriculture also has a key role to play in tackling climate change. Over the following pages, *RQ* explores some of our planet's most pressing issues and the technologies being developed to help solve them.

AIMING FOR CLIMATE-SMART AGRICULTURE

The world's population is growing by more than one per cent per year. That's 83 million more people to feed, at a time when the Food and Agriculture Organization of the United Nations reports that nearly one in ten people in the world are exposed to severe levels of food insecurity and nearly 690 million are hungry.

The soils, water and biodiversity of our planet are under extreme strain. Ocean health is declining. According to the World Bank, these challenges are intensified by agriculture's vulnerability to climate change including the impact of increasing temperatures, invasive plants and pests and extreme weather events. The geographical impact of such changes is unevenly distributed. Countries in the southern hemisphere are not the main originators of climate change yet suffer the greatest share of the damage.

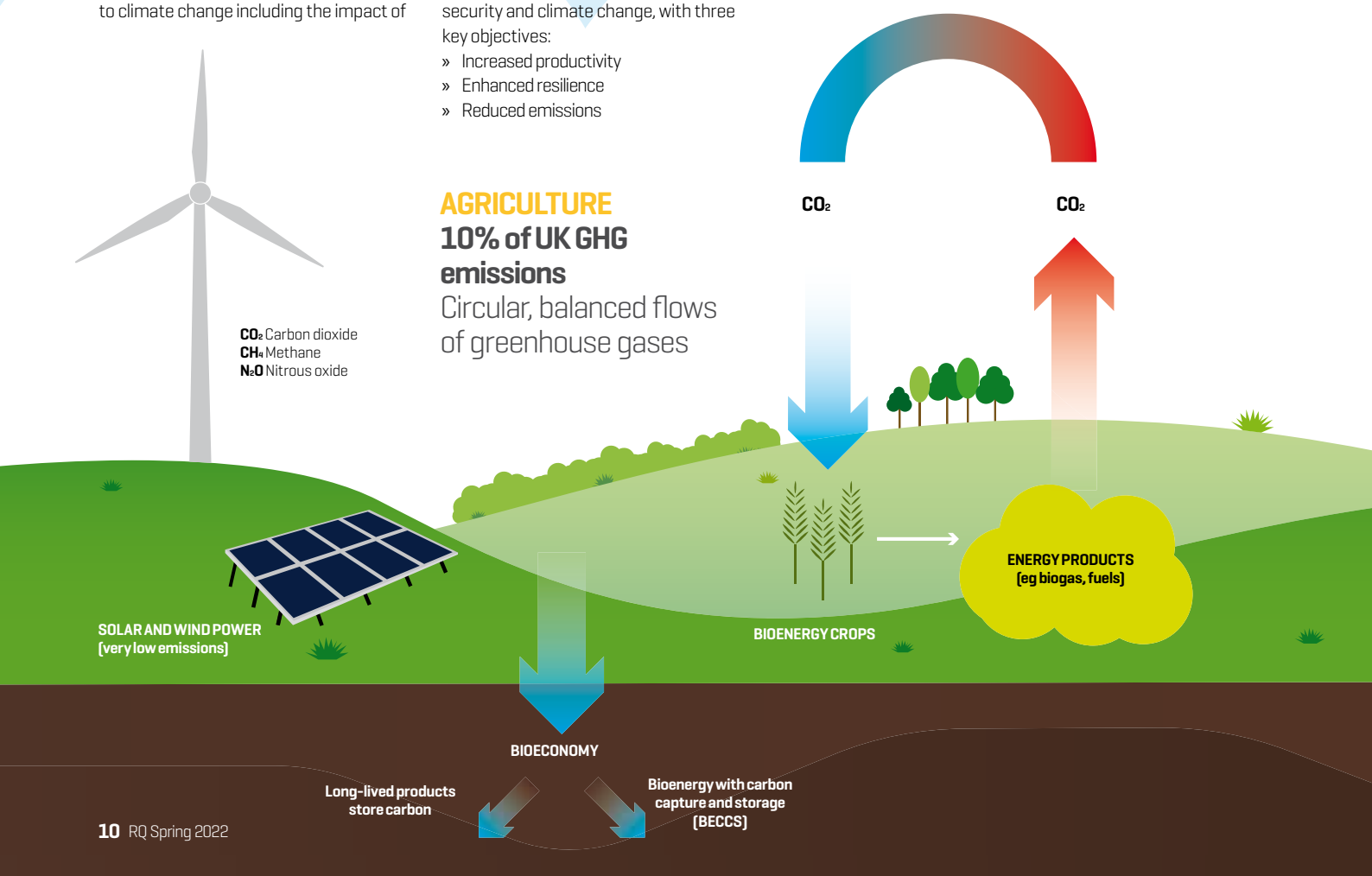
The concept of 'climate-smart agriculture' encompasses crop and livestock production, forest management and fisheries. It is defined by the World Bank as an integrative approach to address the interlinked challenges of food security and climate change, with three key objectives:

- Increased productivity
- Enhanced resilience
- Reduced emissions

Agriculture and the land-based economy is uniquely placed to capture CO_2 from the air and turn it into a wide range of foods, fibres and fuels while balancing emissions of methane and nitrous oxide from food production

Achieving this 'triple win' was at the heart of the World Bank's first Climate Change Action Plan from 2016–2020 as well as its update covering 2021–2025. Two years ago, 52 percent of World Bank financing in agriculture targeted climate adaption and mitigation.

These actions are helping countries implement their Nationally Determined Contributions at the heart of the Paris Agreement in the agriculture sector as well as contributing to progress on Sustainable Development Goals for climate action, poverty and the eradication of hunger.



nised land

AUDITING FOR EFFICIENCY

The National Farmers' Union (NFU) has set the goal of reaching net zero GHG emissions across the whole of agriculture in England and Wales by 2040. This is the sector's contribution towards the UK's ambition of net zero by 2050.

There's no single answer to this problem, says Dave Freeman, Business Area Manager for the Agriculture team at Ricardo Energy & Environment. This is largely because the emissions from UK farms – currently 46.3 million tonnes of carbon dioxide (CO_2) equivalent a year, or one-tenth of UK greenhouse gas (GHG) emissions[1] – come from multiple sources and are produced within a complex biological system.

"Unlike the rest of the economy," Freeman explains, "only around 12 per cent of agricultural GHGs are from CO_2 created by energy use, specifically combustion. On a farm, this might be using mobile and stationary machinery such as tractors or during storage.

"There are two other principal contributors to agricultural GHG emissions. Methane (CH_4) accounts for 56 per cent of farming's emissions and comes from enteric fermentation in ruminant animals – belching and farting, essentially – and from manures as they break down. The remaining 31 per cent is nitrous oxide (N_2O) emanating from soil as inorganic fertiliser breaks down.[2]

"These latter two are particularly important due to their global warming potential. Emissions reporting standardises the impact of each gas on its climate warming potential, using CO_2 as the standard unit. If one unit of CO_2 causes one unit of warming, one unit of CH_4 causes 25 to 28 times the impact while one unit of N_2O drives between 265 and 298 times more warming than a unit of CO_2."

The starting point for a farm seeking to reduce emissions, says Freeman, is a carbon audit: "This helps to pinpoint where the emissions come from and the opportunities for their removal. While the sector is certainly a significant emitter of GHGs, it also has the potential to help mitigate climate change by acting as a carbon sink, drawing down CO_2 from the atmosphere and locking it up into soil and vegetation."

On the one hand, this means helping farmers improve productivity to obtain the same amount of food, or more, with fewer inputs and lower carbon emissions. On the other, it means increasing the amount of carbon being sequestered in soils and plants by making land use changes such as tree and hedgerow planting and peatland restoration.

"There's plenty of evidence," adds Freeman, "that taking steps to reduce emissions is also a good way for farmers to improve their business efficiency. Farms with a low carbon footprint are generally the most efficient because they are getting more from what they put in. Many of the steps to reduce emissions will result in lower costs, improved profitability and greater resilience to change.

"A carbon audit is more than just a tool to assess a farm's environmental performance – it's an audit of a farm's overall efficiency in using resources."

[1] gov.uk/government/statistics/agri-climate-report-2021/agri-climate-report-2021#section-1-uk-agriculture-estimated-greenhouse-gas-emissions
[2] gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2018

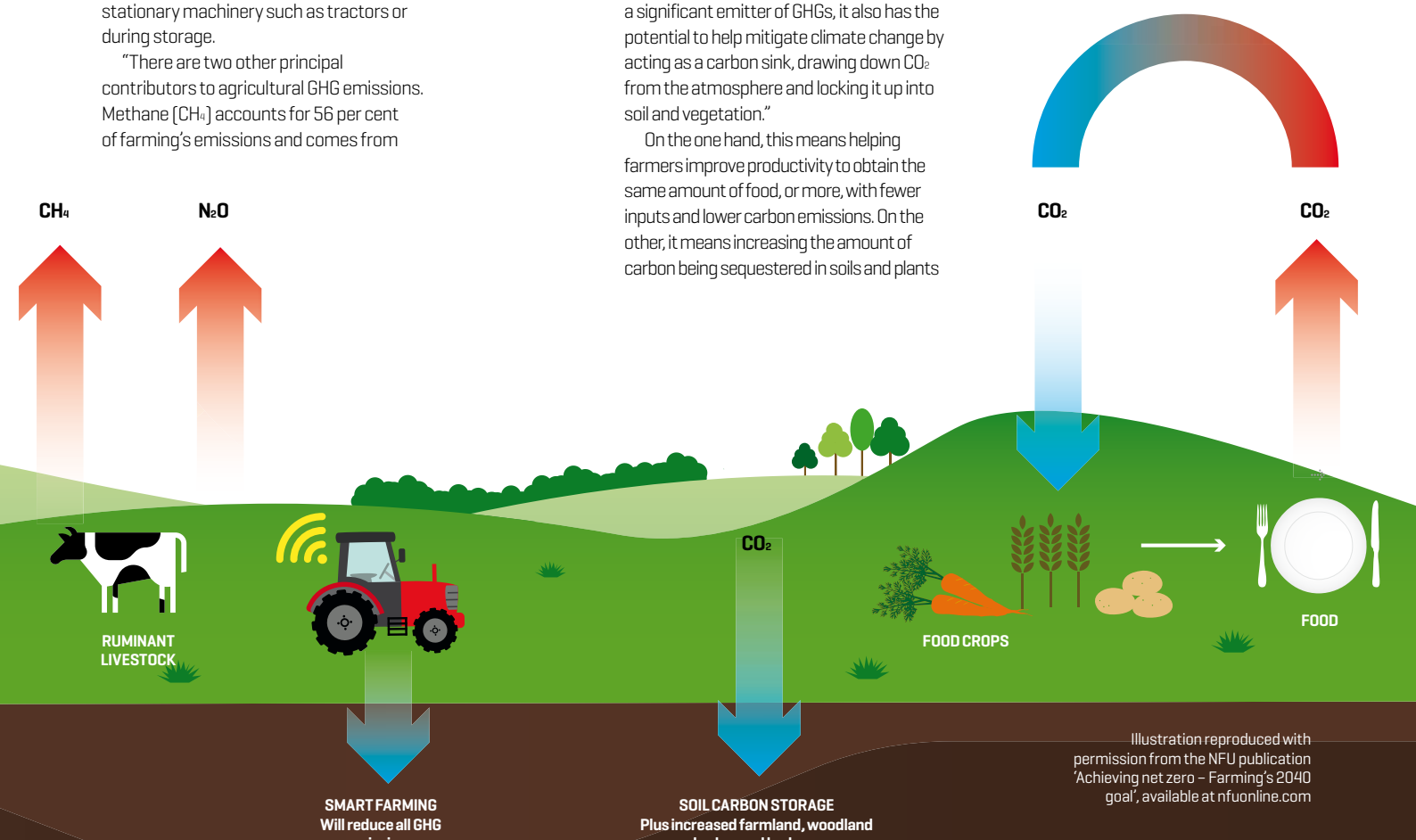


Illustration reproduced with permission from the NFU publication 'Achieving net zero – Farming's 2040 goal', available at nfuonline.com

SUPPORTING POST-EU TRANSITION

Britain's departure from the European Union means the UK is no longer bound by the Common Agricultural Policy. In 2021 the Government set out plans for England to begin a seven-year transition to a new system that will reward farmers for environmental improvements alongside food production on their land.

This change, coupled with the challenges caused by COVID-19 and a number of extreme weather events, has left many farmers and land managers under stress and needing to adapt their business models. In response, the Department for Environment, Food and Rural Affairs (Defra) set up a Future Farming Resilience Fund to provide information, tools and advice during this period of change.

Ricardo was one of 19 organisations appointed by Defra to support the sector through a pilot project offering one-to-one reviews with a farm business adviser, webinars and an online resource toolbox.

"We have so far supported more than 220 farm business reviews," says Dave Freeman, "covering the risks, opportunities and implications of future changes in terms of agricultural policy and market conditions, together with guidance on financial and business planning.

"Our approach has evolved, however, from just the technical aspects of farm management to include a focus on the impact of uncertainty on farmers' wellbeing. We have been working with a charity, the Farming Community Network, to help farmers and their families recognise and address the signs of stress. For many, stress and uncertainty are barriers to taking positive actions such as introducing more sustainable farming practices."

PLANNING TO REDUCE EMISSIONS

A study conducted by Ricardo on behalf of Kellogg's[1] found that up to a 60 per cent reduction in net emissions is possible by focusing on a farm's most productive areas, with no impact on yield or financial performance.

Four options were modelled on a 550-hectare arable farm in Bedfordshire:

- Altering nitrogen management: reducing applications by 25 kilograms per hectare across the farm.
- Expanding uncultivated margins: using agri-environmental options on marginal land to increase biodiversity and bringing in two-year grass/legume rotations across whole fields.
- Introducing 'silvo pasture': planting trees in grassland using species such as cherry and walnut.
- Boosting renewable energy generation: increasing the number of photovoltaic solar panels and installing a biomass heating system.

While the last two options would require some upfront investment, all were being considered for this particular farm as steps towards achieving net zero. Results showed that it would be possible to reduce emissions through any or all of them.

[1] wi.co.uk/arable/kelloggs-study-shows-how-arable-farms-can-aim-for-net-zero

RICARDO ON THE FARM

Ricardo provides a range of agricultural support services including:

- **Natural resource management to protect soil and water quality**
- **Nutrient use efficiency and soil science to develop sustainable agricultural systems**
- **Emissions monitoring, impact assessment and mitigation to provide low-carbon solutions**
- **Supply chain support to deliver greater sustainability throughout the food industry**

To find out more visit: ee.ricardo.com/environment/agricultural-services

'WE'RE ALL FAMILIAR WITH FITBITS FOR HUMANS; NOW THERE ARE FITBITS FOR COWS'

FARMING WITH PRECISION

"Much of our work to reduce greenhouse gas emissions," says Dave Freeman of Ricardo, "is based on understanding the technologies that can facilitate these reductions. Satellite and drone technologies, for example, enable farmers to be more specific and targeted with inputs such as fertilisers.

"Precision agriculture is most often associated with arable farming but significant opportunities lie within precision livestock farming (PLF). PLF draws upon a set of of electronic technologies, including cameras, sensors and feed additives, to allow automated monitoring of animals to improve their productivity, health, welfare and environmental impact. We're all familiar with Fitbits for humans; now there are Fitbits for cows!"

WASTE TO ENERGY FROM CO_2

Carbon capture, utilisation and storage (CCUS) is a key technology in the quest for net zero. **Naser Odeh** and **Josh Dalby** tell *RQ* how biochar, a by-product of some biomass pyrolysis, can help improve the quality and sustainability of the food on our plates.

RQ: What exactly is CCUS?

Naser Odeh: CCUS refers to a combination of technologies where carbon dioxide (CO_2) is first removed from the flue gases of power generation and industrial processes or directly from the atmosphere.

It's then either utilised in other processes onsite or compressed and transported by dedicated pipeline, by road or by ship to a location where it can be used in industry (known as carbon capture and utilisation, CCU) or injected for permanent storage in oil and gas fields or geological saline aquifers (carbon capture with permanent storage, CCS).

The various elements of the CCS chain (CO_2 capture, transport and storage) are well-established and have been successfully demonstrated in industry for decades – but individually. For example, CO_2 removal is an essential process in natural gas sweetening and in the chemical sectors for the production of hydrogen and ammonia. Also, CO_2 injection for enhanced oil recovery is a well-established process in the oil and gas industry.

On the utilisation side, CO_2 is used in the food and drink and pharmaceutical industries, for urea manufacturing, in greenhouses and much more. Also, a wide range of emerging applications are being developed – some of which are intended for permanent storage of the carbon, such as concrete curing and aggregates, while others such as synthetic fuels and e-kerosene are aimed at displacing fossil-based fuels.

The combination of CO_2 removal from the atmosphere (known as direct air capture, DAC) or from the biomass process (for example, combustion or gasification) with carbon capture and permanent storage (BECCS) has the potential of achieving negative emissions – which, according to the Climate Change Committee's sixth Carbon Budget, are essential if the UK is to meet net zero by 2050.

Such methods are known as greenhouse gas removal (GGR) technologies, which also include carbon capture via biochar from biomass pyrolysis as well as nature-based methods such as afforestation.

RQ: Why does CCUS offer such great potential in helping to meet net zero?

NO: The pathways to limit global warming to well below 2°C and preferably to 1.5°C compared to pre-industrial levels all include

CCUS. There are hard-to-abate sectors where CCUS provides the only decarbonisation route or the most economically viable solution. CO_2 removal from the atmosphere through DAC combined with permanent storage of the CO_2 is seen as necessary to balance residual greenhouse gas emissions in 2050 from the agricultural and construction industries.

In addition, modelling by the Intergovernmental Panel on Climate Change clearly shows that BECCS is necessary for temperature rise to be limited to 1.5°C. This highlights the important role that CCUS in general and greenhouse gas removal technologies such as DAC and BECCS can play and why demonstration programmes need to be established and accelerated through the 2020s.

RQ: Ricardo is leading a consortium that is designing a community-scale greenhouse gas removal system that produces biochar as one of its outputs. How can projects like this play a significant role in cutting emissions?
NO: Large-scale DAC and BECCS demonstrations are currently in planning in the UK and across the world. There is also a need to start thinking about small-scale decentralised GGR systems. Ricardo is collaborating with Bluebox Energy to make this a reality.

Bluebox Energy has been developing ultra-low carbon combined heat and power (cogeneration) solutions for business parks, communities, industrial and farming processes since 2014. We've been collaborating with Bluebox since June 2020 to develop a GGR cogeneration system which removes carbon dioxide through two different mechanisms, first through capturing almost half of the carbon in the biochar produced from biomass pyrolysis and also capturing the majority of the remaining carbon in the flue gas via a BECCS system.

Both biochar and BECCS are recognised as GGR technologies and so this solution has the potential to deliver significant negative emissions.

Locating such systems in the vicinity of the biofuel, which can either be waste wood resulting from forestry or another sustainable biomass source, significantly reduces life cycle emissions and improves the case for negative emissions.

What's more, the carbon dioxide can be collected from site and distributed for various applications in industry, so the deployment of such community-scale systems provides significant flexibility and eliminates reliance on complex and expensive CO_2 transport and storage infrastructure.

The Ricardo-Bluebox consortium has finalised the design of this biomass pyrolysis-based cogeneration system with funding from the Department for Business, Energy and Industrial Strategy. We are now in the process of securing additional funding to build a system prototype and demonstrate its performance.

RQ: How does this community-scale GGR system work?
Josh Dalby: The technology uses sustainably sourced waste wood from timber production. Pyrolysis turns this biomass feedstock into biochar and syngas. Recent studies show that the carbon trapped in biochar can potentially stay for hundreds to thousands of years.

The hydrogen-rich syngas is burnt in a combustor, supplying heat to drive the hot air turbine. The turbine generates electricity and large amounts of clean hot air which is used to

"SUSTAINABLE AGRICULTURAL PRODUCTION, SOIL CARBON MANAGEMENT AND CLIMATE CHANGE MITIGATION ARE INEXTRICABLY LINKED" JOSH DALBY, RICARDO

TERMS OF ENGAGEMENT

AFFORESTATION: planting new forests across land without trees. As a forest grows, it naturally removes CO_2 from the atmosphere and stores it in its trees.
BECCS: bioenergy with carbon capture and storage, a greenhouse or carbon dioxide removal technology which applies carbon capture technology to biomass-based energy production in order to capture CO_2 and store it.
BIOCHAR: a black, carbon-rich material similar to charcoal made by burning biomass using pyrolysis.
BIOMASS: organic material used as fuel to produce heat or electricity.
PYROLYSIS: a controlled process by which a high temperature is used to decompose organic materials in the absence of oxygen.
SYNGAS: short for 'synthesis gas': a mixture of carbon monoxide, carbon dioxide and hydrogen. A bi-product of the pyrolysis process.

power the advanced CO_2 capture system.

What makes our solution unique is its ability to generate enough energy from its renewable and dependable biomass fuel source to be energy positive and capture so much CO_2. This means that as well as the removal of the CO_2 from the flue gas and its capture and storage as a commercial product, the technology will also supply local homes and businesses with renewable heat and electricity.

RQ: What can the biochar be used for?
JD: There are several existing and emerging applications for biochar. It can be used by farmers, anaerobic digester operators and wastewater treatment sites.

Soils rich in carbon have greater physical and chemical properties for supporting plant growth. Over time, however, as a result of both natural processes and cultivation, these soil carbon pools become depleted. Adding biochar is a way to sustain the soil carbon pools and maintain productivity.

The biochar creates a layer in the soil which acts in a similar way to a domestic charcoal water filter. It holds chemicals and nutrients and prevents them leaching through to deeper levels and watercourses while improving their availability to plants. At the same time it provides an environment for microscopic organisms, bringing further improvements in soil health. This means it is much in demand in organic farming.

More productive soils also lead to greater production of biomass which, in turn, means a greater amount of CO_2 being sequestered from the atmosphere. In this way, sustainable agricultural production, soil carbon management and climate change mitigation are inextricably linked.

As well as improving the fertility of soil, biochar is also used as a supplement to animal feed in livestock farming as it supresses methane emissions generated in the digestive process. This means that in regions such as Europe and North America, where meat consumption is still high, the demand for biochar is likely to continue to increase substantially.

Analysts have predicted that the global biochar market could reach $3.1 billion by 2025 and expand at a compound annual growth rate of around 14 per cent in the next decade.

RQ: You mentioned that the system runs on waste wood. Where is that sourced from?
JD: This is one of the key strengths of our technology. Many existing biomass systems are powered by wood pellets, which require additional processing steps before they are suitable for use. These wood pellets are typically sourced from sustainable forestry operations with most UK distributors sourcing from either within the country or from abroad.

A key factor in ensuring the maximum amount of carbon capture is to minimise the life cycle or upstream emissions associated with the production and delivery of the feedstock. Because our technology can use unprocessed waste wood, it opens up opportunities for local sourcing. As well as sustainable forestry operations, nearby sawmills and furniture factories could provide enough woodchip to be suitable for our system. Community-scale systems such as this can be located near the biomass source, thus reducing life cycle impacts and upstream emissions.

Negative emissions technologies can generate revenue streams for industry and local communities

RQ: When might we see this technology deployed?
JD: We have identified a site for our first demonstrator plant and our ambition is to have it running in mid-2023.

Then, by focusing on smaller community-scale applications, we can deploy quickly and widely. We can operate close to the source of waste, minimising GHG emissions related to the transportation of the raw materials. And each community can benefit from the by-products.

RQ: Could the UK be at the forefront of community-scale carbon capture technology on a global stage?
NO: In terms of GGR technologies, the focus worldwide is currently on deployment on large stationary stations including power plants and industrial sites.

We propose that deployment on community-scale systems also has a key role to play in CO_2 removal from the atmosphere, thus helping achieve net zero targets while also developing the CO_2 and biochar markets and providing communities with heat and electricity.

However, such community-scale systems are still expensive and so support is needed in the early stages to reduce costs, overcome the technical challenges and develop the supply chain. This will help the UK become a leader in a technology that can be exported worldwide, with the significant emission savings making an important contribution to net zero targets. RQ

Naser Odeh is Ricardo's Associate Director in CHP & Heat, CCUS and Biofuels. Josh Dalby is Ricardo's Chief Engineer in R&D.
To find out more about Ricardo's CCUS work visit: ee.ricardo.com/energy/carbon-capture-utilisation-and-storage

CREATING CHAINS OF VALUE

01 SCOPE FOR IMPROVEMENT

Scope 3 emissions are the indirect greenhouse gas emissions in an organisation's value chain. *RQ* learns that, for Ricardo, targeting these emissions is not just about supporting the global drive towards a low-carbon future but helping companies position themselves as sustainability leaders.

In the late 1990s, the World Resources Institute and the World Business Council for Sustainable Development called for an international standard for greenhouse gas (GHG) accounting and reporting. What emerged was the GHG Protocol which, since 2001, has provided global standards and tools to help organisations measure and manage climate-warming emissions throughout their value chains.

The GHG Protocol groups emissions into three 'Scopes':

» **Scope 1** covers direct emissions from owned or controlled sources
» **Scope 2** addresses indirect emissions from the generation of purchased electricity, steam, heating and cooling consumed by the reporting company
» **Scope 3** includes all other indirect emissions that occur in a company's value chain

"Forward-thinking organisations are seeking to decarbonise their own emissions plus those in their supply and value chains to deliver greater environmental benefit," explains Ian Behling, Ricardo's Associate Director for Sustainability Services. "That's why Scope 3 emissions are becoming an increasingly important part of net zero strategies. Including them will accelerate decarbonisation across a much wider set of activities.

"This holistic approach to emissions reduction – that is, taking responsibility for managing your own emissions and encouraging others to do likewise – moves away from leaving decarbonisation to 'them' and makes it about 'us'."

UNDERSTANDING SCOPE 3

Scope 3 has 15 categories, covering upstream activities including purchased goods and services and logistics, and downstream inputs such as distribution and end-of-life processing. "In other words," says Oli Lockhart, Ricardo's Senior Consultant for Carbon Management and Net Zero, "the GHG emissions across your entire value chain, outside your own operations and therefore outside your direct control.

"These are almost certainly the vast majority of total emissions. In fact, for the clients we've been working with over the last year, their Scope 3 emissions on average made up 93 per cent of their total footprint. Many businesses focus solely on Scopes 1 and 2, which means they are only tackling a small percentage of their emissions. Ignoring the emissions in their value chain means they will never get a grip on their true carbon footprint."

Lockhart believes that tackling Scope 3 emissions "positions a business as a sustainability champion. Measuring and targeting Scope 3 emissions is all about recognising the bigger picture and understanding that impacts and influence extend beyond a company's own operations. This makes Scope 3 action a great opportunity for a company to show environmental leadership by bringing suppliers and customers along on its sustainability journey.

"As well as being seen to be proactive so potential customers, investors and employees know if a business is setting ambitious targets or just doing the minimum, Scope 3 action will also help improve supply chain engagement and identify both key resource risks and long-term cost reductions."

A further reason for focusing on Scope 3 is legislative. Currently, reporting Scope 3 emissions is largely voluntary. However, there are indications that this is beginning to change. The Task Force on Climate-Related Financial Disclosures (TCFD), which consists of 32 members from across G20 countries representing both preparers and users of financial disclosures – has recommended mandatory environmental impact reporting for all premium listed organisations, including some Scope 3 emissions reporting.

Lockhart also comments that one of the proposed policies to emerge from last year's COP 26 UN Climate Change Conference is that by 2023 most large UK organisations must demonstrate how they intend to meet net zero, including reporting and tackling some of their Scope 3 emissions.

> "SCOPE 3 ANALYSIS IS A GREAT OPPORTUNITY FOR A COMPANY TO SHOW ENVIRONMENTAL LEADERSHIP BY BRINGING SUPPLIERS AND CUSTOMERS ALONG ON ITS SUSTAINABILITY JOURNEY" **OLI LOCKHART, RICARDO**

STARTING THE SCOPE 3 JOURNEY

"Many organisations find tackling Scope 3 emissions daunting, particularly around supply chain engagement and data collection," says Fern Spencer, Ricardo's Net Zero and Carbon Management Consultant, who helps businesses develop net zero roadmaps.

"Data collection from a value chain is difficult because value chains are complex. This is essentially the crux of the challenge. Perfect data may not be available immediately. But don't let perfect get in the way of progress. A starting point may be based largely on estimates, which will still enable a business to identify areas of the value chain with the highest carbon impact, known as 'hotspots'; to understand where data gaps exist; and to identify which suppliers to engage with early.

"As more data becomes available, a business can start to make better informed decisions not just about emission reductions but about supply chain resource risk and future procurement decisions to favour low-carbon products or services. At Ricardo we help to target the hotspots using our expertise in life cycle assessment [see overleaf] and sustainable procurement.

"For example, a project we recently worked on with the High Value Manufacturing Catapult, a group of UK manufacturing research centres, identified an opportunity to reduce the emissions associated with the manufacture and distribution of turbine blades by 38 per cent, by moving the production from South Asia to Northern Europe and sourcing more recycled materials. These are the sort of actionable insights that taking a life cycle assessment-based approach can offer."

> "PERFECT DATA MAY NOT BE AVAILABLE IMMEDIATELY. BUT DON'T LET PERFECT GET IN THE WAY OF PROGRESS" **FERN SPENCER, RICARDO**

WHOSE CARBON IS IT?

"We work on the principle that if the Scope 3 emissions are important to your stakeholders, they should be important for you to include in your net zero commitments," says Ian Behling.

"First should be a focus on the areas where use of resources can be reduced, so emissions in the supply chain likewise reduce. Business travel, which is one of the 15 Scope 3 categories, is significant here. One good thing to emerge from the disruption caused by COVID-19 is that we are all now more able to deliver our business without needing to jump on a plane, train or in a car for every meeting. Emissions from travel partners will reduce as a result.

"Because the areas of biggest impact in a supply and value chain will vary by organisation, sector, location and many other factors, this may mean looking at the lifecycle impacts of products, using a procurement policy to demand action of others, or supporting circular economy concepts. It can also mean investing in innovation that changes the way a business does things or enables others to change what they do."

Ricardo's consultants recommend that all organisations should begin measuring their entire value chain impact so that they can make informed decisions about where to focus their sustainability efforts. "For real credibility in the eyes of stakeholders," says Behling, "the emissions that others might attribute as reasonable for you to take responsibility for should be identified.

"For example, if a lot of water is used in the production of a product or its production process, then it would be reasonable to include the emissions resulting from getting that water onto site ready for use.

"Another example might be to consider the brand value of packaging. Where packaging is part of the customer experience or a premium charge, then it would again be reasonable to include the Scope 3 emissions associated with that packaging."

Behling notes that no two cases are the same. However, he adds, "our message is consistent. Showing an awareness of the areas of highest impact, and developing plans to address them, will improve the credibility of any organisation in the eyes of all its stakeholders."

Ricardo is a leader in helping organisations build sustainability into their value chain: ee.ricardo.com/net-zero-en/scope-3-emissions

02 REVOLUTIONARY THINKING

Where should a business focus efforts to improve sustainability throughout its value chain? **Fabio Grimaldi** explains why Life Cycle Assessment is a key tool to achieve evidence-based greenhouse gas reduction.

Life Cycle Assessment (LCA) breaks down the environmental impacts of a product or service into its different life cycle stages – from the extraction of raw materials to manufacturing, transportation, use phase and end of life.

By identifying these impacts through LCA and then taking action to mitigate them, an organisation can benefit in a number of ways, including:

- Improved focus of efforts when aiming for reduced environmental impact (including but not limited to greenhouse gas (GHG) emissions) and efficient use of resources
- Facilitating a more complete and holistic communication to stakeholders of the environmental impact of products or services
- Quantifying the benefits of the circular economy, in which the emphasis is on reusing, recycling and utilising secondary materials

'OPTIMISING THE ENVIRONMENTAL PERFORMANCE OF PRODUCTS AND TECHNOLOGIES GIVES A COMPETITIVE EDGE IN THE MARKET' **FABIO GRIMALDI, RICARDO**

Every strategic plan to reduce environmental impact and GHG emissions has to address the problem of measuring impact correctly (and as completely as feasible) and to identify the activities that are mostly responsible for that impact – known as 'hotspots'.

As Oli Lockhart and Fern Spencer explain on the previous pages, organisations have so far mostly focused on their direct emissions (Scope 1 emissions, such as from fuel combustion) and those from purchased electricity, heat and steam (Scope 2). That means reducing the volume of fuels burnt, switching to less damaging fuels, decreasing energy consumed and transferring to less damaging sources such as renewables.

Attention is now turning to the often even greater amounts of greenhouse gases emitted along a product's supply and value chain, also known as Scope 3 emissions – which is where LCA has a vital role to play.

A recent poll from a Ricardo webinar on 'How to use LCA to reduce your Scope 3 emissions'[1] showed that the main drivers for tackling these embodied emissions were primarily reputation (56 per cent), followed by client pressure (33 per cent) and investor pressure (11 per cent).

Expanding the boundary

LCA is a standardised methodology (ISO 14040/44) that maps out resource use and emissions in a product's life cycle and calculates the associated potential environmental impact throughout the supply and value chain. When LCA is applied only to the production and use of fuels and electricity in transport equipment, this is commonly known as a 'well-to-wheel' approach and has historically been used widely to assess the impacts of biofuels in comparison to conventional fossil fuel alternatives.

However, with the introduction of increasing levels of electrification into transport it has become more important to expand the LCA boundary. LCA is therefore now increasingly applied in the automotive sector to consider all the inputs throughout the full vehicle cycle (including materials, manufacturing, maintenance and end-of-life treatment) as well as the complete fuel/energy cycle (often including fuel production and electricity generation equipment, and in some cases refuelling and recharging infrastructure).

Assessing wider consequences

LCA is most frequently applied to assess GHG emissions, and also often cumulative energy demand in the context of transport. However, it can assess a wider set of environmental consequences, such as acidification, resource depletion or impacts on human health. This helps to ensure that companies do not inadvertently shift the burden by improving performance against carbon while increasing their impact in areas such as the depletion of minerals or water use.

In the context of use of scarce or limited resources (be it renewable electricity, minerals, biomass or water), complementing LCA at an individual vehicle level with a system/fleet-based analysis can be particularly powerful to provide a more complete picture.

So why bother with LCA? First, making informed decisions within a product's supply chain depends on the ability to understand the effect of different choices in, for example, procurement and manufacturing. Optimising the environmental performance of products and technologies gives a competitive edge in the market and avoids costly impact mitigation measures further down the line.

Second, effective sustainability plans depend on fully understanding the impact of products and technologies and being able to make demonstrable claims about their environmental performance.

With transparent and science-based evidence, companies are far better placed to build their reputation for sustainability.

[1] bit.ly/LCAScope3

Fabio Grimaldi is Principal Life Cycle Assessment Consultant for Ricardo. Read his blog, 'Why Life Cycle Assessment is crucial for sustainable product and technology development': bit.ly/FabioGrimaldi

Bright green future

In this exclusive extract from his book, '*Lithium: the Global Race for Battery Dominance and the New Energy Revolution*', **Lukasz Bednarski** explains how looking beyond lithium-ion chemistry could be the key to turbocharging the move towards electrification.

We are at the very beginning of a groundbreaking change, where energy from renewable sources can be stored to run your car. One day, this green energy will power ocean-going vessels and let you take off for a holiday without worrying about the plane's carbon footprint. Lithium-based batteries are the last missing piece of a closed system based on renewable energy.

In order to really turbocharge the development of electric planes and vessels and alleviate anxieties about range once and for all for electric vehicle (EV) drivers, we need to move beyond lithium-ion chemistry. Moving away from lithium-ion does not necessarily mean moving away from lithium, however.

But how do you go about building a better battery? First, we need to remember that a battery is a closed system. In every closed system, if you change one component, you need to carefully consider the impact this has on the other components.

Seen from a higher level, the battery is remarkably simple. It has only three key elements: cathode, anode and electrolyte. If you want to improve aspects of its performance, such as its energy density, power, speed of charging or safety, first and foremost you will work on making elements in this trio better.

So we know that we have three elements to work on, and that, if we have to change one element, we will probably have to tweak the other two, to accommodate the changes and keep the balance within the system. But where to start improving? Do we at least know in which direction we want to go with our research and development?

From theory to practice

In order to answer that, we need to go back to basic, high-school level chemistry. We may still remember that metals are eager to lose electrons and non-metals are willing to accept them. So, if one element is losing electrons and the other is accepting them, this means that electrons are moving, and, as we remember, the movement of electrons means electricity. So, we are definitely on to something here.

Further, the process of losing and gaining electrons is called ionisation. The atom is in a neutral electric state if it has an equal number of electrons and protons. But if you put a metal and a non-metal together in a battery, ionisation occurs: the metal loses electrons and the non-metal gains them.

Atoms that are thrown out of balance and have more or fewer electrons than

protons are called ions. So the term lithium-ion battery should make more sense now. You can have negative ions and positive ions. Negative ions are those atoms which have more electrons than in their electrically neutral state, and positive ions are atoms which have fewer electrons than in their electrically neutral state. Electrons always have a negative charge, so it is easy to remember that if you add a negative electron to an atom which is in an electrically neutral state, you turn the atom into a negative ion.

With that out of the way, to build a great battery we need to consider which elements from the periodic table that are happy to shed electrons, and elements that are willing to gain electrons, to put together to achieve the best performance. This is purely a theoretical exercise, but an immensely important one, because it shows what level of battery performance can be achieved just when factoring in the basic laws of chemistry and physics.

'There is an inherent beauty in the realisation that a bunch of not too complex equations provides us with a detailed roadmap for the future'

Lukasz Bednarski

It is also a really practical one, because it demonstrates why we use lithium in the battery now, why we are interested in putting more lithium into the battery of the future, and why companies and researchers are focused on developing sulphur or sodium batteries for now, instead of other, metals-based batteries. After all, there are quite a few metals in the periodic table to choose from. But to make laptops work on a battery for days, to make EVs go further on a single charge, to be able one day to fly electric from London to Barcelona on a passenger flight, we need energy dense batteries. This is the holy grail of battery research.

Energy density is expressed as the ratio of stored energy to battery mass or battery volume. And in order to have a high energy density and low weight, we are limited to choosing metals and non-metals from the top rows of the periodic table, as this is where the elements with lighter atomic mass sit.

Making fine distinctions

We also need ions that will shuttle back and forth, storing charge, and here our choice for elements is even more limited. It is important to remember that when we speak about energy density, some elements may have a higher mass energy density and a lower volume energy density and vice versa in relation to other elements. This fine distinction matters a lot, because in the case of cars, where space is a more constraining factor than weight, it is volumetric energy density that matters. Cars are of a certain standardised size, and you want the battery to take up as little of the volume of the car's interior as possible to have space for passengers and a trunk.

On the other hand, in aeroplanes, energy density per unit of mass matters more than per unit of volume, as you want to take off into the air with the lightest battery possible. This distinction on the level of the elements in the periodic table also shows that it is difficult, if not impossible, to work on an ideal universal battery. There is no one size fits all here, and we need to look at the usefulness of different battery types toward specific applications.

So as for weight lithium does very well with a very low atomic weight of 7. For the sake of comparison, lead used in lead acid batteries to start the ignition in fuel-powered cars has an atomic weight of 207, while the element sodium, which is often mentioned in the context of batteries of the future, has an atomic weight of 23. This is still very low, which makes it a good candidate for use in batteries, but nonetheless slightly higher than lithium.

Before we go further, why do we even consider sodium for the battery of the future if it is heavier than lithium? Marginal loss on energy density perhaps does not make sodium an ideal candidate for the battery to power an aeroplane. But other factors matter here as well: sodium is much cheaper than lithium and more ubiquitous (it is an ingredient of common table salt after all), so it ticks the boxes as far as price and supply security are concerned.

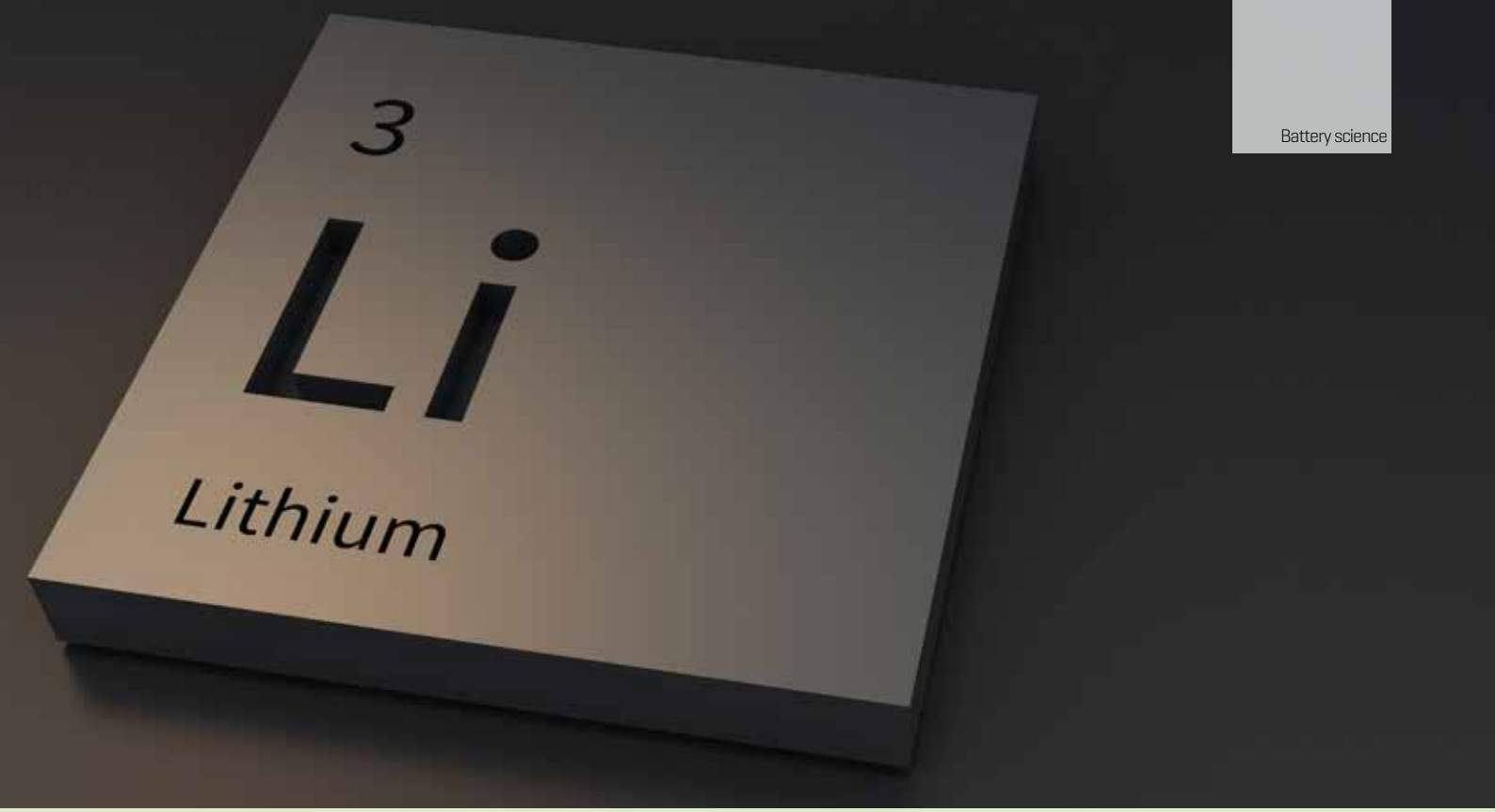
You also need elements that would generate a high voltage. Electric power equals voltage multiplied by current. Accelerating an electric car from 0 to 100 km/h necessitates a lot of electric power released in a short period of time. At present, electric cars already accelerate faster than fuelled vehicles. To check elements that, when put together, can generate a high voltage, one needs to switch from looking at the periodic table to the electrochemical potentials table. There, lithium again excels, offering a maximum of 4.5 V. If we look again at the old lead battery chemistry, lead electrochemical potential is below 2.1 V. Sodium also does very well, at a maximum of 4.2 V.

Using the Faraday constant and the molecular weight of electrochemically active materials, we can also calculate the theoretical capacities of the cell.

The capacity of the cell is the number of electric charges used throughout time that a battery can hold per unit of mass. It might be a tricky concept to grasp at first. This is because this unit of battery performance measure takes into account time, electric current and mass and encapsulates them into one number. To understand it we need to break it down.

The relation between time and electric current is such that the same amount of electric current stored in a battery will last longer or shorter depending on how much current we will draw from it per hour or other unit of time. Some electric devices will obviously draw more and some will draw less current – just think of a fridge compared with a smart watch. Now you need to take this measure of electric current per time and contrast it with the volume of mass where you can store it.

When you do this, you get theoretical values such as 3,860 mAh/g (milliamp hours per gram) for lithium, 4,200 mAh/g for silicon, 1,670 mAh/g for sulphur, or



‘We need energy dense batteries. This is the holy grail of battery research’

Lukasz Bednarski

Will the lithium sulphur battery, now under development, ever fulfil the requirements in terms of cyclability to qualify it for mass market use?

370 mAh/g for graphite. These theoretical values for capacities are very, very high. Even if we talk about graphite, which pales in comparison to lithium or sulphur, and we do not use them in full even in cutting-edge batteries. We would love to get close to theoretical capacity values – only there are many limiting factors that prohibit us from doing so.

Increasing energy density

Building a better battery, a battery of the future, is to a large extent a struggle to overcome these limiting factors.

It is a good thing that even a basic understanding of the electrochemistry guides us into directions in battery development which are worth exploring. For instance, if we know that lithium has high electrochemical potential, is light and has a very high theoretical capacity, we may want to use it to create a purely lithium-made anode replacing the graphite anode that we have now. The same goes for silicon, or for sulphur or for sodium. Fundamental chemistry and physics let us understand that these elements, due to their properties, may find a place in the battery of the future to make it more energy dense.

There is an inherent beauty in the realisation that a bunch of not too complex equations provides us with a detailed roadmap for the future. We know that with lithium sulphur batteries, using lithium metal as an anode and sulphur as a cathode, we will theoretically be able to get to 2,000 Watt-hour per kilogram (Wh/kg) energy density, and with lithium oxygen batteries to 3,000 Wh/kg density. ‘Theoretically’ means that in real life we will never have lithium sulphur batteries with 2,000 Wh/kg energy density, but if we find a way to develop and commercialise a lithium sulphur battery, we will get somewhere near this threshold.

How close, we do not know. For that matter, we do not even know if the lithium sulphur battery, which is now under development, will ever fulfil the requirements in terms of cyclability (number of charges and discharges possible before degradation) that will qualify it for mass market use. We do not know that, but a number of companies invest resources in the belief that one day it will.

Lukasz Bednarski is a battery materials analyst, founder of the lithium industry portal Lithium Today and a former commodity trader.

Excerpted from ‘Lithium: The Global Race for Battery Dominance and the New Energy Revolution’ by Lukasz Bednarski and published by C. Hurst & Co. (Publishers) Ltd. © Lukasz Bednarski, 2021. Used by permission. All rights reserved. Footnotes have been removed to ease reading.

For more information about the author and book, visit: hurstpublishers.com/book/lithium

THIS MUCH I KNOW...

TOM KAY

Consultant Mechanical Engineer, Ricardo Rail, on combining personal and professional passions

Engineering has been part of my life literally since I was a few weeks old. My grandad was one of the founders of the Keighley and Worth Valley railway preservation society in west Yorkshire, set up when the line was taken over from British Railways in 1962 and opened to passengers in 1968. It's a five-mile branch line railway running heritage steam and diesel trains through spectacular 'Brontë Country'. I was first taken along when I was still a baby in arms.

By the age of 13, I realised being smart and clean as a member of the front of house team wasn't for me. I started in the railway's youth volunteer group selling tickets and doing similar duties but a visit to the locomotive department blew me away. I knew this was my happy place. From then on, I was in overalls every weekend.

My grandad and uncle were electrical engineers, dad was a civil engineer and I've now plugged the gap by becoming a mechanical engineer. I completed my Masters degree at the University of Huddersfield then joined the Ricardo graduate scheme. The variety of work was incredible from the start: I was doing engineering design for a Class 317 unit, European Rail Traffic Management System (ERTMS) design for HST Class 43 locos and static testing for the Class 230 Viva Rail Diesel Multiple Unit, along with steam loco mainline certification and testing documentation.

The skills I've learned through volunteering have proved invaluable in my work for Ricardo. Not only in terms of practical engineering but also the ability to lead teams and drive projects forward. Around 600 people volunteer on the Keighley and Worth Valley railway, in roles from catering to getting grubby underneath an engine. I've learned how to convince volunteers to turn up at an agreed time on an agreed day and then do the job you want them to do. Some have a rail or engineering background, others bring nothing more than enthusiasm.

Tom, left, with one of the Keighley and Worth Valley steam trains

> "A VISIT TO THE LOCOMOTIVE DEPARTMENT BLEW ME AWAY. I KNEW THIS WAS MY HAPPY PLACE"

Project planning is a vital transferrable skill. Volunteers can only devote certain amounts of time and the two engines currently under overhaul may take five years to complete. You could do it in one year if there was serious money available to throw at it, but the railway is a registered charity and funds are limited.

Ricardo has a big role to play in the future of clean transportation. Last year's launch of HybridFLEX, Britain's first passenger train that can switch seamlessly between battery and diesel power, is a great example. Ricardo provided engineering support to integrate the mechanical, electrical and critical controls systems of the hybrid powerpack, showing that diesel units with plenty of serviceable life have a future as hybrids on routes that may still be some way from electrification.

I like to keep the wheels turning. Professionally, fleet engineering is where my interest lies. My next target is to become a Chartered Engineer through the Institution of Mechanical Engineering. As for the Keighley and Worth Valley railway, I recently qualified as a yard driver and hope to progress to passenger driver for both steam and diesel. You'll find me there most weekends, helping to keep the trains running for another 50 years and more. RQ

Tom appears in the Channel 4 series 'Britain's Scenic Railways', available for UK viewers to view at: bit.ly/TomKayRicardo

E-bike racing

POWER TO THE PEDAL

Ricardo has become the sustainability partner for an innovative addition to the global cycling calendar – the E-Bike Grand Prix. **Andrew Shields** dons his lycra and helmet to find out more

E-bike racing is making moves in two-wheeled sport. More and more high-profile competitions now include events for electric cycles; indeed, official world championships in mountain bike and cross-country were launched back in 2019.

Later this year, e-bike racing moves to the road – and squarely into the spotlight. Eighty world-class male and female riders will take part in the E-Bike Grand Prix (EBK GP), a series of ten spectacular one-hour city-centre races in iconic locations.

The United Arab Emirates and South Korea have already been confirmed as host countries for rounds of the EBK GP, which will be staged on public roads temporarily adapted to create exciting racing, with each event free of charge for spectators. South Korea's status as one of the world's leading battery manufacturers with a rapidly growing electric vehicle market makes it a natural fit.

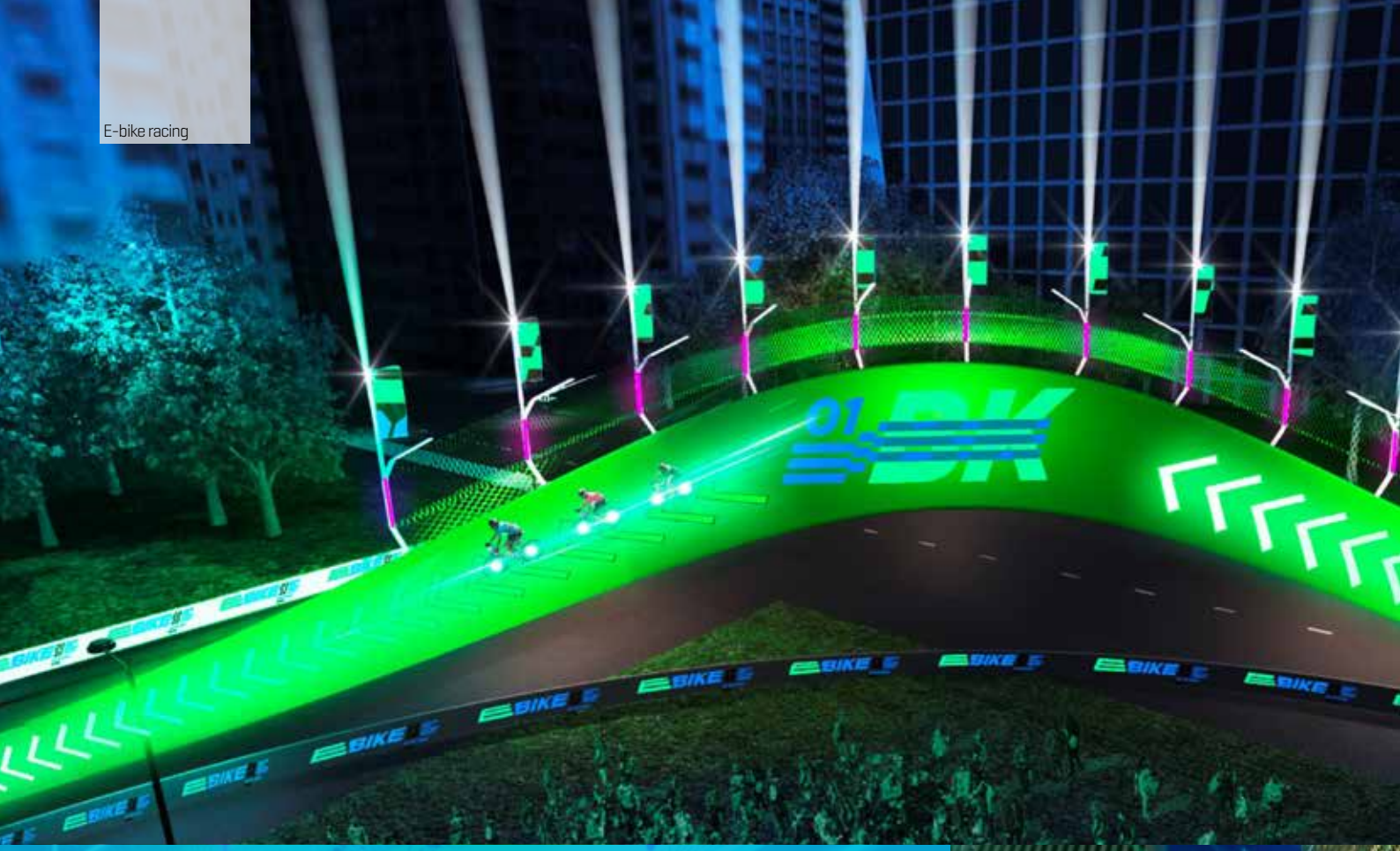
MORE THAN JUST A BIKE RACE

The EBK GP is, however, about more than just elite bike racing. The series is designed to showcase emerging e-bike technology while assisting each host to raise awareness of climate change challenges, mobilising its citizens around environmental issues and promoting cleaner, greener, healthier cities. The evidence for widespread adoption of e-bikes is clear: if used to replace car travel, e-bikes could cut carbon dioxide emissions in England alone by up to 50 per cent, equating to 30 million tonnes less CO_2 per year.

To help achieve these aims, Ricardo has joined the EBK GP as its sustainability partner. Alongside each five-day event, the host city will deliver a tailored three-year Sustainable & Transformative Mobility (STM) programme. This will be designed to trial new sustainable technology innovations and bring about lifestyle and behaviour changes that will reduce greenhouse gas

continued on p25

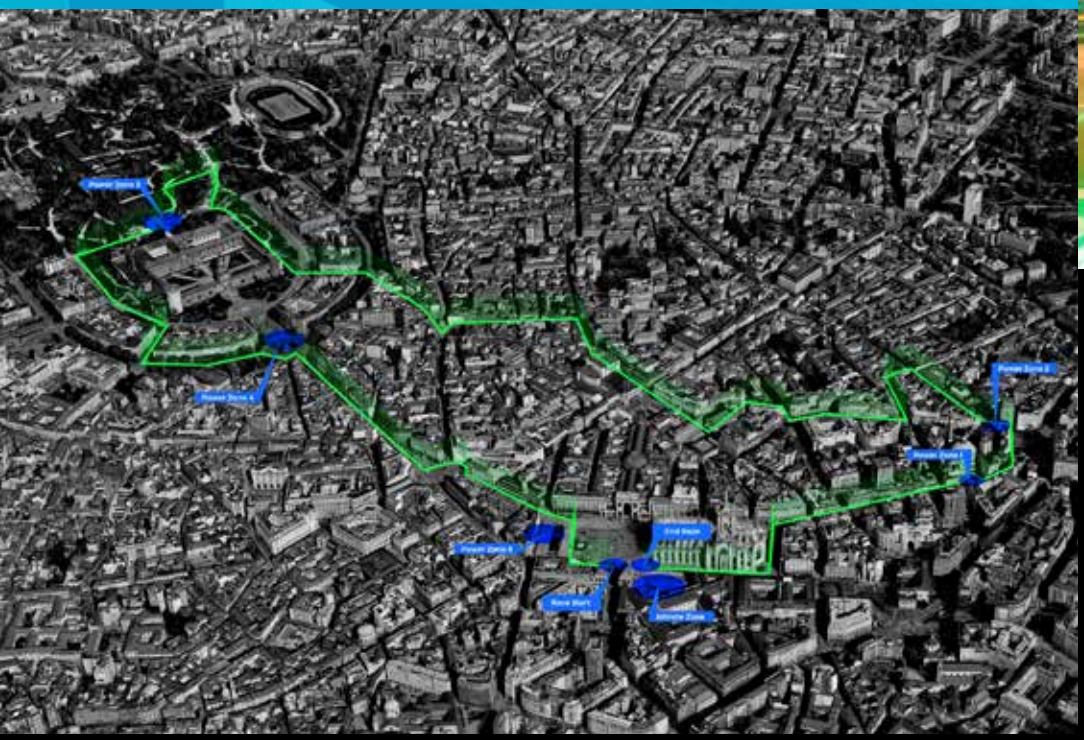
E-bike racing



RACE TO THE TOP

Each EBK GP event will take place over two days: a team time trial on day one, the results of which will decide the starting positions for the Grand Prix on day two. The GP will be a criterium – a race of a specified duration on a closed course using public roads closed to normal traffic: in this case, one hour plus one lap, on a city centre circuit of between 2.5 and 5 kilometres.

As well as intermediate sprints and other familiar features of road racing, the riders will have to contend with specially designed inclines, known as 'Power Zones', that will force them to choose whether to use the finite stores of electric power in their bikes to manage these climbs at a gruelling gradient of 20 per cent, or save it to gain advantage elsewhere on the course. A further intriguing rule is that no recharging of the e-bike batteries will be allowed between the team time trial and the Grand Prix.



Ricardo's experts will help stakeholders in each city to identify ways in which they can increase their climate ambitions over and above existing pledges and actions

E-bike racing

BIKE TO THE FUTURE

Swiss bike manufacturer BMC will build a new e-bike for the series, with the frame, motor and battery specifications the same for every rider. Other aspects of the event are still being finalised.

The bikes will be designed with 'Pedal assist' – which means that the motor will only engage when a rider is actually pedalling. While speeds of 100 kilometres per hour may be possible, power alone won't decide who wins. The electric bike element is likely to bring data-driven tactics to the fore, with teams adjusting their strategies mid-race using live data streams.

All of which should lead to some seriously exciting racing with a fascinating blend of traditional cycling capability and battery-powered technology.

"OUR ROLE WILL BE TO SUPPORT THE EBK GP'S CORE MISSION TO LEAVE A GREEN LEGACY IN MAJOR CITIES AROUND THE GLOBE"
ROSE BAILEY, RICARDO ASSOCIATE DIRECTOR FOR CLIMATE ACTION PLANNING AND TRANSPARENCY

emissions, improve local air quality and enhance green mobility. The STM programme aims to deliver not only shorter-term actions during and between the events but secure commitments by the cities to a longer-term package of measures that will leave a lasting legacy.

"Our role will be to support the EBK GP's core mission to leave a green legacy in major cities around the globe," explains Rose Bailey, Ricardo's Associate Director for Climate Action Planning and Transparency. "We'll put in place a robust monitoring, reporting and verification framework that will ensure the integrity and transparency of the commitments that are made, while supporting the organisers to meet the highest standards for sustainable events.

"Our experts will also enable stakeholders in each city to identify ways in which they can increase their ambitions over and above existing pledges and actions. These might include national climate commitments under the Paris Agreement as well as local climate action plans."

Ian Behling, Ricardo's Associate Director for Sustainability Services, says: "As well as ensuring a lasting legacy from each Grand Prix, we need to make sure the events themselves are delivered sustainably. This includes ensuring the event village, set-up, catering, infrastructure and so on are carried out sustainably to go beyond the ISO 20121 standard for managing an event's social, economic and environmental impacts. Helping our clients and their stakeholders go beyond compliance to deliver meaningful, sustainable outcomes is a real focus for the sustainability team within Ricardo."

CLAIRE IN BRIEF...

Title: UK Consulting Business Manager & Head of Strategy and Service Development, Ricardo Rail
Background: Master's degree in Chemical Engineering, Imperial College London; PhD in Chemical Engineering, University of Bath; previous roles with Atkins and Lloyd's Register; joined Ricardo Rail in 2020

A day in the life...

CLAIRE RUGGIERO

Why International Women's Day is a landmark in the Ricardo calendar

The theme of International Women's Day (IWD) 2022 was 'breaking the bias', as we strive for a world free of stereotypes and discrimination and that is diverse, equitable and inclusive.

The Day enabled us to celebrate the brilliant women already within our Group. It was also an opportunity to reflect on how we create pathways into engineering for those from different backgrounds or with non-traditional life and career experiences. Engineering should not be closed off to those who decide not to go to university, for example, or don't have access to professional networks.

When I was a young engineer, I didn't encounter any specific barriers to my career progression. Looking back, however, I can see that I did face challenges around cultural fit – being the only woman on a project team or in a meeting, for example. Engineering was long perceived as a men's profession and there was a tendency to try and mirror behaviours in a male-dominated environment which made it harder for me to be myself.

I believe there are now many more opportunities for women wanting a career in engineering. Almost 15 per cent of all engineers are female and there's been a 25 per cent increase in the number of women in engineering occupations since 2016. However, there is definitely more to do and we should not be complacent. We also need to consider other aspects of encouraging a diverse workforce and not focus purely on gender.

Ricardo is helping to drive change in a number of ways. We launched our Diversity, Equity and Inclusion (DEI) Council around a year ago to draw together colleagues from every part of the business. The Council and other employee-led groups across Ricardo's global network ensure that difference is celebrated.

I joined the Council because having a genuinely open environment, where people at all levels can challenge each other and find a safe space for difficult conversations, is vital to recruit and retain great people and create a collaborative working environment.

We also have a newly established women's affinity group who offer a support network and take challenges or improvement ideas to the DEI Council or senior management. Some of the important topics we're currently discussing are the shape of workplaces following the pandemic; the impact of work on women's mental and physical health and the work-life balance; and the challenges faced by women returning to work after a long period of absence.

IWD is a focus for raising awareness. Internally, we asked everyone to share the stories of women in their lives who have inspired them, using the hashtag #inspiringwomen. And externally,

> **"THERE ARE NOW MANY MORE OPPORTUNITIES FOR WOMEN WANTING A CAREER IN ENGINEERING"**

the annual Ricardo Engineering Prize encourages talented female engineering students. The winner gets a work placement to help them take a positive first step in a professional engineering career.

Sometimes, however, you have to overcome preconceptions within your own family. When my kids were very young and I'd moved into the rail sector, they bizarrely decided that I was the person wheeling the refreshment trolley up and down the aisle and they'd be able to eat as much chocolate as they liked if they did my job when they grew up. I'm pleased to say that one of them is now studying physics at university!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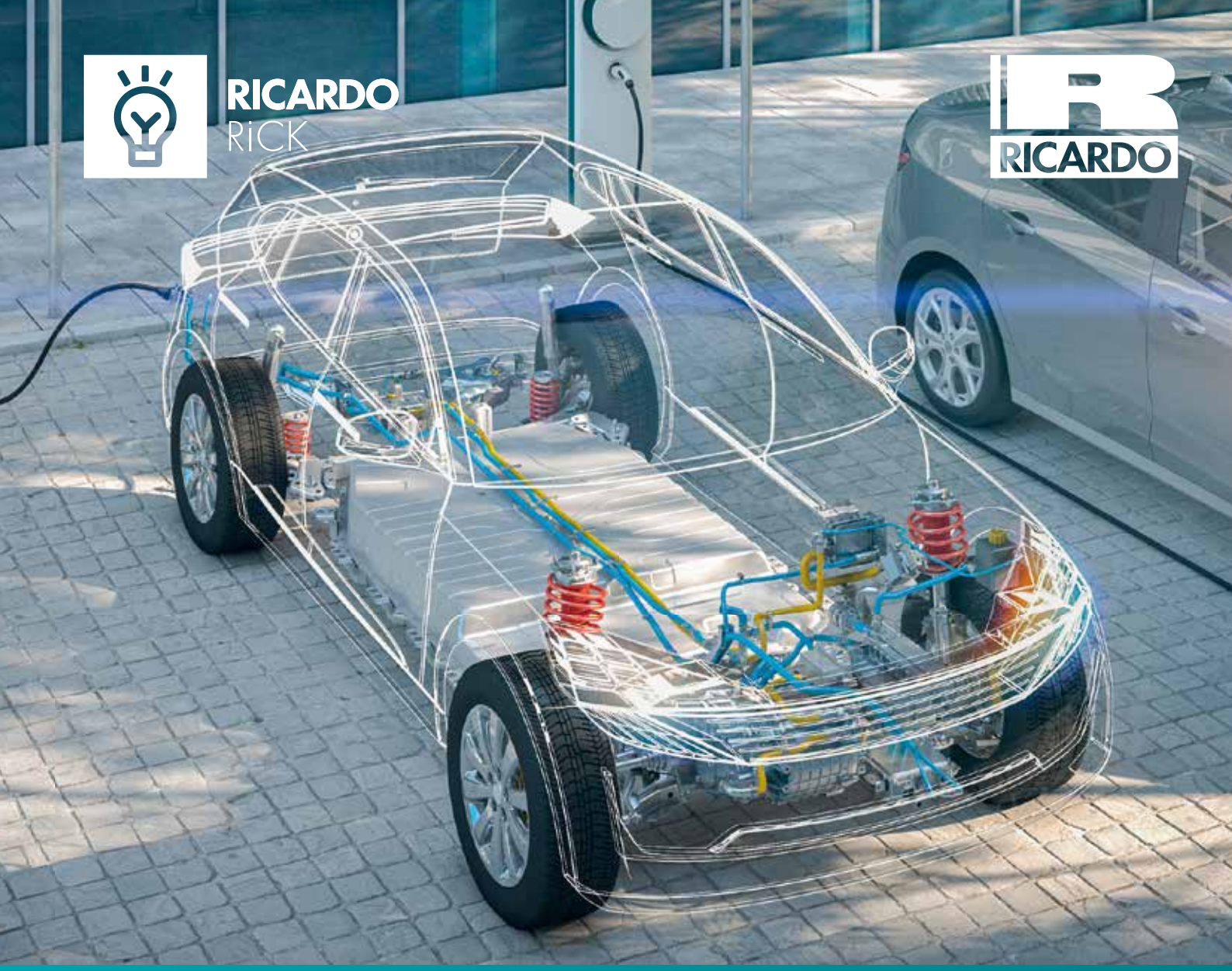

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