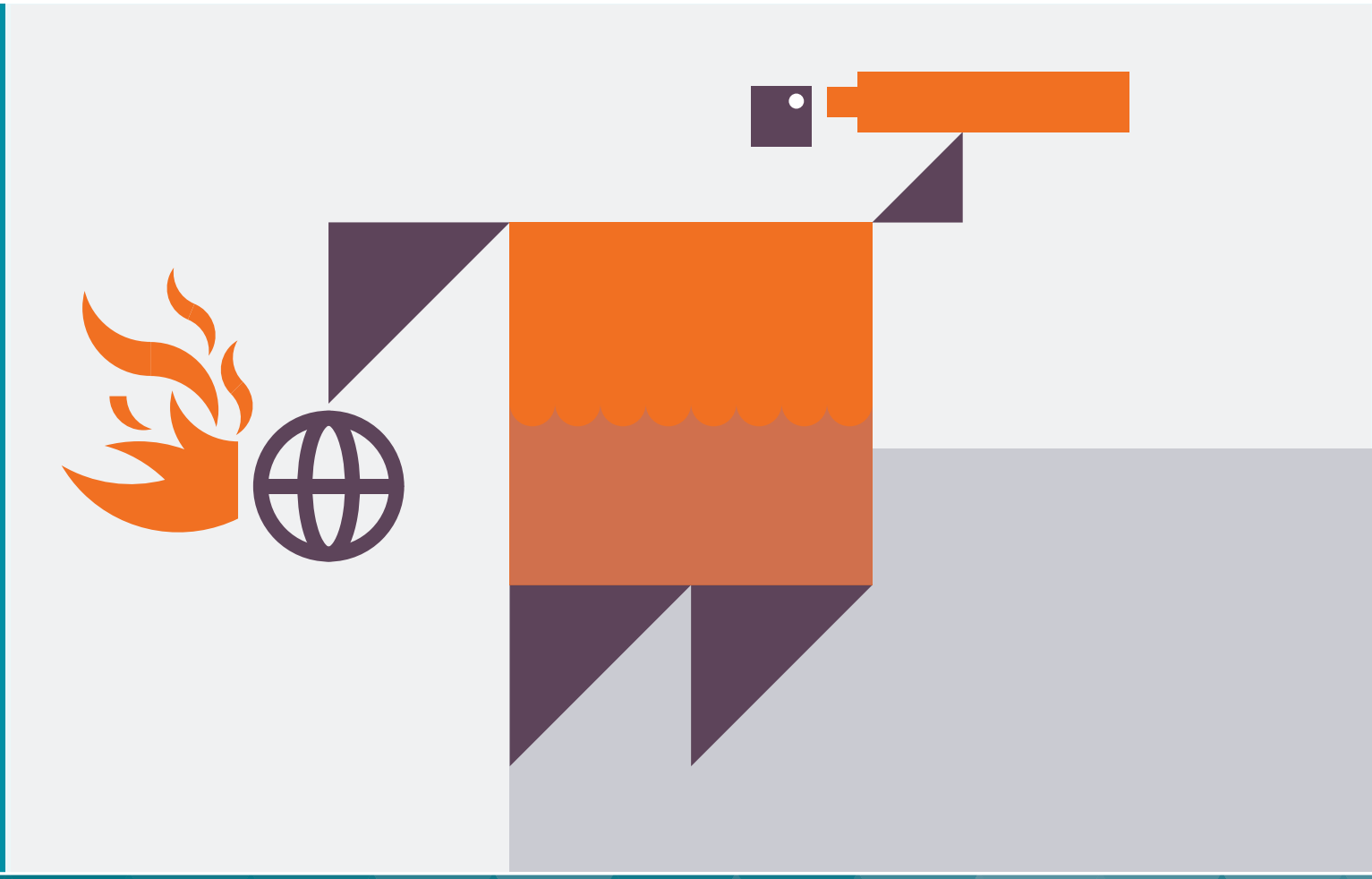
ice
Institution of Civil Engineers



STATE OF THE NATION 2021

Six ways for civil engineers to act on climate change

ice.org.uk

"This report explains how civil engineers are stepping up and are ready to own their role in acting on climate change."

Rachel Skinner, ICE President

Foreword

Rachel Skinner
President
Institution of Civil Engineers

In one month, world leaders will gather in Glasgow for the United Nations COP26 Climate Change Conference. We anticipate – and hope for and need – bold new targets and agreements to act on climate change, including faster decarbonisation towards net zero carbon in tandem with efforts to improve our collective resilience to the unavoidable impacts of a global changing climate.

The UK Government, as host, is determined to show global leadership through its own commitments. Yet the UK's current rate of progress towards net zero is too slow. Efforts to build climate resilience into our existing places and infrastructure systems are far from mature.

It is time for civil engineers to turn climate talk into climate action.

Infrastructure is responsible for more than half of the UK's carbon emissions. As civil engineers, we have a long-established responsibility for infrastructure. We must, therefore, step up and seize the opportunity to use our skills and influence to bring about transformational change, at speed. The carbon impacts of the infrastructure decisions we make and support exist through the whole life of every asset, so we have to address both our existing infrastructure systems and all infrastructure assets of the future.

This report assesses the current state of the nation in terms of its infrastructure carbon footprint and associated trajectory. Through regional roundtables we have assessed our members' state of readiness to take climate action.

We have devised a headline checklist of six key areas where civil engineers and infrastructure experts can take direct action and use their influence to make real change, now. At their heart is a clear need for us to change our behaviours and recognise our ability to influence others to do the same, unlocking new creativity, ideas and solutions by putting a new climate and carbon 'lens' on all that we do.

Taking proper ownership of the climate challenge for infrastructure, around both net zero and resilience, is a transformational and urgent pivot point for civil engineering. It is key to enhancing our reputation, attractiveness and wider public understanding of what we do as we continue to protect and improve the quality of life for people across the world.

It is time.

About State of the Nation

ICE has published an annual State of the Nation report since 2002. The aim of these reports is to stimulate debate and to highlight the actions ICE believes are needed to improve the UK's infrastructure services.

Last year's report, State of the Nation 2020: Infrastructure and the 2050 Net Zero Target, examined UK infrastructure's contribution to achieving the net zero emissions target by 2050 and recommended a series of policy solutions.

State of the Nation 2021 supports those recommendations by exploring how the civil engineering profession, as the designers, builders, operators and maintainers of infrastructure, can take ownership of the whole infrastructure carbon reduction challenge associated with the UK's legal obligation to reach net-zero carbon by 2050, whilst also improving our infrastructure systems to create resilience.

It begins with an assessment of the current progress in decarbonising infrastructure, based on research conducted by The Carbon Project at ICE, before identifying and exploring six key actions that all infrastructure professionals can take to significantly increase the pace of change.

This report is the culmination of interviews with industry leaders and has sought input from about 170 ICE members who have contributed via nine UK regional workshops or through ICE's community advisory boards and communities of practice. This level of member engagement is crucial in grounding the report as accessible to all. Enormous thanks to all who contributed.

Project board

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Introduction
Owning the responsibility for climate action

NUMBERS

70%
Around 70% of all carbon dioxide emissions can be linked – either directly or indirectly – to the creation and everyday use of infrastructure

54%
of all UK greenhouse gas emissions are attributed to infrastructure construction, operation and use

The climate emergency is real, and its effects are being felt around the world, in everything from devastating floods and wildfires to droughts and energy shortages.

Everyone on the planet has to play their part, but civil engineers have a particular responsibility because this profession designs and builds the infrastructure that shapes the way that people live their lives.

Civil engineers designed the infrastructure that has enabled people to live comfortably and to access all of the goods and services they need for generations. Still, that physical infrastructure carries a high environmental cost – in the way it is built, operated and used.

The climate crisis presents the engineering profession with the biggest challenge it has ever faced. To help stave off environmental catastrophe, engineers need to completely rethink the infrastructure they provide and offer alternatives that do not deplete the world's resources or contribute to carbon emissions.

In fact, they should go further: engineers should be providing infrastructure that actively encourages a shift to low-carbon behaviours. A carbon net zero world will involve changes in lifestyle that currently seem unimaginable, but will soon become routine. Engineers must adapt, and provide the infrastructure that will enable this to happen at speed.

Engineers may not always realise the impact of the decisions they make, but everything they do will influence people's behaviour. Decisions about whether to build, what to build, where to build and how to build all influence how infrastructure is used.

As humans, every time we make a choice we are not faced with a blank canvas. We are far more likely to choose options that we chose before, that are easy, available and familiar, that are seen as normal[1]. This is particularly true in engineering design and construction, where there is often a 'default' choice based on what has been done before: using familiar materials, standard designs and assessments. But in doing so, engineers may be nudging end users towards higher carbon choices, whether they intend

1 www.wri.org/climate/expert-perspective/what-goes-around-comes-around

Everything engineers do influences people's behaviour. Decisions about whether to build, what to build, where to build and how to build all influence how infrastructure is used

to or not. They need to be even more aware than the rest of society of the choices they are making and how they affect the drive for net zero carbon.

Infrastructure delivery often involves repetition of what has been done before: using familiar materials, standard designs and assessments. But engineers do have a choice to do things differently; to challenge and reject the 'business as usual' position.

Infrastructure that enables a lower-carbon lifestyle will come about when engineers challenge their own assumptions about what is needed and begin seriously to explore what is possible – taking end users on that journey. The rapid pursuit of a net zero carbon balance is our best strategy to reduce the risk of these impacts becoming catastrophic. But in parallel, efforts to build resilience to the onward effects of climate change are essential as we have already baked in many of the worst impacts.

Watch

- ICE President Rachel Skinner's Shaping Zero film: https://ice.org.uk/news-and-insight/latest-ice-news/shaping-zero-watch-the-film
- ICE 13th Brunel International Series lecturer Seth Schultz's animation 21st-Century Leadership is Partnership: How a Coalition of the World's Engineers Can Change the World: www.bit.ly/icebrunel
- ICE A Systems Approach to Infrastructure Delivery animation: www.bit.ly/icesaid

"There's no point in just looking at low-carbon asphalt in a motorway surface. We need to address why we're building the motorway in the first place."

Paul Morris, director, Civic Engineers

Progress to date

The current status of infrastructure carbon

NUMBERS

54%
of all UK greenhouse gas emissions are attributed to infrastructure construction, operation and use – a total of 419 MtCO2e

3%
The current rate of UK carbon emissions reduction, which means the UK will not meet its net zero commitment by 2050

44%
The greatest percentage reduction in infrastructure carbon emissions has been in those areas over which the industry has direct control: capital and operational carbon

A recent report to Parliament by the Climate Change Committee (CCC)[2] on 24 June made headlines by revealing that the UK only has the policies in place to meet 20% of its legally mandated carbon emission reduction commitments by 2035, and betrayed a sense of frustrated urgency.

Last year, ICE's Carbon Project commissioned research into how the industry has responded since the first Infrastructure Carbon Review in 2013. The results, first presented in the Unwin Lecture 2020[3], confirmed that the proportion of carbon emissions deriving from infrastructure is still more than half (54%) of the UK's total, and this proportion is likely to increase as the UK's carbon footprint decreases. The footprint of other sectors is expected to reduce at a faster rate than that of infrastructure.

The research also showed that between 2010 and 2018 there was a 23% reduction in total carbon emissions relating to UK infrastructure's construction, operation and use. Clearly, change is not only possible but happening. What, then, explains the sense of frustration accompanying the CCC's latest report?

A 23% total reduction in emissions over eight years translates to an annual rate of 3%, a pace at which the UK will not meet its legal commitment to reach net zero by 2050[4]. For that, an annual reduction rate exceeding 4% is now required, starting at once. In other words, as a minimum, we need to reduce the UK's annual carbon emissions from infrastructure more than 30% faster than we are doing now.

Each year that we fail to accelerate change, the problem worsens, and a stringent yet achievable target eventually becomes unreachable. As the Infrastructure Carbon Review: Seven Years On report[5], published earlier this year, puts it: "Good progress but not fast enough."

Progress in reducing carbon emissions has varied widely between infrastructure sectors – communications, energy, transport, waste and water. The reductions in emissions from the waste and energy sectors (-33% and -37% respectively), for example, stand in

2 www.theccc.org.uk/publication/2021-progress-report-to-parliament
3 ice.org.uk/news-and-insight/latest-ice-news/carbon-reduction-falling-short-of-net-zero-target
4 www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law
5 www.constructionleadershipcouncil.co.uk/wp-content/uploads/2021/04/Infrastructure-Carbon-Review-seven-years-on_March-2021.pdf

What is so important about carbon?

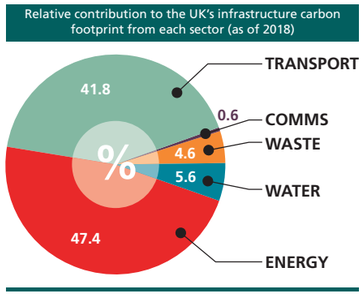
There are a number of different greenhouse gases – named because they block heat from escaping the atmosphere – including carbon dioxide (CO2), methane, nitrous oxide and chlorofluorocarbons (CFCs). They all cause damage and need to be reduced.

We tend to focus on CO2 because carbon dioxide emissions are the primary driver of global climate change. CO2 is the most dominant greenhouse gas, and is produced by burning fossil fuels, industrial production, and land use change. Humans have increased atmospheric CO2 concentration by 48% since the Industrial Revolution began. Most of the change has been recent. In 1950, the world emitted 6bn tonnes of CO2. By 1990 this had almost quadrupled to 22bn tonnes, and we now emit more than 36bn tonnes each year.

contrast to an increase in emissions from transport in the same period (+3.9%). It's true that each sector faces different challenges, including varying degrees of influence over the emissions relating to each stage of an asset's lifecycle. But it's notable that in the two sectors with the most impressive carbon reductions to date – energy and waste – hugely ambitious policy packages were put together more than a decade ago to drive the changes we see today.

Similar ambition across all sectors would achieve the results we need in the years to come. Some aspects may require the development of new technologies or creative approaches such as systems of asset sharing or re-use.

Many, however, are simple to enact immediately, involving such mundane measures as better data management, less excavation or less waste. Consistent effort, driven by policy, may be more important than a stroke of genius, and would make a far greater difference. In PAS 2080[6], the UK developed the world's first standard for carbon management in infrastructure. Five years on, adherence to this guidance remains largely voluntary and uptake is patchy. While comparable countries are beginning to introduce compulsory whole-life carbon assessments and limit permissible emissions for construction projects, the UK's progress in introducing policies to drive change is mixed at best.



There are encouraging developments, such as the new Construction Playbook[7]. Published in December last year, this stated for the first time that contracting authorities "should require that solutions put forward by potential suppliers are accompanied by a whole-life carbon assessment" and were obliged to "embed a whole-life carbon approach early in the identification and selection of solutions". The lack of such robust measures is exactly where the CCC's current frustrations lie, but engineers can help.

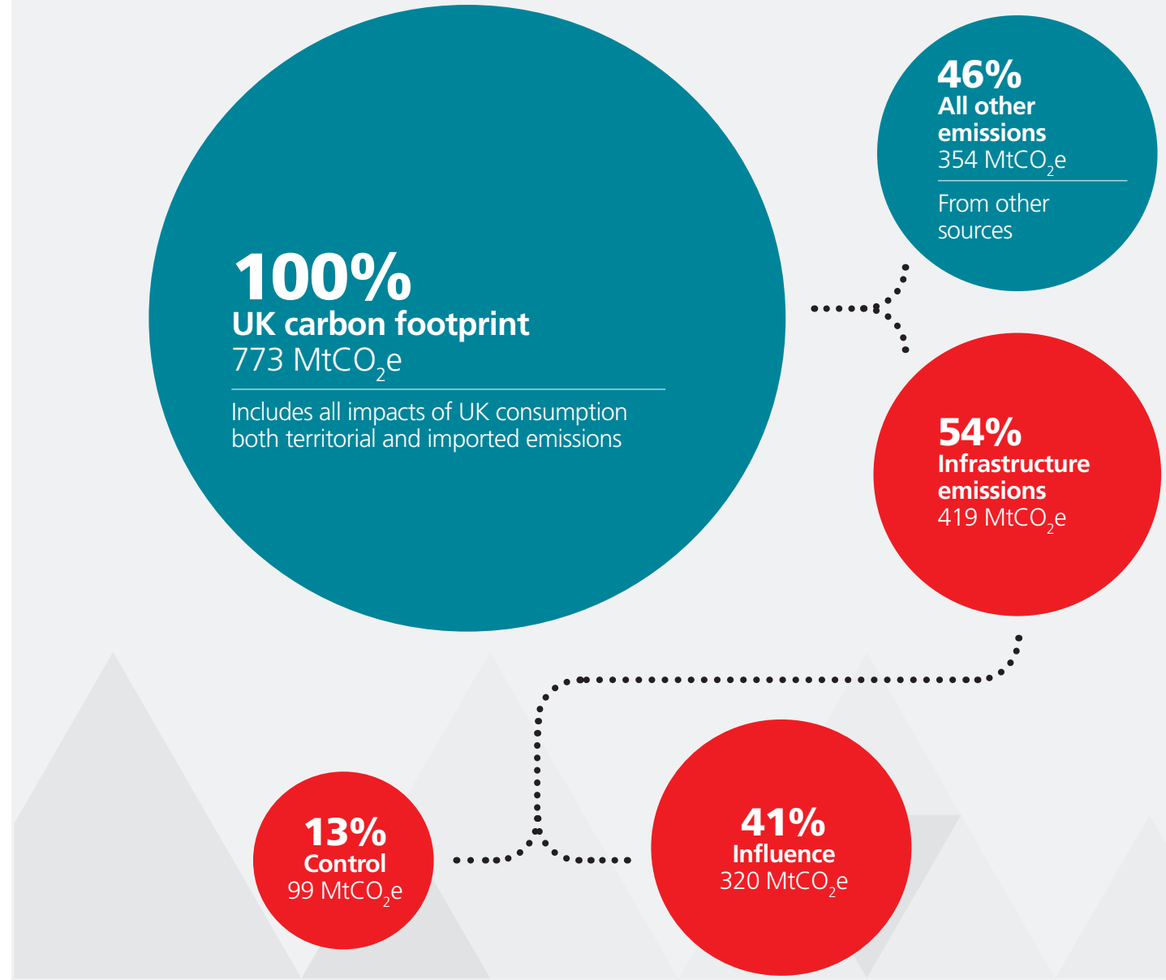
The greatest percentage reduction in infrastructure carbon emissions (44%) has been in those areas over which the industry has direct control: capital and operational carbon. These areas, however, represent only 13% of the UK's carbon footprint, with user-related emissions making up the other 41% of infrastructure's 54% share of the whole. Put simply, 41% of the UK's emissions derive from people using the infrastructure we provide. Infrastructure enables lifestyle, and both will have to change.

Engineers are often reluctant to discuss the fact that the infrastructure we create inevitably shapes public behaviour, predicting or fearing public resistance and consistently underestimating the appetite for change. The recommendations of Climate Assembly UK suggest that a majority of people in the UK want protection and restoration of the natural world and are prepared to embrace quite radical change as long as it is delivered with consistent leadership, attention to fairness, sufficient explanation and involvement.

The tragedy of Covid-19 has brought a historic opportunity to embed changes in behaviour that will emphatically reduce carbon emissions in the future. What should we, as infrastructure providers, do to support this?

6 www.greenbuildingencyclopaedia.uk/wp-content/uploads/2016/05/Guidance-Document-for-PAS2080_vFinal.pdf
7 www.gov.uk/government/publications/the-construction-playbook

Figure 1: Carbon emissions associated with UK infrastructure in 2010 and 2017 (ICE Carbon Project research)



Current state
Member readiness

NUMBERS

10
workshops were staged by ICE to explore lower-carbon options

170
UK ICE members attended the workshops

In summer 2021 we held nine regional workshops[8] plus a session with our community advisory boards and communities of practice that together were attended by more than 170 UK ICE members. The aim was to explore how members could influence others to promote lower-carbon options in the built environment.

Key findings

Our qualitative analysis revealed that participants believed there was an urgent role for the civil engineer to drive the net zero agenda but that they didn't feel they connected sufficiently with the public, let alone designed projects for the infrastructure end user. This was likely to be because there was a dissonance between themselves as individuals making low-carbon choices and their professional roles in the workplace.

Attendees thought that more training on how to communicate and consult more widely was needed. They agreed that they were bound by clients' briefs, deadlines and budgets. This underpins our finding that civil engineers often look to ICE, policy makers and clients to lead change to enable them to think more holistically, rather than taking immediate actions themselves – hence why we have identified six ways to act today in this report.

Personal versus professional

Participants gave many examples of how they had reduced their personal carbon footprint – from buying electric cars and switching energy suppliers to trying veganism. A lot of this behavioural change was caused by the pandemic. "I checked my carbon footprint[9] before the pandemic and then in lockdown – by not travelling I went from 240% to just below 100%," said one Northern Ireland participant. "That was a huge revelation."

Attendees said they were inspired to act by their children and by documentaries. Education and awareness campaigns were seen as successful ways to encourage low-carbon choices.

That said, when asked about solutions they had introduced professionally on their projects, participants couldn't always give examples so readily. One said: "I do present a low-carbon option, if the client asks for it. Otherwise, we have our usual ways to deliver projects within budget." Another noted: "Traditional methods and products that we know are likely to be better to reach deadlines, as they are set with these methods in mind. They are driven by standards and policies – these need to change."

8 ice.org.uk/news-and-insight/latest-ice-news/state-of-the-nation-2021-how-enable-low-carbon
9 footprint.wwf.org.uk

Many members said they did not understand carbon data and that they did not know what their carbon footprint was. They said more visual information was needed on what carbon meant for civil engineers, consumers and clients. A process akin to the traffic-light system for salt, sugar and fat was suggested at the East Midlands workshop, to inform engineers and clients about where a product originated and its resulting footprint.

Participants agreed that climate change was the biggest challenge to humanity in their lifetime and that civil engineers had a responsibility to do the right thing. "Engineers can't wait for mandates before taking action" was the biggest takeaway from the East of England workshop. As one participant put it: "We have a duty to encourage clients to adopt a whole-life approach – it is our role to educate them."

Best practice examples

As part of the research we called for case-study examples of successful initiatives in the transport, water, energy, waste and buildings sectors across the UK, to showcase good-practice solutions that had enabled consumers to opt for low-carbon options. While we didn't uncover as many examples as hoped, we found that strong case studies highlighted by the workshops had been led by local governments and community-led grassroots organisations.

Nottingham, Sheffield, Bristol and Norwich were cited as local authorities with holistic plans to create mobility hubs, encourage active travel and drive the net zero agenda with the end user in mind. The ReFLEX project in Orkney, Connswater Community Greenway and the Glider in Belfast were cited as projects that were outcome-focused and had adopted a systems approach, with a view to transforming communities.

Attendees felt that technology and smart solutions would be at the heart of future advances and that more funding should be allocated to research. They highlighted the water industry as one sector leading innovation in carbon reduction, with initiatives by Anglian Water, Northern Ireland Water and Scottish Water widely discussed.

What needs to change?

Some members agreed that setting out outcomes and clarifying what they were trying to achieve was where every project should start. Comments included: "We should be asking, do you need to build something new or can we re-use something that is already there?" and: "We should [be able to] make big mindset changes that are within our influence without destroying our businesses."

Collaboration was critical: "No single profession or person can do this on their own, and collaboration needs to happen outside of silos to be truly effective," said one attendee. Education of civil engineers and students, empowering younger generations and embedding sustainability in the education system from an early age were also cited as priorities.

Carbon budgeting was a popular topic of discussion. It needs to be part of the procurement process, with the carbon budget throughout the whole lifecycle of the asset being presented to the client. "There is no other way, otherwise lowest-price-wins will remain the norm," one participant said.

Ultimately, national priorities need to shift from rhetoric to action. "We need tighter regulations on carbon through carbon pricing and penalising emissions," suggested one attendee. A change in tax regime to favour re-use of existing buildings and infrastructure over new-builds was seen as crucial.

"I would like to see stronger pressure from ICE, including a code of conduct and its enforcement," one participant said. ICE should educate members on how they can design better, what new technology is out there and what can be learnt from other countries.

"We should be clear to clients that we need to do the best for the planet as well as for them."
Workshop participant

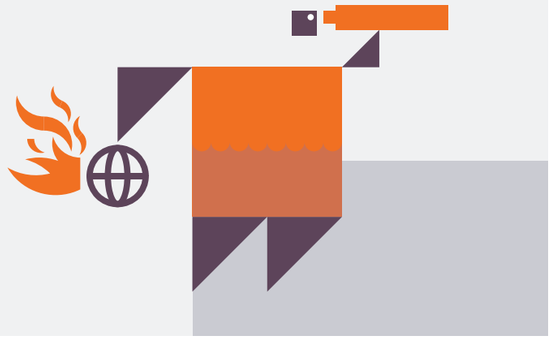
"Better understanding of carbon and what it means would change how we present projects to clients."
Workshop participant

"We need to communicate examples in a way that can be understood by a wide range of groups, from professionals to end users."
Workshop participant

Our checklist of key actions that all civil engineers can take to tackle the climate emergency and encourage low-carbon choices

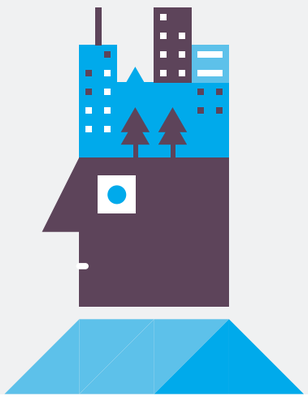
Six ways for civil engineers to act on climate change

01 This is an emergency – treat it like one



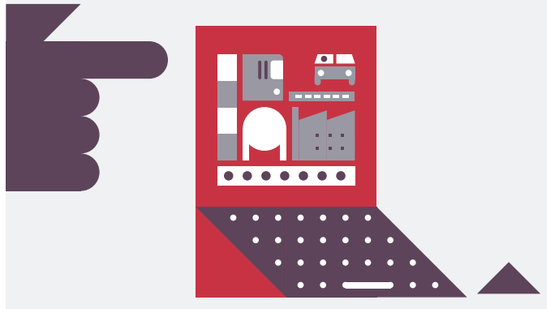
02 Bring carbon into every conversation

03 Understand and influence end users

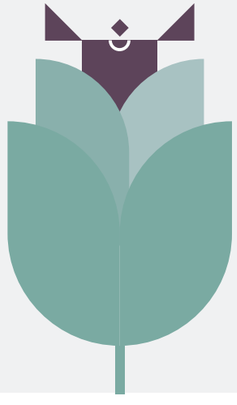


04 Design and build for the 'right' outcomes

05 Strive for creative solutions



06 Be responsible for resilience



"We can't continue to do what we've always done. We've been a big contributor to the problem, so now we have to think differently, and that thinking has to be disruptive because we don't have much time."

Paula McMahon, Chair ICE North East and Engineering Together Tees Valley

01 This is an emergency – treat it like one

NUMBERS

1.1C
of warming since 1850-1900 (known as pre-industrial levels) to 1.5C

1.5C
The 1.5C threshold is crucial because beyond this level we reach a tipping point where changes in the climate are irreversible

2C
If we reach 2C of global warming, heat extremes would exceed critical tolerance thresholds for agriculture and health

Engineers are the right people to have on board in an emergency. In recent weeks, engineers attached to the US Federal Emergency Management Agency (FEMA) have been at the heart of the response to flooding in the north-east US caused by Storm Ida.

Before that, they were helping to deal with wildfires. Engineers have helped to coordinate humanitarian action in Mosul, Iraq, when thousands of people were displaced after fleeing battles between Iraqi troops and Islamic State forces. Engineers have set up water, hygiene and sanitation programmes for refugees escaping from fighting in South Sudan into northern Uganda. More recently, UK engineers managed to design, construct and equip temporary hospitals at seven locations in a matter of weeks to deal with the potential impact of Covid-19.

Problem-solving skills, logical thinking, technical knowledge and understanding of materials make engineers ideally suited to respond to emergency situations. Climate change is an emergency, and the same thinking that engineers bring to natural disasters or war situations needs to be applied to solving this crisis.

In August, the UN Intergovernmental Panel on Climate Change (IPCC) issued a stark warning about the deepening climate emergency, saying it would already take centuries for some changes to be reversed. The IPCC's Sixth Assessment Report[10] set out the scale of the emergency, saying changes were already having an impact on every region of the planet. UN Secretary-General António Guterres described the report as "a code red for humanity", and said: "The alarm bells are deafening, and the evidence is irrefutable: greenhouse gas emissions from fossil fuel burning and deforestation are choking our planet and putting billions of people at immediate risk."

Many organisations within engineering are already treating this as an emergency. Globally, client organisations in both the public and private sectors are committing to reducing their carbon emissions. Worldwide, 2,025 jurisdictions covering 1bn citizens in 35 countries have declared a climate emergency[11], and should be expecting their suppliers and partners to help them tackle the impact of climate change.

10 www.ipcc.ch/assessment-report/ar6/
11 www.climateemergencydeclaration.org/climate-emergency-declarations-cover-15-million-citizens

"When we need step-changes, incremental improvements can actually be damaging because they lead to localised optima, but still leave us stuck on the wrong side of a valley always trying to climb incrementally higher, when we really need to jump to a different mountain altogether."

Toby Park, principal advisor and head of energy and sustainability, Behavioural Insights Team

In the private sector, the 4,000-strong B Corps global network of companies has called on businesses to declare a climate emergency and make a public commitment to cut carbon. Some have already pledged to improve their climate impact, for example under the UN's Race to Zero campaign[12].

Closer to home, Engineers Declare is a global petition uniting all strands of the engineering profession. It is both a public declaration of our planet's environmental crises and a commitment to take positive action in response to climate breakdown and biodiversity collapse. ICE is a signatory to UK Civil Engineers Declare, one of 125 clients, contractors, consultants, academia and institutions to have joined the movement.

This is definitely an emergency, and, as climate activist Greta Thunberg says, we should "act as if the house was on fire". Engineers need to bring this mindset and activate the skills they use in other emergency situations to help solve this crisis.

However, looking at infrastructure through the lens of carbon emissions appears to present a very real and direct threat to civil engineers. Suggesting a no-build solution to a client; recommending a water conservation programme rather than building a new treatment works; walking away from a project because of its potential to increase carbon emissions – choices like these seem to call into question the entire basis of the profession and the work it does. It seems like turkeys voting for Christmas – why would you do anything that risks jobs and income, even if it does save the planet?

But this does not mean the end of the profession. Quite the opposite: this is the moment when we rise to the challenge, with civil and infrastructure experts at the very heart of the transformation needed to break the many links between infrastructure and carbon. The problems presented by the climate emergency present an opportunity for engineers to take a more creative, collaborative and holistic approach. Still, if they are to look at infrastructure through the lens of carbon reduction and climate resilience, engineers at every level and in every role will have to think and act differently.

Some skills that have been valued highly in the past will become less important, while others will be needed: collaboration; understanding of human behaviour; systems thinking; knowledge of how to adapt existing structures; asset operation; and community engagement. Civil engineers need to be able to promote their design ethos and the impact of their solutions on people and the environment, and to see their projects in a wider context. And they will have to learn how to work with a diverse group of experienced people. Carbon literacy will be a crucial skillset.

It must also be recognised that civil engineers are working as professionals at every point in the project lifecycle and at every level of the infrastructure supply chain – including in government, policy formation and education. In all of our diverse roles, we should be exercising our expertise to cut carbon and driving this agenda in our organisations.

ACT NOW

This is an emergency – treat it like one

- Understand the science and communicate the urgency to everyone you work with.
- Understand carbon declarations or commitments made by your organisation or your organisation's clients.
- Understand and show how you are contributing to solving the crisis.
- Join a local collective working to create change.

12 www.unfccc.int/climate-action/race-to-zero-campaign

"Don't wait for the standard to tell you what to do – just do it better. Move it on a step at a time."

Bridget Rosewell, commissioner, National Infrastructure Commission

02

Bring carbon into every conversation

NUMBERS

15%
Only 15% of ICE members always consider climate issues in their work

22%
of ICE members cite "lack of own knowledge" as limiting their ability to address greenhouse gas emissions and climate change adaptation

As individuals, we are getting used to thinking and talking about the environment and carbon in our everyday lives: conversations with our families about reusable coffee cups; with our neighbours about changing to a renewable energy supplier; with our colleagues about which is the best electric car. It's time to bring these conversations into our working environment.

These days, it would be unthinkable to procure, design, deliver, operate or maintain an infrastructure asset without thinking about and discussing the safety implications. The same should be true of carbon. At every stage and at every decision point, engineers should be asking, "What are the carbon implications?", suggesting lower-carbon alternatives and discussing the merits of lower capital carbon versus higher user carbon.

These conversations should be happening at every level: between clients and designers, engineers and policy makers, among colleagues and within construction teams. Research carried out by ICE in 2020[13] found engineers were keen to take more account of carbon emissions in their work, but many said they were waiting for advice, standards and industry-wide measurement mechanisms to help them. There is no time to wait. We know the broad direction of travel and there are plenty of examples of best practice to show how cutting carbon at capital, operational or user stage can often be achieved without additional cost.

Legislation will catch up, but engineers should be influencing policy and legislation rather than waiting to see what it says. There are already standards that provide a framework for informed opinion, such as PAS 2080: Carbon Management in Infrastructure[14], which was developed to help infrastructure professionals reduce carbon emissions over the whole lifecycle of projects (see panel, page 27).

Public opinion is changing faster than many in the industry realise. Engineers are sometimes reluctant to discuss the fact that the infrastructure they create shapes public behaviour, because they fear resistance. But evidence shows that this underestimates the public appetite for change. The recommendations of Climate Assembly UK[15] suggest that

13 ice.org.uk/knowledge-and-resources/briefing-sheet/what-makes-good-design-report
14 www.shop.bsigroup.com/products/carbon-management-in-infrastructure
15 www.climateassembly.uk

What if it's too late to change the project I'm working on?

Many infrastructure projects being implemented now were designed before current carbon commitments were made and may be based on ways of life that we now realise are unfit for a lower-carbon future.

Despite these obstacles, it's never too late to put carbon on the project agenda. Net zero will be achieved by multiple contributions, not by huge success in a few areas and 'business as usual' in others.

Where it's too late to influence design, look at implementation, operation or usage. Are there carbon savings to be made further down the line?

Radical carbon savings can be generated through fresh thinking about outdated practices that may be surprisingly easy to change. You don't necessarily have to be a technological innovator to make a difference – you just need to understand what you're looking for, and how important it is to act.

a majority of people in the UK want protection and restoration of the natural world and are prepared to embrace quite radical change as long as it is delivered with consistent leadership, attention to fairness, sufficient explanation and involvement[16].

ICE's 2020 State of the Nation research found that many engineers working in consulting roles felt constrained by the brief they were given by their client. Professional design and construction engineers work at their best when clients see them as trusted advisers. If that relationship is strong, clients will explain the issue they have to engineers and the outcomes they are trying to achieve rather than simply issuing a brief. At that stage, engineers should be focused on the purpose of infrastructure, for example asking, "What are you trying to achieve?" rather than, "What do you want me to design?" By asking the right questions and challenging the brief, engineers can develop solutions that deliver more sustainable outcomes.

This should also be the case where engineers don't have that relationship with their clients. They still have a responsibility to challenge and offer alternatives. Buro Happold director Dr Mike Cook says in his blog for ICE's The Carbon Project: "Engineers are good at finding answers. Even those clients who do not proactively seek carbon reduction advice – or those who actively resist it – need to be able to rely on engineers' expertise in this area. Remaining silent is not an ethical option."[17]

However, corporate client organisations are starting to be audited on their environmental, social and corporate governance (ESG), and within a few years it is likely that all companies will be required by law or regulation to report against a broad range of ESG metrics, including carbon.

ESG issues are becoming increasingly important to companies' reputations and how they are perceived by people who might want to join. Adverse activity within the company or in the supply chain can have a dramatic impact on this. Put simply, businesses are seeing that if they do not have targets for reducing carbon and other ESG metrics – and an action plan to meet these targets – they will be undermining their own shareholder value.

Engineers also have a role to play with lenders and investors, advising them on decarbonisation challenges and investment risks. Internationally recognised reporting procedures, such as the Taskforce on Climate-related Financial Disclosures (TCFD), are starting to provide a common language to help identify how companies are performing (see panel, page 27).

Engineers have a responsibility to help public and private sector clients to meet the targets they set themselves and the expectations placed on them. This involves challenging traditional solutions and methodologies and offering lower-carbon solutions, even if the move to net zero in infrastructure costs more in the short term. Understanding this background can help engineers to frame their advice, challenge their clients and raise the issue of carbon in context.

Conversations about carbon should also be taking place in every organisation where engineers work; people in positions of influence should foster an atmosphere where

16 www.jannikgiesekam.co.uk/research/presentations/Unwin_Lecture_Slides_081020_Jannik_Giesekam.pdf
17 ice.org.uk/news-and-insight/the-civil-engineer/july-2021/carbon-project-role-of-the-engineer

Case study: Citu Leeds

Project: **Climate Innovation District, Leeds**
Client: **Citu**
Engineer: **Civic Engineers**

Leeds Climate Innovation District has been designed with the aim of creating sustainable communities in low-carbon developments. Drawing on international best practice, it is harnessing the latest technology to create more than 500 low-carbon homes alongside manufacturing, leisure, offices and climate-resilient public realm.

Phase 1 of the development comprises 312 homes, built to Passivhaus principles using timber frames manufactured by Citu, which has moved its manufacturing base to the development. The infrastructure has been designed to add as much value to the development as possible through enhanced biodiversity and amenity.

A site-wide sustainable drainage system (SuDS) enables all storm water to be managed at source, attenuated and conveyed through a functional landscape that includes tree planting, permeable paving, rain gardens and ponds. It shows how a high-quality SuDS scheme can reduce flood risk and contribute to amenity, biodiversity and ecology while minimising below-ground drainage and avoiding the need to bury plastic attenuation tanks.

Civic Engineers redesigned the existing street network to prioritise walking and cycling and to help everyone living and working in the district to make sustainable transport choices, using app-based communication.

"Our role as professionals is not only to meet the requirements of the brief, but also to proactively guide clients and deliver engineering solutions that address their needs in a sustainable way."

Kirils Holstovs, transportation engineer, AECOM

"Nobody would fault an organisation for pointing out that a particular solution is going to be high carbon and that there may be an alternative way of solving the problem that is low carbon."

Richard Threlfall, global head of infrastructure, KPMG

engineers at every level feel comfortable and empowered to discuss carbon reduction in their working environment and in the work they do.

Regional workshops staged by ICE in 2021 (see page 14) found that some engineers were experiencing dissonance between the low-carbon choices they were making as individuals and their ability to incorporate these choices into their workplaces and the work they did. They can find themselves making personal lifestyle choices to reduce their environmental impact while delivering infrastructure that promotes high-carbon choices among end users.

Of course, it is much easier for individuals to change their behaviours to adopt low-carbon choices in their personal lives than for organisations to do so. Individuals can quickly decide if they want to live differently or take on the potential extra costs of lower-carbon options. Companies have a more complex set of criteria to manage, such as trying to keep all of their employees in work and making money for their shareholders. But the two need not be mutually exclusive – as the drive for low-carbon infrastructure accelerates, firms that have taken it on board will also benefit financially. And, as with all companies, infrastructure employers also risk appearing unattractive to new employees if they are not creating an environment in which low-carbon choices are the norm.

We are starting to see commitments from infrastructure companies that reflect an understanding of the importance of carbon reduction. For example, the UK water industry has committed to being net zero by 2030, and some major consultants have pledged to halve the carbon impact of their consultancy advice. For commitments such as these to have genuine value, they need to be meaningful throughout the organisation, giving all employees licence to discuss carbon reduction in every aspect of their working lives.

ACT NOW

Bring carbon into every conversation

- Refuse business as usual: keep carbon reduction on every project agenda.
- Be the expert: keep yourself informed about how approaches to the climate crisis are evolving at the highest levels – internationally, nationally, environmentally, socially and economically – and research the implications for your own sector.
- Be aware of current standards and commitments. Look for examples of best practice, seek out gaps in knowledge and exchange your ideas with professionals.
- Be willing to share your successes, big or small.

18 icevirtuallibrary.com/doi/abs/10.1680/jcien.2016.169.3.99?journalCode=jcien

PAS 2080

PAS 2080: Carbon Management in Infrastructure[18] is the world's first standard for managing infrastructure carbon.

It was developed by the Construction Leadership Council's Green Construction Board with the British Standards Institute (BSI), and provides a consistent framework for evaluating and managing carbon across the whole infrastructure value chain.

PAS 2080 is designed to help professionals involved in infrastructure provision to achieve the huge reductions in carbon emissions that are needed across the whole lifecycle of projects. It provides a common process to encourage the right behaviours and approaches from clients, constructors, designers and product suppliers to deliver reduced carbon and cost infrastructure.

If all parties involved in infrastructure delivery follow the processes set out in PAS 2080, the sector will develop a more integrated value chain, communicate in a common language and work in a culture of collaboration and innovation, as well as helping value chain members to be comfortable about challenging the status quo.

TCFD

The Task Force on Climate-related Financial Disclosures (TCFD) was set up by the Financial Stability Board to help identify the information needed by investors, lenders and insurance underwriters to assess and price climate-related risks and opportunities.

In 2017 the TCFD published recommendations for disclosing clear, comparable and consistent information about the risks and opportunities presented by climate change. The Task Force believes that widespread adoption of these recommendations will ensure that the effects of climate change are routinely considered in business and investment decisions. They will also help companies to better demonstrate responsibility and foresight in their consideration of climate issues, which will lead to smarter, more efficient allocation of capital and help to smooth the transition to a more sustainable low-carbon economy.

The Task Force's recommendations on climate-related financial disclosures are applicable to organisations across all sectors and jurisdictions. They are structured around four thematic areas: governance, strategy, risk management, and metrics and targets.

How does 'nudge' work?

People are 'nudged' to change their behaviour if the new behaviours are Easy, Attractive, Social and Timely – a framework known as EAST that has been developed by the Behavioural Insights Team[19]. Examples include:

Make it easy
Residents were found to be significantly more likely to purify their drinking water when one-push chlorine dispensers were installed on community taps calibrated for a standard jerry can, compared with distributing purification tablets to homes.
Lesson – Ensure desirable behaviours are made easy in the built environment, whether that is by providing access to public drinking fountains to avoid unnecessary plastic use, providing secure and safe cycle infrastructure, or installing low-flow shower heads by default.

Make it attractive
Incentive design, such as painting electric vehicle charge points and parking spaces green or putting green footsteps on the pavement leading to recycling bins, encourages facilities to be used, in the same way that footsteps on the Tube escalators remind you to stand on the correct side.
Lesson – Draw people's attention to the relevant features of their physical environment.

Make it social
Households consistently reduce their energy consumption when told that they're using more energy than their neighbours, while solar panels have been found to be 'contagious' within neighbourhoods[20].
Lesson – We are social creatures. We tend to do our bit when we know others are doing so as well, and use others' behaviour as a source of information on what is normal, right or acceptable. We should make good behaviours more visible and normalised (e.g. green number plates to highlight electric vehicles).

Make it timely
In one study, new home-movers were found to be four times more likely to take up a new cycle share scheme compared with existing residents[21].
Lesson – Adopting new behaviours is far easier to do when old routines are disrupted.

03

Understand and influence end users

NUMBERS

55%
Increase in cycling on London's Blackfriars Bridge in the six months after a protected cycle lane was introduced

51%
Increase in active travel among Bromley schoolchildren after a footway on a key highway bridge was widened

Infrastructure and the physical environment have an enormous impact on the choices people make about how they live. Civil engineers' work determines the nature of the physical environment, and leads directly to whether or not people adopt low-carbon behaviours.

Better understanding of how people use infrastructure will enable engineers to make more informed responses to clients and present options that will help end users to reduce carbon.

All individuals have a degree of agency when it comes to choosing to enact sustainable behaviours, but various factors influence whether they do or not. On the one hand are internal factors – such as beliefs, values, ingrained habits, and emotional and cognitive bias. On the other are external factors – which psychologists call the 'choice environment' – these include price, the digital and physical environment and social dimensions. Physical influence on the choice environment is largely down to the built environment – the way infrastructure makes certain behaviours more readily available and straightforward.

From a psychological point of view, to encourage a person to adopt a particular behaviour, it will have far more of an impact to edit their environment than to try to change their internal intent. This is the basis of 'nudge' theory – making tweaks within the choice environment, such as putting fruit rather than sweets near a supermarket till. The principle is equally true for bigger changes, such as biasing urban design towards cycling rather than private car use. For example, cycling on London's Blackfriars Bridge rose by 55% in the six months after a protected bike track was installed[22].

People are 'nudged' to change their habits if new behaviours are Easy, Attractive, Social and Timely – a framework known as EAST that was developed by the Behavioural Insights Team (see panel, facing page).

19 www.behaviouralinsights.co.uk/wp-content/uploads/2015/07/BIT-Publication-EAST_FA_WEB.pdf
20 Allcott, H. (2011). Social norms and energy conservation. Journal of Public Economics, 95(9-10), 1082-1095.
21 Kirkman, E. (2019). Free riding or discounted riding? How the framing of a bike share offer impacts offer-redemption. Journal of Behavioral Public Administration, 2(2).
22 http://content.tfl.gov.uk/pic-161130-07-cycle-quietways.pdf

Transport choices

Involving local people and communities in infrastructure delivery can unearth socioeconomic and demographic factors that engineers may not otherwise be aware of. For example, on the whole, transport networks are predominantly designed around people who work 9-5 in an office and travel at peak times, and ignore the needs of people with different lives or work patterns. This can disproportionately affect transport provision for women and people from ethnic minority backgrounds.

According to a Civitas report, women's travel patterns differ from men's in many ways: they are likely to travel shorter distances than men, are more likely to use public transport, engage in more non-work travel outside rush hours, make more multi-stop trips, run household errands and escort other passengers (usually children or dependent older people).

Transport for London has also discovered usage differences according to ethnic background. For example, 65% of BAME Londoners use the bus at least once a week compared with 56% of white Londoners, while the use of cars among BAME Londoners is lower: only 32% of BAME people in the capital drive a car at least once a week compared with 41% per cent of white people.

People like owning and driving cars: it is convenient, is a strong default, and taps into feelings of independence, status and, possibly, ego. That makes it a difficult behaviour to change by persuasion alone. The solution is to create an environment where lower-carbon choices, such as walking, cycling, using electric vehicles or public transport, are made much easier in terms of their practicality, effort, perceived safety, social norms and cost. These are things that the individual themselves can't change but that civil engineers can, at least in part. The more engineers and other infrastructure professionals create an environment in which lower-carbon options are easy, available, desirable, familiar and normal, the more end users will adopt lower-carbon behaviours.

Civil engineering solutions do not exist in isolation – they are part of a wider context that includes affected communities and the natural environment, as well as the behaviour of infrastructure users. To prevent infrastructure contributing to carbon emissions, or leaving an unanticipated negative legacy, engineers need to understand end users as people; engage with communities as equals and respect their knowledge of local needs and constraints; and incorporate the behavioural aspects of choice as part of the solution.

Looking at infrastructure through these alternative lenses requires different skills from those required for traditional civil engineering design. However, the potential for deriving wider benefits – for example, better health or socioeconomic benefits – should not be ignored. Approaching infrastructure and the built environment in a wider context enables more of these benefits to be explored.

Reallocating space from vehicles to pedestrians in a town centre can encourage local people to work and shop there, rather than going to out-of-town shopping destinations, while the town centre can thrive and more journeys can be made by active travel or public transport. There may even be knock-on benefits in terms of reduced crime and more local employment – all generated by redesigning streets for people rather than vehicles.

Engineers are ideally placed to think more holistically about the built environment: they understand the policy drivers and the science, and are trained to be 'systems thinkers', so should be able to take a bigger role than merely basing decisions on 'steel and concrete'.

ACT NOW

Understand and influence end users

- Acknowledge that your work has an impact on people's behaviour.
- Know who your end users are and involve them by treating them as experts.
- Consider the needs of everyone affected by your infrastructure and engage them.
- Understand the EAST principles and apply them to your work.

Case study: Viaduct improvement, Bromley Heath

Project: **Bromley Heath Viaduct design, strengthening and improvement works**
Client: **South Gloucestershire Council**
Project manager, structural assessor, designer and site supervisor: **WSP**

Built in the 1960s, Bromley Heath Viaduct is 100m long and carries more than 55,000 vehicles and 500 cyclists a day. The structure was understrength and deteriorating, and the existing footway was unfit for purpose and posed a major safety risk as well as being a barrier to sustainable travel.

The client had also identified that the viaduct's existing footway was substandard and had plans to construct an adjacent structure solely for non-motorised users in the future.

Refined analysis and assessment techniques showed that some aspects of the planned strengthening work were unnecessary, but the structure still needed essential maintenance works requiring a full closure that would cause significant delays and have an impact on the local community.

As this couldn't be avoided, WSP suggested that a package of planned preventative maintenance works should be done at the same time. The consultant also calculated that, by widening the structure using lightweight, modular reinforced polymer deck units spanning between bespoke lightweight concrete ribs, a new segregated footway and cycleway could be installed that was fit for future use – eliminating the need for a new 100m-long footbridge.

As a result of the decisions to widen the existing footway, together with extensive community engagement, there has been a significant adoption of sustainable transport methods:

- Road usage at peak times dropped by 20% and the number of cyclists increased by 30%.
- The nine schools nearest to the viaduct have reported a 51% increase in pupils opting for active travel.
- Major local employers have reported significant increases in staff opting for active travel.

Comments from local people include:

- "We have fully embraced cycling in our household [as a result of the viaduct works] and do a daily 16-mile round-trip commute each."
- "I bought a bike and am loving it. I'm cycling three days a week and feel so much better when I get to work."
- "The cycle path and walkway are great. It was extremely dangerous before, with cyclists heading face-on into traffic on a very narrow path."

Anglian Water: commercial model

Anglian Water, like all other water companies in England, has signed up to being net zero carbon by 2030. The company has so far achieved a 61% reduction in capital carbon since adopting an alliance arrangement with its delivery partners.

Under a traditional contracting approach, the client specifies the asset they want to be delivered or improved, agrees specifications and standards, and then a contractor gets paid for building that asset. If anyone involved in the process comes up with a more sustainable solution or changes the design to use fewer resources or re-use existing assets, they will get paid less, so it is not a very sustainable business model.

Under Anglian Water's alliance approach, affordability targets are agreed for delivering a specific outcome – for example, treating wastewater to a specific standard or moving water from A to B. How the supply chain delivers against that outcome is entirely up to them as long as they meet the affordability targets and the water company's tough carbon targets.

Any significant reduction in cost is shared between Anglian Water and its alliance partners, so if a design engineer comes up with a solution that involves re-using assets, they are encouraged and incentivised to do that.

This thinking underpins the enterprise business model advocated by Project 13, which is designed to connect infrastructure owners and their supply chains in a way that jointly incentivises performance, aligns reward with delivery of outcomes rather than volume of work done, and promotes greater understanding of cost drivers and risk across all organisations in the enterprise, with commercial incentives for collaboration to jointly mitigate risk, not transfer it.

04

Design and build for the 'right' outcomes

NUMBERS

61%
Reduction in capital carbon achieved by Anglian Water since adopting an alliance model and focusing on outcomes

600%
Potential return on investment to city of Belfast from Connswater Community Greenway owing to its outcome focus

To achieve lower-carbon infrastructure, we need to shift our thinking from what infrastructure is to what infrastructure does.

Until now, infrastructure delivery has traditionally been aimed at delivering specific outputs, usually in the form of a fixed asset, such as a new road or waste processing facility.

But thinking about the purpose of infrastructure can change the output completely. For example, the main purpose of transport is to provide access. Most people travel for this purpose, and the value is at the end of the journey – the workplace, shops, school. It may be possible to achieve this purpose without the journey, for example by providing online health consultations, employment opportunities within communities, or social activities within walking distance. This will render part or all of the journey unnecessary or enable it to be undertaken by active or public transport. Investment can be diverted into different areas of infrastructure, such as the rollout of 5G or local work hubs and employment centres.

This is true of all sectors, not just transport. In the water sector, for example, one purpose of infrastructure is to ensure that wastewater is appropriately dealt with and does not pollute the environment or cause harm. It is not specifically to build wastewater treatment works. The same outcome might be achievable through working with landowners to reduce run-off, or with householders to encourage greywater re-use.

This is the foundation of an 'outcome-based' approach to infrastructure – focusing on what is trying to be achieved rather than making assumptions about what might be built. This outcome focus is central to the Project 13 principles[23], which advocate an enterprise approach to project delivery that brings together owners, partners, advisers and suppliers, working in more integrated and collaborative arrangements, underpinned by long-term relationships. Participating organisations are incentivised to deliver better outcomes.

An outcome-based approach enables engineers to deliver infrastructure that meets a range of different needs and meets a variety of different outcomes, including lower-carbon choices. It should make it easier to consider the potential for improving health and wellbeing, for generating socioeconomic benefits. It stops infrastructure solutions

23 www.project13.info

"As a consultant, the first question you ask the client should be, 'What is this for?'"

Paul Hammond, business development manager for integrated transport and global practice lead for economics, Mott MacDonald

"If you're measuring yourselves purely on capital cost, you won't get the best solution."

David Riley, head of carbon neutrality, Anglian Water

being one-dimensional, or solving one problem while creating others, and it should make it more likely that any new infrastructure is integrated effectively with existing systems, in balance with the needs of people and nature over the long term.

Even infrastructure specifically intended to enable lower-carbon choices can be designed to meet a wider variety of outcomes. For example, cycle lane infrastructure that incorporates tree planting and sustainable urban drainages (SUDs) will create a more resilient landscape, make it more attractive, manage surface water, provide cooling and shading, improve amenity space and promote biodiversity. It may even have longer-term impacts such as encouraging people to live in city centres rather than moving to the suburbs and commuting – resulting in lower carbon emissions.

An outcome-based approach also encourages engineers to look at ways to reduce demand, rather than always focusing on the supply side and trying to remove carbon from the construction and operation of infrastructure designed to meet ever-increasing demand. Solutions that help to encourage fewer car journeys will reduce carbon emissions more effectively than trying to reduce carbon in road construction. Reducing energy consumption is a cheaper and easier way to cut carbon than developing technological solutions to meet higher demand; education and public participation to overcome barriers and perceptions to greywater recycling reduces the need for expensive and carbon-intensive treatment methods.

Engineers may not be accustomed to looking at infrastructure through these alternative lenses, but it is important that they learn to think in this way if infrastructure is to be fit for purpose in the future. And it must be applied at every stage in that process, including operations and maintenance, to derive the widest possible benefits – including carbon benefits.

It helps if the client adopts a commercial model that incentivises key outcomes, including sustainable and low-carbon ones, so that every party involved in delivery has an incentive to focus on these issues. This requires a change in behaviours compared with traditional commercial models, as well as collaboration between people with different skill sets to ensure that the wider implications of every decision are understood.

Again, this is different to the traditional approach to infrastructure delivery in which engineers focus only on a limited area. But when projects are put through a carbon lens, everyone involved has to look at the impact of the total project and ask: "What part can I play in delivering a lower-carbon solution?"

ACT NOW

Design and build for the 'right' outcomes

- Understand and apply an outcome-focused approach, for example by using Project 13 principles.
- Define the outcomes you want and make low-carbon behaviour one of the outcomes.
- Where possible, implement, promote or suggest a commercial model that incentivises outcome-based solutions.
- Make your infrastructure – whether creating a new asset or operating an existing system – works harder to achieve multiple outcomes.

24 www.tandfonline.com/doi/full/10.1080/23748834.2020.1766783

Case study: Water quality

Project: **Marston Water Recycling Centre**
Client: **Anglian Water**

Marston Water Recycling Centre, located near Grantham in Lincolnshire, processes wastewater for a population of 63,500. This is expected to rise to 76,000 by 2031, with plans for new housing developments in the area. The capacity at the recycling centre would be insufficient to cater for this growth, and the centre was also at the limit of its ability to remove ammonia to required discharge water quality standards.

The tertiary treatment process consists of four large grass plots covering 64 acres. Initially, the plan was to stop using these grass plots and build a new pumping station and nitrifying sand filter, which would involve erecting new concrete structures and phasing out the natural cleaning process. This would have a detrimental effect on biodiversity and public amenity, so the Anglian Water team came up with a revised plan to remodel the grass plots to provide greater treatment capacity instead.

Adopting specialist digital surveying techniques, the project team created a 3D model detailing the site's topography, vegetation, crevices, water bodies and pipework. Three of the existing grass plots were cleared of vegetation before all pipework was sluiced to ascertain the amount of additional drainage needed, and remedial works were undertaken on the inlet channel to ensure flows across all four plots were correctly distributed.

Soil from excavations and maintenance was re-used to repair crevices on the grass plots. Gravel from previous works was re-used. Water used to clear the draining pipes was recycled in a circular system to minimise the amount needed; dirty water was taken back to the head of the treatment works for cleaning/discharge. Waste from the project was diverted from landfill, including 1,608 tonnes of green waste, which was composted. Re-using the plots resulted in capital carbon savings of 90% compared with building a new treatment works, plus a 39% reduction in the overall cost.

Case study: Health, wellbeing and active travel

Project: **Connswater Community Greenway, Belfast**

The Connswater Community Greenway is a 9km linear park through east Belfast that follows the course of the Connswater, Knock and Loop rivers, connecting open and green spaces. The Greenway has created vibrant, attractive, safe and accessible parkland for leisure, community events and activities.

The £40m million project aims to improve the quality of life for the people of east Belfast, including 40,000 residents, pupils and students attending 23 schools and colleges, visitors, tourists and people who work in the area.

It links local residents to parks, leisure facilities, businesses, shops and places of education, while an £11m flood alleviation scheme incorporated into the project has helped to reduce flooding for 1,700 properties.

A paper published in 2020, Social Return on Investment Analysis of an Urban Greenway[24], by Queen's University Belfast, showed that for every £1 invested there was an expected return of £2-£6 over the lifetime of the Greenway.

Key facts and facilities:

- Has 16km of foot and cycle paths and 26 new or improved bridges and crossings
- Up to 5km of rivers cleaned
- Hubs for education, interpretation points and tourism and heritage trails
- Wildlife corridor from Belfast Lough to the Castlereagh Hills
- C S Lewis Square, a space for events and activities

"We need new heroes in civil engineering. The new heroes are achieving outcomes by building nothing – by adapting existing infrastructure or changing the way we use it."

Dr Jannik Giesekam, chancellor's fellow, University of Strathclyde

05

Strive for creative solutions

NUMBERS

3,200
unnecessary strengthening anchors avoided through careful data analysis of Glasllwch Interchange Bridges

01
entirely new and unnecessary wastewater treatment works avoided by increasing the level of phosphorous removal at two other Welsh wastewater treatment works

Engineers' education and training is almost entirely focused on designing and building new physical assets. Images promoting the profession usually show large-scale infrastructure assets – tall buildings, multiple-lane highways, statement bridges – all of which attracts a workforce that is inspired to make a valued physical mark on the landscape.

This focus on built assets makes it difficult for engineers to be open to different solutions, but that is what is needed in the future. To achieve the best low-carbon outcomes, engineers have to be solution-agnostic when they approach every problem. There should be no presumption as to what that solution might be. It might result in building a new asset, but equally the best solution might involve re-using or reconfiguring an asset; reducing demand; or changing the operation strategy for an existing infrastructure asset.

Committing to a zero-carbon future means investigating alternative scenarios that involve re-use, adaptation, and encouraging behaviour change that will radically reduce users' need for the asset. The role of engineers in the future will be to look at all possible options and recommend the solution that best meets all of the requirements – including lower carbon – whether that involves building or not.

This focus on creative solutions also demands acceptance that infrastructure does not exist in isolation. Every asset is part of a complex, integrated system of networks and services that includes physical, economic and social elements. These systems are becoming even more complex as asset owners expect their infrastructure to deliver a range of outcomes, including urban regeneration, decarbonisation and wider access to jobs and opportunities.

Traditional infrastructure delivery models do not reflect this, so ICE advocates a systems approach to infrastructure delivery (SAID) that will provide better outcomes for owners and users and help the sector to contribute to achieving net zero carbon emissions by 2050 (see panel, page 44). The approach is driven by the needs of users and places

"As advisers and designers, the 'why' and 'what' questions have never been more important, before we start with the 'how'. We must challenge the norm and strive to achieve smarter outcomes for all – collaboration and connected thinking are key to enabling this."

Graham Mortimore, manager of Mott MacDonald's water consultancy business

the onus on infrastructure owners and operators to translate those needs into clear outcomes, around which assets and networks are designed, delivered and operated as whole systems.

Policy-makers are already shifting their requirements away from the presumption that infrastructure solutions require new assets to be built. For example, the Infrastructure Commission for Scotland last year set out its blueprint for future infrastructure[25] provision, in which it recommended that asset management strategies by public sector infrastructure asset owners should contain a presumption in favour of "enhancing, repurposing, or maintaining existing infrastructure over developing options for new infrastructure". It added that new infrastructure should only be considered "where the relevant authority has demonstrated this is the most appropriate response".

This does not mean that engineers will no longer design or build infrastructure. New infrastructure will be needed to facilitate lower-carbon living: electric vehicle charging networks, renewable energy generation, active and public transport provision.

Clients, designers, constructors and asset operators cannot assume that the solutions of the past are suitable in today's lower-carbon world. They will have to be more imaginative and creative; more radical; more aware of wider issues and implications. Engineers should be challenging traditional approaches, changing the way problems are framed and approaching every project with an open mind as to what the best solution may be.

ACT NOW

Strive for creative solutions

- Be prepared to be radical. Learn how to re-use and adapt existing infrastructure.
- Understand how infrastructure is a complex system of systems.
- Understand, quantify and seek to mitigate whole-life carbon impacts and consider climate change in every project.
- Define yourself not by what you build but by what you achieve.

25 www.infrastructurecommission.scot/storage/245/FullReport_200120.pdf

Case study : Phosphorous reduction

Project: **Gwili Gwendraeth phosphorus reduction**
Client: **Dwr Cymru Welsh Water**
Engineer: **Mott MacDonald Bentley**

To improve water quality in the rivers Gwili and Gwendraeth Fawr – into which seven wastewater treatment works discharge – Dwr Cymru Welsh Water (DCWW) and Mott MacDonald Bentley collaborated to challenge the original plans for constructing a new treatment works and sewage transfer mains across ecologically sensitive land. Instead, a more sustainable and cost-effective systems-based solution was developed according to the Natural Resources Wales principles for the sustainable management of natural resources.

The solution decreases the level of phosphorous discharges at two of the seven existing works, adopting an innovative 'fair share' catchment approach that considers whole-life carbon, environmental and social outcomes.

This approach meets the objective of improving water quality in the two rivers, achieving a 78% carbon reduction (100,000 tonnes of CO2) and eliminating a 30km socially and environmentally disruptive pipeline, all at 25% of the cost of a conventional solution.

Case study: Glasllwch Interchange Bridges

Project: **Glasllwch Interchange Bridges**
Client: **Welsh Government/ South Wales Trunk Road Agent**
Project manager and structural assessor: **WSP**

WSP developed risk-based management and maintenance strategies for two hinged-deck structures, Glasllwch Crescent Interchange east and west overbridges, which form the gyratory above the M4 motorway. During previous structural assessments, the structures were found to have theoretical shear deficiencies, which would normally have required traffic restrictions and strengthening works. By undertaking a more detailed assessment of the structures, WSP minimised construction interventions and kept the bridges in operation using low-carbon methodologies.

WSP UK has collaborated with European experts to develop and implement new European standards for assessing and strengthening existing structures. The recent document CEN/TS 17440 gives engineers the tools to robustly demonstrate that some existing structures are stronger than previously thought.

If standard approaches had been used, 3,200 strengthening anchors would have needed to be installed into the deck of both Glasllwch overbridges. It would have taken about 52 weeks and required gangs to be working each night, with lane and full closures on the M4, resulting in increased journey times. By analysing data from the structure, WSP showed that sufficient reliability could be achieved without the need for any strengthening, avoiding the carbon impacts associated with the work as well as the socioeconomic effects and the noise impact on the local community.

"Civil engineers need to understand how infrastructure systems will cope when they are hit by climatic extremes. We need ingenious solutions to make infrastructure systems more resilient."

Jim Hall, professor of climate and environmental risks, University of Oxford

06 Be responsible for resilience

NUMBERS

10%
In Thailand, more than 10% of citizens now live on land that is likely to be inundated by 2050

25%
of London's rail stations are already at risk of flooding

100%+
Annual renewable electricity generation in Orkney comprises more than 100% of annual electricity use

In parallel with urgent action on carbon, equally urgent action is needed to build resilience to the onwards effects of climate change. Civil engineers' expertise needs to be refined to tackle this intensifying challenge.

Climate change is the long-term shift in average and extreme changes in weather across the world, primarily due to increased concentrations of greenhouse gases in the atmosphere[26]. This causes temperatures to rise and leads to long-term changes in climate, such as warmer temperatures, changes in precipitation and an increase in extreme weather events.

Climate change increases flood and erosion risk in coastal areas due to rising sea levels and increased storm surges, while inland areas see an increase in river and surface water flooding risk owing to an increased intensity of rainfall. The impacts of flooding on people, communities, wildlife and the economy are vast.

London is a case in point: new analysis released by Mayor Sadiq Khan shows that nearly half of the capital's hospitals, one in five schools and a quarter of rail stations are already at risk of flooding[27]. The analysis warns that if temperatures continue to rise at current rates, the London Underground could become unbearably hot for more than a month every year.

Meanwhile, the Organisation for Economic Cooperation and Development's modelling of the potential impacts of a major flood in Paris found that 30%-55% of the infrastructure sector would suffer from the direct flood damages but that 35%-85% of business would suffer from the disruption to the transportation and electricity supply and not by the direct flood itself[28].

There is plenty that needs to be done to understand the impacts of the current weather on infrastructure networks – not to mention future extreme events. In view of a highly uncertain future, we need to plan, design and operate flexibly to cope with climate change, and emphasise the need for resilient infrastructure systems.

26 IPCC (Intergovernmental Panel on Climate Change) 2019
27 Climate Risk Mapping – Greater London Authority and Bloomberg Associates, https://data.london.gov.uk/dataset/climate-risk-mapping
28 www.oecd.org/environment/cc/policy-perspectives-climate-resilient-infrastructure.pdf

"The only way to deliver an affordable, resilient and sustainable energy service to society is through an integrated, whole systems approach."

David Flynn, professor of smart systems, Heriot-Watt University

Networked infrastructure systems are central to our civilisation and are particularly vulnerable to the impacts of climate change, such as sea level rise, flooding, landslides, wildfires and droughts. More than 200,000km of roads are currently exposed to climate-related hazards globally. This could increase to 237,000km by 2050 owing to climate change[29]. The location, design and operation of infrastructure will determine how societies are affected by the risks of climate change.

In 2017, Hurricane Harvey demolished oil refining operations in Texas, causing flooding and power cuts and affecting an estimated capacity of 2.4m barrels per day – representing 13% of total refining capacity in the US[30]. This caused an increase in gasoline prices.

Infrastructure systems have several qualities that make them a priority for climate adaptation. Such networks provide vital services for society and the economy. They reach across borders. They provide protection against climate hazards. They operate as an interdependent 'system of systems'. Infrastructure investment locks in patterns for decades to come. They are essential to public services and institutional capacity.

One of the challenges that the infrastructure sector faces is the interconnected nature of its assets. For example, our mobility networks are becoming increasingly electrified, so a power outage will not only affect the electricity grid but also transport. A greater dependence on renewable energy may mean more offshore wind exposed to storm damage.

These systems need to be adapted so that they are more resilient even in an increasingly severe climate. An infrastructure system is resilient when it can resist the impacts of climate change and when, if conditions occur that exceed the strength of an asset, the system is still able to cope, respond, recover and learn from the experience.

Ensuring that systems are resilient requires engineering analysis and ingenuity. Climate adaptation (or resilience) is about understanding the shocks or stresses that are already in the pipeline: how increasing temperatures may affect communities financially, environmentally and socially, and what solutions can be developed to either adapt or prepare for these shocks or stresses. There needs to be a more comprehensive approach to adaptation of infrastructure. Climate adaptation and resilience need to be embedded throughout the whole lifecycle of infrastructure.

While there is an agreed target for carbon emissions – net zero – there is no specific target for climate resilience. The amount of adaptation that is needed will vary from system to system and from place to place. Engineers need to work with other professionals and stakeholders to agree how much should be invested in resilience.

Adaptation needs to be considered from the earliest stages of the planning process. Decisions regarding the location of new infrastructure are often made early in the process, yet they are critical for determining the exposure of infrastructure to climate risks.

Systems that can adapt when unexpected changes or changing future conditions affect them will better withstand uncertainty. Infrastructure systems are often costly to adapt or retrofit but there are ways that civil engineers can plan for better climate

29 Hall, J.W, et al. 2019. Adaptation of Infrastructure Systems: Background Paper for the Global Commission on Adaptation. Oxford: Environmental Change Institute, University of Oxford

30 www.money.cnn.com/2017/09/11/investing/harvey-refinery-texas-gulf-coast/index.html

Case study: Boston Tidal Barrier

The Boston Barrier in Boston, Lincolnshire, is one of the biggest civil engineering projects the town has seen. With more than £100m Flood Defence Grant in Aid invested, it protects more than 14,000 properties from tidal flooding.

Boston is a historic market town with an important maritime history, but it lies entirely within a floodplain. The most recent tidal surge, in December 2013, flooded more than 800 properties in 55 streets, leading to significant economic, social and environmental damage.

In 2014, the UK Government announced that the Boston Barrier was a national priority and in 2016 the scheme was approved by the Treasury.

Main components of the project are:
- Rising sector gate – a 362 t, 26m wide, 11m high gate that will be raised during tidal surges by two 55 t hydraulic cylinders.
- Barrier control building – provides control of operation and maintenance of the barrier.
- Wet dock entrance – an 18m wide, 11.5m high pair of vertical sector gates to complete flood wall protection around the port.
- Left bank works – an 830m long, 2m high flood wall; a 590m long, 19m deep anchored sheet-piled quay wall in the port; and three piled load-relief platforms for port crane operations during the wet dock closure period.
- Right bank works – a 525m long, 19m deep anchored sheet-piled flood defence wall and new landscaped embankment along the Macmillan Way to enhance the social and environmental impact of the project.

The Boston Barrier primary gate is now fully operational on its main hydraulics. Once complete, it will provide one of the best standards of tidal flood defence in the UK outside London.

The project builds local social, economic and environmental capacity to improve the overall resilience of communities to climate shocks and stresses.

The barrier is not only setting a new benchmark for flood defence construction with its innovative design, construction and implementation, but is a true demonstration of how the impact of a natural disaster can be assessed and responded to in a way that transforms an entire community, safeguarding the long-term future of generations in Boston.

The UN SDGs provided a framework for monitoring and evaluating the wider benefits of the project and enabled its full societal benefits to be understood and communicated by all key project stakeholders. The primary barrier, completed in 2020, has delivered benefits against all 17 goals across 25 targets and shows how sustainability can be embedded into all aspects of a civil engineering project.

To make sense of such a significant investment, the scheme needs to be considered in the context of wider societal benefits as well as the emissions cost of 'do nothing', such as multiple post-flood rebuilds. The Boston Barrier scheme has delivered increased climate resilience to Boston by providing improved protection from tidal flooding. It has also been shown that its construction, as a climate-adaptation project, has provided wider social outcomes.

"We need to make sure we are teaching engineers differently – at college and in practice – to better equip them to become the engineers we really need to help get us to a zero-carbon future."

Dr Mike Cook, director, Buro Happold and adjunct professor of creative design, Imperial College

resilience – for instance, by designing for future adaptation, reducing demand on infrastructure services or leaving land available for future adaptation.

As we build for the future, civil engineers are in a great position to help adapt to the climate risks. It is an opportunity for the profession to lead the way through innovation and systems thinking to drive new adaptation and resilience ideas.

The climate emergency presents an opportunity for engineers to take a more creative, collaborative and holistic approach.

Civil engineers' expertise needs to be refined to tackle these intensifying challenges: better understanding of the impact of climatic extremes on infrastructure systems and of human behaviours; systems thinking; and knowledge of how to adapt existing structures and of asset operation.

ACT NOW

Be responsible for resilience

■ Consider the total impact and value of your project – for example, what effect a project may have on the resilience of other nearby infrastructure.
■ Adopt a systems approach to infrastructure delivery.
■ Understand that it is in the early stages of the design process that we can have the most influence on resilience – for example, project location and conceptual design.
■ Stress test your plans with respect to a wide range of possible climate extremes that we could see in the future. Analyse what your system could resist.

Take a systems approach

Infrastructure does not exist in isolation. Every asset is part of a complex, integrated system of networks and services that includes physical, economic and social elements.

These systems are becoming even more complex as asset owners expect their infrastructure to deliver a range of outcomes, including urban regeneration, decarbonisation and wider access to jobs and opportunities.

Traditional infrastructure delivery models do not reflect this, so ICE advocates a systems approach to infrastructure delivery (SAID) that will provide better outcomes for owners and users and help the sector to contribute to achieving net-zero carbon emissions by 2050.

The approach is driven by the needs of users and places the onus on infrastructure owners and operators to translate those needs into clear outcomes, around which assets and networks are designed, delivered and operated as whole systems. It includes:

■ **Think outcomes, not edifices** Owners must clearly define the user outcome so that engineers can deliver the best solution.
■ **Owners must own projects** Owners should give direction on everything from functional requirements to acceptable risks.
■ **Think shovel worthy, not shovel ready** Front-end project development gives clearer definition, creates a more stable delivery environment and improves stakeholder engagement and management.
■ **Agile leadership** Spread authority through empowerment models that listen to the right voices at critical times, enable frontline people to make decisions and support baton handovers.

Get involved

"Taking ownership of the climate challenge for infrastructure, around both net zero and resilience, is a transformational pivot point for civil engineering."

Rachel Skinner, President, Institution of Civil Engineers

As an institution, we have put decarbonisation and climate resilience at the heart of our agenda alongside productivity, digital and other key transformation strands.

In line with the UN's Sustainable Development Goals (UNSDGs) and the UK's 2050 net zero target, we want to draw on the expertise of our global membership to build an international repository of practical measures that will allow civil engineers to implement the drive to net zero and provision of resilient infrastructure through their day-to-day lives.

On carbon, ICE's Carbon Project is creating a vibrant community of practice with our Carbon Champions as founder members to serve as a place to exchange best practice and test new ideas and methodologies. With no limits on lifecycle stage, sector or type of initiative, the responses so far have been diverse and impressive – and their potential to support a more sustainable future, from now, feels much more tangible.

With more than 40 submissions received so far, we have already seen some brilliant case studies, and have awarded the Carbon Champions status to nine projects so far, which are made up of 27 individuals representing 15 organisations. We want this cohort to grow at pace in 2022 and would encourage those finding success in carbon reduction to speak out. The Carbon Champions programme is open to all, not only to ICE members.

On resilience, ICE is committed to working with the International Coalition for Sustainable Infrastructure to act as a catalyst for engaging with the engineering community on the global agenda for climate action and resilience building. ICSI has been accepted as a Partner Initiative for the UN Framework Convention on Climate Change Race to Resilience global campaign, the sibling campaign of Race to Zero.

The campaign sets out to catalyse a step change in global ambition for climate resilience, putting people and nature first in pursuit of a sustainable and resilient world where we don't just survive climate shocks and stresses, but thrive in spite of them.

As a Partner Initiative, ICSI has pledged by 2030 to have influenced and/or delivered 12,600 projects in 2,000 cities to improve the climate resilience of 400m people. As a key early action, through 2022 ICE will be working with ICSI to publish an Innovation Project Database, which will establish an overview of global climate adaptation innovations, and their best practices and government champions.

This work will be based on global infrastructure research and ICE will be reaching out for case studies and best practice examples. These will be communicated as a searchable database with a user-friendly framework for any engineering discipline or location.

Established in 1818 and with more than 95,000 members worldwide, the Institution of Civil Engineers exists to deliver insights on infrastructure for societal benefit, using the professional engineering knowledge of our global membership.

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