Net zero infrastructure

Where UK engineers, investors and policymakers must focus to achieve the transition.

A 30-year transformation

In May 2019 the UK government legislated to cut greenhouse gas emissions to net-zero by 2050. It acted on advice and recommendations from its advisory group, the Committee on Climate Change (CCC), that rapid and total decarbonisation of the economy is required to achieve a stable climate and a sustainable future.

Engineers have a professional duty of care to safeguard society from harm. Codes of professional conduct are clear on exercising the precautionary principle, and on taking an inter-generational view of risk. While they do not currently address climate change by name, the issue is there 'written between the lines'. Every engineer should discharge their responsibility.

In addition to recognising the UK's need to play its fair part in decarbonising the entire global economy, the CCC and government also note that the UK's net-zero target is realistic – and economically desirable. The transition offers immense social and economic opportunities.

However, it requires a transformation of both the infrastructure we create and the political, social and behavioural systems that govern the way it is managed and used.

This paper is a synopsis of the CCC's recommendations. For those that wish to lead the way, the intention is that it will provide guidance and encouragement to build strategies that will accelerate us towards a net-zero future.

For those that choose to follow, the hope is that it informs an understanding of where industry and society are headed, and why, so that they won't unconsciously hinder progress.

Clare Wildfire
Global practice leader for cities, Mott MacDonald

Mott MacDonald has led the creation of an infrastructure industry collaboration to develop practical solutions for the net-zero challenge in the UK. If you'd like to know more please contact **clare.wildfire@mottmac.com** or **sam.friggens@mottmac.com**

Why net-zero?
Climate change is a response to the rising concentration of carbon dioxide and other greenhouse gases in the atmosphere, which trap short-wave radiation from our sun. The Intergovernmental Panel on Climate Change calculates that once the global temperature passes 2°C above the pre-industrial average a tipping point will be reached at which the climate change develops its own momentum. The 2015 Paris Agreement from the United Nations Framework Convention on Climate Change aims to keep the global temperature rise well below this, and commits to pursuing efforts to limit the temperature increase to 1.5°C. The UK's target of reducing greenhouse gas emissions to net-zero by 2050 is part of meeting its obligations under the Paris Agreement and ending its contribution to the rising global temperatures.

What is net-zero?
The concept of 'net-zero' is important. It recognises that achieving absolutely no manmade greenhouse gas emissions is all but impossible. To compensate for unavoidable emissions, ways will have to be found to remove CO_2 and the other greenhouse gases from the atmosphere, in volumes equivalent to the greenhouse gases emitted. For example, methane has a global warming potential around 25 times greater than carbon dioxide, so roughly 25t of CO_2 would have to be sequestered for each single tonne of methane emitted.

What are we counting?
At present, the UK carbon budget is 'territorial', meaning we don't measure or count emissions which our economic activity created elsewhere in the word. Strictly speaking therefore, not all the carbon emissions associated with manufacturing the products and delivering services we use are fully accounted for. Also, our carbon budgets exclude emissions from sectors of the economy which are traded in the EU Emissions Trading Scheme (thermal power generators and energy intensive industry, mainly). This is because they form part of EU-wide targets and including them would mean we double count in international reporting. Different nations and regions are able to move on the net-zero agenda faster than others, and there are different recommended transition programmes for each of the nations of the UK.

Additionally, individual regions and cities are declaring a higher level of ambition, trying to get to net-zero more quickly. Thought and clarification are needed as to how emissions are attributed and accounted for.

Carbon accounting will also need to make sense of offsetting. How fast are crops growing year to year and decade to decade? If emitters pay to offset using forestry, landscape restoration or bioenergy with carbon capture and storage (BECCS) schemes outside the UK, how will this be measured and audited?

The CCC has shown the way to net-zero

We in the infrastructure industry have 30 years to get there. Three decades is a long time in terms of our daily lives. It's long enough to raise a family and develop a career – or two. But in terms of business planning, regulatory cycles and investment payback, it is very short indeed. There is no time to waste.

The net-zero commitment in May 2019 replaced the UK government's preceding 2050 goal of cutting greenhouse gas emissions to 80% below the 1990 baseline. The government's advisory, the Committee on Climate Change (CCC), concluded that net-zero can be achieved for the same cost as originally predicted for the 80% target – around 1-2% of GDP. It illustrated one pathway, backed up by a wealth of original research and analysis of work by others.

Although the CCC's route to net-zero is not the only possible option, alternatives will likely involve playing with the same components. New technologies will undoubtedly come on stream in the coming three decades, but timescales are such that brand-new technologies (not already investigated by the CCC) will not help much for the crucial changes needed over the next 10 years.

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For us all, the burning question now is how to respond

To date the infrastructure industry has made some progress on doing what it does already in better and lower carbon ways. The CCC's message is now about transformative change in what we do as well as how we do it. New types of assets fit for a net-zero future will come on line, some assets currently in use will have to be decommissioned or re-purposed and plans for some new assets will need to be revised or scrapped.

Construction or life-extension of greenhouse gas-emitting infrastructure will increasingly become an 'option of last resort'. It should become impossible to implement those options without a clear link to compensation elsewhere.

Each planning, investment and operational decision must be focused on 2050 and the neutralisation of all UK emissions – net-zero.

Three strands of activity are required (below). The UK has tackled the low hanging fruit for the first two strands with relative success. Net-zero has brought into focus the need for action on aspects that are more difficult. And it is only now that a net-zero target has been set that the significance of the third strand, carbon capture and storage, is truly understood. It requires the infrastructure industry to consider how far it can go in reducing its emissions.

Three strands of activity

1. **Clean energy revolution: transform the energy system, including how we produce and use this energy**

2. **Curb energy demand: radically transform our approach to energy conservation, in construction and operation**

3. **If you can't remove it: capture and store remaining carbon emissions, forever**

Overcoming industry inertia

Anyone with experience of trying to change our industry knows that it is slow to respond. Therefore, the process of plotting what we have to do differently, and then doing it, should start now. But there are some factors to overcome:

- 2050 seems remote – still three decades away. In an industry governed by five-year business planning, regulatory and political cycles, a target 30 years distant is off the business-as-usual radar. How can net-zero be accorded the necessary urgency?
- The picture is complex. In practice infrastructure is a system of systems. Responsibility for emissions will be spread across those interconnected systems, and between asset creation, operation and use. For any one party, it is difficult to see where best to direct effort, where to draw boundaries, with whom to co-operate, and what changes to current business practices to make first.
- Net-zero requires underpinning with policy. That involves difficult choices, and political energy, which is currently focused elsewhere.

We need to kick into a much higher gear. Traditionally, when talking about infrastructure and carbon reduction, energy efficiency is the first major topic. Though it remains an essential component of success both economically and technically, a path based on conservation alone is no longer anywhere near adequate. Therefore, the focus here is first on the most radical changes we need to make.

Strand 1

The clean energy revolution

The pillars of a clean energy revolution are a rapid increase in the supply of renewable and other sources of very low carbon generation; and the conversion of demand for hydrocarbon-based energy into demand for electricity and other low or zero carbon fuels.

Increasing renewable electricity production

In the move away from reliance on fossil fuels there has always been some uncertainty over what mix of low carbon alternatives the UK should be aiming for. The CCC has clarified which alternatives are most feasible and cost effective for the UK. The emerging front-runner is renewable electricity generation, such as wind and solar. The CCC's scenario sees at least 45GW of new offshore wind, 35GW of onshore wind and 54GW in solar PV in order to create the scale of renewable technology needed for net-zero.

This will require accompanying changes to the architecture of the electricity grid. The variable nature of wind and solar affects the stability of the grid and its ability to match supply with demand. However, electricity storage is becoming a practical proposition. Factors include the falling price of batteries and the application of new energy trading mechanisms to encourage its uptake. (Surplus renewable energy results in fines and negative pricing; storage avoids penalties when supply outstrips demand and enables electricity to be sold for a profit when the supply-demand balance changes.)

The net-zero goal cannot be met through renewable electricity alone. The limitation on renewables' ability to ramp up production as demand dictates, despite the introduction of storage, means that other low/zero carbon power sources such as nuclear and biomass are still needed in order to provide a robust and constant supply.

Transforming our economy

To replace hydrocarbons with low carbon energy requires a transformation of our economy. It involves rapidly weaning transport, industry and the built environment off their diet of coal, diesel and petrol. Natural gas can have a much lower emissions footprint than other fossil fuels, and so will play an important transitional role in some areas of the economy. Overall this requires radical change to the products and services the energy industry provides and how the public uses them. It feels like a large and complex challenge that includes:

- Creating new infrastructure capable of generating and distributing low carbon energy
- Converting our everyday residential, business and leisure assets to run off it

For example, the CCC's net-zero pathway envisages almost total transformation of the transport industry to electrically fuelled vehicles, with hydrogen meeting the need for higher fuel density of large passenger and heavy goods vehicles.

A new hydrogen economy

Hydrogen meets other needs in a net-zero future. It is essentially an 'energy vector' – a means of storing and transferring energy. Renewable electricity produced in remote locations can be converted to hydrogen for transportation, then converted via fuel cells back into electricity at or near the point of consumption. This avoids the capital and maintenance costs associated with long distance high voltage electricity transmission, and also substantially reduces transmission losses.

Hydrogen can also be burned and is thus a potential replacement for natural gas in industrial processes that require a flame, or in the production of heat. A further attraction is that the UK has extensive existing natural gas infrastructure that can be modified and repurposed to store, transmit and distribute hydrogen.

Hydrogen is already produced commercially by reforming natural gas in a process called steam methane reforming or SMR. Hydrogen can also be produced from other hydrocarbons. Capturing the CO and CO_2 and sequestering it would supply so-called 'blue' hydrogen – carbon-free (or very low carbon) but from a carbon-based source. In conversion efficiency terms a preferable way of producing hydrogen is by electrolysing water, using electricity to split H_2O into its component parts. Electrolytically produced hydrogen from a renewable source results in an ultra-low carbon solution known as 'green' hydrogen.

At present neither carbon capture and storage nor the production of hydrogen through electrolysis are commercially proven at scale in the UK and the economics of each technology need further study. The costs of both technologies at scale are not yet clear. Costs of using steam methane reformation can be very location specific, and the cost of electrolysis depends on electricity prices and technology improvement, among other factors. Technology development and upscaling of both are urgently needed so that we can gain more real-world understanding.

For now, the CCC pathway includes both green and blue hydrogen, with recommended early activity to test the viability and competitiveness of each.

Zero carbon heat

Renewable heat is another critical piece in meeting net-zero targets, but how we get there is a major topic of debate. Electrification with heat pumps, replacement of natural gas with hydrogen and heat networks with renewable heat sources all may have a role, but none of these industries is at anything like the scale required. France, where heating is almost entirely electric, installs nine to ten times more heat pumps than the UK annually. But it will take time to develop a domestic industry of comparable scale. Also, commercial heat pumps are not optimised to UK building stock and climate – putting a commercial heat pump in a very poorly insulated house could result in a very expensive and unsatisfactory solution for the user.

The logistical requirements, infrastructure costs, trade-offs and regional/local variations between different heat supply options are still poorly understood. It is even possible that different regions of the country will take different paths. It is also likely that government will direct initial investment towards those parts of the country not connected to the natural gas grid. The carbon footprint of off-grid fossil fuel heating is much higher than for gas heated homes with modern appliances, and there are strong correlations to fuel poverty.

A role for nuclear power

Historically the bête noire of the sustainability movement, there is a broadening consensus that nuclear power, as a low carbon fuel source, is necessary in our journey to zero carbon. This is despite the ongoing moral concerns over creating increasing legacies of waste for future generations to deal with, and challenges in its financing and delivery. Although wind and solar photovoltaic output is increasing much faster than predicted even a couple of years ago, it is still estimated that we can't decarbonise fast enough to halt the increase in carbon in our atmosphere without nuclear.

It also serves a purpose in providing stable base load generating output and, although traditional nuclear power stations are slower to respond to fluctuations caused by variations in renewable output or consumption, they can to some degree assist with regulating the grid frequency. New generations of nuclear technology could be more flexible by design or be used to provide large amounts of low carbon heat. Thus, nuclear power has its place in the CCC scenario.

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Bioenergy

Bioenergy has an important role to play in the net-zero transition.

- As a transition pathway: it is possible to convert power generation and some industrial processes to burning biomass, and to blend biofuel into existing liquid fuel or inject biogas into the existing gas grid, to gain relatively quick initial carbon savings.
- It might be needed in applications which are very hard to decarbonise totally through other means.
- Bioenergy can be combined with carbon capture and storage (BECCS) to achieve net negative emissions – see below.

However, bioenergy is also the most controversial renewable technology for three reasons, listed right.

Despite these concerns, most of the feasible UK scenarios will require some level of deployment of a bioenergy solution that includes carbon storage given its potential to produce net negative emissions. Focus is thus on evolving the technology of biofuels to address wider impacts, for example by improving energy yield per hectare.

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Bioenergy is the most controversial renewable technology for three reasons.

1.

Burning biomass is not guaranteed to be low carbon. The benefit is clear for manufacture of biofuels from waste, or from well managed farming, especially if this displaces fossil fuels. But if the market for biomass includes wood from old forests the carbon footprint will be much higher, as CO_2 formerly stored in the natural environment will be released.

2.

Using land for biofuels can come into conflict with other land use, like growing food.

3.

Burning biofuel releases other gases and particulates harmful to the environment and public health. This is why burning wood products in urban areas is a focus of potential regulatory change.

Strand 2

Curbing energy demand

Decarbonising the energy system is a massive undertaking, with significant technical, political, social and economic challenges. The scale of the supply-side task can be reduced by cutting demand. Impacts and costs will be reduced if we step up efforts to improve energy efficiency to make what we have go further.

Improving energy efficiency

There is vast potential to improve the efficiency of our energy-using systems, products and services. In many areas of business and personal energy use, investing in energy efficiency makes financial sense. But there is a whole host of reasons why pure financial benefit is not sufficient to create the change needed. Not least are the complex supply chains involved in some of the most significant energy segments.

The government's response is likely to need a combination of incentivisation and regulation to step up the pace of change. In particular, regulating for improved energy efficiency is one of the simplest things that government can do, and it is 'fair' in the sense that it doesn't create unintended market distortions that some incentives have in the past.

The UK has managed to meet and exceed its carbon budgets so far, and has been more successful than any other G7 nation at growing the economy without growing emissions. Primary energy demand has fallen as our economy has changed – we have lost most of our heavy industry – and thanks to real gains in energy efficiency.

Many of the biggest changes have been driven by regulation, which has raised standards and removed the worst performing products from the market. Good examples of this are lighting products, with the introduction of first fluorescent and then LED lighting, and the regulatory requirement to phase out non-condensing gas boilers.

The timescale to 2050 means that, for many products in our economy, the innovation cycle could be repeated several times. With the right regulatory environment each cycle could create a product with improved efficiency. But there is one significant energy segment in which frequent improvement through innovation does not happen: our building stock. UK buildings are still some of the poorest performing in Europe, and this significantly correlates to fuel poverty and social deprivation. The lifetime of a building is typically many decades, so most of the buildings likely to be around in 2050 already exist. Despite at least 15 years of energy efficiency focus in building standards, the inroad into reduced building-related energy use has been slow because of this low rate of renewal. For this reason, any net-zero response will need to step up the focus on full-scale decarbonisation of existing buildings as well as setting net-zero targets for all new buildings.

Effort must be focused on creating practical and affordable solutions for mass retrofit in existing buildings, noting that even the 'easy' things we have already done such as cavity walls took a very long time to become normal practice. It is likely that the first movers will be large property owners like housing associations, local authorities and lenders and investors in the property market, who are concerned about long term asset value and can act at sufficient scale to create viable supply chains.

There will be a push for much tougher standards in areas where the benefit is easiest to realise, for example in new buildings. This is because building properly in the first place is generally cheaper than retrofit. Other target areas will be buildings in areas with no gas connection, as solid fuels have a much higher carbon footprint than gas. With an average lifespan of only 25 years, commercial buildings also present significant potential for improvement as part of a market-driven renewal cycle.

Managing energy responsibly

Even as supply and demand become ever more diverse and complex there is an imperative to find new ways to optimise efficiency.

The digital age has already enabled vast improvement in how energy use is managed. Sensors provide more accurate understanding of when inputs are needed, and real-time feedback combined with automatic control enable quick reaction to supply and demand fluctuations – all helping to reduce energy wastage. New forms of monitoring and detection also allow assets to be managed more effectively, with one outcome being that replacement of assets can be based on accurate assessment of condition, thus saving on materials and the carbon associated with their production when compared with a preventative regime.

But technology is also heralding a more significant shift in how we generate, distribute and use energy.

Driven by the built environment low carbon agenda, deployment of building-scale renewables – mainly photovoltaic electricity – means that energy no longer just flows from utility provider to consumer. Some consumers already operate independently of the grid or sell more than they buy.

Storing surplus

Electric vehicles will add substantially to power demand, but also represent an opportunity to provide the essential energy-optimising storage function: when vehicles are not in use, owners are incentivised to charge up the batteries when supply is high and demand low, then draw the power down from their vehicle rather than buying from the grid later – or sell power back to the grid. Building-scale battery storage ('behind the meter' storage) is starting to catch on, operating in a similar way. Industrial-scale storage is already being provided by a small number of multi-megawatt chemical battery plants and pumped hydropower schemes.

Plans for compressed air power storage are well advanced and the role of green hydrogen as a storage medium is also recognised.

Digitally assisted decision making

There is one more facet of the digital revolution: improved scenario planning in decision making. Developments in computer processing power coupled with better real-time feedback give the ability to check the impact of decisions as never before. As we develop increasingly accurate virtual models of our energy systems, we should be able to transform and operate our real systems with increasing sophistication and reliability.

> "There is potential to influence desired outcomes through the design of our infrastructure systems and how they come together to form the places where people live, work and create communities."

Behaviour change

The amount of energy we use is not just to do with the efficiency of systems that employ it. It is also directly impacted by our personal choices. These include whether we turn off heating, lighting or the TV when not needed; air dry our clothes or use a tumble dryer; travel by plane, car, public transport, or even take a trip at all (for example if a conference call is a viable alternative). Many lower carbon lifestyle choices even come with other direct benefits: for example, walking and cycling improve health and wellbeing.

The CCC scenarios rely on an element of behaviour change in many areas, which may involve a combination of public education, incentivisation and taxation. There is also the potential to influence desired outcomes through the design of our infrastructure systems and how they come together to form the places where people live, work and create communities. Examples of where these may play out include the design of urban areas to encourage more sustainable travel choices or community energy projects where there is a more direct link between personal energy use and its availability.

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[1] Extrapolated from the Infrastructure Carbon Review, 2013 (page 10). At the time the ICR was written the UK was committed to cutting carbon by 80%, relative to 1990 emissions. The percentage ratio of embodied/capital carbon to operational carbon was projected to shift from 4:96 in 2010 to 7:93 by 2025 and 18:82 by 2050. The relative significance of capital carbon will increase as the grid is decarbonised andoperational emissions reduce. At the same time, the substantial planned increase in infrastructure investment will tend to increase capital carbon emissions in spite of future construction efficiencies.

The carbon burden of how as well as what we build

Most of this paper is focused on the assets that will be needed to make the UK a net-zero or net-negative emitter of CO_2 from 2050 onwards. However, these assets all have a carbon component locked in by the nature of their construction. The carbon used in construction is known as embodied or capital carbon. Currently the infrastructure sector's capital carbon emissions as a proportion of the UK total is in the order of 6%.[1]

The progressive displacement of fossil fuel power generation by renewables and the transition from natural gas to hydrogen will bring down capital as well as operational carbon emissions. But production of steel, cement and other construction materials/products is heavily reliant on the high-intensity thermal energy provided by fossil fuels. The construction products industry is expected to be in the rear-guard of decarbonisation. We need to find new ways to produce steel and concrete, and also ways to reduce our reliance on them.

Strand 3

If you can't remove it, store it (forever)

The majority of scenarios for meeting 1.5°C globally involve some level of CO_2 sequestration, because they assume the global economy will not be able to transition away from fossil fuels fast enough. Sequestration options include land-use change, ecosystem restoration and reforestation, as well as technological solutions to capture and store carbon.

Nature based sequestration options

The CCC scenario includes a requirement to change the way we farm and use land, to lock carbon into plants and soil (as well as produce biomass). This includes land-based carbon sequestration from:

- Afforestation, via a significant increase in trees, hedges and other vegetation. Trees are viewed as a preferable method due to the 'sequestration density' they provide compared with other forms of vegetation.
- Peatland restoration; peatlands capture and store large amounts of carbon dioxide, but erosion caused by weather, grazing or land use has exposed and eroded the peat, leading to the release of carbon.

The recommendations could result in a transformational change in land use in the UK, with reward systems to recognising the 'public good' served by using land to mitigate the causes and adapt to the physical impacts of climate change. The multiple benefits of more responsible land use are recognised by the CCC, which concludes that 'enabled by healthier diets and reductions in food waste, our scenarios involve a fifth of UK agricultural land shifting to tree planting, energy crops and peatland restoration.'

Carbon capture and storage

An essential technology in the storage stakes will be carbon capture and storage (CCS). This is a broad term to describe artificial methods to take carbon out of the atmosphere and store it, typically in underground geological formations. It is a commercially immature but theoretically attractive solution to offset carbon emissions from industrial activities, including power production, that cannot be converted to clean energy sources.

The UK is blessed with geological conditions that provide significant technical potential for undersea storage of CO_2 and has a lot of gas infrastructure, with corresponding engineering competence. It was one of the earliest nations to seriously investigate CCS but proposed industrial scale pilot projects have not yet moved beyond the drawing board. The barriers to date have included cost: CCS as a CO_2 offset mechanisms for fossil fuel power production is currently more expensive than renewables.

As attention is focused on the net-zero end game, however, CCS has a role in the implementation of other contributors such as hydrogen. While it is widely speculated that the growth in renewables will make the production of green hydrogen economically viable, it is likely that the transition to a hydrogen economy will involve blue hydrogen in the near to medium-term. For example, there are plans to create industrial hubs at which hydrocarbons would be reformed to produce hydrogen. Captured carbon can be used directly in some industrial processes (eg in making cement), and surplus would be shipped to depleted oil and gas fields, with hydrogen supplied to energy intensive processes either co-located at the hubs themselves or connected via transmission pipelines.

The majority of CCS applications involve capturing carbon at the point of production – where fuels are burnt or methane is converted to hydrogen, but some potential for removing CO_2 from the air is also under investigation. Whatever technology is used, CCS solutions are likely to be much more viable at scale and when located close to the sites where CO_2 can be used, and/or large underground storage reservoirs exist. This is why the CCC scenario proposes clustered blue hydrogen plants, and also why CCS as a low carbon fix for individual gas appliances is not currently under discussion.

"While growth in renewables will make the production of green hydrogen viable, the transition to a hydrogen economy will involve blue hydrogen in the near to medium-term. An essential partner technology will be carbon capture and storage."

Playing our part

The change agenda brings cost and risk, but also opportunity.

Employment, health and cost savings
The significant need for new types of infrastructure is an opportunity for skills and jobs across the UK. A shift away from fossil fuels will have health benefits in terms of air quality. Behaviour change such as an increased walking and cycling for short journeys will improve health and wellbeing.

The cost of action also needs to be considered against the long-term costs of inaction, resulting in higher levels of loss from the impacts of climate change. Investment in mitigation must be balanced by investment in adaptation and resilience to the physical consequences of climate change, which are already locked in as a result of past and present emissions. However, the extent of losses and of the resilience investment required can be limited by decisive action to curb the concentration of atmospheric carbon.

The CCC's recommendations are not the whole story. Action is needed globally to prevent severe climate change. The UK's current contribution to global emissions is small but, as noted by the CCC, due to our cumulative historical emissions 2-3% of human-induced global warming to date has resulted from GHG emissions in the UK. The CCC route map shows how we can play our part equitably and, if all other nations do the same, the result for humankind and our planet can be a good one.

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Combating the causes and effects of climate change.