Presidential Address:
Climate Change – Engineering to Fix It – or Live with it
By Marguerite Sayers, CENG, President 2019-2020, First delivered. 24 September 2019

Engineers have always sought to harness the power of nature and the natural resources of the planet to deliver a better quality of life to mankind. This has been happening since the invention of the wheel, and at a greatly increased pace since the dawn of the industrial revolution. All of this advancement was considered – if people thought about it at all- as an unrivalled success. Advancement largely without negative consequence, free of harmful impact, chasing more and more, delivering better and better. The only concern, perhaps, was inequity in the distribution of wealth, education and infrastructure throughout the world.

The discovery of the potential climate change impact of all of this advancement actually began in the early 19^{th} century when the greenhouse effect was first identified. At that time, scientists first argued that additional greenhouse gases could be responsible for future changes to the climate. This viewpoint became increasingly more accepted by the scientific community in the 1970s. 98.5% of scientists now agree that climate change is real and there is no doubt that discussion on the topic has ramped up significantly in the last 5 years.

The Greenhouse Effect is actually a natural process, which results in the Earth's surface being about 33 degrees Celsius warmer that it would otherwise be. Because of the increased temperature, life can be sustained and thrive on earth. Far from being a bad thing – the Greenhouse Effect is vital to our existence.

The problem now is that since the Industrial revolution, human activities on earth – particularly the burning of fossil fuels (coal, oil and natural gas) – have increased the concentrations of greenhouse gases which has resulted in an enhanced greenhouse effect. Too much of a good thing if you will. Therefore earth is warming more than normal, and has been taken out of its natural balance. The atmospheric concentration of CO2 is now 45% greater than it was at the start of the Industrial Revolution. The increase in emissions caused by fossil fuels has been compounded by the reduction in CO2 sinks as a result of deforestation and changes in land use.

Until relatively recently, there was still a huge resistance to the acceptance of climate change – still is in some quarters. Public and political opinion has slowly changed, and the focus brought by schoolchildren in the past 18 months is also calling out older generations and raising the profile of the issue. The mood has therefore certainly changed. The actions, though, are so far lagging, and there currently is very little chance of staying within the 1.5 degree change that is considered the outer limit of 'safe' for our planet.

All over the world, it seems like there are more freak storms, floods and droughts. With the Earth undoubtedly getting hotter, heat waves are more intense and frequent, and as a result of higher temperatures, more water evaporates, leading to higher average global rainfall. Anyone under the age of 35 has never experienced a month with average temperatures that fall below the historical norm and, without action, probably never will.

July 2019 was the hottest month on record worldwide. 19,000 glaciers have now been studied in detail and they are melting – fast – at a rate of about 335billion tons of ice per year, which is three times the entire ice volume stored in the Alps. Extreme weather has claimed lives and destroyed livelihoods. Australia and

Argentina have suffered extreme heatwaves, while drought continued in Kenya and Somalia, and the South African city of Cape Town struggled with acute water shortages. At least one-third of the ice in the Himalayan Mountains will disappear by the end of this century because of rising temperatures, threatening water supply to 1.9 billion people. In 2016 alone, weather-related disasters around the world displaced 23.5 million people. In Europe, hydrological events have quadrupled since 1980 and have doubled since 2004. All global maximum record temperatures have now been exceeded – except, interestingly, Ireland's, measured at 33.5 degrees in Kilkenny Castle in June 1887.

According to Met Eireann, Ireland is also going to experience more extreme events in future. The last four years here were the warmest on record, and 2018 was 0.4°C warmer than the average temperature between 1981 and 2010. The winter of 2015/2016 was the wettest since records began, with in excess of 500mm of rain. Without changed behaviours, we are on track for a 4 degree global increase in temperature by 2100 which will rise sea levels by 0.5M – 1M, with the associated risk of flooding. Interestingly, we are likely to see less Atlantic storms in Ireland, but they are likely to be much more severe when they do occur.

If you are not concerned by those issues, maybe this one will resonate. 60% of the world's cocoa comes from Ghana and the Ivory Coast. If the temperature rises by 2.3 degrees C – and it may by 2050 - then it will be too hot in these locations to grow cocoa, hugely impacting on the world's ability to produce chocolate.

In all of the weather events that we have experienced to date, the most widespread impacts are interruption to services, and damage to the infrastructure that we rely on for safety, for shelter and for the smooth running of our society. Increasingly severe weather events will put huge strain on our existing infrastructure, which was designed with historic weather patterns in mind. A further complication is the current physical state of infrastructure. What we now have is a perfect storm (excuse the pun) between poor and deteriorating infrastructure, a lack of planned investment, population growth, less patience for service interruptions and a much higher volume of damaging weather events.

There is no doubt that the scientific world has provided excellent research and will continue to monitor trends in our climate challenge. However, finding the urgent practical solutions that will reverse the effects of climate change, will make our infrastructure more resilient in the face of increasingly frequent extreme weather events and will address the human condition in poorer parts of the world, falls to engineers.

Infrastructure is fundamental to our wellbeing, and even our survival. It is the first line of defence against flooding, storms, extreme heat, wildfires and other disasters. We need to start valuing it, to stop taking it for granted. The long-term nature of infrastructure presents a problem, because in the absence of a dramatic failure, it is difficult to generate any pubic sense of urgency or necessity for action. This has resulted in general deterioration and huge maintenance infrastructure backlogs throughout the whole world. The concern is that, when reality finally dawns, the lead-times and costs to correct the situation may well be untenable.

In the Irish State of Ireland report, we assessed the national infrastructure and mostly awarded C grades, except for Ds for housing, energy efficiency, private water schemes and coastal flooding. In the US, the American Society of Civil Engineers issue their equivalent infrastructure Report Card every four years. The latest grade awarded in the 2017 report was D+, as it was in 2013. Given the scale of the United States, the size of its economy and the resources at its disposal, this rings huge alarm bells for the state of international infrastructure. The ASCE estimates the US needs to spend some $4.5 trillion by 2025 to improve the state of the country's roads, bridges, dams, airports, schools, and more. For instance, there are estimated to be 56,000 structurally deficient bridges and over 15,000 high-hazard dams in the US.

In Russia, the Government has identified a $96 Billion, six-year plan to maintain and revamp the motorways, railways, ports and airports, though the plan is already behind schedule. India is expected to be the world's third biggest economy in a few decades but again, its infrastructure is lagging, with a significant $500 Bn investment programme announced and an estimated $4.5 trillion needed by 2040. And that is before the impact of climate change and extreme weather events is layered on top. Our international infrastructure is already compromised and under maintained – suffering for decades of underinvestment – and we have never asked so much of it.

While infrastructure has traditionally been designed to hold up to rare but expected extreme weather events, these events are no longer rare, and their durations and intensities are now well beyond original expectations. Modern society is highly dependent on infrastructure from telecommunications to energy, water to roads, airports to waste facilities. It was developed and is quietly managed by the engineering community and generally remains invisible to the general public – until there is an interruption in service. Such service interruptions have happened in virtually all parts of the world over the past number of years for various reasons – but very many of the interruptions have been as a result of severe weather events. What becomes very obvious in these situations is how quickly patience runs out, society starts to break down, and people get understandably frustrated and look for someone to blame, even for natural disasters.

There was a time when Wilma brought to mind a Flintstone, Ophelia a character from Hamlet, Darwin a famous biologist, Katrina the front woman with the Waves and Sandy was Olivia Newton John!

Now, hearing those names is just as likely to immediately remind people of severe storms. It is worth reviewing a number of these significant weather events and the impact that they had. They will be familiar to everybody – but it is amazing how quickly we forget the impacts and move on. And that is a challenge for engineers in garnering support for the huge investments required for both maintenance and climate change adaptation of infrastructure.

Hardly a season goes by now without a weather event or climate-related natural disaster of global significance – including

- The most recent – the devastation caused by Hurricane Dorian, with sustained windspeeds of 295km per hour, gusts of over 350km per hour, which decimated the Bahamas, resulting in at least 50 deaths, with 1300 people still missing, caused €7Bn of destruction, leaving at least 70,000 people homeless, and causing additional destruction in Canada with 450,000 people left without power.
- Hurricane Harvey (which has been described as a hurricane on steroids) a tropical storm in August 2017, making landfall in Texas with hurricane-level winds and 40 inches of rain, resulting in 80,000 homes being flooded, displaced 30,000 people, 6,200 distribution electricity poles and 850 transmission towers knocked, 21GW of generation affected. Harvey was the wettest tropical cyclone on record in the United States and it is estimated that up to 40% of the rainfall was as a result of climate change. It cost €161billion in damages and resulted in 107 deaths.
- Hurricane Maria was a deadly Category 5 hurricane that devastated Dominica and Puerto Rico in September 2017. Two months after the hurricane, fewer than half of Puerto Rico's 3.4 million residents had regained electric power.
- This summer, the rainforests, which produce approximately 20% of the world's oxygen and absorb 3 billion metric tons of carbon annually- equivalent to one third of our fossil fuel emissions - blazed with 70,000 individual fires.
- In the UK during August 2019, the damage to the dam at the Toddbrook Reservoir after unprecedented rainfall. The risk of over 1 million tonnes of water being released required 1,500 people to be evacuated and needed 400 tonnes of aggregate dropped on the spillway to temporarily stabilise it.
- The California Camp Fire at the end of 2018 was the deadliest and most destructive fire in California's history. It killed 85 people, burned 153,336 acres, destroyed 14,000 homes and cost $16.5Bn. The fire was facilitated by five years of drought.

And there are many others including Irene, Ivan, Isabel, Irma, Hugo and Haiyan.

Closer to home, we generally have more moderate weather – but we haven't escaped. In the past decade, we have had some notable Irish events, all identified as either record or once in a generation occurrences. There have, of course, been some severe weather events in the past – for instance Storm Debbie in 1961, Hurricane Charlie in 1986 or the Big Snow of 1947. However, the frequency of these severe weather events is undoubtedly increasing – and they are hugely challenging our infrastructure, causing social chaos, costing millions of Euros and threatening lives.

Reminding ourselves of some of the impacts:

Storm Darwin struck Ireland on 12th February 2014, with winds of up to 155km per hour, had the highest wave ever recorded at the Kinsale gas platform in Cork (25m), 280,000 customers lost electricity supply, 7.5 million trees were blown down (1% of the national total), airports were closed, there was severe damage to buildings and roads. Darwin was just one in series of nine storms that winter which accounted for millions of euros of damage and five people lost their lives.

Flooding early in 2014 was severe and devasting, particularly along the Shannon, despite 400 tonnes of water per second being discharged through Ardnacrusha (equivalent to an Olympic-sized swimming pool every six seconds) and an additional 275 cumecs per second through the Parteen Weir. The Poulaphuca reservoir was at record high levels, at its limit in terms of mitigating flooding in Kildare and Dublin and all-weather stations recorded at least twice the normal monthly rainfall in February.

Storm Desmond in December 2015 brought record wind and rain, more rainfall in a month than would be normal in an entire winter – the wettest and warmest December in over 100 years of records, caused €10M of damage to the roads infrastructure in Munster and significant flooding losses sustained by householders and farmers. And probably most famous for Teresa Mannion and her advice.

Storm or Hurricane Ophelia was the easternmost hurricane ever since records began and it reached Ireland on 16th October 2017, with gusts of up to 191km/hr recorded, and sustained windspeeds of over 110km/hr. Between Ophelia and the following storm Brian, five people lost their lives and the direct costs were €113M between insurance claims and state expenditure. 380,000 electricity customers lost supply, some for eight days, ESBN used three months' worth of materials, including 2000 poles and 350km of conductor, in one week of repairs.

Storm Emma was something completely different … The 'Beast from the East' struck Ireland at the end of February 2018 and was one of the most significant snow events ever recorded with maximum snowfall of 22 inches. The country effectively shut down, with severe disruption to travel, public transport, hospital appointments, schools and colleges, farming, crops and disruption to utilities. 10,000 Eir customers, 18,000 Irish Water customers and 100,000 ESB Networks customers all lost supply and the condition of the roads and weight of snow greatly hampered restoration.

Drought Summer 2018 : Nine months after the wind and rain of Ophelia, and four months after the Beast from the East, the summer of 2018 brought a heat wave and long-lasting drought conditions that forced Irish Water to declare a hose-pipe ban – or officially a 'National Water Conservation Order' – that lasted for nearly three months.

I understand that by now, you are probably weary of hearing details of a litany of storms – though it is only a small selection. But – that in and of itself is symptomatic of the weariness of our physical assets given unrelenting and incessant pummelling that they have been experiencing as a result of increasingly-severe weather events. And it is only going to get worse. 2017 was the most expensive year yet on earth for storm damage. In the US alone, there were 16 separate billion-dollar disasters and the total cost amounted to $306Bn. It is likely that even here in Ireland, the future cost to the state of dealing with extreme weather events will be upwards of €1Bn per annum, as reflected in the National Adaptation Framework. Flooding alone has cost €192M per annum in recent years, and is expected to increase six-fold by 2050. Who pays? We all do. Either in taxes, bills or in higher insurance premia.

There is also a high degree of interdependence between different infrastructure types – and that interdependence is increasing. Once one type of infrastructure is disrupted, it often results in disruption to another infrastructure or utility, which may appear to have escaped. The result of the UK and Wales power outages in August this year created gridlock in parts of London as a result of the loss of traffic lights, trains stopped running and major train stations were evacuated. The traffic chaos made it difficult for electricity personnel to get to where they needed to be and impacted response times. In the aftermath of Hurricane Maria, Puerto Rico lost almost total power and communications. As a result, the main airport could not function and so help could not arrive and people could not leave. The system to provide clean water, pumps to deal with flood water and life-sustaining medical equipment were all also compromised, causing additional disease and fatalities.

On the face of it, we have a choice when it comes to dealing with climate change. We can rapidly change our behaviours to ensure that we halt or reverse global warming by rapidly reducing emissions to mitigate or fix it. Or we can focus our attention on living with a world changed by climate change to adapt to it, or live with it. Both approaches are heavily reliant on the engineering community. And the reality is that it is not an either/or. If we just focus on living with the impact of every increasing climate change, we will probably not ever manage to catch up. And if we just focus on just mitigating global warming and the associated climate changes by reducing emissions, then we will be ignoring the damage already done, the climate changes already upon us and the current weakened state of our infrastructure. We therefore need to do both.

Firstly, let's look at what we need to do as engineers to work on mitigation – to engineer to fix, or at least reduce, the impact of climate change.

The first global attempt to rein in climate pollution was in1997 with the development of the Kyoto protocol. The objective of the protocol was to reduce greenhouse gas concentrations in the atmosphere to "a level that would prevent dangerous interference with the climate system." What is concerning about Kyoto is that it only applied to developed countries, did not include emissions from shipping or air transport, the US never signed up, Canada pulled out, and Russia, Japan and New Zealand are not taking part in the second commitment period. It therefore now only applies to about 14% of the world's emissions. Kyoto was followed in 2015 by the Paris Agreement. The Paris Agreement's long-term goal is to keep the increase in global average temperature to well below 2 °C above pre-industrial levels. To do this is arguably the greatest challenge humanity has ever faced.

Looking at the emissions profile in Europe, energy accounts for 31%, manufacturing for 22%, households for 22%, transportation for 12% and agriculture, forestry and fishing for 2%. In Ireland, it is different. Energy is 19%, Manufacturing is 5%, Agriculture is 32%, Heating (or Households) is 19% and Transport at 23%.

So, it is obvious that there is a particular challenge in Ireland because of the significant percentage of emissions that stem from agriculture. New Zealand has the same issue. However, it is not easy to reduce emissions from agriculture – not withstanding growing calls for vegan diets – and ironically, on the global scale, Ireland is also one of the most efficient counties in which to produce quality meat. So – a lot of the load has been falling on the energy industry to date. Ireland's EU target is for 16% of the country's total energy consumption to come from renewable energy sources by 2020. We also need to achieve a 20% reduction in Greenhouse Gas emissions by 2020. And to do so in the absence of nuclear, which is significantly of use in minimising emissions in other countries.

It is worth looking at the individual sectors and what has been done to date through engineering changes – and what developments might be considered in future – because significant changes have taken place to our traditional systems, with more planned.

Energy

The electricity all-time system peak in ROI was 5,090MW in 2010. As a result of now having 4,200 MW of renewables connected in ROI, the national generation portfolio has radically changed. One third of Ireland's energy was produced from renewable sources last year. Our target is to reach 40% by 2020, and with an additional 3000MW of renewables contracted for connection over the next couple of years, then that target should be reached. In Northern Ireland, the Northern Assembly also set a target of 40% electricity generation from renewable sources by 2020, and that target has already been reached. This is really positive in the context of our climate change targets, but it has required significant investment and is not without challenges for our traditional infrastructure.

One complication is that of system security. There is a general understanding that there needs to be back-up available when the wind isn't blowing or at night, when solar generation is non-existent. But – operating an electricity system is more complicated than that, with demand and supply needing to be balanced at all times by EirGrid to prevent frequency deviations. In the event of an issue on the power system, traditional synchronous generation from large thermal and hydro machines provided inertia or fault ride-through to keep the frequency reasonably stable until replacement generation kicked in. That frequency response is not available from smaller, non-synchronous wind turbines and renewable sources, and so the more renewable generation that is added to the system, the more grid security is potentially compromised. The blackouts this summer in London and SE England, as well as Argentina and Uruguay, are still being investigated but they are symptomatic of the energy transition and will become much more commonplace if we do not find some new solutions to system security. A new market (estimated to be worth €50-€70M Bn in Europe alone) is rapidly developing to provide replacement system services.

The overall energy system is changing in three key ways

(a) addition of increasing amounts of climate-friendly generation
(b) providing system services to replace the traditional synchronous generation and
(c) seeking to provide reserve for a 'rainy day' that fossil fuel stocks provided in the past.

In relation to providing clean generation, developments on our system include

- Significant use of on-shore wind resources, a dramatic upswing in grid-scale solar interest, as well as the emergence of microgeneration and 'prosumers'
- Waste-to-energy plants like the Covanta plant in Ringsend
- The use of renewable gas by Gas Networks Ireland (GNI), as a clean, renewable and carbon neutral fuel and can reduce the reliance on imported gas. There are plans to achieve 20% Renewable Gas on the network by 2030.
- The possible use of Carbon Capture and Storage for Irish CO2 emissions, with the signing of a memorandum of understanding with Norwegian company Equinor.

In relation to the other two areas of system services and storage, developments include

- demand-side management schemes, whereby customers agree to reduce their demand at critical times and are compensated accordingly
- multi-functional grid-scale battery installations to commercially provide the frequency response traditionally provided by synchronous machines, to store renewable energy for when the sun is not shining or the wind is not blowing and also to solve other network constraints
- Vehicle-2-Grid use of available EV batteries to provide system services.
- Other storage solutions such as pumped storage, and hydrogen. Hydrogen may yet provide the best solution to storing excess renewable generation, providing some system resilience and national self-sufficiency.

Therefore, a lot of progress has been made in respect of renewable energy. However, we are in danger of missing both our 2020 and 2030 overall ROI emission targets because other sectors are not making as much progress – or not making progress quickly enough.

Transport

In relation to renewable transport, we have reached 7.4% of the 2020 binding target of 10%.

Therefore, there needs to be a much more rapid adoption of EVs or other low-carbon transport solutions and public transport if we are to reach our renewable transport target. The most advanced and readily available technology for private cars is battery electric vehicles (BEVs). There is no doubt that with the increased ranged of EVs and the presence of national infrastructure, there has been a recent surge of interest and sales of BEVs have gone up 273% increase relative to last year. 2,758 BEVs have been sold so far in 2019, compared with 48,291 diesel and 42,349 petrol cars. Hybrids made up 12.5% of sales.

Ten years ago, ESB provided one of the first national EV infrastructures in the world. However, with the increase in demand, change in technology and vehicle ranges, significant enhancements to the network are required and now planned for the next number of months. Private restricted networks are slowly being developed by companies such as Ionity and Tesla and supermarkets/businesses are providing charging facilities for their customers and staff.

HGVs account for only 3% of the vehicle population, though over 40% of the transport CO2 emissions and need a solution other than electricity. GNI has a number of Compressed Natural Gas plants planned or in operation (Dublin Port, Cashel, Kinsale and Shannon) to provide an alternative fuel source for HGVs. Biofuels and Bio-CNG is of significant interest to companies with big transportation requirements, both ecologically and commercially, as the best answer currently for their emissions challenge. Fuel cells using hydrogen formed by spare renewable energy could also yet prove to be the ultimate solution to overall transport emissions. But – no matter which technologies win out, it is critical that the conversion of our transport to low carbon takes place urgently, as 14% of global CO2 emissions come from transport.

Householders / Heat

An even greater challenge is that of renewable heat. There has been good progress on the energy efficiency for new homes with over 90% of houses built since 2011 being A or B rated. However, overall, Irish household emissions are 58% higher than the European average. GNI intend converting 20% of gas to renewable gas by 2030 which will significantly improve national carbon emissions. However, over 900,000 households are not connected to the national gas network and need an alternative solution

The Government's current target is for an energy retrofit – including heat pump installation – to 400,000 homes by 2040. Achieving this target will require a huge national change-of-mindset and incentives to overcome the inertia associated with decades of tried and trusted fossil fuel domestic heating solutions.

So – we are working our way through various solutions to mitigate emissions but it requires huge investment, leadership by politicians, technical solutions provided the engineering community and public mindset changes. And mindset changes are slow. A sobering parallel is the pace of change which applied to the global attitudes to smoking, despite overwhelming evidence of harm. If the same pace of mindset change applies to low-carbon choices, then even the countries that have signed up to the international treaties, will miss the target dates for critical climate change by 125 years.

Now – moving to our second issue of living with or adapting to the climate change effects that have already taken place. As mentioned, the world's infrastructure is already in an weakened state, requiring billions of dollars of investment just to maintain the current levels of service. And that is before global population growth and raising the infrastructure standards in the 2nd and 3rd worlds is considered – not to mind climate change impacts. Even if we are successful in mitigating climate change, and keeping global temperature increases under the critical 2 degrees required by the Paris agreement, we will still have to live with the increased number of violent weather events that global warming to date will bring about. Extreme events cause societal and personal discomfort through loss of service, but also loss of life and it is our job as engineers to minimise those impacts. New infrastructure will be required to adapt to climate change – irrigation systems and water provision in areas that are now drought-prone, more resilient physical telecommunications, gas and electricity networks, robust dams that have greater capacity to cope with record rainfall, significant instances of coastal and flood defence systems due to a rise in sea levels and flash floods, fit-for-purpose waste water systems, relocated and stronger road systems, new energy systems and all manner of storage systems to mitigate service disruptions.

There is a lot of research, technological development and planning already taking place as a result of these issues. Some of it would be happening anyway as a result of normal innovation and the need to cope with global population growth of 45% by 2100. However, we are also striving to maintain 'normal service', to protect life, and to minimise damage in the face of the new realities of more frequent, extreme weather events. In the past, pumps, for example, were sized based on historical precipitation events. Electricity circuits were designed to maintain safe clearances at historic ambient air temperatures. Bridges were designed for expected flow rates in the rivers they cross. Historic design parameters are now no longer fit-for-purpose. Infrastructure design and the environment are intimately connected. And the environment is changing.

The American Society of Civil Engineers is advocating the idea of integrating climate change into the design of infrastructure, and have written into their Code of Ethics that engineers have an obligation to 'strive to comply with the principles of sustainable development in the performance of their duties'. They also have a committee dedicated to ensuring infrastructure resiliency. New infrastructure needs to be planned, designed and built, keeping in mind the impact of climate change over its lifetime – not just on the day it is commissioned. Existing infrastructure may need to be retrofitted, or reinforced, or operated differently.

Traditionally, infrastructure was designed to manage 1 in 100 year or 1 in 1000 year events, and then oversized to provide a safety margin. No thought was given to these margins being breached, as they were not expected to be. Given the increased frequency of extreme events, and the increasing climate uncertainty, it is virtually impossible to practically provide the level of robustness that would be required to cope with every climate eventuality. The focus therefore needs to move away from fail-safe infrastructure to planning operation and recovery strategies. Emergency work-arounds if you will. By way of example, in the Netherlands, rather than build bigger levees for water management during extreme events, it is considered more cost effective now to compensate the farmers for loss of their crops during such events.

In future, more intense rainfall will result in damaged and impassable roads, airport closures, bridge failures, overflowing storm drainage, overloaded wastewater and water treatment facilities. Higher temperatures will result in damage to and 'melting' of roads, melted and inaccessible runways and power system failures due to high air-conditioning loads. Stronger winds will cause structural roof and building damage, power and telecommunication network failures (including broadband), closed airports and damage to ships / ports. More severe thunderstorms will cause flooding, lightning-related fires, hail damage, power and communications outages, transport delays and more significant snow and ice storms will cause roof and building collapse, power and telecommunications outages with consequential loss of heating and possible subsequent flooding.

There are solutions – or at least improvements – that help with many of these issues. To deal with extreme heat, the use of more concrete or asphalt with an altered composition would help roads retain their function – particularly important with the increasing incidence of mass evacuations as a result of climate events. The use of digital roadway markings so that capacity and directionality can be easily changed, as well has having dedicated access for emergency vehicles, could also make a huge difference. Higher capacity culverts and drainage systems, as well as dual function recreational/storage ponds and permeable paths will help cope with intense rainfall. Paths in ice and freeze-prone locations may be built with phase-change materials which can store and release energy to increase the safety performance of the path. However, as a result of sea-level rises, roads may need to be relocated which is extremely expensive. New buildings may require deployable flood barriers, with energy equipment designed to be water-resilient or installed at height. Houses can be designed with V-shaped roofs or green roofs to efficiently absorb rainwater, which reduces run-off and can be stored in tanks for future use.

All over the world, the provision of quality drinking water is a vital and challenged service – and is becoming more so. Irish Water has a particular challenge with the predicted drier summers giving rise to drought management concerns as happened in the summer of 2018. At any point in time, there is only so much water that can be extracted from the rivers without negatively impacting the ecology, so bigger reservoirs and a more extensive, higher capacity, more interconnected network will be required. Water provision is an acute issue in Dublin, with current daily extraction levels from the Liffey at 570 million litres per day, and an absolute daily limit of 600. With increasing frequency of summer droughts, population increases, and the lead-time in providing such infrastructure, there is an urgent need to find a new water supply for Dublin. Hence, the planned Shannon Water Extraction Scheme.

In Ireland, the two climate impacts that we have seen most of to date are high winds and intense rainfall. As a result of instances of intense rainfall, dealing with wastewater is one of our biggest future challenges - particularly in Dublin, but there are issues throughout the country needing significant investment. Combined sewer-storm water systems were the standard for many cities to manage wastewater and storm water in the late 1800s and early 1900s. However, due to changes in public health and environmental concerns since these systems were built, most cities now recognize that the cost savings of combining these systems is outweighed by the hazards created when sewage overflows into waterways during heavy precipitation events. As a result, some cities have spent millions upgrading and de-coupling their wastewater systems.

In Dublin, the Ringsend Wastewater Treatment plant treats about 40% of the country's sewage. By using on-site storage, Ringsend can cope with 22,000 l of wastewater per second. However, the storage has a three-hour capacity, and after that, the choice is spill into the bay or to risk flooding domestic houses and businesses around the city with sewage. The increase in population in the city has already strained that infrastructure, but it really was not designed to cope with the volume of wastewater caused by the intense bouts of rainfall that we now see caused by climate change. As a result, there have been over 100 incidents of untreated waste water have overflowed into Dublin Bay, including the well-publicised incidents this summer which temporarily closed a number of beaches. Clearly, huge investment is needed to resolve this issue – either by separating the wastewater and surface-water systems or increasing the storage and treatment capacity.

We also need to consider flexibility in design and learn from our international colleagues. A really novel (though expensive!) example is Kuala Lumpur's Smart Tunnel, which transitions from carrying traffic to storm water when there are high levels of precipitation. The tunnel was built in 2007, is 9.7km long and cost €450M. It has three levels, but the upper two are converted from traffic tunnels to storm water tunnels using water-tight gates as soon as there is heavy rain, diverting water away from the city centre. The tunnel has solved traffic congestion, but also saved millions of dollars of flood damage since its opening.

More frequent flooding incidents – either from rising sea levels or from intense rainfall events -are another growling problem here which is bringing misery and financial hardship to farmers, householders and businesses. The flat hinterland of the slow-moving Shannon floods almost annually, Cork has had serious flooding incidents in 2009, 2012 and 2014, and even non-traditional flooding locations like Donegal have had events. The clean-up in all cases has cost millions and significant insurance and personal losses. €430 Million has been allocated for flood defences between 2017 and 2021 but while such measures are effective in towns and cities, it is much more difficult to deal with the banks of a river as extensive as the Shannon. One specific city plan being advanced by the OPW, in conjunction with Cork City and County Councils, is the Lower Lee Flood Relief Scheme. The scheme will run from the Inniscarra dam to the City Centre, protecting over 2,100 properties, against tidal and river flooding. This is the largest flood relief investment project ever undertaken in Ireland, and represents a €140M investment in Cork City.

It is also worth considering the specific future impacts of intense weather events on key national services such as gas, telecommunications and electricity. The overhead telecommunications network can be as badly affected as the electricity network, but the pervasive use of mobile phones now means that once the mobile communication towers continue to operate and have power supply, then the negative impact that would have been there in the past is hugely diluted. The gas network is quite resilient, being largely underground. However, pipelines crossing floodplains need to be monitored, as the relatively lighter gas can result in the pipes becoming buoyant and rising, resulting in physical stresses.

As we have seen many times over the years, the electricity network is very susceptible to damage during storms and also has a knock-on effect on interdependent services such as heating systems, vital medical equipment, water pumps, telecommunication towers, WIFI, traffic lights – and now, personal transport with the increased use of EVs. The estimated cost to each electricity utility in the US of storm damage and lost revenue over the past 20 years is €1.4Bn, and with the increasing intensity of storms, is expected to increase by almost 25% by 2050. With the impact on customers and their lifestyles, as well as costs of this magnitude, utilities are considering what they can do to strengthen for their network. Given that there is a 20% probability at present of having a severe storm in any year, some utilities have hardened their grid by 'super-sizing' their poles and structures on a select number of critical circuits in the hope that they can withstand more severe storms. In the wake of Storm Sandy, New York's ConEd spent $1Bn in making their substations and control panels flood-proof. Similarly, Florida Power and Light spent more than $3Bn on the same programmes and undergrounding some circuits in the aftermath of Hurricane Wilma. However, it still suffered over $1Bn of damage during Storm Irma in 2017.

Some of the other strategies being used to cope with grid outages are to seek to localise generation using solar farms or utility-scale batteries, which can be used in combination with microgrids to reduce the impact of a storm to some communities. However, the relief is quite restricted and for a small catchment (typically used for critical services like police stations, medical centres and media) and is more a side-benefit of the other advantages that these installations can bring. A lot was made of the world's biggest lithium-ion battery was installed in South Australia in 2017 by Tesla in the Hornsdale Power Reserve near Adelaide after a total blackout. It is a 100MW, 129MWhr battery which is used in tandem with a local windfarm. The installation cost $64M but during its first full year of operation in 2018, it earned $20.7M in revenue, demonstrating the market for new grid services. Hence, it is a commercial success – though it is uncertain what relief it will actually bring after a severe storm. The insurance industry is very interested in working with utilities on these new technologies as it reduces consequential losses, and also the claims by the utilities, so it has a vested interest in mitigating the severity of the impacts. The total costs of natural disasters in the US since 1980 is estimated at over $1.5 trillion.

In conclusion, palaeontologists who have studied historic extinctions are warning that we are riding our luck and rapidly heading towards a critical threshold with global warming, from which the world will not be able to recover, no matter how many mitigations we subsequently put in place. To some extent, we have engineered our way in to this situation, and we need to engineer our way out of it. Scientists and climatologists have been shouting about the seriousness of the situation for some time - and the message if finally getting some traction, as demonstrated at events the Climate Strikes this September.

However, it is up to the engineering community to educate people more specifically on the limits of infrastructure in light of climate change. Not to just exist as the silent problem solvers, working away in the background - because we cannot solve this crises on our own. If we do not draw attention to the growing global infrastructure issues and the likely impact of climate change, the public will remain in the dark and will be blindsided as weather events cause major disruption to their lives when infrastructure fails. As an engineering community, we therefore need to be front and centre of the call for action on climate change. We need to explain the consequences for all of us of inaction so that we provide necessary information, promote necessary behavioural changes, encourage the right choices and garner the financial support necessary to invest in the world's infrastructure.

The cost of engineering our way out of climate change is going to be enormous. The cost of not doing so is unimaginable.

Thank you.