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Do we need an 'Energy System Architect'?

Richard Beake, Dr David Cole, Adam Gait

Meeting the UK's 2050 Net Zero target is achievable, but the risk of falling short is very high.

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Executive Summary

We have less than 30 years until 2050, by which time the UK is committed to be a 'Net Zero' greenhouse gas emitter. The Government's announcement of the 'Ten Point Plan for a Green recovery' (TPP) and the Prime Minister's announcement of the 68% target for 2030 signals the recognition that urgent action is required across government if we are to achieve Net Zero by 2050 (NZ2050).

The TPP initiatives are most welcome. They address critical sectors of the energy system including electric vehicles, heating, hydrogen, carbon capture and storage (CCS), offshore wind and nuclear, all of which require urgent action which cannot be achieved without decisions from government.

The Prime Minister announced his intention to establish Task Force Net Zero. Whilst a task force might address some of the shortcomings of the present arrangements; we think a radical shake up is required and believe an Energy System Architect (ESA) must be an integral part of that reorganisation. Looking back just a few years, the Government set up an Olympic Delivery Authority to drive the preparations for the London Olympics, which was a great success. Compared to the challenge of Net Zero, the Olympics were simple.

Surely, if we are to achieve Net Zero in 2050, we need to mobilise the best systems and programme management talent we have. Perhaps the Prime Minister's task force should be charged with setting up the ESA.

Nobody knows exactly what our energy system will look like in 2050, but we have a strong indication that our electricity demand will be at least twice what it is today. Furthermore, given the age and the technologies in our existing generator fleet, almost all of it will have to be replaced by 2050.

So, to be clear, between now and 2050 we must build sufficient electricity generating capacity to produce at least twice as much power as we consume today.

If the future system is dominated by intermittent generators whose load factor is 60%, replacing firm power with a load factor of 80% then in terms of generating capacity, we would have to build 2.7 times our current generating capacity. In July this year we published our report 'The Race to Net Zero' [Ref 4] in which we showed that, for the energy supply side of NZ2050, our current build rate is less than half what we need. The National Audit Office [Ref 20] has made extensive comments and recommendations regarding the cross-government working required to achieve NZ2050, but it is clear that the required mechanisms are not yet in place.

> The CCC's NZ2050 scenario shows that 40% of the nation's energy in 2050 will depend on CCS and this will require 176Mt/yr of CO_2 storage

The doubling our electricity production in the Climate Change Committee's (CCC) NZ2050 scenario will depend on an entirely new system of infrastructure for Carbon Capture and Storage (CCS). It is now 17 years since the 2003 Energy White Paper identified the need for CCS. We have had two failed demonstrator competitions and extensive consultations, and yet not one molecule of CO_2 has been sequestered.

The TPP has identified the current shortfall in performance and brought forwards the ambition to have two CCS clusters operational in the mid 2020's and two more by 2030. The target is to have the capacity to sequester 10Mt/yr of CO_2 in 2030. The CCC's NZ2050 scenario shows that 40% of the nation's energy in 2050 will depend on CCS and this will require 176Mt/yr of CO_2 storage, 18 times the TPP's ambitious 2030 target. Rational risk-based analysis quickly identifies this as one of the major risks to achieving NZ2050 according to the CCC's scenario.

We hope that detailed proposals will show how the TPP's demanding 2030 target can be achieved and note that the £1bn of funding mentioned in the TPP is the same sum as was available in the previous two competitions, neither of which managed to bring forwards any demonstrator projects. To paraphrase the Select Committee's April 2019 report [Ref 18], this time really must be 'Third Time Lucky', otherwise the CCC's scenario which underpinned the UK's commitment to NZ2050 is non-viable.

The CCC's scenario for 2050 also requires a system of hydrogen production, storage and distribution which will deliver 30% of our energy. There remain many unresolved issues, both technical and commercial, that are holding back the use of hydrogen. No substantial deployment of hydrogen can be contemplated without a firm policy framework and infrastructure strategy.

The TPP recognises this and sets an ambition to create a demonstration of hydrogen adoption at the neighbourhood level (600 homes) in 2023 and growing to a full-size town by 2030. This initiative must be driven to a conclusion by 2030 at the latest.

The success or failure of the CCS and hydrogen initiatives will have a massive impact on the requirements for electricity generation. With respect to the selection of generation technologies the electricity market created after privatisation and reformed in the 2013 Energy Act is now effectively defunct.

Through a complex web of technology specific market interventions, the Government is now the effective central buyer of electricity. Government decides what technology gets built and when. For any who doubt this, the TPP announcements with respect to offshore wind auctions and future nuclear capacity provide absolute confirmation – it is government that decides what we build.

There is however no published evidence of a strategic plan guiding this enormous purchasing power which, step by step, is 'locking in' our 2050 energy system.

The complexity of the energy system and the interdependence between electricity (which must be balanced second by second) includes: hydrogen (which may both deliver to the end user and act as a buffer in the system); and CCS (which could underpin as much as 40% of our energy in 2050). This means that decisions effecting the future system configuration should be made on a whole system basis and that both strategic and operational risks should be properly factored into those decisions. It is not evident that this is the case today.

We believe that an Energy System Architect could provide a holistic, risk-based approach to strategic planning, facilitate enhanced operational risk management and, by separating delivery responsibility from policy development, provide greater transparency and accountability for a programme of investment amounting to hundreds of billions of pounds over the next 30 years. Currently the shape of our future system is heavily influenced by economic modelling in pursuit of the least cost pathway to NZ2050. Whilst this is an essential tool in strategic planning, it is not a sufficient basis for detailed definition of our future energy system, which must rely on a strategic approach including risk-based systems engineering and the established practices of programme management.

To reiterate, we recommend that the Prime Minister's Task Force Net Zero should urgently consider the establishment of an Energy System Architect, along the lines set out in this brief paper.

1. Background

In October 2019 Atkins published its 'Engineering Net Zero' Summary and Technical Reports (ENZ) [Ref 1]. These reports focussed on major capital projects in the energy sector and summarised Atkins' internal assessments of the risks, challenges and opportunities arising from the UK Government's commitment to achieve Net Zero in 2050 (NZ2050).

Over the past 12 months Atkins has published follow-up reports on specific aspects of NZ2050, which can be found on our Engineering Net Zero micro-site.

Little did we know in October 2019 what a turbulent year 2020 would be for all of us. Covid-19 has had a massive economic and social impact, and this continues. Such disruption of patterns of working, social interaction and travel are unprecedented in modern peacetime experience. It is particularly sobering to realise that the potential implications of climate change, although measured on a different timescale, could be even more profound. Covid-19 has not even begun to point to the more fundamental changes that will be driven by climate change, for example massive pressures of population movement driven by changes in patterns of agriculture and sea level change.

The last 12 months has seen the continued flow of papers and opinions on NZ2050, many of which are conflicting. The human tendency to look for good news drives governments to trumpet successes, while failures are given less prominence. Even the Climate Change Committee (CCC), in the foreword to its 2019 Statutory Progress Report to Parliament [Ref 2] stated in paragraph two that there were "grounds for optimism" but by paragraph five it was calling for urgent action and by paragraph eight it was advising that government should start planning for climate change of 4^{0}C. The 2020 report reiterated the main message calling on government to 'Act Courageously'. The UNEP, in the introduction to its 2019 'Emissions Gap Report' [Ref 3] began paragraph three with "The summary findings are bleak" and paragraph four ended "it is evident that incremental changes will not be enough and there is a need for rapid and transformational action".

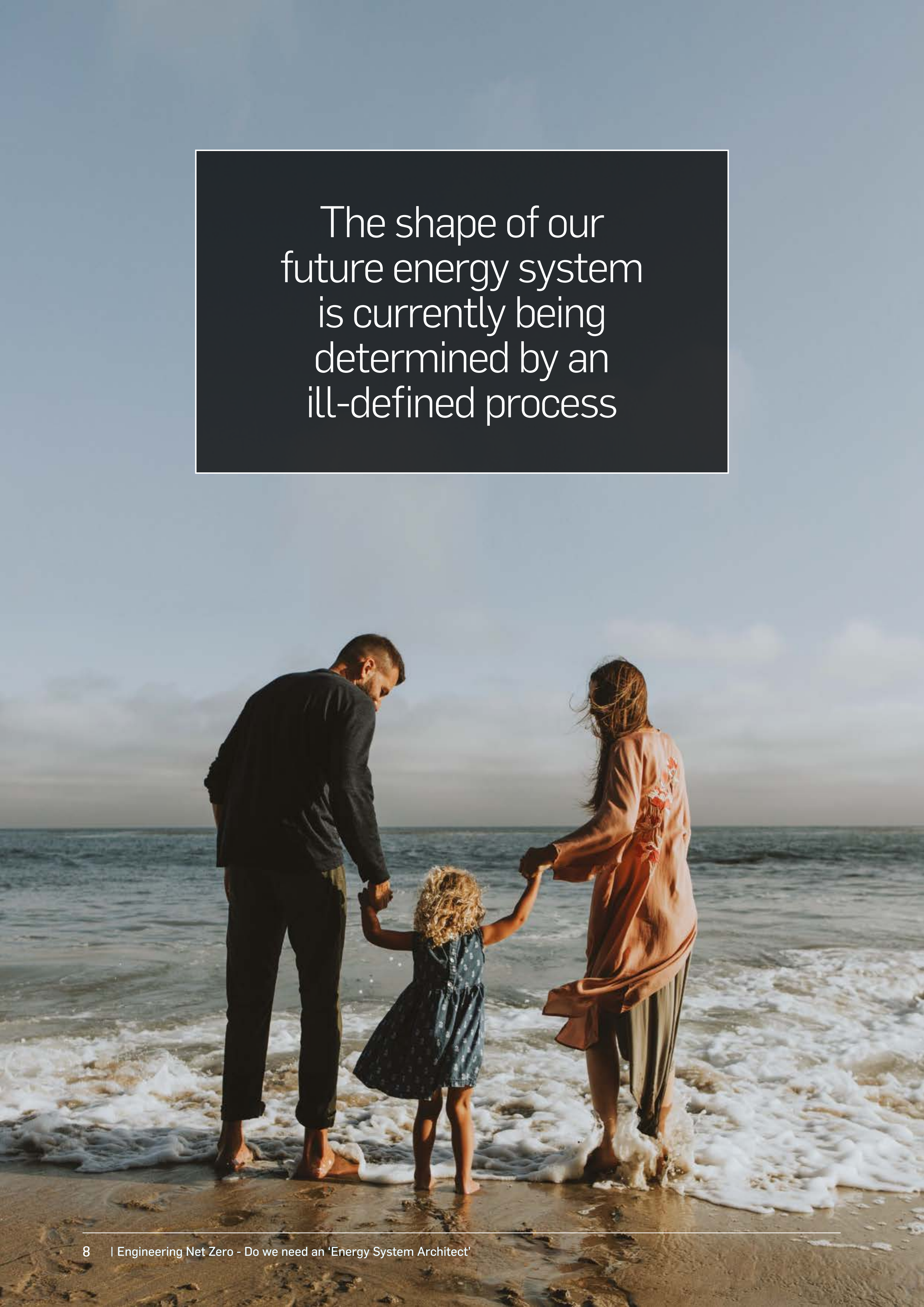
In 2020, Covid-19 has had a massive economic and social impact on all our lives, but this does not even begin to point to the more fundamental changes that will be driven by climate change

In July this year we published our report 'The Race to Net Zero' [Ref 4], which showed that, for the energy supply side of NZ2050, our current build rate is less than half what we need. The further we fall behind the harder it will be to achieve NZ2050.

One of our recommendations in ENZ was the creation of an 'Energy System Architect'. We note that Prof Dieter Helm [Ref 5] has recently proposed such a role. The 'energy market' is defunct in any strategic sense, we are not on course to deliver Net Zero in 2050 and some radical rethinking is required. We conclude that the need for an ESA is becoming ever more urgent. This brief paper sets out some of our reasoning and suggests two options for creating the ESA.

The Prime Minister's Ten Point Plan for a Green Recovery (TPP) [Ref 6] set out on 18th November is most welcome. It clearly recognises the urgency of decisions on CCS and hydrogen. The Ten Point Plan and the energy white paper to follow will set the course towards NZ2050 for the next decade, during which decisions will be made that determine whether the UK achieves its goal or falls short. Now is the time to bring together the many parallel strands of this complex national investment programme under a single point of responsibility, answerable to parliament.

The shape of our future energy system is currently being determined by an ill-defined process



2. The Risks to Net Zero

Our ENZ report took the scenario described in the CCC Net Zero report [Ref 7] and headlined changes to the energy system as follows:

- **A significant increase in low-carbon electricity generation is required** – specifically, a four-fold increase from 155TWh in 2017 to 645TWh in 2050.
- **Hydrogen will play a key part in decarbonising heat and some transport** – hydrogen use increases ten-fold, from 27TWh in 2017 to 270TWh in 2050.
- **Carbon capture and storage (CCS) is a critical component** – CCS capacity increases from zero in 2017 up to a potential 176MtCO_2 in 2050.
- **Effective system balancing is essential** – stability and continuity of supply require greatly increased flexibility and real-time management in a more complex system, with increased intermittent generation sources.

We summarised these main thrusts for the NZ2050 system, and the risks threatening to derail them, in the simple diagram reproduced as Figure 1.

In ENZ we have used the term 'risk' rather loosely, as we would in non-technical discussion. By risks to NZ2050 we mean events/issues the consequence of which would be that the UK fails to achieve NZ2050. We might consider these risks as STRATEGIC risks.

In this paper we also consider the possibility that the UK may achieve NZ2050 but that in so doing there may be times (both in the short and long term) that the energy system fails to deliver the reliable energy that customers need and society expects. We might consider these risks as OPERATIONAL risks.

The shape of our future energy system is currently being determined by an ill-defined process in which economic modelling to find least cost pathways is much quoted, and single-issue lobbyists produce system models with radically different outcomes.

Many of the engineers who will design, build and operate the future energy system see risk as a key determinant of the system. Least cost system models driven by economic optimisation rarely explain how they address risk in either their methodology or conclusions. This should be a concern for us all and is an issue that the ESA must bring to the fore.

For the successful, robust and reliable operation of the system over the next 30 years, many separate but mutually dependent projects must be designed, built and brought into operation with a high degree of coordination

3. The Energy System

What do we mean by 'the energy system'? Everything we do requires energy, from the act of breathing to launching a rocket to the moon. We need to narrow our terms of reference when we talk of an Energy System Architect.

The critical word here is 'system', for which there are many definitions, two of which are of particular relevance in our case:

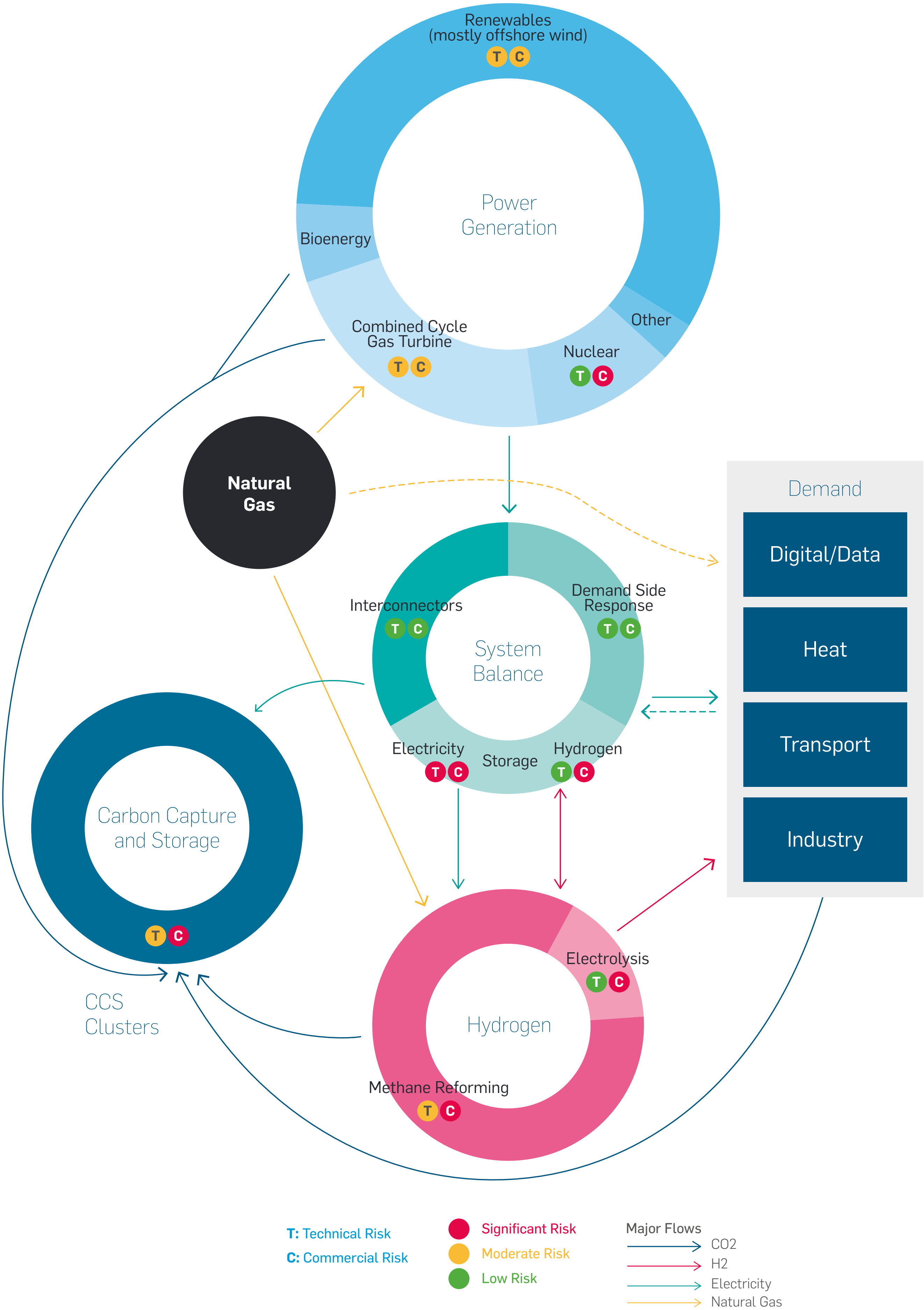
- In the physical sense:
  'A group of independent but interrelated elements comprising a unified whole'
- In the non-physical sense:
  'The instrumentality that combines interrelated interacting elements designed to work as a coherent entity'.

The 'unified whole' or 'coherent entity' comprises the physical assets as well as the rules, regulations, market frameworks and contractual relationships that harness, convert, transport, and deliver energy to end users across our entire economy.

We are concerned with both the physical assets: electricity generators, gas /hydrogen producers, the storage and transport infrastructure; and the non-physical: the rules, market mechanisms and decision algorithms that manage the interfaces between all the physical elements to ensure that energy is available, when, where and in the quantity required.

From a systems perspective the detailed upstream processes of primary energy production or conversion are not of concern. For example, in electricity generation the System Architect is primarily interested in the characteristics of the supply: How much power is available? Where is the generator located? When is it available? What is the start-up time and ramp rate? What are its technical characteristics (e.g. frequency synchronicity)? What is the cost? Similarly, at the downstream end, the System Architect does not much care what the end user does with the power, the primary concern is the demand characteristics: How much? When? Where? etc.

These concerns closely mirror those of the grid operator as they relate to operational risk. However, the Energy System Architect, whilst seeking to maintain short and medium term system operability, must also have a holistic view of the long-term goals and the strategic direction of the system, the capability of the supply chain, technological development and the relationship between the energy system and other sectors of society. The Energy System Architect needs to have a strategic plan, a strategic risk analysis, and a suite of risk mitigation options.



Renewables
(mostly offshore wind)
T C
Power
Generation
Bioenergy
Combined Cycle
Gas Turbine
T C
Other
Nuclear
T C
Natural
Gas
Demand
Digital/Data
Heat
Transport
Industry
Interconnectors
T C
Demand Side
Response
T C
System
Balance
Electricity
T C
Storage
Hydrogen
T C
Carbon Capture
and Storage
T C
CCS
Clusters
Electrolysis
T C
Hydrogen
Methane Reforming
T C
T: Technical Risk
C: Commercial Risk
Significant Risk
Moderate Risk
Low Risk
Major Flows
CO2
H2
Electricity
Natural Gas

The simple representation of the energy system in Figure 1 can be used as a framework through which to appreciate the many uncertainties in each sub-system and how the interdependency between systems amplifies both strategic and operational risks.

On the demand side we have three major sectors:

- **Heat** – Residential, commercial and institutional buildings. In the UK, the vast majority today are heated by natural gas or oil-fired systems, all of which must be removed to reach NZ2050. Replacements could include hydrogen-fired systems, electrical systems or hybrid systems. District heating using industrial waste heat may also play a role. In all cases heat has a large seasonal variation, how this variation is addressed and the split between hydrogen and electrical demand is a major uncertainty in future system architecture.
- **Transport** – Most light road vehicles will be powered by batteries. Heavy road vehicles may be more hydrogen with some battery. Most rail will be electrified but some hydrogen is possible on local trains. Shipping and aviation are less clear. The impact on the electricity system is huge and the decision to bring forward the ban on petrol and diesel vehicle sales to 2030 will intensify pressure on the electricity distribution system.
- **Industry** – Diverse industrial processes will need to remove hydrocarbon heating to be replaced by hydrogen or electric. Process emissions will be eliminated by changing process or, where unavoidable, will be captured by CCS or compensated by direct capture from the atmosphere. Other industrial demands such as agricultural transformation and reindustrialisation may also be considered.

With TPP in mind, we can identify some critical decisions over the next decade that will determine our success or failure in delivering NZ2050

Of increasing importance in energy consumption terms, and perhaps of disproportionate significance in societal impact terms, is a fourth sector:

- **Digital Economy and Data** - Impacting almost every aspect of our lives today and to be increasingly ubiquitous through smart technology, the 'internet of things', AI, autonomous vehicles and ever-increasing energy cost of data storage. The digital economy is totally dependent on secure stable electricity supply and increasingly vice versa as our whole energy system becomes more complex.

When energy efficiency measures are fully deployed, and few further reductions are available, the energy demand becomes relatively inelastic, the only option being demand side response, which is in effect an agreement to reduce supply. Diurnal variation will be ameliorated but not eliminated by SMART systems, demand shifting and short-term storage. Seasonal variation, mostly in heat, will remain a significant challenge.

Currently the major uncertainty on the supply side is the balance between energy delivered as electricity or as hydrogen. This has a substantial impact on the design of the NZ2050 system. In an ideal market, consumers would choose which they use on a cost or other personal preference basis.

Figure 2 Past and Planned Energy-Related Milestones and Energy Demand

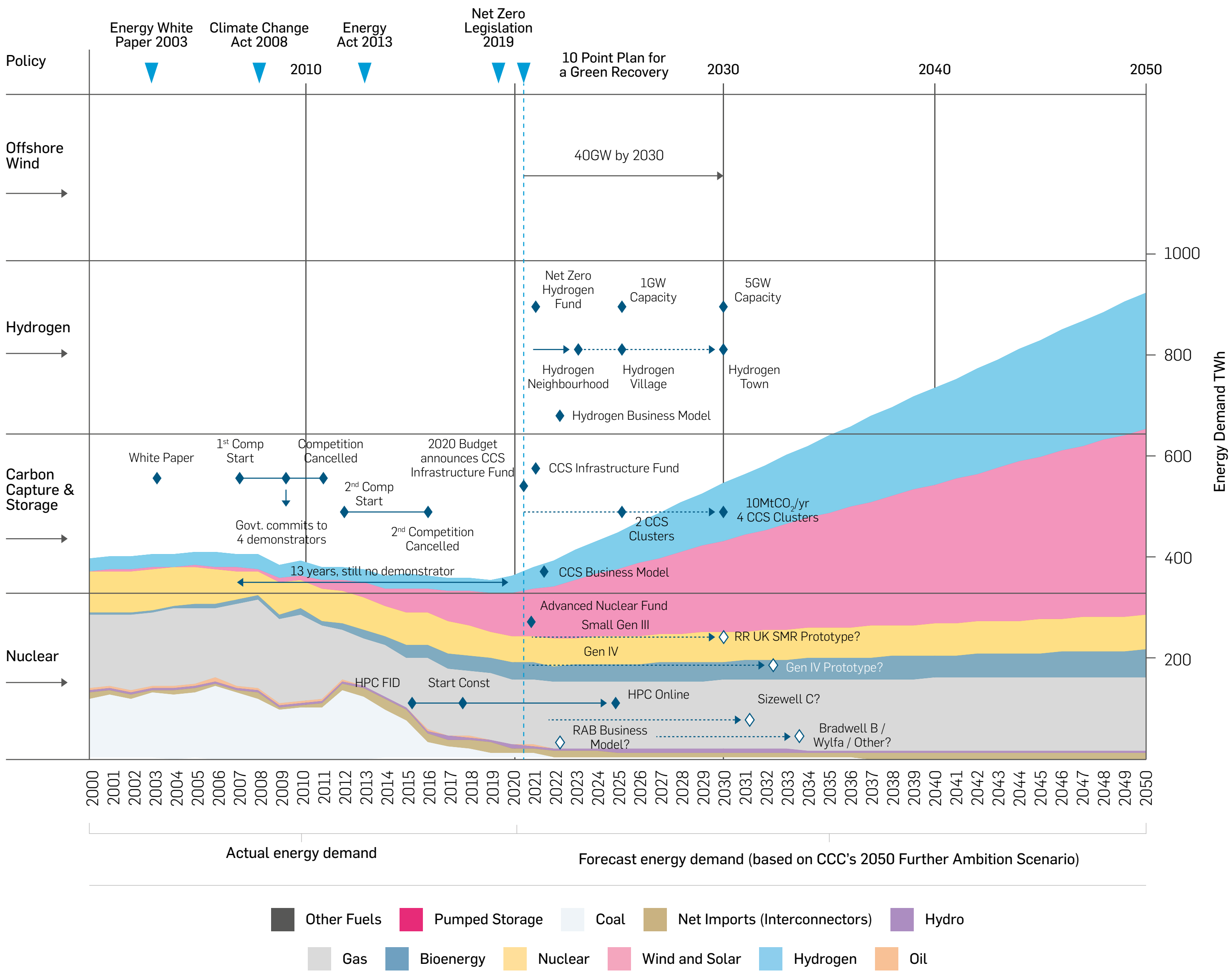
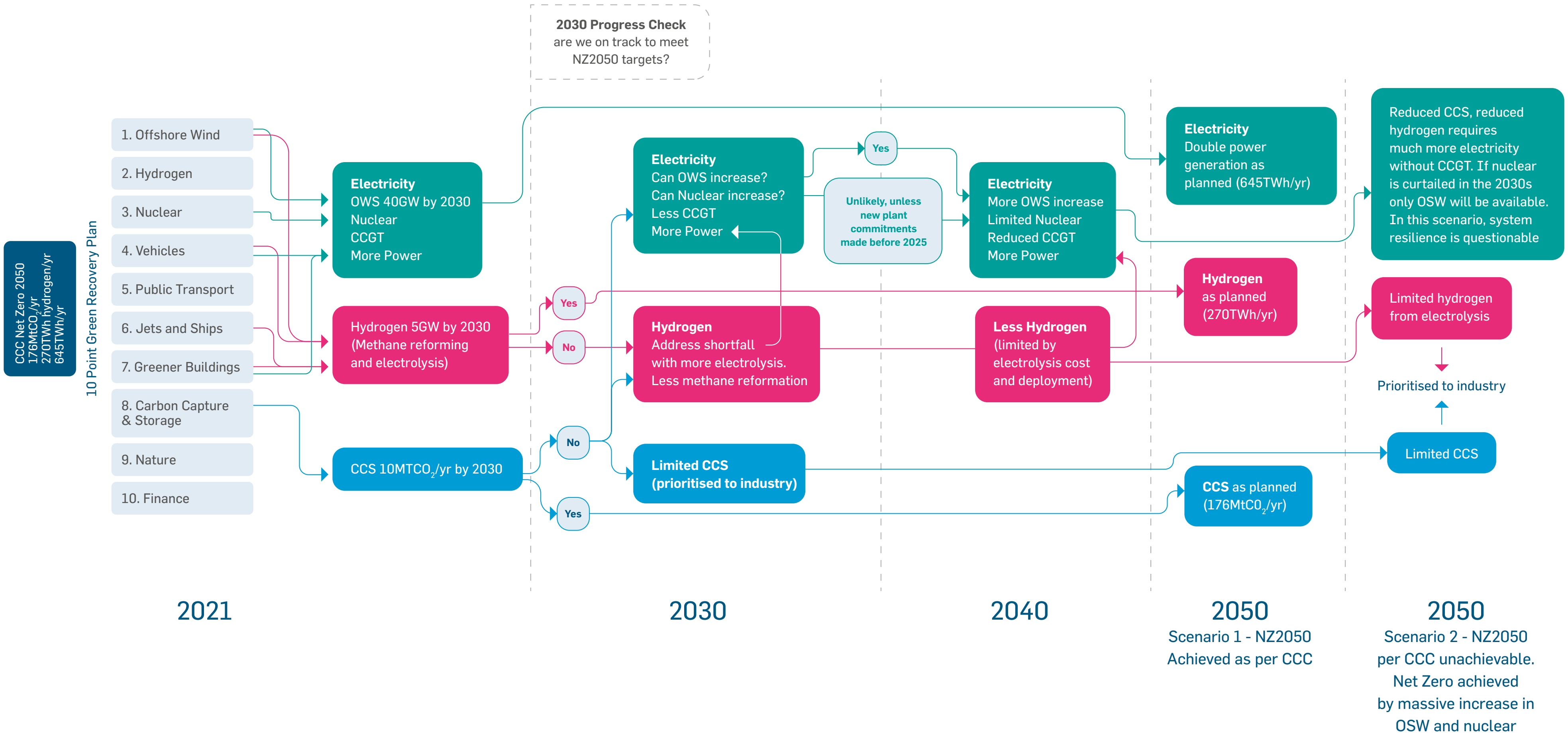


Figure 3 Net Zero Pathways after the Ten Point Plan 2030 Timeframe

(NB: this example follows from an assumption that CCS is either uneconomic or undeliverable at the scale envisaged by NZ2050 – there are many other decision pathways that could be mapped)



However, availability of hydrogen will depend on infrastructure and policy decisions that can only be made by government. Therefore, market-based decisions are likely to be marginal to the electricity/hydrogen split, which will in fact be decided not by the market but by policy. Without clear policy decisions and effective implementation of the required infrastructure the option of hydrogen will simply not be available to most consumers. The TPP has recognised this.

When demand becomes inelastic the supply side must operate as a zero-sum game, at any moment in time supply must exactly balance demand. Reduced supply from one source must be balanced by increases from other sources. The Electricity System Operator (ESO) must maintain balance in real time, second by second 24hrs a day, 365 days a year. In Appendix A we briefly discuss the major power outage of 9th August 2019, which illustrates how the increasing complexity of the system will magnify operational risk, even when all the parties involved have discharged their responsibilities.

A further indication of the operational risk posed by increasing system complexity and reliance on intermittent renewables was the ESO's issue of Margin Notices on 3rd and 5th November, the first such notices for four yearsand notably during a time of mild weather and lower than normal industrial activity.

For the successful, robust and reliable operation of the system over the next 30 years, many separate but mutually dependent projects must be designed, built and brought into operation with a high degree of co-ordination. Uncertainty regarding what assets will be required, whether they can be financed and when they will be delivered increases the operational risk and will exacerbate strategic risks.

The illustrative timeline in Figure 2 shows how decisions already taken could limit our future options. A major risk we identified in ENZ is the compounding of strategic risk by reliance on CCS and the potential pre-emptive demobilisation of our new nuclear capability. This stems directly from past decisions that may have been taken on a narrow or case-by-case basis, with insufficient appreciation of their long-term strategic risk consequences.

Those decisions being:

- The cancellation of two CCS demonstrator tenders and subsequent four-year hiatus for various consultations and studies. Hopefully now to be addressed with urgency under the TPP.
- The imposition of a financial structure on new nuclear projects which is demonstrably not fit for purpose. The RAB consultation was intended to address this and its conclusions are urgently needed.
- The resulting abandonment of the Wylfa project clearly exposed the Government's commitment to new nuclear build. Again, the TPP has reaffirmed government's support for new nuclear, but with caveats not stated elsewhere in the document and noticeably with no commitment to Sizewell C. Failure to move forward with RAB and Sizewell C will effectively close the large nuclear option for the foreseeable future, placing reliance on small or advanced reactors that are unproven.

Looking forward, and with the headline milestones of the TPP in mind, we can identify some critical decisions over the next decade that will determine our success or failure in delivering NZ2050 and could significantly impact the potential cost to consumers. Figure 3 presents a very much simplified analysis of some of these decisions. By 2030 we will know if the TPP milestones will be reached and, more importantly, will have a much clearer indication of whether the CCC NZ2050 scenario is achievable. Figure 3 shows some of the decisions that would follow from a recognition that CCS is either uneconomic or undeliverable at the scale envisaged by NZ2050. There could be many other causes of failure resulting in other alternative outcomes.

The ESA would be responsible for mapping out the future decision tree and developing the options that could be needed depending on the outcome of specific programmes, for example the cost and deliverability of CCS, the cost reduction of hydrogen produced from electrolysis, the cost and deliverability of new nuclear including smaller plants.

4. Fragmented Thinking or Holistic View?

The foregoing discussion gives a limited picture of the complexity of the energy system, the interdependencies between many sub-systems, and the necessity of assessing risk on a whole system basis.

In the absence of a published future system strategy it is inevitable that different interest groups will project different views of how the system should evolve. Prof Helm [Ref 5] has noted that Government is now the de facto central buyer of electricity, operating in a complex web of technology specific subsidies and negotiated deals.

The CCC, whose NZ2050 report [Ref 7] led directly to the legislation committing the UK to NZ2050, is the formally constituted advisor to government. CCC's scenario, whilst not purporting to be a plan, is de facto, the only officially recognised Net Zero system description. The National Infrastructure Commission (NIC) has a remit that includes energy infrastructure and has published its own report on Net Zero in the power sector [Ref 8].

Whereas the CCC's NZ2050 scenario envisaged 58% of electricity generation from renewables, the NIC took 60% as a starting point and claimed that 90% would be achievable and would be lower cost . The potential for different groups of economic modellers to 'outbid' each other with regards to the optimal level of renewable penetration is worrying, particularly when their reports are heavily caveated with regards to future costs (the key determinant of technology selection), often rely on poorly defined amounts of interconnector flow, DSR or storage (in unspecified facilities) and scarcely mention operational risk. In its response to the NIC's report, HM Treasury (HMT) [Ref 9] disagreed with the NIC in respect to nuclear.

On the point of operational risk we note that at the time of writing this report, on the morning of 7 December 2020, a cold day with anticyclonic conditions over the UK, power demand is 40GW and power supply is 61% fossil fuel (of which 5% coal), 16% nuclear, 10% interconnector imports, 7.5% biomass and 3% renewables (solar 0%, wind 1.4%, hydro 1.7%). We would invite both CCC and NIC to model these conditions, removing the coal and placing an appropriate risk weighting on the gas and biomass that are both reliant on CCS in order to advise what would be the required level of nuclear and offshore wind capacityto sustain supply at 2050 levels.

Against an uncertain backdrop and in the absence of a published strategy, the field is open for single issue lobby groups to press their cases, offshore wind and nuclear are discussed below but there is lobbying for many interests including: onshore wind, solar, hydrogen, carbon capture and storage, bioenergy, tidal power. The list is long.

Noting the uncertainty of future system configuration, HMT stated that it is important to maintain options by pursuing additional large nuclear projects. This was reiterated in HMT's National Infrastructure Strategy [Ref 10].

Offshore wind

The offshore wind industry was effectively born out of the UK Government's decision to pursue this technology. In the early stages the subsidised price paid to offshore wind was three times the market price of electricity. Government always tries to avoid 'picking winners', having picked a winner it is tempting to alter the rules of the game to ensure success. Prioritised offtake, 'take or pay' contracts and allocation of system wide integration costs to all forms of generation have ensured the mass deployment of offshore wind, resulting in dramatic falls in Levelised Cost Of Electricity (LCOE). This success does risk a downside, when overwhelming support promotes one technology others are 'frozen out' – leading to attempts to raise their subsidy and the risk of subsidy to subsidy competition and cannibalisation.

> A fully independent and well-resourced ESA would be able to objectively assess the merit of different pathways to NZ2050

LCOE is not a suitable measure for comparison of generating technologies with different operational characteristics. Whole system costs must be the basis for system architecture decisions. BEIS [Ref 15] has begun to estimate the impact of system-wide costs of different technologies baselined against large nuclear. Results were presented as 'enhanced life cycle cost of electricity' (ELCOE) for various scenarios. For offshore wind, the additional system wide-costs varied between £17 and £38/MWh, resulting in ELCOE of £59 to £82/MWh. These confirm the conclusions in our ENZ report [Ref 1], that the marginal cost of offshore wind at high renewable penetration may be comparable with that of large nuclear.

With NZ2050 anticipating 75GW of offshore wind deployment as the main element in the 58% renewable generation in the electricity mix, the Offshore Wind Industry Council (OWIC) launched a study to consider how hydrogen might be used to help the integration of high levels of intermittent generation into the UK energy system.

The study report was published in July 2020 [Ref 11]. It made a proposal for a radical change to the NZ2050 energy system outlined by the CCC, eliminating the large element of hydrogen production using steam methane reformation with CCS and replacing this with hydrogen production by electrolysis using offshore wind generation. Offshore wind capacity would rise to between 95 and 150GW by 2050. The Government's current strategy of clusters of CCS would be replaced by hydrogen hubs. Furthermore, the report recommended a Government funded subsidy programme to rapidly increase electrolytic hydrogen production and develop an international hydrogen supply capability, it envisages offshore wind rising to between 130 and 233GW in such a scenario. The OWIC study did not assess the potential for combining increased offshore wind with increased nuclear to produce hydrogen; the efficiency of some electrolysis processes is enhanced at higher temperatures, and nuclear plants have large amounts of waste heat. The Royal Society assesses nuclear cogeneration options in their policy briefing report [Ref 19].

The TPP reaffirmed Government's commitment to offshore wind and a target of 40GW installed capacity in 2030. Offshore Wind will be the mainstay of the UK's renewable power generation in 2050 and is critical to net zero. The proposal to radically change the NZ2050 strategy based on a huge expansion of offshore wind demonstrates that there are significantly different pathways to the 2050 destination. A fully independent and well-resourced ESA would be able to objectively assess the merit of different routes.

Nuclear

Nuclear has provided about 20% of the UK's electricity over the past 40 years. The current nuclear fleet is at retirement and by 2035 all existing plants will be retired unless Sizewell B obtains a life extension. Since 2007 it has been government policy to replace the existing fleet with new nuclear. 13 years later just one plant has started construction at Hinkley Point C (HPC); it will be almost 20 years from the policy decision to the completion of the first plant. As we write, the approval of a similar plant at Sizewell C is still awaited.

The current funding model for nuclear is not fit for purpose. In June 2018, the Government announced a review to consider an alternative Regulated Asset Base (RAB) model. Consultation closed in October 2019 and the report with recommendations is still awaited. It is hoped that government will introduce a more workable model in the near term. Notwithstanding the difficulties with the current funding model, the Government's decision not to proceed with the Wylfa project and Hitachi's consequent definitive withdrawal has called into question the Government's commitment to new nuclear. The UK has no current pipeline of new nuclear projects after Sizewell C (SZC), except for Chinese interest in Bradwell B (BRB). The TPP is ambivalent about commitment to nuclear, stating that "we are pursuing large scale nuclear projects, subject to value for money".

The CCC NZ2050 scenario shows approximately 9GW of nuclear from the three plants under active development (HPC, SZC, BRB). It assumes that new nuclear is curtailed when these three plants are completed. The NIC goes one better and proposes to curtail new nuclear after just HPC and SZC are completed.

Organisation (Model Scenario)	Electricity Twhr/yr	%OSW	%Nuclear	%CCGT	%Bioenergy	% Other	Hydrogen TWhr/yr	% SMR	% elect	CCS Mt/yr
CCC (Further Ambition)	645	57.2%	10.7%	23.0%	6.4%	2.6%	270	83.7%	16.3%	176
NIC (scenario Elec_80_2.9Mt) ***	596	49.9%	12.1%	0.4%	0.0%	37.6%	Not stated	Not stated	Not stated	
OWIC ESC- (FA Unfactored) ^	~750	64.1%	4.8%	0.0%	4.0%	27.1%	~225	0% **	73%	Not Available
Energy Systems Catapult (Run 1a Tech 100) ^	~540	32.0%	58.0%	4.0%	Not Stated	6.0%	220	80%	20% ^^	
ESO FES 2020 (Leading the Way)	579 *	54.4%	5.9%	0.0%	11.0%	28.7%	235	0%	80% (remaining 20% from imports	Not stated

Table 1: NZ2050 system architecture

^ Approximated values
^^ none from Methane Reforming stated, however advanced nuclear cogeneration makes up the remaining 27% so assume this is likely to be electrolysis
** includes 21TWh imports*
*** assumes non-electrolysis produced hydrogen is from biomass*
**** note that this scenario used assumes 80% renewables generation (not specified in terms of explicit OSW) by 2050 used, to reflect a nuclear capacity in 2050 equivalent to HPC and SZC*

Undeterred, the Nuclear Industry Association (NIA) has proposed [Ref 12] that nuclear could provide up to 40% of the UK's low carbon electricity in 2050. The NIA study has, like the OWIC study, neglected to develop the arguments for combination of electricity generation from both sources with waste heat from nuclear to enhance hydrogen production. Nuclear provides firm, low carbon, synchronous power, which is essential for maintaining grid stability. The only alternative would be Combined Cycle Gas Turbines (CCGT) equipped with CCS, which is also required due to the scale of the future demand.

The Energy Systems Catapult modelled a number of scenarios and concluded that to commit to deployment of 10GW of new large nuclear plant in addition to HPC (resulting in 13.2GW) would be a 'no regrets' policy [Ref 13].

Further deployment, beyond this initial commitment, would be determined in light of experience, and new technologies such as SMR would be considered.

Atkins assessed the minimum commitment that would be required to sustain a viable UK nuclear new build capability [Ref 14]. We believe a minimum of one new twin reactor plant every five years could sustain our capability. This would lead to about 19GW of installed capacity, capable of supplying 23% of the electricity demand in the CCC NZ2050 scenario.

The affordability challenge of large reactors has prompted many in the nuclear industry to consider small modular reactors (SMR). No such reactors have yet reached commercial deployment in western markets and their competitiveness is yet to be proven.

Rolls Royce has proposed a 440MW pressurised water reactor for UK fleet deployment and the TPP indicates government support for the development of this new reactor design for deployment in the early 2030s, again subject to value for money and future spending rounds.

As for offshore wind, we know that nuclear has a critical role to play in the 2050 Net Zero system as reliable low carbon firm power. A fully independent and well-resourced ESA would be able to objectively assess the merit of the scale of the nuclear component and the sustainable route to achieve it.

Summary

Table 1 summarises some of the conflicting visions of the future energy system expressed by just five parties. It serves to illustrate the fragmented thinking prevalent in the industry, which, lacking clear strategic leadership, continues to promote widely varying visions of the future. The layman might ask how can different groups of very clever people model the same system and reach such different conclusions? The answer of course is that in such a complex system, with multiple variables, huge interdependencies, multiple unknowns and reaching 30 years into the future it is inevitable that apparently small differences in the input assumptions can result in very different conclusions. No modelling report should be considered complete unless it describes the robustness of the model and the stability of the results when tested against variations in key input parameters. Since most models optimise to find the least cost system, it is also important to understand how they price risk into their evaluations.

In our view one essential role of the Energy System Architect would be to hold the 'authoritative model' of the energy system. The ESA should provide full transparency of its modelling, including the stability of results against reasonable ranges of variation in input parameters.

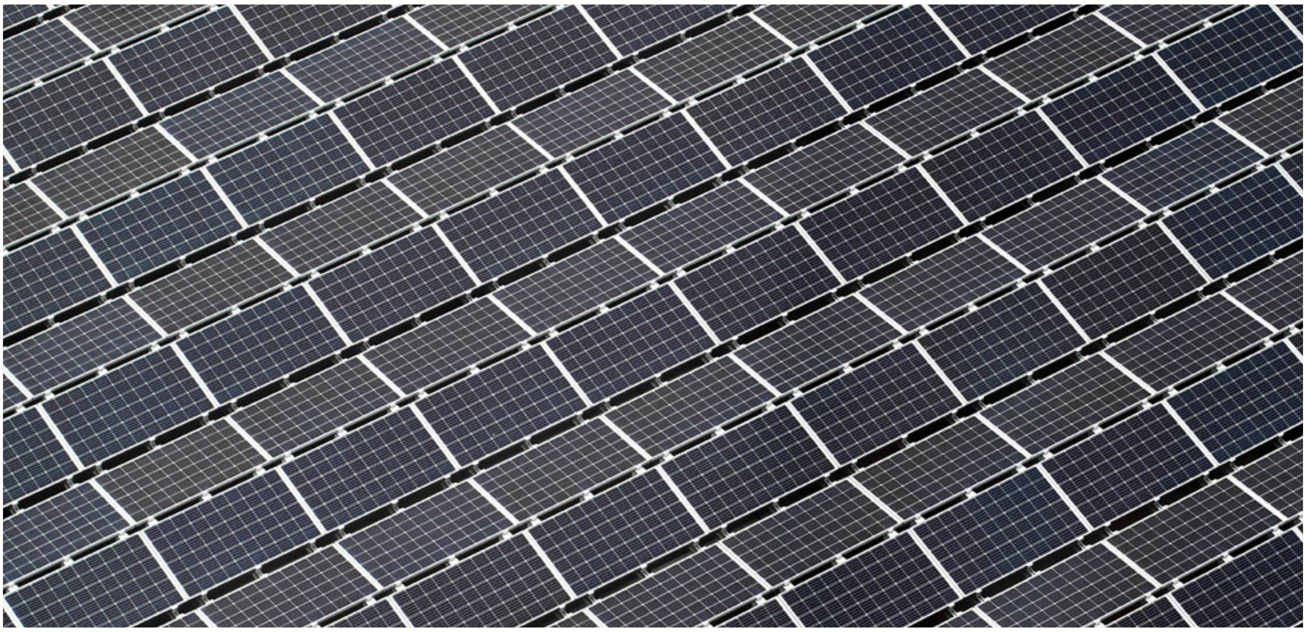
The model should be independently reviewed, and it should be made available to others. This would limit the propensity for single interest lobbies to produce alternative models pressing their case. Since it is apparent (and probably inevitable) that different industry groups will promote different scenarios and not actively seek optimal joint scenarios, this can only be credibly undertaken by an independent System Architect.

It is, of course, essential to consider value for money when defining the future energy system. This can only be done by comparing costs on a whole system basis. Frequently the lifecycle cost of electricity (LCOE) is quoted when comparing the costs of different generating technologies. This simplistic comparison can be grossly misleading and should not be used as a basis for strategic system decisions. It is particularly misleading when system wide costs are disproportionately allocated or when different purchasing criteria are applied to different technologies .

We believe an early priority for the ESA will be to work with OFGEM to review the current 'market' arrangements, which, as we have stated elsewhere, are effectively defunct in respect of technology selection. The ESA should consider that a competitive market can only be created and effective when all technology specific subsidy schemes are eliminated and all generators are required to bid to supply on a firm delivery basis and bearing the specific system-wide costs incurred to support their technology.

The Institute for Government [Ref 21] has stated "BEIS lacks the authority to develop a comprehensive net zero plan and assure it is delivered", and recommended that the Cabinet Office should take over responsibility for Net Zero.

5. Who 'Owns' the Risks?



In the US Department of Energy management best practices, Best Practice No1 is the rule of 'R2A2': the clear assignment of Roles, Responsibilities, Authorities and Accountabilities.

So, let us apply the R2A2 principle to the strategic risk register developed in our ENZ analysis [Ref 1]. First let us identify some of the entities that might reasonably be expected to play a part in managing the programme to achieve Net Zero in 2050.

The Government

Parliament has legislated (Climate Change Act 2008, amended by secondary legislation 2019) that UK will achieve NZ2050. So, who is responsible? Who will enforce if we fail? It is not at all clear how this legislative commitment would be policed. Perhaps, prompted by private action, the Supreme Court would sit in judgement? For the purposes of our analysis we will assign the over-arching government responsibility to BEIS, although of course NZ2050 cannot be achieved without positive action across numerous government departments.

BEIS has primary responsibility for energy strategy, it initiates changes to energy legislation and to market structure. BEIS also initiates market interventions such as Contracts for Difference for specific technologies, it manages allocation of funding such as for offshore wind licensing and it negotiates support to major projects such as new nuclear build. BEIS determines what new generation technologies are built.

Prof Dieter Helm [Ref 5] precisely described the 'competitive markets' fallacy with the conclusion "By the second decade of this century, the UK Government had become the central purchaser of almost all new generation on the system (and much of the existing generation too), through subsidy contracting to renewables and nuclear, and through the capacity market. The liberalised generation market was effectively killed off."

A cursory review of the BEIS report 'CARBON CAPTURE, USAGE AND STORAGE A Government Response on potential business models for Carbon Capture, Usage and Storage' [Ref 16] shows just how complex it is to contrive market interventions to initiate new infrastructure for CCS and hydrogen, two of the central thrusts of the CCC's NZ2050 scenario.

Climate Change Committee (CCC)

Created by the Climate Change Act 2008, the CCC is the principal statutory advisor to government on the issue of climate change. Its R2A2 are set out in 'Committee on Climate Change, Framework Document, April 2010' [Ref 17], and can be summarised as:

- Advising government on measures related to achieving the carbon reduction target (now NZ2050) and on adaptation to climate change.
- Setting five-yearly carbon budgets.
- Reporting to parliament annually on progress towards NZ2050 and adaptation.

The CCC is an advisory body with no responsibility for outcomes and no authority to direct programmes. Its emphasis is on analysis of greenhouse gas emissions, policy options for emission reduction, economic modelling to identify least cost pathways to decarbonisation, and reporting on progress.

> CCC's Net Zero report [Ref 7] provided a scenario that suggested it was technically feasibility to achieve NZ2050 and on this basis, government legislated to do so.

Although the CCC does not claim that its scenario is a 'plan' or design for the NZ2050 energy system it is the template to which we must refer.

Atkins believes that although the CCC's scenario suggests that NZ2050 is theoretically feasible, it does not adequately assess the engineering challenges involved and does not demonstrate how various risks have been priced into its analysis nor their potential impact on the outcome.

OFGEM

Empowered by statute, OFGEM is the financial regulator of the gas and electricity industry. Its principal duty is protection of customers interests, particularly with regards to cost of gas and electricity but also with regards to customers interest in security of supply and environmental protection.

The duties on OFGEM include:

- Promotion of efficiency and economy in gas and electricity production and transport
- To secure that all reasonable demands for gas and electricity are met
- To protect the public from the dangers of the conveyance of gas and electricity
- To secure that licence holders in gas and electricity can finance their activities, which are subject of their licence obligations.

In addition, in the exercise of its duties, OFGEM is required to:

- Have regard for the need to contribute to the achievement of sustainable development.
- Secure a diverse and viable long-term energy supply, and shall, in carrying out those functions, have regard to the effect on the environment.

So, whilst being mainly concerned with pricing, OFGEM must also consider security of supply, system efficiency and sustainability. However, OFGEM has no responsibility for the operational performance of the system.

National Grid 'Electricity System Operator' (ESO)

National Grid is a privatised company that owns the high voltage national electricity grid and gas transmission pipelines, and it is regulated by OFGEM. The ESO is an 'arms-length' subsidiary of National Grid and it is the operator of the national high voltage electricity and gas transmission grids. It must balance electricity supply and demand on a real time basis 24 hours per day, 365 days per year. It is central to the stable operation of the electricity system and the security of supply to customers. The ESO has multiple tools at its disposal to maintain system balance and stability. There are currently 15 different types of balancing services contract and there are 15 'aggregators' listed.

Risk	Description	Who owns the risk?
1	CCS commercial structure/policy	The development of policies to ensure deployment of CCS is the responsibility of BEIS.
2	CCS deployment: We need to get from zero today to 176Mt/yr CO_2 sequestration	Even though supportive policies may have been put in place that would support bankable CCS projects, the industry may be unable to build capacity quickly enough. BEIS would be seen to own this failure, particularly if the failure is seen to be due to the late procurement of demonstration projects and commercial framework.
3	Hydrogen production and distribution technical risks	There are multiple technical risks associated with the production, distribution and use of hydrogen. BEIS has initiated a research programme to resolve some of these issues and this will inform BEIS policy development, which is essential for implementation.
4	Decarbonisation of domestic heating - adoption risk through scale and pricing	Decarbonisation of domestic heating will reach into every home in the country. The default solution will be electrification, unless hydrogen is available – which depends on BEIS policy decisions. A system of incentivisation or subsidisation of costs will be needed, again a BEIS policy responsibility?
5	Renewable energy sources: system costs associated with high intermittent penetration	BEIS determines how much renewable energy to authorise. The system wide costs at high renewable penetration are, as yet, far from clear. BEIS effectively makes the decisions determining the amount of renewable in the system, OFGEM would have to approve system investment through National Grid.
6	System integration: lack of overall Energy System Architect and/or Programme Delivery Office	The ESO has to ensure that the system is operable to the required standard but BEIS is effectively determining what generation capacity will be built and when. Overall system configuration responsibility is not clearly assigned.
7	Nuclear: major capital programme construction risk	The current financing mechanism and risk allocation has proven to be not fit for purpose. BEIS is undertaking the assessment of alternatives such as RAB. If nuclear cannot be delivered then the future system will be dependent on renewable and firm power from CCGT with CCS, which has yet to be shown to be economically attractive.

Table 2: Assessment of Risk Owners for the Top Seven 'High' risks identified in Engineering Net Zero [Ref 1]

The task of maintaining stability becomes increasingly complex as the proportion of intermittent asynchronous generation rises.

The system used to be relatively simple when there was only one generator, the state owned CEGB, and the National Grid was also state owned. That is not to say the system was more efficient. Privatisation has brought forward many advantages, but it has also resulted in great complexity and the corollary of this is that the R2A2 of the many entities involved is less clear.

The greatest loss following privatisation was the ability to plan the system wide infrastructure, as no one entity held this responsibility. National Grid, itself privatised, became a transporter of power from wherever a generator chose to build to wherever the consumer was located.

Where generators chose to locate within the distribution system, they were even more remote from the grid control. The power disruption incident of August 2019 exemplified some of the weaknesses of this complex system and is briefly discussed in Appendix A.

The ESO develops scenarios to assist in planning its operations, these Future Energy Scenarios (FES) are published annually and provide useful insights into how the system may evolve. However, the ESO has no responsibility or authority to design the future electricity system, outside of the grid itself. It cannot determine what technologies the generators build, and it cannot dictate how much generation should be built.

Others

Across the entire energy system there are dozens (perhaps hundreds) of other entities generating, transporting and selling electricity (and gas). Each is constrained and required to comply with various technical codes of operation and contractual obligations. However, none of these entities are responsible for management of operational risk in the system. Certainly, none have responsibility for the strategic risks.

Looking to the future, it is entirely possible that decentralisation of power generation and smart grids at the local or regional level could lead to local energy management initiatives by cities enjoying greater decentralised governance. New commercial entities may arise with a cross-sectoral energy management offering at the local or regional level. For example: at the city level an energy supplier might invest in a small nuclear reactor supplying a local grid, produce hydrogen by electrolysis at the reactor site, distribute waste heat to district heating systems and provide an 'energy service' covering all the community's needs.

Summary

Referring to the risks identified in Atkins' ENZ, we can assess which of the above organisations may have responsibility, authority and accountability for each risk. A brief analysis of the top seven 'high' risks is presented in Table 2.

The inescapable conclusion of this high-level analysis bears out the adage that "Government always owns failure". For the avoidance of doubt, just three examples:

- BEIS has become the central buyer of electricity, it decides what generating capacity gets built.
- Since the energy white paper of 2003, CCS has been recognised as an essential element in a low carbon strategy. 17 years later BEIS has yet to commission the UK's first full scale CCS demonstrator and there is no clarity regarding the commercial structure to make CCS bankable. In the CCC scenario, 40% of the nation's energy depends on CCS. This seems to be an increasingly fanciful ambition. The TPP is addressing this issue by bringing forward dates for CCS demonstrators.
- If hydrogen is to deliver 30% of the nation's energy in the CCC scenario, the UK hydrogen demand will increase ten-fold and extensive storage and distribution infrastructure will be required. BEIS has initiated research into various technical issues but there is no clarity regarding the extent of hydrogen infrastructure required and the commercial basis for its creation. The TPP will accelerate hydrogen demonstration projects.

Clearly BEIS must own the majority of the risks in this analysis, they are the big strategic risks that could prevent achievement of NZ2050.

Underlying these strategic risks are many operational risks related to the successful completion and operation of individual projects. In these cases, the individual project risks will rest between owners, contractors and operators. Even where individual project risks are clearly owned by others there will remain an overall network operational risk that may appear in the first instance tolay with the ESO. However, since the ESO has no control over what generation gets built and where it fits in the system's operational requirements, a large part of the operational risk effectively lays with BEIS.

The potential for creation of local or regional 'all energy' companies operating their own 'mini grids' could radically change the risk allocation. The ESA should look beyond today's structure to envisage how the entire system might evolve and 'fragment' as smart technology enables 'all energy' management at local or regional level.

6. Who has the Authority to manage the systematic risks?

There can be no doubt that BEIS is the only entity that has the authority required to manage systematic risk. It sets policy, brings forward legislation where needed, and controls the market for new generation.

It also effectively controls a large proportion of the Research & Development for new technology through the funding of science such as the UKAEA's fusion programme, current research into aspects of hydrogen utilisation, and funding of demonstrator projects for technology such as CCS.

Of course achieving NZ2050 is a truly cross-governmental issue, the departments of Transport, Agriculture, Environment, and HM Treasury are all crucially involved in the wider endeavour to achieve Net Zero, but it is to BEIS that we must look for leadership on the implementation of the energy system infrastructure to support full decarbonisation. It is the Secretary of State at BEIS who will lead as the UK Chairs COP26.

So, given that the primary responsibility and relevant authority lies within BEIS, how will this authority be exercised and by whom? Which Minister carries responsibility for Net Zero? Is it the:

- Minister of State (Minister for Business, **Energy and Clean Growth**)
- Parliamentary Under Secretary of State (Minister for Business and **Industry**)
- Parliamentary Under Secretary of State (Minister for **Science, Research and Innovation**)
- Parliamentary Under Secretary of State (Minister for **Climate Change** and Corporate Responsibility)

Whilst the focus above is on BEIS as the department with authority aligned to a number of key energy system decisions, it should also be noted that policy decisions from other departments will impact the overall system through demand, and therefore require assessment, coordination and planning e.g. the Department for Transport's policy decision to ban of new petrol and diesel cars sales from 2030 will impact the energy system requirements alongside housing initiatives from Ministry of Housing, Communities & Local Government, and ultimately, funding decisions from Her Majesty's Treasury.

Ministers are, of course, supported by extensive staff and have access to advice from the Department's Chief Scientist. A notable omission is that there is no such position as the department's Chief Engineer, yet many of the issues that will frustrate NZ2050 are as much, if not more, related to engineering than science. We believe that if BEIS is to effectively discharge its responsibilities in respect of NZ2050 it must appoint a Chief Engineering Advisor without delay in addition to the CSA. This role may in time move into the ESA.

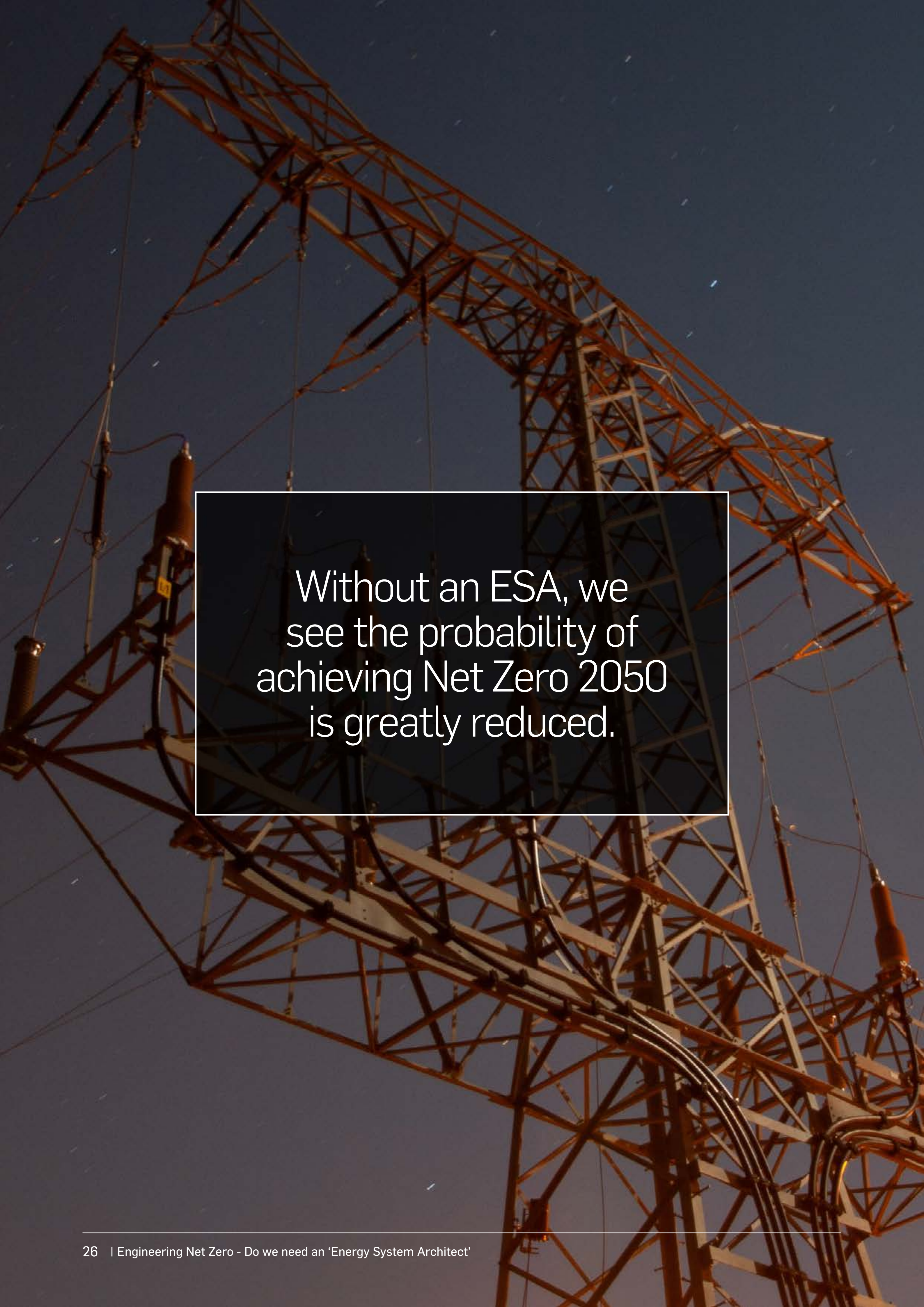
Many experienced executives would say that shared responsibility is no responsibility. Net Zero is an issue that impacts across government, many believe it is the existential issue of our time. If so, it would seem important enough to have a clearly assigned single point of Ministerial responsibility. We recommend that the Prime Minister's Task Force Net Zero should address this as matter of urgency.

If we look back over recent years, the record is not encouraging. Figure 2 illustrates how some recent decisions are now impacting the pathway to Net Zero. It is generally the case that Policy Departments are not good at delivering programmes of work. Policy and implementation tend to be separated. Examples in government today:

- Department of Transport – Highways Agency
- Department of Health – NHS England
- BEIS – Nuclear Decommissioning Authority

We have already mentioned the example of the London Olympics, where the ODA was created. Delivery responsibility was not left within the DCMS.

The need for a distinct single point of responsibility for implementing Net Zero is overwhelming. The current structure is not working, refer to the CCC's annual reports to parliament. They are becoming somewhat predictable; a few encouraging bright spots, a litany of recommendations not followed, an increasingly urgent call for action.



Without an ESA, we see the probability of achieving Net Zero 2050 is greatly reduced.

7. The R2A2 of the ESA

We believe the UK needs an ESA, without it we see the probability of achieving NZ2050 is greatly reduced, and the probability of achieving an optimal NZ2050 delivering best value is even lower.

What would the ESA's responsibilities be? How would it be set up and what would be its relationship to other relevant bodies? For example: CCC, OFGEM, NIC, BEIS and the owners of energy assets? Given that government is not the owner of energy assets and should not become the owner, it is not directly comparable to the examples given above.

Above all, the ESA is fulfilling a strategic planning role. Until privatised in the 1990s, the CEGB provided the strategic planning role for electricity.

> Privatisation undoubtedly succeeded in many of its goals, but the market structure adopted has now been effectively abandoned in so far as it impacts strategic technology selection.

Privatisation eliminated strategic planning and the current 'market' will not deliver an optimal system in the absence of a strategic plan. For the avoidance of doubt we are not advocating the 'return of the CEGB' but seeking a balance in which the ESA develops a strategic framework with flexibility that will enable the selection of technologies through competition based on whole system economic impact.

We believe the role of the ESA should, as a minimum, include:

- To develop a strategic plan for achieving the energy system's contribution to Net Zero with reference to overall cost effectiveness, system operability, reliability and risk.
- To evaluate all potential delivery models including for example the creation of local 'energy companies' providing power, hydrogen and heat to a city, and consistency with national plans.
- Hold and maintain the definitive UK energy system model, publishing annual status and projections with full transparency.
- To evaluate strategic risks, develop risk mitigation strategies and alternative scenarios.
- To determine development pathways for each technology with possible upper and lower bounds of deployment.
- To advise on government funded research and development.
- To determine what new capacity and infrastructure is required.
- To advise what market interventions or modifications are required to implement the strategy.

We consider two options for the creation of the ESA (there could of course be several others, including setting up a unit within BEIS perhaps overseen by a Board of external appointees).

Option 1 – ESA as part of the ESO

Prof Helm [Ref 5] has suggested that the System Architect role should in fact be performed by the ESO, and that the ESO should be taken back into the public sector. This approach has the merit that the ESO undoubtedly has most of the key skills required. It exists today and could easily take on the additional roles of the ESA. Prof Helm also suggests that, since it will determine what new capacity is required, the role should manage the procurement process, the responsibility and authority for which would need to be transferred from BEIS.

What are the key attributes of the ESA in this case?

Option 2 – ESA as an Advisory Body

The strategic planning role of the ESA could be performed by an advisory body, it does not have to be a part of the ESO. This has the advantage that, the ESA will be exclusively focussed on its strategic role. However, if this function is subsumed into the ESO, which has real time second-by-second responsibility for the nation's energy supply, the operational role will inevitably outweigh the strategic in the ESA's priorities.

Would an advisory body have sufficient 'weight' to effectively influence the delivery of NZ2050? We believe that this is possible, and we look to the CCC as an example. CCC has no delivery responsibility and has no contracting or operational authority, and yet, it has caused the UK to commit to NZ2050.

Should the CCC be expanded to encompass the role of the ESA? This is a possibility, but we believe it is not the best option. Achieving Net Zero requires action across a very wide range of activities, including agriculture, air and sea transportation, and engagement in international agreements.

> The CCC has a primary focus on the climate science, the pathways towards Net Zero and the policy initiatives to support action. The ESA must be much more focussed on the UK energy system and much more delivery focussed.

There should, in our opinion, be a tension between the CCC and the ESA. The CCC must press for action across a wide front, while the ESA must assess the feasibility of options and drive delivery. Whereas the CCC has developed scenarios through modelling least cost pathways, the ESA must make engineering risk-based assessments, formulate a delivery strategy, develop back up plans for risk mitigation and continuously update the strategy to take account of actual performance and emerging technologies.

If the ESA were to be created within the CCC then the remit of the CCC would need to be changed, and its organisation, staffing and board would need to be changed to reflect its revised role. These changes might extend to making the new body responsible for delivery in the same way as described for the ESO – this would require more significant change to the CCC and delegation of contracting authority.

If created as an advisory body, the ESA would have similar attributes to those described in Option 1 above, but it would not have delivery responsibility so would not need to have contracting authority.

To give the ESA the same effective standing as the CCC we would add that it should be answerable to Parliament as is CCC and that it should report independently, but at the same times, as CCC.

What are the responsibilities, authorities and accountability of the ESA?

The question of responsibility is inseparable from that of authority. The authority to discharge the functions of the ESA is currently vested in BEIS. Therefore, the level of responsibility to be placed on the ESA will depend on the level of authority to be delegated.

Option 1

The ESO will be separated from National Grid and taken into public ownership, presumably as a state-owned corporate body or possibly as an NDPB (let us call it New ESO). The New ESO remit will be extended to include the responsibilities of the ESA including responsibility for delivery of the NZ2050 energy system. Significant contracting authority currently vested in BEIS will need to be delegated to New ESO so that it can contract for new generating capacity.

Option 2

Create the ESA as a stand-alone advisory body, on a par with the CCC. Its primary government interface will be through BEIS, but it will be directly accountable to parliament. The ESA would potentially draw some staff from CCC, BEIS and the ESO. It would not have delivery responsibility and so would not require delegation of contracting authority from BEIS. A significant disadvantage of this arrangement is that delivery responsibility remains with BEIS, and therefore the separation of policy and implementation responsibility is not achieved.

There may be other viable solutions. As of the 4th December the National Audit Office [Ref 20] has released its report 'Achieving Net Zero', highlighting many of the challenges we have identified through our 'engineering net zero' assessment. NAO particularly highlights the challenge of delivering collective objectives across multiple government departments compared to responsibility with a single central body. This report, among multiple recommendations, also highlights the need for a plan or strategy and assessment of progress.

8. Conclusions

Our conclusions are simple.

- Achieving Net Zero by 2050 is an extremely ambitious goal, the risk of failure is high.
- The nation's energy supply will become increasingly dependent on electricity and in the digital age the very fabric of society will depend more and more on a stable, secure and reliable power supply.
- The changes in the electricity system are unprecedented, the risks to system stability are greatly magnified as dependency on intermittent renewable generation increases.
- Government's commitment to achieve Net Zero, based on a theoretical scenario developed by CCC, requires a radical reappraisal of our energy system and development of a strategic plan for Net Zero using a risk-informed systems engineering approach.
- At the strategic level, the 'competitive energy market' is defunct. Through a complex web of market interventions, the Government has become the central buyer of electricity. There is no published evidence of a strategic plan guiding government's exercise of this overwhelming purchasing power.
- In the energy system all the key strategic risks are currently held by BEIS, government always owns failure, in this case the attribution could not be clearer.
- Implementation of Net Zero is a massively complex programme management challenge. Such implementation tasks have historically been separated from policy departments.
- There is a strong case for the creation of an Energy Systems Architect, answerable to parliament for the delivery of the Net Zero commitment.
- Decisions being taken now are impacting our ability to achieve NZ2050 and the reliability of our energy supply in the intervening period.
- Any delay in the creation of an ESA to a later date will be detrimental to achieving Net Zero 2050; action is needed now, and so the ESA is needed now.

9. Next Steps

The Ten Point Plan, which presumably foreshadows the long-awaited energy white paper, marks a recognition that we must accelerate our progress towards Net Zero. This is most welcome. However, the Ten Point Plan is also currently a Ten Year Plan, we need a strategy for the next 30 years and beyond.

The Prime Minister's Task Force Net Zero should assess the current arrangements for strategic planning of the energy system and co-ordination of actions across government. It should evaluate the need for an Energy System Architect, consider options for its formation and make a clear recommendation for action.

If an ESA is to be created, it must be done without delay, it will require legislative action. The necessary powers this should be included in the Energy Bill to follow the white paper.

Appendix A: The Power Outage of 9th August 2019

On Friday 9th August 2019, a power outage caused interruptions to over 1 million consumers' electricity supply. This caused widespread disruption in which the rail services were particularly affected with more than 500 services disrupted and trains stranded. Other essential services were protected by their internal emergency supplies but, in some cases, these were shown to be inadequate.

OFGEM investigated the causes of the failure. As is appropriate for an investigation by a regulator, the focus was on whether any party failed in its obligations, what lessons could be learned and what actions need to be taken to avoid a recurrence. Taking a step back from that immediate focus we might ask a wider strategic question about how our entire energy system is developing, not just the electricity system.

The report gives a detailed insight into the 'cascade' of events, including automatic system responses triggered in fractions of a second. The initial causal event was a lightning strike on a National Grid transmission line, an event described as 'routine'. The grid operation reacted to this in less than a tenth of a second. Within a second of the fault, the Hornsea 1 offshore wind farm 'deloaded' taking 737MW offline, and the steam generator at Little Barford CCGT tripped off losing 244MW. In addition, the instability caused numerous small generators in the distribution system to shut down through loss of main protection and Rate of Change of Frequency relays.

Within less than a second of the lightning strike 1130MW of generation was lost, much of it from equipment located far away from the causal event. This loss caused a frequency drop triggering further distributed generation to disconnect and one second after the strike around 1500MW was lost. This exceeded the frequency reserve of 1000MW held by the ESO. Before the frequency could fully recover, a further turbine was lost at Little Barford, the fall causing further loss of distributed generation (although technically the frequency was recovering). A minute after the lightning strike, one of the gas turbines at Little Barford tripped followed by further embedded generation losses. At this point at least 1990MW of generation had been lost.

The continuing frequency drop and was exacerbated by the last gas turbine at Little Barford tripping, triggering automatic low frequency demand disconnection of 5% of the system load to protect wider system integrity.

The automatic disconnection within about a minute of the lighting strike hit a million customers and led to the stranding of trains and other customer impacts. However, it protected the system from further degradation and within five minutes the system was back to normal frequency. In under 45 minutes, all electricity supplies to customers were restored.

The report shows what a highly complex system we have, no single party was found to be responsible for the event, although there were some minor failures, particularly in the contracted rapid response suppliers.

The sophisticated automatic systems effectively protected the wider grid operation. This might be taken as reassuring but there is an underlying trend that was identified by OFGEM and should be recognised more widely. This is the rapid change that decarbonisation is bringing to the grid, particularly due to the loss of 'firm' synchronous generating capacity. The impact of a huge increase in asynchronous intermittent power generation has far reaching cost and risk implications.

At the same time, the widespread increase of dependency on digital controls in almost all aspects of our lives will magnify the consequences of even a short interruption of power supply. The event also highlighted the lack of visibility of embedded generation and its impact on the network frequency and inertia.

The grid will become increasingly complex as we decarbonise, asynchronous intermittent generators and distributed generators will increase the operational challenges. In NZ2050, 28% of our electricity is expected to be from CCGTs and bioenergy equipped with CCS. The CCS will be provided by separate systems beyond the control of the ESO and these will have their own risks and dependencies.

One of the issues flagged by the 9th August outage is the impact of distributed generation that is not under the control of the ESO, the automatic shut-down of just a few hundred MW of this capacity was a significant contributor to the failure. A significant increase in grid dependency on external systems beyond the control of the ESO (or even invisible to it) could increase the overall operational risk of the system.

Agglomeration of large offshore wind farms with common control systems and the introduction of large nuclear plant such as Hinkley Point C will introduce the risk that a single generation system failure could take out at least 1500MW, the kind of loss that triggered the 9th August event.

Report Contributors

Richard Beake
Consultant
richard.beake@atkinsglobal.com

Dr David Cole
Market Director
david.cole2@atkinsglobal.com

Adam Gait
Associate Director
adam.gait@atkinsglobal.com

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