Energy Storage for Constraint Management

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nationalgridESO

Exploring ways to relieve network constraints

Foreword

The drive to net zero requires the energy system to evolve at unprecedented scale and pace. For decades we have been transitioning away from carbon intensive fuels including oil, coal and gas towards cleaner, greener, renewable technologies. But where our power comes from isn't the only part of the energy system that must evolve – our infrastructure and networks must also transform, enabling a whole energy system that delivers reliable, affordable and zero carbon energy for all.

In Great Britain, we have one of the fastest decarbonising electricity systems in the world. As the Electricity System Operator (ESO), we sit at the heart of the energy system and part of our role is about building the energy system for the future. We are driving change across the energy industry, transforming our approach to system operation so that by 2025 we can run the system during periods with zero carbon emissions, building to meet the government's commitment to decarbonise the electricity system by 2035.

As the electricity system decarbonises, the volume, timing and location of both electricity supply and demand will change significantly. As a result, we will see very different flows of electricity across the entire system compared to what we currently see. In line with the Government's target to build and connect 40GW of offshore wind by 2030, investment in offshore wind is rapidly increasing. However, this also means that network constraint costs are rising, and will continue to rise until new network infrastructure is built to support this increase in generation.

Minimising the cost for consumers is a core part of what we do. As we transition towards a net zero economy, we are looking for new and innovative ways to alleviate network constraints, ahead of new transmission capacity being built, to keep consumer bills as low as possible.

In 2021, we published a 5-point-plan outlining how we plan to minimise network constraint costs in the years ahead. As part of the 5-point plan, we commissioned a detailed analysis which looked at the role of energy storage in alleviating network constraints and reducing system balancing costs between now and 2030.

This report summarises the findings of this analysis and what this means for the electricity system.

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1. Executive Summary

This report sets out the findings of a study into the feasibility of storage technologies being used for transmission system constraint management and discusses their implications. We commissioned consultancy firm DNV to carry out the analysis and help us to better understand the technical and economic characteristics of storage technologies providing constraint management services, as part of the objectives set out in our Constraint Management 5-Point Plan.

Key messages

1. In a net zero world, the electricity system looks very different to the one which we have today.

The Government's target of net zero by 2050 is driving the biggest change in energy technologies since the industrial revolution. The electricity network we have today was built for a centralised system with a generation mix predominantly made up of large, dispatchable, synchronous generation. Tomorrow's energy system will see increasing amounts of transmission connected renewable generation, changing consumer behaviour patterns, and more decentralised, embedded generation. We need smarter, flexible technologies to help manage the inherent variability we get from renewable generation connected to the transmission system.

2. Energy storage is an essential part of the electricity system transition to net zero.

Our Future Energy Scenarios indicate that significant volumes of energy storage will be required to efficiently manage growing variability in electricity generation and demand, as we decarbonise the energy system. We see storage as a technology that can provide the electricity system with a range of different zero carbon services.

Storage is already the main technology used to provide the grid with very fast frequency response services, and we expect this role to continue to grow. Some storage technologies can also provide other balancing services such as helping manage voltage and inertia. As renewable generation continues to displace traditional dispatchable generation, we see storage playing a role in shifting electricity from when it is generated to when there is the demand for it. As electrification of heat grows, winter electricity demand will increase, creating a new role for inter-seasonal storage which can store larger amounts of electricity for longer periods of time.

3. Whilst storage has value in other markets, our analysis indicates that using storage exclusively for constraint management would be uneconomic.

Operating energy storage exclusively for constraint management leads to low utilisation because for most of the time, the storage is in the wrong state of charge[1] or the wrong location to alleviate the constraint. This low utilisation would make it very difficult for current storage technologies to recover their costs and be a more economic option for consumers than other constraint management solutions.

[1] For example, charging the storage would help the constraint but the storage is already fully charged

4. Combining constraint management with other services is possible, which would improve the economics, but it may be difficult

Most of the transmission system services that storage can provide can be combined with constraint management services. This indicates that the utilisation of storage providing constraint management could be improved. However, many balancing services cannot be usefully delivered from behind an active export constraint, which may limit the utilisation of storage at the most constrained locations.

5. In the long term, additional transmission infrastructure is the best way to minimise constraint costs. Until then, we are continuing to explore other ways to reduce constraint costs for consumers.

The best way to realise the full benefits of renewable energy generation and to reduce network constraints is to rapidly build additional transmission infrastructure, alongside new technologies and commercial solutions, so that the energy generated can be transported to where it is needed. However, we understand that new network infrastructure isn't something that can be built overnight, so in the short to medium term we are continuing to work with stakeholders to identify new and innovative ways to reduce network constraints and minimise costs to consumers. Our 5-Point-Plan sets out some of the other options we are looking at to manage constraints.

Net Zero is driving massive transformation of the energy system

One of the biggest differences between today's electricity system, and the electricity system of the future is the amount of renewable electricity generation that will be connected to the transmission system, with most of this renewable generation coming from offshore wind farms. In November 2020, the Government published its 10 Point Plan for a Green Industrial Revolution, where it set out its ambition to deliver 40GW of offshore wind by 2030 - quadrupling todays offshore wind capacity in the UK. In 2021, the Government went further, committing to decarbonise the electricity system by 2035, reducing the UK's reliance on fossil fuel generation and exposure to global natural gas prices.

Our 2021 Future Energy Scenarios indicate that credible pathways to achieving net zero by 2050 include reaching 100-130 GW of renewable generation by 2030, providing 85-90% of all domestic electricity supplied. At 70GW, wind generation will account for over half of that renewable generation capacity and over three quarters of the renewable electricity supplied[2].

Electrification of transport and heat will also be well underway by 2030. There will be 8-16 million electric vehicle cars on the road, consuming 20-40 TWh of mostly renewable electricity. There will also be 2-8 million homes with heat pumps, consuming 7-25 TWh of electricity[3]. The shift to electric heating will add a much larger seasonal variation to electricity consumption, with demand being much higher in winter, spiking even higher during very cold spells.

Unlike fossil fuelled generation, which can be dispatched to generate when there is demand, wind and solar generation only produce power when the wind blows and the sun shines. As the capacity of renewable generation grows, an increasingly large share of the zero-carbon electricity will be produced at times when it is not needed. Another challenge with renewable generation is that it cannot always be relied upon to generate when there is demand.

Energy storage has an essential role to play in achieving net zero

Storage will be critical in a highly renewable system, to absorb electricity when there is too much being produced and then release it when there is not enough. High power capacities of storage will be required to make sure that at any moment demand can be met, and high energy capacities will be needed to make sure that the storage can continue providing power for as long as necessary, without running out.

Our three FES scenarios that achieve the net zero target by 2050 see 9-16 GW of electricity storage by 2030, in addition to vehicle to grid flexibility and hydrogen fuelled generation. The hydrogen fuelled generation will be associated with very large underground storage of hydrogen, big enough to fill up using excess renewable generation in the summer and hold it till the winter when it is needed to meet the increased demand from heat pumps and hydrogen boilers. This storage will develop more slowly, with 1-2 TWh of storage in 2030 and 10-50 TWh in 2050[4].

[2] Future Energy Scenarios 2021, tables SV.22, SV.25

[3] Future Energy Scenarios 2021, tables CV.35, CV.31-33, CV.14, CV.9

[4] Future Energy Scenarios 2021, tables FL.13, FL.6

Figure 1: Electricity storage capacity (excluding vehicle-to-grid) in FES 2021

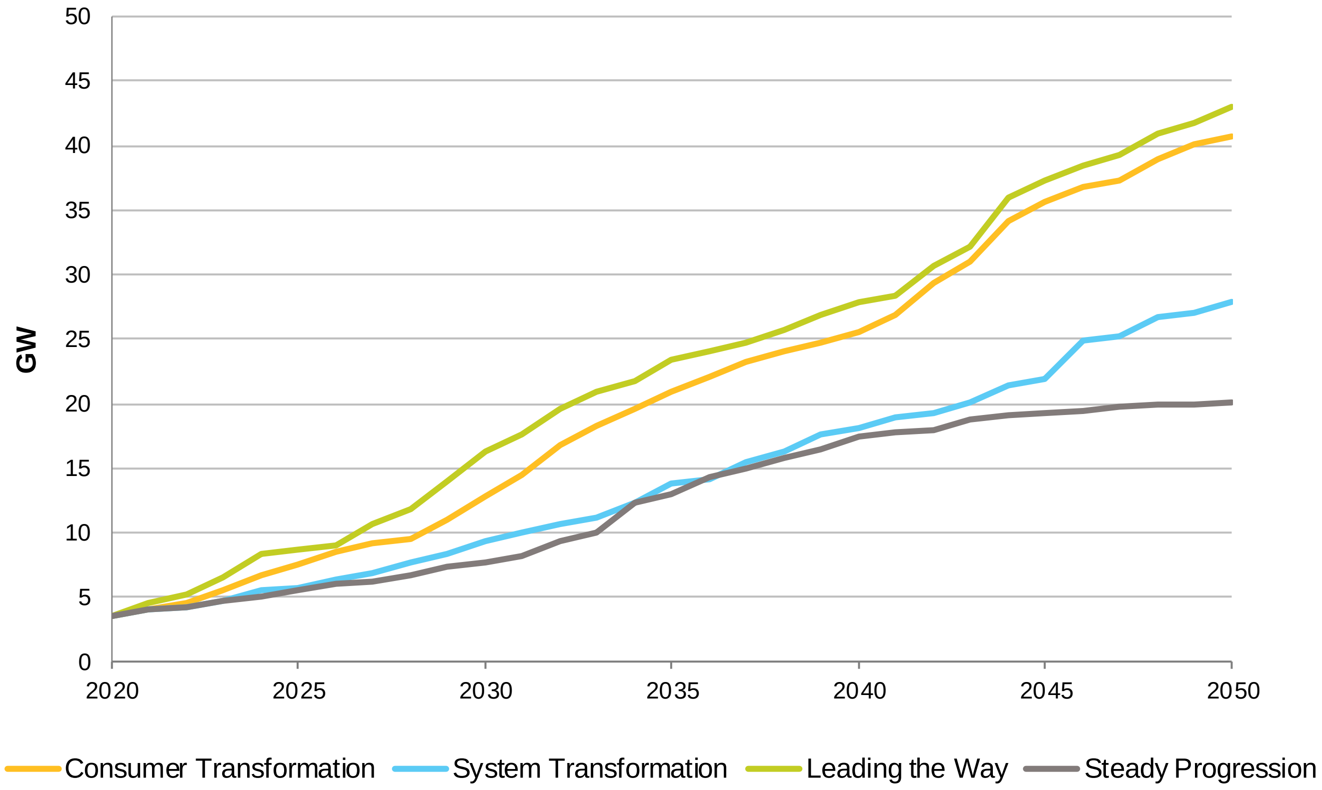
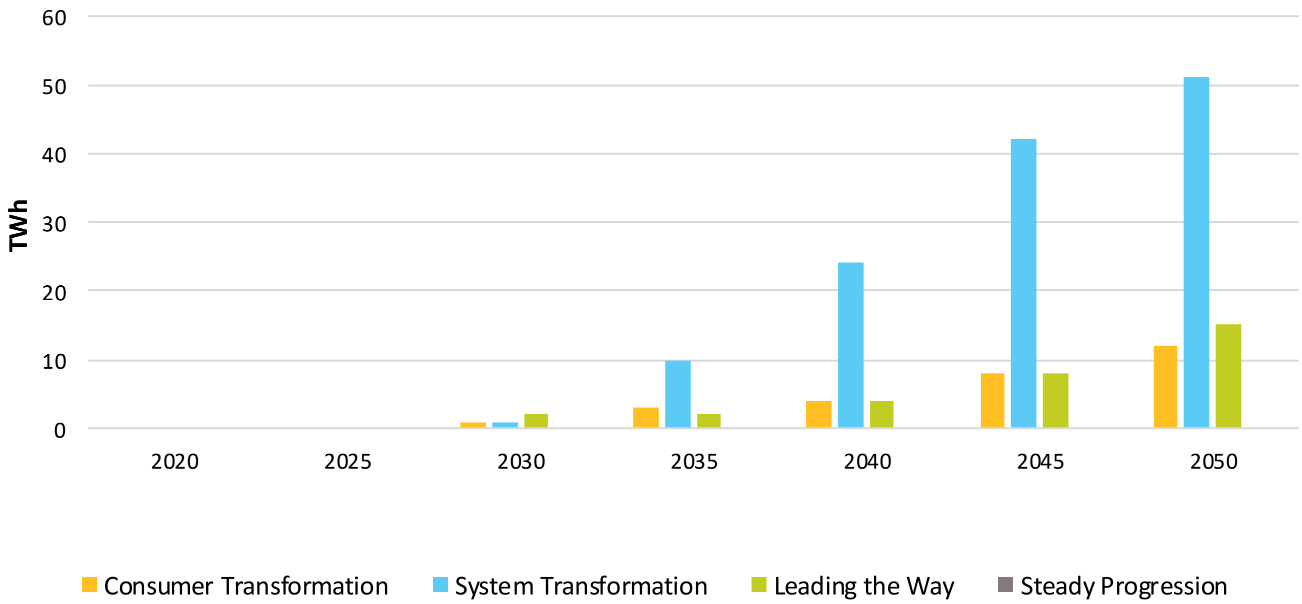


Figure 2: Hydrogen storage capacity requirements in FES 2021



Analysis by others, using different decarbonisation scenarios and generation mix assumptions, has found a need for even more storage, for example a recent study by Aurora Energy Research found a need for 46GW by 2035. Our A Day in the Life 2035 report, looking at how the electricity system might operate in 2035, highlights an important role for storage in meeting peak demand on a cold winter day and sees the durations of energy storage increasing over time, as the value in shifting energy from low to high price periods increases.

The main role we see for storage in a net zero electricity system is moving renewable energy from times when there is too much being produced, to times where there is not enough. But this is not the only service that storage will provide to the system. Very fast acting storage will provide frequency response services, quickly changing their levels of supply and demand to help keep the system balanced and the frequency stable. Slower and longer acting storage will provide reserve services, taking over from the shorter duration storage as it gets exhausted. Depending on how the storage connects to the grid, it may also be able to provide reactive power and stability services such as inertia and short circuit level.[5] Depending on where the storage is connected, it may be able to help manage network constraints, by reducing the flow of power across overloaded circuits.

The impact of wind generation on constraint costs

In line with Government ambitions, there has been a large increase in wind generation being built, and to avoid causing delays that would put climate targets at risk, it is being connected ahead of network investment[6], leading to increasing network constraints. Network constraints occur when the physical limits on parts of the transmission network are reached and there isn't enough transmission capacity to transport electricity from generation to demand. To keep the system secure, before this occurs, we take balancing actions which limit the flow of electricity over the part of the network that is at risk of being overloaded. These actions, e.g. paying generators to reduce their power output, have costs which get passed through to consumers.

Every year we run the Network Options Assessment (NOA) to assess the impact of building new infrastructure, comparing constraint costs and investment costs to minimise overall costs for consumers. Getting this balance right is made harder because it takes a long time to build new transmission network capacity, so we have to predict how much infrastructure we will need in the future, to make sure it starts getting built in time.

As more generation connects to the system the size of the network needs to increase to transport the power. A lot of the new generation is wind, which tends to connect far away from centres of demand, increasing the investment needed, making it more expensive to transport the electricity. The Government's ambitions to grow offshore wind generation have increased significantly and it will take years for the planned increases in network capacity to catch up.

The need for more strategic transmission infrastructure investment will be addressed by our Network Planning Review, Ofgem's Electricity Transmission Network Planning Review and Government's Offshore Transmission Network Review. In the short term, the cost of managing constraints on the network will increase then, as new network capacity gets built, the balance will shift, the cost of paying for network investment will increase, but constraint costs will decrease by more, lowering overall costs for consumers.

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[5] For more information on the system services mentioned (frequency response, reserve, reactive power, inertia and short circuit level) please refer to our Markets Roadmap to 2025 and our Operability Strategy Report.

[6] The 'Connect and Manage' regime was trialled by Ofgem in 2009 and then made an enduring regime for network access by Government in 2010.

Recognising that there will be a significant increase in costs at a time when energy prices and inflation are high, we launched our Constraints Management 5 Point Plan. Through the Plan, we are exploring what can be done to mitigate the increases in constraint costs. One of the five points on the plan was to explore the potential for using energy storage to reduce constraint costs in a heavily constrained network.

Using energy storage to manage network constraints

Previous studies have analysed the economic opportunity for storage in electricity systems with high shares of renewable generation. Some of these studies have included estimates of the value from supporting constraint management. To our knowledge no other studies have used a full Great Britain network model to understand the impact of storage on constraints.

In August 2021, we appointed consultants DNV to analyse whether storage would be an economic solution to reduce constraints between now and 2030. This analysis is now complete, and a summary report has been published, with full details of the methodology and results.

This analysis showed that energy storage providing only constraint management services would very rarely be economic.

Operating energy storage exclusively for constraint management leads to low utilisation because for most of the time, the storage is in the wrong state of charge or the wrong location to help with the constraint. Often the storage gets full before the constraint ends, or the local circuits are overloaded so much of the time that the storage cannot discharge fully between constraint events, or the most constrained circuit on the boundary is too far from where the storage is connected for it to be effective. This is why the location of storage on the electricity system is key, to make sure it can be used effectively.

The storage types modelled typically achieved a utilisation of around 23% and were 'idle' the rest of the time, resulting in levelized costs of 120-400 £/MWh, which were higher than the constraint costs of around 110 £/MWh on average across the 6 boundaries. The 'merit orders' of historic constraint payments at two of the boundaries analysed are presented below to illustrate this.

There were some occasions in the modelling where the storage could reduce constraint costs, if it was the most efficient storage, at the most effective connection location, on the boundary with the most expensive balancing actions. However, the benefits were small compared to the investment required, and highly uncertain. Small changes in the scenario modelled could remove the benefit.

Figure 3: Representative 'merit order' of BMUs on Boundary SC3[7]

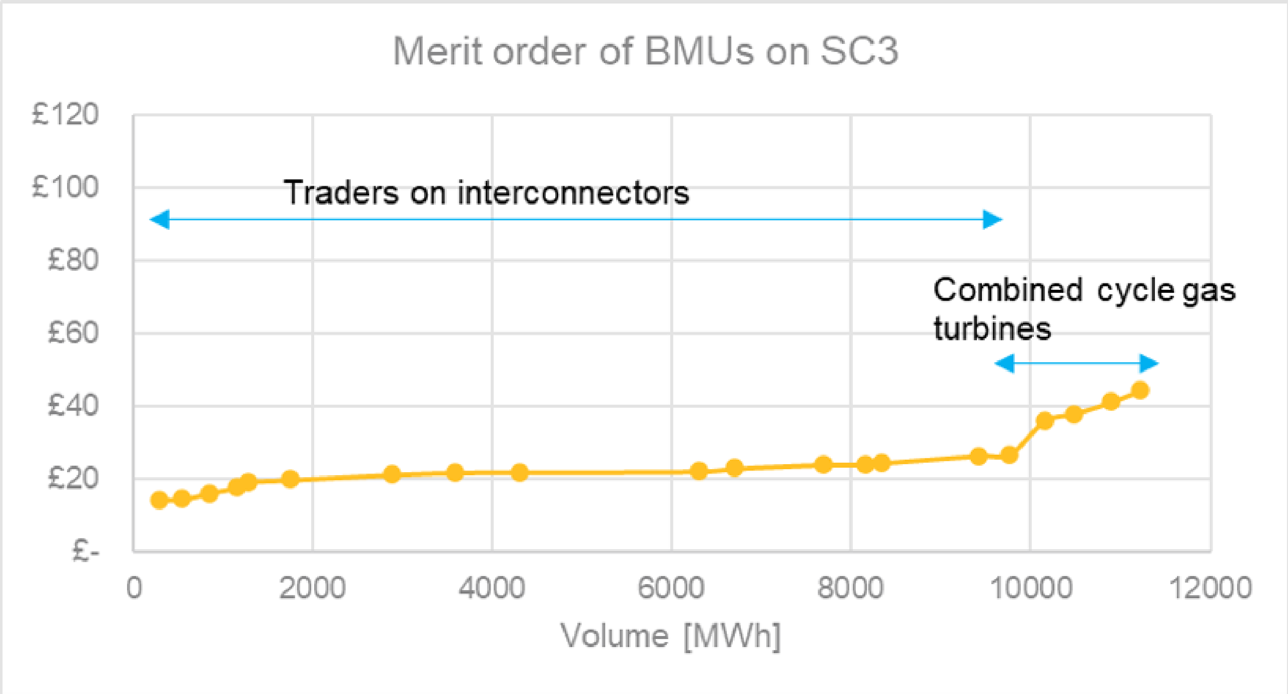
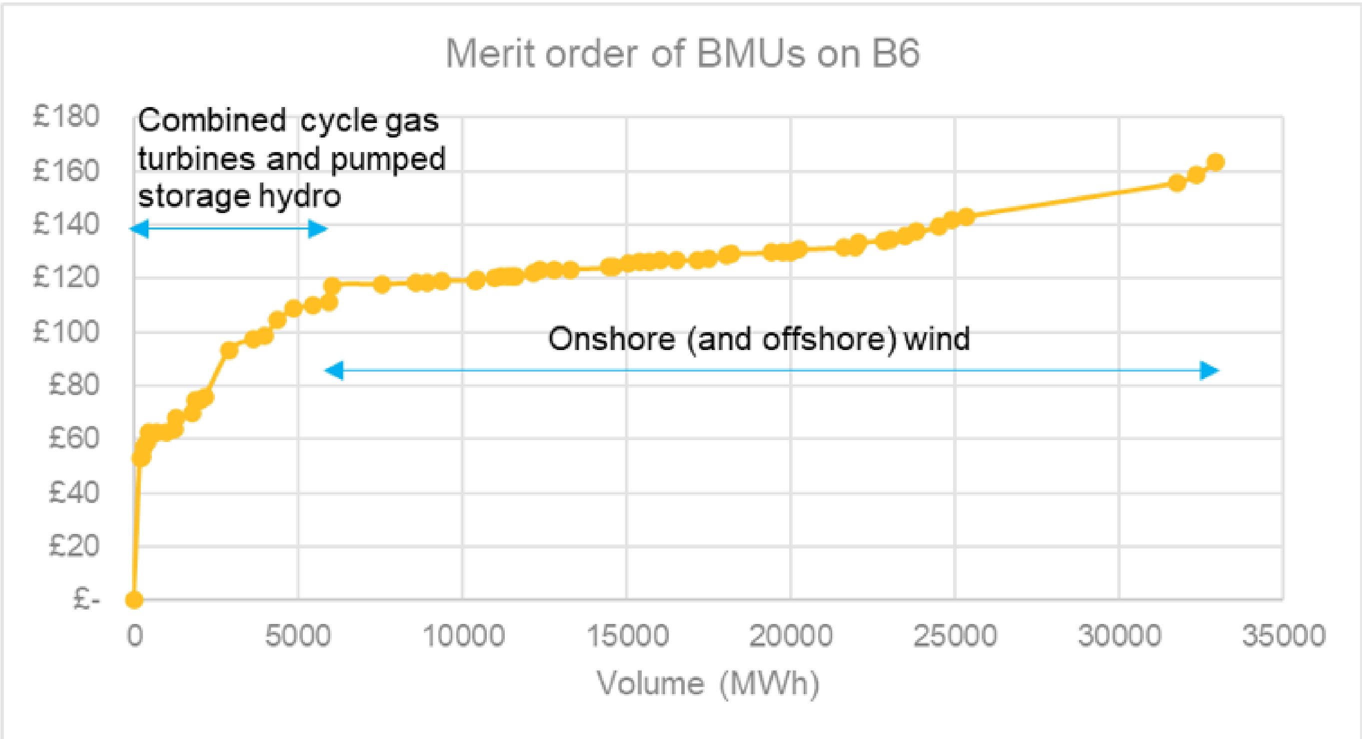


Figure 4: Representative 'merit order' of BMUs on Boundary B6[7]



[7] SC3 and B6 are boundaries between different areas of the GB transmission system. SC3 is in the south east of England. B6 is near the border between England and Scotland. See our ETYS and the Network Planning Process page for more information.

A qualitative analysis of all the transmission system services that storage can provide, the suitability of different types of storage for each service, and the ability of storage to stack these services with constraint management, showed that most of the services can be combined. This suggests that storage could provide constraint management services and increase its utilisation by also providing other services.

However, it may be very difficult for storage to deliver high volumes of constraint management and also achieve high utilisation, because many balancing services cannot be usefully delivered from behind an active export constraint. Very constrained parts of the network may not be the best location for storage because the same constraints the storage is trying to help with may limit the other services the storage can provide.

It is not yet clear how far storage providing constraint management could increase its utilisation by stacking other services. To understand the upper limit, a theoretical minimum levelized cost of storage was calculated. In a best-case scenario, where the assets are able to stack enough other services and trading activity to achieve 95% utilisation, the levelized cost of storage falls to about 55 £/MWh which would be competitive with other constraint management actions in some locations.

What does this mean for storage providers?

Investment in short duration storage is growing rapidly, indicating industry confidence in the future market, but we do not see the same pipeline of future projects for medium and long duration storage[8]. We are hearing from our storage stakeholders that the market signals to justify investment in longer duration storage are not strong enough yet, the costs of large storage projects are high and future revenues too uncertain. Through the work we are doing on Net Zero Market Reform and our Markets Roadmap, we are exploring the drivers for future flexibility requirements, such as long duration supply and demand imbalances, and we are working with stakeholders to determine the market designs that could deliver those requirements. We believe these future market arrangements will be more effective at signalling the value of technologies like storage, which will improve the investment case, but we expect that these changes alone will not be sufficient to deliver the scale and pace of growth required.

Wherever possible, we try to use technology neutral markets to provide the services the system needs, only resorting to bespoke technology specific arrangements when there is a compelling consumer benefit from doing so. Having considered this analysis, we have decided that we will not seek long-term bilateral contracts with storage providers exclusively for constraint management. We believe that in most cases we would not be able to agree terms that would be in the interests of both consumers and the storage industry, and in the few cases where it might be possible, the benefit to consumers would not justify moving away from technology neutral market arrangements.

We want to see competition from a range of technologies for all of the services we buy, so if storage providers feel they can provide constraint management services at a competitive price we encourage them to participate. When we trial new markets for constraint management services, we will ensure that storage can participate and compete as appropriate. If there are any unnecessary barriers to storage stacking constraint management with other services or competing with other providers, we encourage stakeholders to let us know so that we can address them.

[8] There are currently no accepted definitions for short, medium and long duration storage. Within the ESO we are starting to use short duration to mean up to a few hours, medium duration to mean a few days and long duration to mean at least a week.

Looking to the future

Building new network infrastructure

As we transition towards net zero, it is crucial that we embed whole system thinking in our approach to designing an electricity network that is fit for purpose. This means thinking holistically across electricity transmission and distribution, as well as considering future interactions between the electricity system and other technologies such as hydrogen and Carbon Capture Usage and Storage (CCUS). The most effective solution for realising the full benefits of offshore wind generation will be to build rapidly new network infrastructure to move more of the renewable energy from where it is made to where it is needed. Appropriate price signals will help new sources of generation and demand to make more informed decisions about where to connect and how to operate. For example, electrolysis to produce hydrogen may choose to locate and operate so that it can help to balance wind generation.

Managing constraints in the short to medium term

While we don't believe that energy storage is the silver bullet for managing constraints, we see it as a very important part of the transition to net zero, providing many services that will be essential for keeping the electricity system secure and efficient.

Minimising the impact on constraint costs from the rapid growth in wind generation will be an important contribution to making sure electricity remains affordable for consumers. As detailed in our 5 Point Plan, we are also looking at other options to help manage constraints including:

- Developing intertripping capability through our constraint management pathfinder
- Improved BSUoS[9] forecasting for generators and suppliers
- Working with regional networks on a whole system approach
- Continuing to improve the existing GB network

The future of storage

We will continue to analyse the role of storage in a net zero electricity system, and on the pathway to getting there. In particular, the quantities and durations of storage needed, and how they will be used, to keep the electricity system efficient and secure.

We will also consider the interactions between storage and other technologies that can provide similar flexibility. Smart demand from electrified heat and transport, plus vehicle-to-grid electricity supply could provide large volumes of cost effective within-day flexibility, competing with storage that has a duration of a few hours. Hydrogen fuelled generation, CCUS and residual unabated gas generation can provide power indefinitely, competing with very long duration storage to move energy between weeks, months and seasons. Green electrolytic hydrogen production, located on the same side of a network constraint as renewable generation, could be a much more effective solution than storage for constraint management. The electrolysis could absorb power when there is too much of it, providing hydrogen for use in other sectors, without having the problem of needing to wait for an unconstrained period to release the energy before it can act again.

Reforming markets for flexibility

Through our Net Zero Market Reform programme we will continue to work with stakeholders to design and agree the best market arrangement to provide appropriate signals for the investment and operation of the technologies needed for a net zero electricity system. Our regularly updated

[9] Balancing Services Use of System

Markets Roadmap will set out the pathway for transitioning to future market arrangements, helping stakeholders to understand the commercial arrangements they will operate within in coming years. Our annual Bridging the Gap to Net Zero publication will identify critical activities and milestones needed to remove barriers and maintain the pace of the transition, to keep us on track for our net zero targets. Innovation projects and trials, such as our Local Constraint Market will provide more detailed understanding of the options available and how they would really work in practice.