FES 2020 FAQ document

FAQ’s during FES 2020 launch

September 2020 Version 3.0

nationalgridESO

Contents

Introduction

This FAQ document is just one publication in the suite of documents that make up FES 2020. In addition to the main report we also publish the summary document - FES in 5, our Modelling Methods and the Scenario Framework that details all the assumptions and levers that are used as input into our models. The Data Workbook contains all the outputs from the numerous models: the detailed tables, graphs and charts.

For more information and to view each of these documents visit our website.

This FAQ document seeks to answer the main questions we received during the week of the FES 2020 publication and launch.

To provide answers as soon as we can, rather than waiting for all questions to have be addressed we are releasing this document in instalments. Later iterations will have any new content clearly marked (e.g. in different colour font).

Questions and answers from:

- the first iteration (published on 17/08/20) are in black font;
- the second iteration (published on 24/08/20) are in green; and
- the third iteration (published on 07/09/20) are in blue.

Note that, for questions related to costing of the scenarios, we will be sharing information on this later in the year so please look out for this (more information will be provided in the FES Newsletters).

Please contact FES@nationalgrideso.com If you have any queries.

Many thanks

FES team

Net zero and scenario framework

1. Is there any chance that you could show how this year's scenarios relate (in data terms) to last year's? It is always interesting to compare and track the evolution of the forecasting.

The Data Workbook from FES 2019 is available on the website and can be compared to the FES 2020 Data Workbook we have uploaded this year. Due to the sheer volume of data it is impractical to produce comparisons in an easily usable format. We have however published a "FES 2020 Key Changes" document that describes the changes at a high level.

2. How substantially do you expect the impacts of the pandemic to change these scenarios, particularly the expected date for negative emissions in the power sector?

The long-term impacts of COVID are very uncertain. The economic impact has been huge but how that translates into longer term impacts on energy supply and demand is something we will be assessing in FES21. For the avoidance of doubt, the FES 2020 analysis does not include any impacts of COVID. As we start our modelling in December, we were already well underway when COVID implications for the UK started to emerge and there was also too much uncertainty for us to go back and make any changes. Later in the year we will be sharing some of our findings around how COVID (and any associated mitigation measures) may impact energy demand and supply.

3. How does the FES incorporate risk/uncertainty? For example, is it a high-risk assumption to assume large scale CCUS is deployable? If so, can you compare the uncertainty of each scenario?

FES doesn't apply explicit risks or uncertainties to the scenarios that can be expressed e.g. as percentages in the Data Workbook. Instead, where assumptions are made these are set out clearly and transparently (e.g. in the assumptions tab of the "Scenario Framework" supporting document or in the "Modelling Methods" document) so that they can be reviewed and, if necessary, challenged. If you have suggestions about how a more risk-based approach could be applied to FES we would be keen to discuss this.

4. What infrastructure improvements do we need for the network for industrial clusters?

This is explored in National Grid Documents which build on the FES - specifically the Network Options Analysis (NOA), Electricity Ten Year Statement (ETYS) and Gas Ten Year Statement (GTYS). The electricity and gas distribution companies also produce investment plans and scenarios, some of which are closely aligned to FES.

5. To what extent does reinforcement of existing local electricity networks constrain our ability to make these large transitions from Natural gas to Electricity?

FES is intended to show customer needs. Network requirements are then explored in National Grid Documents which build on the FES - specifically the Network Options Analysis (NOA), Electricity Ten Year Statement (ETYS) and Gas Ten Year Statement (GTYS). The electricity and gas distribution companies also produce investment plans and scenarios, some of which are closely aligned to FES.

6. If you were to take an educated guess - Which scenario do you believe is most likely to transpire?

We use scenarios to assess the credible pathways for future supply and demand in GB. Rather than trying to decide which scenario is likely to most closely represent the 2050 energy system, the scenarios are designed to represent the “credible range of uncertainty” that this 2050 energy system could fit into.

7. Do you see specific areas of the UK reaching significantly faster than other areas? Either due to either local government ambition, or the creation of net zero "clusters"?

Our emissions analysis is not location specific as we do not have the data for the non-energy sectors broken down.

8. Is 2048 really the earliest you can go?

In our analysis this year, we have kept the non-energy sector emissions like land use constant across all three net zero scenarios - i.e. we've not flexed them across the scenarios. In Leading the Way we've tried to push the energy sector decarbonisation as early as we can by aggregating all the different modelling areas and this is what gives the 2048 date. If the non-energy areas were also flexed, or potential other negative emissions technologies applied, there is potential for this to be brought earlier.

9. Please could you explain how negative emissions can be achieved and do you believe Net Zero is possible without CCS?

In all of our net zero scenarios we assume that CCUS is required. This is because of its ability, when paired with bioenergy, to form Bioenergy with CCUS (BECCS) which delivers negative emissions. Across the scenarios, we believe that negative emissions are required to meet net zero because we have identified some sectors of the economy which will not be able to fully decarbonise and which will require other sectors to offset. We've looked to BECCS to provide negative emissions (mostly through the power sector although System Transformation also includes some biomass gasification to produce hydrogen) and so this requires CCUS. Unless you can find other ways of generating negative emissions without CCUS, we think that it is required for net zero.

10. BECCS and land use change seem to be the main ways of achieving negative emissions, has direct air capture been considered in any of the scenarios?

In our FES 2019 Net Zero Sensitivity, and in line with the approach taken by the CCC at the time, we met 96% of the net zero target by 2050 and we relied on speculative technologies like Direct Air Capture (DAC) to meet the remaining 4%. In FES 2020 we meet 100% of the target and we do so without using DAC. Part of the reason for this is that it is an energy intensive process as a lot of additional energy is required to achieve the negative emissions. If it was to be included it could potentially bring forward the net zero date from where it is currently in FES 2020.

11. How is security of supply maintained in the scenarios?

For electricity, each year in each scenario meets the Reliability Standard set by the Secretary of State of no more than 3 hours Loss of Load Expectation (LOLE) - the same standard as used in the Capacity Market. This basically means that the peak electricity demand in a given year, plus the reserve required on the system, can be met. For gas, we make sure that for each year in each scenario there is enough gas supply capacity available to meet something called the 1-in-20 peak demand which represents weather conditions that, in a long series of winters, might occur once in 20 years.

12. Figure SV32 of FES2020 shows that BECCS only achieves 10GW of energy by 2050 in the optimistic scenario. Isn't this a high price to pay to the problems with BECCS like biodiversity impacts, water supply, and air pollution?

Firstly, on units, 10GW is the capacity and we assume in FES that BECCS will run at a high load factor across the year (i.e. close to baseload) and so there will be a lot of energy in a given year when considered in TWh terms. However, it's not just the energy that we get out of the BECCS generation that is important here and the reason for its prominent role in the net zero scenarios is instead to do with its ability to generate negative emissions. Impacts on things like biodiversity are really important and that's why its key for the bioresources (i.e. the fuel that goes into the BECCS process) to be sustainably sourced.

13. Have you assumed in all four scenarios that the UK does not have any access to international carbon credits in seeking to achieve its net zero target? What do you assume about the net emissions from the UK LULUCF (agriculture and land use) sector?

Yes, it is assumed that the UK meets net zero in its own right. In terms of agriculture and land use emissions, these are included in the "other" category of emissions in the tables in the main FES document and in the Data Workbook. For this year, the total number in 2050 is 15 MTCO2e - this includes the emissions from agriculture but also the negative emissions from reforestation and afforestation (i.e. planting trees). We work closely with the CCC on these numbers.

14. I would like to know more about the regional breakdown of consumer view components - please advise if it will be released. Thanks.

A regional breakdown of some FES component is published on the website (see supporting documents). The ESO Data Portal also includes some of the "Building Block" data that is used in some of our work on the Open Networks project alongside distribution companies and the ENA.

15. All the net-zero scenarios rely on BECCS, how does the accounting for this work? SV.27 implies the negative emissions occur when the biomass is burnt. Are emissions not slightly positive at this stage (due to processing and transport act.) and only go negative as the new biomass grows?

From a modelling and carbon accounting perspective, FES assumes that negative emissions occur in the year that bioresources are used to generate power or hydrogen via BECCS and the resulting CO2 stored or used for another purpose.

16. How do you see the hydrogen network being established? To what extent is it a conversion of the existing (methane) gas network, or is there a need for a newbuild hydrogen network?

Across the scenarios, we assume that hydrogen development takes place initially in clusters before then spreading out more widely for the scenarios with hydrogen networks (e.g. System Transformation and Leading the Way). In terms of whether the existing natural gas networks are converted to hydrogen or a newbuild hydrogen network is developed, this is something that is being discussed currently by the gas transportation networks.

17. If you are going for 62MtCO2 negative emissions by 2050 from BECCS where is the 62MtCO2 positive emissions coming from - please break down this figure?

The sectors still emitting in 2050 can be found in the FES document and the Data Workbook and largely consist of "non-energy" emissions related to Agriculture and LULUCF (Land use, land use change and forestry), Waste, F-gases, Aviation and Shipping (in Steady Progression). The 62MtCO_2e is for Leading the Way in 2050.

18. What do you see as being the key factor(s) determining whether or not H2 will be used in heating, and when do you expect we might see those factors and the associated uncertainties start to be resolved?

In terms of what we think will drive the future technologies for heating, this is something that is reflected across the "Level of societal change" axis with hydrogen boilers being a relatively low societal change technology from a consumer perspective (i.e. just changing an existing methane boiler for a hydrogen-ready boiler) compared to electrification of heat which may require a higher degree of change for consumers. Therefore, this is a key factor alongside policy setting around which route should be followed. In terms of when the uncertainties need to be resolved, our Key Messages highlight the need for industrial scale demonstration projects to be operational this decade.

19. Why is bioresource considered in the Sankey energy flow diagram if there are so many losses? Please explain what the "losses" are on methane reformation and biomass on the energy flows?

There is a real need for negative emissions to reach net zero by 2050 and part of that is delivered by BECCS and therefore from bioresources. This means that this ability to produce negative emissions outweighs the losses associated with this. In terms of methane reformation, we assume that the process does get more efficient and reaches about 82% by 2050.

20. What do you think the probability is of a scenario in which there are net negative emissions from electricity generation by 2030, given where we are in 2020 and the fact that there is little progress in commercialising negative emissions technologies??

We don't assign probabilities to our scenarios. Rather than trying to decide which scenario is likely to most closely represent the 2050 energy system, the scenarios are designed to represent the “credible range of uncertainty” that this 2050 energy system could fit into. One of our Key Messages in FES 2020 refers to CCUS saying that "Industrial scale demonstration projects need to be operational this decade". If this happens alongside the uptake of renewables in the scenarios, we think this is credible.

21. How does this [FES results] fit with the 2045 net zero target for Scotland?

FES analysis is carried out on a UK basis in terms of emissions (and GB in terms of energy systems) in line with the legislated target. However, we appreciate that there will be regional variation as well as variation between different sectors in terms of when net zero may be reached.

22. In regards to the uncertainty of Brexit, how have your assumptions adjusted to that?

Leaving the European Union introduces some uncertainty around future energy trading. Given this uncertainty on future trading arrangements, our FES analysis assumes continued market harmonisation between GB and Europe once the Transition Period ends. This includes for example that GB continues to participate in the Internal Energy Market, or similar future arrangements are developed. Should further information on future

European energy trading arrangements become available, we will consider how any such changes impact our analysis. In our modelling of gas supply patterns, we assume that the UK's decision to leave the EU will not materially affect flows of gas, in either direction, between GB and Europe.

23. How much of the achievement of net zero is actually met by offshoring our carbon emissions, for example through interconnectors? If the whole system including offshoring and upstream was included, could we still meet net zero?

Our net zero analysis is carried out based on emissions generated in the UK and does not include consumption of products and the associated upstream emissions involved in their production. Specifically on interconnector imports and exports, we assume that these are carbon neutral (i.e. we assume that emissions from UK generation is counted in our figures and that generation on the other end of the interconnector is accounted in their figures).

24. How reliant will the UK be on the cooperation of other nations if these scenarios are to be successful?

Our scenarios focus on UK carbon emissions and GB energy systems to meet the UK net zero target and don't rely specifically on cooperation from other nations (e.g. we treat interconnector flows as zero carbon). However, there is implicit cooperation required in terms of things like trading arrangements, global technological developments etc.

25. What energy imports (interconnectors or biomass or gas) do the scenarios assume?

Energy imports in the form of electricity, gas, hydrogen and biomass are considered as part of our energy supply analysis for the individual sectors and can be found in the relevant sections of the FES document and in the Data Workbook.

26. For system security have you also considered impact on black start for each of the scenarios?

FES analysis ensures security of supply across all scenarios and years in terms of energy being available to meet peak demand. However, specific ancillary services such as black start are not specifically considered in FES (for more information see the "System Operability Framework" and "Distributed Restart" sections of the ESO website).

27. Has maintaining system inertia been considered in all net zero scenarios?

The FES analysis focuses on energy supply and demand and does not model aspects such as inertia in great detail as these are covered in other ESO processes such as the System Operability Framework (SOF) - information on which can be found on the ESO website. However, SOF analysis uses FES data and so, while it is important not to prejudice this analysis in FES itself, the two processes are coordinated.

28. Do National Grid consider planning application issues as a key risk or source of uncertainty in each scenario?

As part of our electricity generation analysis, the progress of different projects through the planning application process informs the levels of generation capacity in different years and, by flexing this across the scenarios, this allows the uncertainly to be explored. Also, for scenarios that are higher up the "Level of societal change axis", we assume that planning permission is less of an obstacle as we appreciate that it has the potential to cause delays etc.

29. Is demand UK or GB?

Energy demand and supply (e.g. gas, electricity, hydrogen etc) are modelled on a GB basis to align with the current networks and do not include Northern Ireland. Where UK is relevant is in relation to the net zero target which is applied at across the whole UK economy.

30. Do you think that individual companies that set their own early Net Zero target have a tangible effect on our progression? Or is it minimal?

In FES 2020, we consider changes by consumers, companies and government as all being important to be able to meet Net Zero and the degree to which this takes place across the scenarios is modelled according to the "Level of societal change" axis in the scenario framework.

31. Can you reinforce that hydrogen only has a place to play alongside effective CCUS and its later timeframe? (concern that a strong hydrogen presence in scenarios and hydrogen messaging scuppers electrification of heat)

The scenarios have been designed to try to explore the uncertainties associated with the decarbonisation of heat. Consumer Transformation has a lot of electrification, System Transformation has a lot of hydrogen and Leading the Way is more balanced. However, even in System Transformation, electrification plays an important role and by 2050 there will be over 10 million homes relying on a form of electrified heating.

32. Are any embodied emissions (e.g. in wind turbines etc) included in analysis at all?

Assuming that this question relates to emissions in the manufacturing and transportation of assets like wind turbines, these are not captured in our emissions figures. This is because we follow the accounting method widely used (e.g. by government and CCC) and only consider greenhouse gas emissions in UK. UK manufacturing is captured in our I&C modelling (including associated emissions).

33. Having identified need to prove and scale up CCUS, what are the needed drivers to ensure this happens?

As highlighted in our 2nd FES 2020 Key Message, industrial scale demonstration projects need to be operational this decade to prove and scale up CCUS. This will require policy support as well as coordination across policy, regulation, and industry.

34. When would you expect further clarity on which scenario most closely represents the likely approach to be taken, and what do you consider will be the key lead indicators as to whether we are successfully on track with the various scenarios?

In terms of clarity on which scenario most closely represents the likely approach to be taken, given how the scenarios are designed to provide a credible envelope of possible future developments in energy, it may be the case that the approach taken combines elements of each. However, in terms of a key indicator for whether we are successfully on track with the various scenarios in general, this is probably to do with how the progress that the UK is making on decarbonisation more generally and can be monitored going forwards against the carbon budgets produced and assessed by the CCC.

35. Why is there such little energy demand in Consumer Transformation?

Consumer Transformation and Leading the Way have high degrees of energy efficiency (across residential, I&C and transport demand) and this leads to a lower energy demand than System Transformation and Steady Progression. Consumer Transformation has lower demand than Leading the Way due to a greater penetration of heat pumps in the residential sector which are very efficient in converting electricity into heat. Leading the Way uses more hydrogen.

36. Why isn't the "Leading the Way" the scenario which gives the lowest energy demand?

Leading the Way has the highest levels of energy efficiency of any scenario. However, it has higher levels of end consumer demand than Consumer Transformation, largely because of the relative efficiencies of the technologies involved. E.g. for residential heating CT primarily uses heat pumps, while LW has a greater role for hybrid heat pump/hydrogen boiler systems. Heat pumps are around 250% efficient and above, while hydrogen boilers are only around 90% efficiency, leading to a higher energy demand to produce the same amount of heat. There are also conversion losses involved in producing hydrogen leading to greater primary energy input needed in areas that use hydrogen.

37. How do the scenarios consider local decision making and its influence on societal change? For example, the Yorkshire authority recently announced retrofitting up to 665,000 houses with heat pumps by 2038.

For the most part, FES analysis is carried out on a national basis and more regional detail is covered in downstream analysis (e.g. ETYS /GTYS or by distribution companies). However, specific localised projects are often used to support assumptions on elements such as technology readiness, policy changes etc. There is a regional breakdown of FES data on the website which may provide more localised electricity information.

38. On the energy flow charts, there are energy losses for hydrolysis, natural gas, off-shore wind and biomass. Biomass particularly has large loss on some scenarios (e.g. LW). Please can you explain EACH loss, and why the biomass loss of energy is so large?

Energy losses occur at points where energy is converted or transported. Losses shown are: Natural gas shrinkage (CT, ST), Electrolysis conversion losses (All 4), Biomass/BECCS thermal generation losses (All 4), Electricity storage round trip efficiency losses (All 4), Electricity transmission and distribution transportation losses (All 4), Hydrogen thermal generation losses (CT, ST, LW), Dedicated offshore wind electrolysis conversion losses (LW), Natural gas thermal generation losses (SP). For methane reformation, we have assumed an 80% efficiency, so for every 100 kWh of natural gas input, 80 kWh of Hydrogen is produced, while for the bioresources losses, these are associated with the thermal generation of biomass combustion with BECCS. Thermal electricity generation (such as biomass generation), has significant losses associated with it, as steam is produced and used to drive a turbine to produce electricity, but a large amount of energy is lost as heat. Adding CCUS reduces the efficiency further.

39. Why is there little emphasis on the electrolytic production of hydrogen?

Electrolysis production of hydrogen is focused in Consumer Transformation and Leading the Way scenarios. However, it is also present in System Transformation alongside methane reforming and even in small quantities in Steady Progression. For details please see the 'Hydrogen Supply' section of the main FES document.

40. The IPCC 1.5C report (published in 2018) requires a halving of global emissions by 2030. As an advanced economy, the UK should actually be cutting faster than this. But the emissions graph you showed us indicated emissions would have reduced by less than 50% in 2030. Can you comment on this?

Leading the Way is the scenario in which the energy sector decarbonises fastest within in the credible range based on our analysis. This has taken account of how fast the decarbonisation technologies can be developed in each sector, how fast the infrastructure can be built to support the transition and also the limit of bio resources that can be available in a sustainable way. There may be other non-energy reductions over and above what we have modelled for Leading the Way (i.e. we have kept this constant and in line with the CCC across the scenarios).

41. How much CCS capacity MTCO2/yr do CT, ST and LW require? What is the assumed build rate 2020 to 2050?

For CCS capacity with Bioenergy (including BECCS for power generation, hydrogen production, industrial heat), by 2050 System Transformation = 55MtCO2/yr, Consumer Transformation = 53MtCO2/yr, Leading the Way = 62MtCO2/yr. For CCS capacity with methane reforming for hydrogen production, System Transformation = 116MtCO2/yr, Consumer Transformation = 9MtCO2e/yr.

42. Has the ESO looked at greater tree planting (globally) to offset emissions (i.e. akin to BECCS)?

Our scenarios focus on the resources produced in or imported for UK. Afforestation and reforestation are considered within our emissions calculations alongside our BECCS analysis.

43. Of the negative emissions provided by BECCS across the net-zero scenarios, what proportion is provided by BECCS in power generation compared to BECCS in other areas?

In System Transformation, 90% of negative emissions provided by BECCS is from BECCS in power generation. In Consumer Transformation and Leading the Way, the percentage is 99% for both.

44. Speed of decarbonisation has an axis break, separating net zero scenarios from Steady Progression. How far apart are these scenarios in reality?

The axis break is designed to demonstrate that the net zero scenarios in FES 2020 decarbonise further and faster than the FES 2019 scenarios that met the previous 2050 target of an 80% reduction in greenhouse gas emissions based on 1990 levels. While this year's Steady Progression scenario broadly aligns to the similar scenario last year in terms of decarbonisation, Consumer Transformation and System Transformation meet net zero by 2050 and Leading the Way reaches net zero before this.

45. What about international aviation and shipping and what about feedstock?

For international aviation, we assume high levels of bio fuel as a feedstock. For international shipping, the feedstock is ammonia in System Transformation and Consumer Transformation scenarios, and for Leading the Way, the feedstock is a combination of ammonia and bio fuel.

46. Have you calculated annual and cumulative CO2 emissions under each scenario? And how do these compare the UK's share of the global carbon budget if we are to keep global temperature increase as per Paris agreement? i.e. below 2 degrees?

We calculate annual emissions for each scenario. For the current carbon budgets, Consumer Transformation and Leading the Way scenarios meet (exceed) all the carbon budgets; System Transformation scenario doesn’t meet 5th carbon budget in the period between 2028 to 2032, and it makes larger progress in late 2030th and 2040th to catch up. Steady Progression scenario doesn’t meet either 4th or 5th carbon budget.

47. Who is actually responsible to deliver 2050 carbon neutral? Who's the minister for carbon zero?

Achieving net zero by 2050 requires support and coordination across policy, regulation and industry - behaviour changes from consumers will also be essential to achieve net zero. There is no "Minister for carbon zero" but George Eustice is Secretary of State for Environment, Food and Rural Affairs.

48. Would you say Steady Progression - represents business as usual or does it require more drivers than we have currently?

None of our scenarios are "business as usual". Steady Progression is the scenario that represents the slowest credible rate of decarbonisation. This is a result of us doing robust research and stakeholder engagement to understand what the speed of decarbonisation and societal change might look like.

49. What percentage effectiveness (% of CO2) is being assumed for CCS?

In our scenarios, we have flexed the efficiency of CCUS and it is assumed to operate at between 90 and 97% by 2050.

50. In terms of an international carbon market forming have you considered a baseline price of carbon that's required? And similarly, a market price for hydrogen and how the two interact?

In our analysis, we model GB carbon prices by considering the EU ETS and interactions with GB-specific policies such as the carbon price floor (i.e. rather than an international carbon price). We don't explicit model a market price for hydrogen across the different sectors although potential interactions could be relevant for hydrogen produced by methane reforming.

Industrial and Commercial demand

1. What infrastructure improvements do we need for the network for industrial clusters. To what extent does reinforcement of existing local electricity networks constrain our ability to make these large transitions from Natural gas to Electricity?

FES is intended to show customer needs. Network requirements are then explored in National Grid Documents which build on the FES - specifically the Network Options Analysis (NOA), Electricity Ten Year Statement (ETYS) and Gas Ten Year Statement (GTYS). The electricity and gas distribution companies also produce investment plans and scenarios, some of which are closely aligned to FES.

2. Can industry electrify completely?

We have not included 100% electrification for all of industry in our net zero scenarios (even in Consumer Transformation) and some hydrogen or even natural gas usage is assumed to different levels across the scenarios to meet energy demands from parts of industry which are hard to electrify. The emissions from any natural gas use will be captured using technologies such as CCUS or offset by use of BECCS in other sectors.

3. What are the key factors in the significant demand reduction for the Consumer Transformation and Leading the Way scenarios?

On average the efficiency of appliances, motors and space heating improves by 20% by 2030 in Consumer Transformation and by 25% by 2030 in Leading the Way.

We have upgrades to motors, pumps, compressors and fans as well as innovative designs for new ways to produce steel. We also have improved waste heat recovery and material efficiency. For example, for those scenarios with higher levels of societal change there is less packaging, use of lighter bricks and greater recycling of steel. There is also energy efficiency that comes as a result of clustering and pairing certain industries. For example, an industry that uses low grade heat can be paired with an industry that produces low grade heat. So you can couple, for example, the food and drinks sector with the steel sector.

Total demand is lower in Consumer Transformation than Leading the Way in 2050 due to technology used to decarbonise space heat. Heat pumps can be around 4 times as efficient as boilers.

4. Why is Leading the Way I&C demand much lower in 2020 compared to the rest of the scenarios?

This is mainly because LW has the highest fuel price assumptions. It has higher gas prices than CT and higher electricity prices than ST. The fuel prices in LW represent the credible high case, forecasted by a group of external economic experts. The electricity dataset includes a strong uptick in 2020/21. Higher prices act to discourage energy demand and incentivize energy efficiency improvements. We have applied the historical relationships between energy demand and fuel prices in each sub sector.

5. Where are the assumptions of retail and wholesale energy prices in the model?

Our wholesale price assumptions have been published in the workbook. Unfortunately, we are unable to publish the full data sets of our electricity and natural gas retail prices. These are provided by an external consultancy. We can provide basic numbers for the overall trend.

6. Was there consideration given to recapture of secondary heat from industrial processes?

In our highest societal change scenarios, we have included the recapture of secondary heat from industrial processes in industrial clusters. For example, locating the iron & steel sector near to the food & beverages sector, (a sector which produces low grade heat with a sector that uses low grade heat). The effects of this can be seen by the higher energy efficiency in these scenarios. We are hoping to look at this in more detail in FES 2021 with our new spatial heat model.

7. Are industries more likely to go hydrogen-based instead of electrification?

Our aim with FES was to capture a range of credible pathways to get to net zero. We believe all scenarios are credible. None of the scenarios move 100% towards hydrogen or electricity. Hydrogen is unsuitable for some processes such as limestone calcination in the cement sector and in ceramics kilns. Whereas electricity is unsuitable for some processes where there is direct heating at high temperatures where the process gases interact with the end product.

We believe that the fuel used for decarbonisation will be specific to each sector and will depend on fuel prices, government policy and outcomes of technology trials - all of which are very uncertain at this stage.

8. More details on the South Wales industrial cluster? Access to CCUS?

The South Wales Industrial Cluster (SWIC) project has recently received grant funding for South Wales from UK Research and Innovation. The project brings together different sectors in South Wales that will be key to decarbonisation and the infrastructure that will be needed, including for the development of the hydrogen economy, for large scale CO2 capture, usage and storage (CCUS) and for transport.

Our FES industrial and commercial modelling has been undertaken on a national level, hence no specific clusters have been modelled. However, a South Wales hub is a credible option.

9. Is it possible to have access to different gas, CO2 and electricity prices assumes across different scenarios? The data workbook only has a set of price forecasts.

We are unable to publish the full data sets of our electricity and natural gas prices. These are provided by an external consultancy. We can however provide basic numbers for the overall trend.

10. What infrastructure improvements do we need for the network for industrial clusters? To what extent does reinforcement of existing local electricity networks constrain our ability to make these large transitions from Natural gas to Electricity?

FES is intended to show customer needs. Network requirements are then explored in National Grid Documents which build on the FES - specifically the Network Options Analysis (NOA), Electricity Ten Year Statement (ETYS) and Gas Ten Year Statement (GTYS). The electricity and gas distribution companies also produce investment plans and scenarios, some of which are closely aligned to FES.

11. What is the impact of insulation on moving to hydrogen boilers or heat pumps? Is there information on what the current insulation standards should be?

All heating technologies work more efficiently in well insulated buildings and this is especially so for heat pumps. Hydrogen boilers on the other hand deliver radiant heat and can maintain comfort levels even in poorly insulated buildings. However, more hydrogen will be needed and therefore increased running costs. We think insulation should be a top priority for heat decarbonisation as it's a no regret action.

12. Are these scenarios for GB or UK?

FES covers GB. We do model exports/imports from Northern Ireland but do so in less detail than in GB.

13. Is there any offshoring of industry in the scenarios?

In FES, we had the assumption that GB decarbonises at the same rate as our nearest trading partners and this means there is no offshoring of industry, there are no carbon price differentials between us and the other countries so there is no incentive for industry or manufacturing to move offshore. We have this assumption because we wanted to show that the UK could reach net zero without any offshoring.

14. How is heat in industrial processes considered in your analysis?

We broke down all the industrial sectors into their different processes. These include high temperature processes, low temperature processes, direct and indirect heat. We then match relevant fuel switching technologies for each process in a given sector for the relevant scenario.

15. Can you tell me why there is so little biomass demand in the net zero scenarios?

In FES, we wanted to optimise our limited biomass supply and we thought it was most efficient to use biomass in order to produce negative emissions in the power sector and therefore there is limited biomass in the I&C sector. Biomass is also unsuitable for many direct heat processes such as glass and ceramics. We do use biomass to decarbonise the hardest sectors (e.g. cement).

16. Could you tell us a little bit about what assumptions have been made on Brexit [in relation to I&C]?

Similar to our GDP assumptions we fixed our Brexit assumptions across all four scenarios as we did not want to suggest that a certain net zero pathway was dependent on a certain Brexit outcome. We have obtained our economic forecast from group of economic experts. This forecast predicts that the transition period will continue until the end of 2022 and that the UK will reach a basic trading agreement with the EU by 2023. UK productivity will slowly increase up to 2030 but we won't see the highest that we did to pre-financial crisis.

17. Can you tell me what the biggest drivers of industrial and commercial demand are?

In the earlier years, the greatest driver is fuel prices as we have found a strong historical relationship between fuel prices and energy demand. Beyond 2030 the greatest differentiator between the four scenarios is fuel switching. In fact, a study carried out by Element Energy for BEIS last year suggested that there is 96 TWh potential of fuel switching by 2040.

18. We already know that the industrial and commercial sectors are very varied and different. Is it possible to fuel switch and electrify everything?

In our Consumer Transformation scenario, we have electrified as much as we think is credibly possible. We do not think it is worth electrifying certain industries that only have small amounts of high temperature processes. Electricity is also unsuitable for some processes where there is direct heat or where gases interact with the end product. Electrification is not the answer to everything. We believe CCUS is also required to capture certain process emissions produced from the breakdown of raw materials.

19. It seems you have a single price for fuel prices. How do you apply high gas price scenario in consumer transformation and leading the way?

In the Data Workbook, we show the wholesale fuel prices. However, in I&C modelling we use retail prices which are not included in the Data Workbook. It is retail prices that we differentiate across the scenarios. For example, the most decarbonised scenario, Leading the Way, has high electricity and gas prices to discourage energy demand. Consumer Transformation has slightly lower electricity prices in order to encourage electrification. In System Transformation, we use slightly lower gas prices to encourage a move towards using natural gas to produce hydrogen. In Steady Progression, we use our lowest fuel prices.

20. Could you tell me about how decarbonisation of industrial and commercial would compare to other sectors?

There are a few strong differences especially around industrial clusters. We believe there will be at least five clusters around the Grangemouth area, Teesside and the North West, the Humber and potentially south wales. Therefore, there is a grouping of relevant technology together. We believe that the use of CCUS in industry is more likely compared to residential since you can group customers together increasing the cost effectiveness of the infrastructure. There are some similarities between the I&C sector and the residential sector. We have decarbonised commercial space heat in a very similar way to residential space heat.

21. What is the cost of hydrogen (electrolysed and ATR) by 2050 in your scenarios?

We are currently doing some work on costing scenarios and we will publish some of our analysis and outputs later this year.

22. What is the average reduction in energy demand through energy efficiency by 2050?

The energy efficiency is as follows across the scenarios:

- in Steady Progression, we have incremental energy efficiency improvements which represent business as usual
- in System Transformation, we have around 10% energy improvement in energy efficiency by 2030.
- in Consumer Transformation, we have a 20% improvement energy efficiency by 2030 which is in line with the UK Clean Growth strategy
- in Leading the Way, we have a 25% improvement of energy efficiency by 2030.

In the following decades, we then model energy efficiency at half the rate of the previous decade. For example, in consumer transformation the energy efficiency improvement between 2030 and 2040 is 10%, half of 20%. We can provide you with more information around specific sectors after this session.

23. Do we see any closures as a result of the cost of decarbonising in the I&C sector?

We have tried to avoid any closures in the I&C sector. We have used economic forecasts alone to forecast at the output of industries and then and then we have used fuel switching technologies in order to best decarbonise industries whilst keeping them open.

24. What infrastructure improvements do we need for the network for industrial clusters?

We need improvements in CCUS technology and for it to be proven on a large scale. We also need infrastructure in place in order to transport the carbon captured to where it will need to be stored.

25. CO2 pricing is same between Gb and Europe, what about other global areas where offshoring of heavy industry more likely?

Similarly to Europe, we made sure we have the same decarbonisation assumptions between UK and the rest of the world and we wanted to ensure there are no differences in the carbon prices between the UK and the rest of the world. This was to avoid any offshoring and to show it is possible to decarbonise the I&C sector without moving industry offshore.

26. If there's no off-shoring, where is the energy included that's currently consumed in manufacturing in other countries? How much additional demand does this comprise?

Industry currently abroad is not included in our analysis, only domestic production. FES comprises a UK picture. We do consider the impacts of the interconnected countries for the price differentials which effect I&C and there may be further connections for gas supply.

27. Do you see the cost of gas going up?

We believe the cost of gas may go up in the net zero scenarios, perhaps if there is an increase in carbon tax or to support the cost of developing big strategies to support net zero. However, on the other hand, the cost of gas could go down as the demand for gas reduces in certain scenarios moving away from gas and towards electrification. More information is available in the Data Workbook.

28. It sounded like you believe that biomass will mostly be used for power generation, leaving little availability for use in industry (with cement being the only industry you expect it to be used in). Is that right?

Yes, cement was the only industry in which we used biomass to assist decarbonisation this year. 70% of our fuel switching in the cement sector was to biomass.

Bioresources are limited and we wanted to use most of our biomass capacity in the power sector with carbon capture in order to produce negative emissions. This meant that we wanted to avoid using biomass boilers for example where you can't attach CCUS.

Furthermore, our research suggested that there is a high level of uncertainty around the scale and cost of biomass use and that it can be unsuitable for most direct heating applications (Glass, Ceramics, other non-metallic minerals) due to the impacts on product quality. Biomass also only offers partial emissions reduction for many processes - Bloomberg estimates that a biomass blast furnace would only reduce emissions by 30% relative to a coal blast furnace, whereas the use of hydrogen for direct reduction (with an electric arc furnace) could reduce emissions by up to 98% relative to a coal blast furnace – basic oxygen furnace.

That said, the 2050 roadmaps identified potential for using bioenergy with CCUS in the chemicals, cement, food & drink and paper & pulp sectors and it this certainly something which we would like to research in more detail for FES 2021.

29. In relation to energy efficiency in the iron and steel sector, you said you assume general increases in industrial energy efficiency for each scenario in each decade to 2050 (10%, 20%, and 25% by 2030 in ST, CT, and LtW respectively, then halving in each subsequent decade). You also said you could send out the specific energy efficiency assumptions for the iron and steel sector. Please could you provide these?

In the iron and steel sector we only modelled improvements in motor efficiency (around 12% of total electricity demand in the sector). By 2030:

- 10% motor efficiency improvement in System Transformation
- 20% motor efficiency improvement in Consumer Transformation
- 27.5% motor efficiency improvement in Leading the Way

In order to decarbonise the sector, we have deployed direct reduction with electric arc furnaces (DR-EAF) in all scenarios. For all scenarios, we have assumed that the efficiency of h2 for direct reduction is 0.92 and the efficiency of electric arc furnaces in 0.9. The efficiency of a counterfactual blast furnace is assumed to be 0.92. This is in line with CCC assumptions.

30. With the strong decarbonisation, how do you tackle carbon leakage in your scenarios? do you have any assumptions on this?

In FES, we have the assumption that all of the UK's trading partners decarbonize at the same rate to the UK. Hence, we assume that no carbon price differential across countries and therefore no incentive for industry to offshore as a result of decarbonization. Of course, offshoring industry is not solving the problem, it's just passing the emissions on to another country so we wanted to show that is it possible to decarbonize the industry without simply offshoring.

Residential demand

1. What are your assumptions regarding the cost per household of achieving a 'High' degree of heat pump deployment and the electrification of heat?

Costs vary depending on the dwelling size and the level of insulation assumed. Typical upfront costs range between £6k and £9k with additional running cost of about £650 per year

2. Does residential heating include hot water generation? Many homes already have storage for hot water. Is this what is envisaged for 'heating storage'?

Heat storage mediums could be water, phase-change materials or conventional storage heaters.

3. Are the peaks for the whole UK or domestic only?

Residential peaks are for GB only. It includes heat and non-heat demand but excludes demand from electric vehicles.

4. What government direction are you considering?

Decarbonisation of heat would probably require a broad range of policies that both incentivise the uptake of zero carbon heating appliances (e.g. grants, tariffs, etc) but also incentivise reduction in energy consumption e.g. home retrofitting schemes and higher standards for new buildings.

5. Are heat batteries considered in FES as a significant technology addition?

Yes, heat batteries would form part of heat storage solutions on offer.

6. How likely are the customers to go for heat pumps, considering that retrofitting homes is expensive. Has data from pilot schemes been used?

Consumers are generally reluctant to adopt new technologies and it's no different for heat pumps. Lessons from pilot studies have however shown consumers report high levels of satisfaction with heat pumps. This suggests the need for more concerted awareness effort needed for heat to achieve mass acceptance.

7. Do you think that district heating helps reduce overall energy consumption?

Yes. New generation heat networks have made significant improvement in reducing heat loss in transit. New policies and standards for heat networks can help drive further innovation and adoption in this area.

8. Knowing that heat pumps are much more efficient than hydrogen boilers, why is the hydrogen being used for heat applications instead of electricity generation in the System Transformation scenario?

Consumer Transformation and System Transformation scenarios are exploring alternative pathways for heat decarbonisation. The Consumer Transformation emphasises consumers' contribution to upfront cost (capex) whereas in System Transformation the emphasis is on the change to network infrastructure.

9. What do you assume for domestic storage of heat and the flexibility of response this facilitates?

We've assumed both flexible and inflexible storage. Inflexible storage is provided by the traditional storage heaters on standard TOUTs (e.g. economy 7 or 10). Flexible storage is provided by technologies like hot water storage and phase exchange materials. These can respond to within-day price variations of electricity or gas if coupled to a hybrid system.

10. When are we expecting installation of heat pumps ramping up?

There is a wide range of outcomes here. The lowest case scenario assumes a doubling of heat pump installations by 2025. See the Data Workbook for more detail on this.

11. Who were the consultants who helped you develop your domestic heat model?

Our current model was developed by Delta-ee. We are however building a new heat model for FES 2021 in collaboration with Element Energy.

12. The proportion of households in rented accommodation is growing. This will affect the speed of uptake of new technologies as renters will not want to invest in a property they don't own. Is this considered? How important will the regulation of owners be?

We have not considered detailed consumer segmentation in our modelling up to this point. This feature is however incorporated in the new model under development. Housing tenure type will no doubt drive policy choices towards decarbonising heat.

13. What is the impact of insulation on moving to hydrogen boilers or heat pumps and is there information on what the current insulation standards should be?

All heating technologies work more efficiently in well insulated buildings and this is especially so for heat pumps. Hydrogen boilers on the other hand deliver radiant heat and are able to maintain comfort levels even in poorly insulated buildings but more hydrogen will be needed and therefore increased running costs. We think insulation should be a top priority for heat decarbonisation as it's a no regret action.

14. To replace my gas boiler with electric heating would triple my annual energy bill, and if you are using electricity to generate hydrogen, this would be even more expensive. As a pensioner on fixed income, this would be disastrous. How do you propose to overcome consumer resistance?

The FES framework considers a range of societal change for the scenarios. The Steady Progression scenario considers low societal change, potentially due to consumer resistance, and consequently has a significant proportion of heating via natural gas - with the impact that climate change targets will not be met. Other scenarios recognise that higher levels of societal change will be necessary to meet the climate change targets. A range of technological, economic, regulatory and political changes will be necessary to complement those greater levels of societal change, which will involve the whole nation, not just the Electricity System Operator.

15. In the scenarios have you indicated which areas of the country have a hydrogen or electricity solution for heat?

FES is national document and doesn't tend to go into detail at a regional level across the scenarios. However, we refer to current innovation projects taking place on heat to develop this national picture and we are also developing our heat modelling so that a more regional picture may be provided in FES 2021. A regional breakdown of electricity demand and supply can be found in the "Supporting Documents" of the FES 2020 Documents page of the website which includes some electrification of heat.

16. What are the main hurdles in achieving the level of societal engagement required to bring about this wide scale deployment of non-gas heating?

The energy industry will have to collaborate with the government and consumers to come up with a way to finance a zero-carbon economy without putting an unnecessary burden on consumers as they change their current heat source. The industry need to ensure they can provide a level of reliability for heating sources. This is something manufacturers and energy companies will need to lead on. There needs to be a high level of awareness on this area with more work that is still needed.

17. As per the CCC report, no new homes on the gas grid by 2025. Is that possible as per FES analysis?

We have looked at this proposal and tried to map it out in our scenarios where we think it is possible. In the System Transformation scenario, we think the existing gas network may be used for hydrogen. Therefore, there will not be a need to push the policy on new buildings connecting to the gas grid as the gas will be re purposed to provide hydrogen and hydrogen-ready boilers can be installed. Across the scenarios, we have included a range in the policies and the uncertainty around depending on what heat decarbonisation pathway gets adopted.

18. Good Energy has recently announced a tariff specific for heat pumps which is the way forward. However, the one thing that these tariffs need to take into account is that heat pumps run for most of the day to be efficient and also maintain the warmth in their home. My question is have you had any dialogue with energy providers?

We engage extensively across the industry with energy providers, heat pump manufacturers and consumer groups to gain insight into what needs to be done to make that transition.

19. When do we see residential heat demand peaking, if we go with hydrogen as the main replacement for gas?

It is likely that residential heating demand has already peaked. We have seen in recent years a massive increase in boiler efficiency and some home insulation and this trend is likely to continue. For individual fuels, we expect different trends going forward. For instance, whilst gas demand for heating may continue to decline, hydrogen and electricity demand will grow in the coming years.

20. Has the team looked at Germany's experience with trying to achieve the level of (particularly heat) demand reduction in housing - with a view to assessing the risk of policies not achieving the required levels of retrofit measures/performance required for the FES scenarios?

This study of Germany has not been specifically applied in FES. The scenario framework and the whole concept of scenario analysis is to allow us to vary the range of energy efficiency assumptions across the scenarios. Consumer Transformation has higher levels of energy efficiency uptake whereas System Transformation has a lower level of societal change and, as such, assumes lower levels of home insulation. This is an area of continued debate and study and we always appreciate any further information or evidence.

21. Please can you explain how hybrid heat pumps work, especially as it gets colder?

Hybrid heat pumps during very cold weather will rely on the gas component of the system because the performance of heat pumps drops when the temperature drops. You will see an increasing of the shifting load of the gas component of this system. On colder days, you will see the heating demand will be supplied by that gas component: whether it is hydrogen or natural gas.

22. Two related questions on insulation: - There is clearly a need to reduce energy demand from heating by improving domestic insulation and other fabric measures, but how can we determine the level of cost effectiveness required to justify a fabric measure, as compared with the cost of generating more clean electricity/hydrogen and possible grid reinforcement? How does the value of flexible demand affect this? (i.e. well-insulated homes with heat pumps can be used to store energy).

How we balance the cost of fitting individual homes versus building a bigger network to meet the decarbonisation target all depends on factors which we stress within our scenarios within the societal change axis. Along this axis, you have the societal change with people being willing to change in terms of their walls and windows within their homes in order to reduce demand. We believe home insulation is important and should be pursued in all scenarios. The question here is how far you want to go. We are currently working on costings for the scenarios which will be published later this year which will further inform FES 2021.

23. Your scenarios assume a lower level of fabric [insulation] in the "System Transformation" scenario than "Consumer Transformation" or "Leading the way" (assumption 4.1.22). Is this purely because there aren't the same pressures for insulation in individual homes, as from a heat pump? It would seem to ignore the likely high cost of hydrogen, that would make fabric measures much more cost effective than they currently are.

System Transformation compared to Consumer Transformation is a scenario that assumes less societal change. Insulating is disruptive with the assumption that people wouldn't want to go through that process for the deep level of fabric that you need to build high levels of energy efficiency that we see in Consumer Transformation. However, there are a high levels of energy efficiency in all our scenarios with a lot of uncertainty around this topic. On this topic, we have liaised with BCC and BEIS and all the stakeholders and will continue to have that conversation to try and be more precise on what are the energy potentials on energy savings that can be achieved when different levels are applied.

24. What technologies have you considered for thermal storage and what will this look like in a home?

We looked at a whole range of technologies that help thermal storage. A lot of homes still have water storage which will play a role in enabling thermal storage. We think with new technologies coming online which have high energy densities may be installed in homes even with limited space for storage. The traditional technology used such as storage heaters, could help with thermal storage. Thermal storage includes high levels of insulation. Thermal storage is a back up to the improvements in buildings to make them more well insulated.

25. Interesting to see EVs not yet included in domestic energy setting - what's your views of the growth of home charging (if 0% now, what % when out to 2050)?

FES 2020 assumes that the majority of EV users charge at home if possible (i.e. if they have offshore parking etc). This is largely covered in the transport section but page 40 of the main FES document shows how EV charging fits in with the broader domestic energy setting across the scenarios. We would welcome the opportunity to discuss subjects like Active Buildings with stakeholders - both in terms of the technical aspect and more general treatment within the scenarios.

26. What assumptions you have made about the improvement in domestic energy efficiency in each scenario?

The assumptions for domestic energy covers three areas.

1. Building fabric retrofit;

2. Improve appliance efficiency standards for both heat and non-heat appliances, and

3. Improved behavioural changes.

Building fabric and behavioural changes are projected to reduce heating demand by between 10% and 36% for an average dwelling compared to today, depending on the scenario. Improvements in appliance efficiencies of similar magnitudes are assumed given underlying assumptions about technology maturity and technical potential.

27. Germany had similar domestic demand reduction aspirations as underpins these scenarios. They have not managed to achieve the hoped-for demand reductions - especially space heating. Should FES factor in some (significant) uncertainty concerning housing retrofit?

There are no doubt lessons for the UK from the German experience. The purpose of the scenarios is to help understand the uncertainties around achieving the targets. The interactions between policy, economic, social, and technological factors are almost impossible to predict long term and the scenarios help define a credible envelope. But regardless of the scenario, we believe energy efficiency is a no-regret activity and should be pursuit with the utmost seriousness.

28. The reduction needed in residential energy demand hinges on significant home improvement – in terms of insulation, and presumably, airtightness. How is National Grid focussing Government attention on this need?

FES is a key part of NGESO's engagement with government around decarbonisation issues. We also contribute to this debate through responses to government consultations and through business and forward plans of our entities. Government will have a central role to play in setting up the environment for success but the industry will also need to invest in innovation and training.

29. Consumer Transformation and Leading the Way scenarios require high levels of installation of ASHPs – what SPF/COP is assumed for these? And what market transformation mechanism/s are considered appropriate to achieve this?

We have assumed the following SPF levels across the scenarios (based on a 2019 level of 2.9):

Consumer Transformation - 3.5

System Transformation - 3.2

Leading the Way - 3.5

Steady Progression - 3.0

We appreciate there are many studies showing SPF significantly below these but also some with SPF above. We have tried to reconcile these divergent views using data from mainly field trials, including from DRHI statistics. The other factor in determining SPF is the system boundary selected. We've assumed SPFH2 boundary in this year's analysis to align with RHI specifications but we'll be reviewing this for next FES cycle in consultation with stakeholders to see if SPFH4 might be a more realistic boundary to use.

Achieving these targets will require innovation, a joining up with programmes to improve building insulation through retrofitting existing buildings and setting higher constructions standards for new builds; new business models to reduce capex costs for consumers such as heat-as-a-service models. Also better sizing and installations standards.

30. For V2G + electrified home heat in LW, do we assume residential upgrade to 3 phase?

The specifics of residential connection are decided by the local distribution network when an EV charger is connected. This is not something we model directly in FES.

31. Can you describe the thermal characteristics of the 2050 housing stock that will benefit the grid at that time, particularly with reference to heat supply?

Housing stock in 2050 are projected to be much more well-insulated than today. We think this will help to manage the grid by reducing underlying demand at peak and by improving the effectiveness of peak flexibility management tools like thermal storage.

32. What supply costs for gas and electricity were modelled?

Our modelling is based on retail price data for gas and electricity.

33. Have you considered what policy changes (e.g. carbon taxation) would be required to encourage consumers to switch to other sources of heat given the upfront cost difference of installation?

We have not modelled individual policies explicitly for heat decarbonisation. We think it is likely that a combination of supportive (e.g. tariffs, grants, etc) and punitive (carbon and sales taxes, etc) policies might be required to incentivise switch to renewables. But in addition to policies, energy suppliers would need to come up with new business models to reduce the upfront cost burden on consumers. Heat-as-a-Service is a potential option for doing this.

34. Do we have data on off gas grid homes in FES and what type of heat pumps they are likely to install?

The Data Workbook includes numbers for off grid properties. While we haven't specifically targeted these, properties with oil burners, solid fuels or bio fuels from a heating perspective are off grid from which an inference can be made from the numbers we have provided in the Data Workbook. The types of heat pumps they will use will be gas associated heat pumps due to space availability. As for older homes the heat pumps are more suited as they have higher efficiency in comparison to gas associated heat pumps. All other properties with electric heating will be prioritised to improve the efficiency of the overall system.

35. When we are interfacing with residential consumers we are starting to see what seems to be a new trend, namely residents preferring to not have combustion in their homes. The Grenfell tragedy is increasingly being quoted as an influence. There are also mutterings about indoor air quality issues related to combustion for cooking and increasing resident concerns about health and wellbeing with some research in this area to support this concern. Have either of these been considered in formulating the scenarios?

No, these trends have not been considered in the scenarios explicitly but seem to map quite well to the societal change axis of the scenario framework. It's interesting to see non-climate change related factors (such as safety) driving a switch to renewable heating technologies and this is something we need to explore further.

Transport demand

1. What is your view on the feasibility of banning new combustion engine cars by 2030? Is this a realistic goal or just pie-in-the-sky? If plausible, please briefly outline what investments would need to happen when.

FES is intended to show a broad range of credible future outcomes. The UK Government is in talks with the car industry on bringing forward the 2035 petrol/diesel car ban to 2032. There is the possibility that 2030 be an outcome of talks. Policy certainty in the next few years would bring investment certainty to the car, battery and mining markets. There are historic parallels where manufacturing has rapidly up-scaled to meet demand. We would welcome your views and any information you have on this.

2. Have you taken into account the availability of battery materials for electric vehicles? If you assume that other than lithium, cobalt and/or nickel-based battery chemistry will be used, which chemistry will that be? Will it be compatible with the charging infrastructure that is currently being implemented?

FES is intended to show a broad range of credible future outcomes and makes no judgement on which technologies will dominate, or the specifics of how they will be operated. It is assumed technologies will remain compatible. The range of scenarios for electric cars is intended to show a possible early and late date (Steady Progression petrol/diesel car ban 2040, Leading the Way petrol/diesel car ban 2030). During scenario development, we draw on external reports, stakeholder feedback, and discussions with manufacturers and the car industry. Some stakeholders believe there are enough materials, others do not, so FES 2020 shows a range of outcomes. Steady Progression in particular retains petrol and diesel buses/heavy goods vehicles by 2050. We would welcome your views and any information you have on this.

3. What do we mean by vehicle to grid, can you expand a little on that element?

Electric vehicles are "batteries on wheels." Vehicle to Grid is the idea of using the battery to supply the grid during times of high price (and benefit the driver). Vehicle to Home supplies the home directly where grid export is not possible. In our scenarios, we assume smart software under user control, which will ensure sufficient battery charge is available for travel the next day.

Most electric vehicle manufacturers are developing systems that allow owners to monitor and control their vehicle charging. If the right tariffs and market signals emerge (and the car is connected to a V2G charger), it is possible that owners will be compensated for exporting power back to the grid whilst the vehicle is parked (e.g. at a car park or at home). Aggregator Companies are also working in this space to develop apps that allow (user permitted) control of charging within limited parameters e.g. minimum battery charge state. If successful, aggregators will be able to control batteries and provide market tools or take part in the wholesale electricity market. (National Grid ESO procures services in the 1MW range and upwards). The EU CCS V2G charging standard is expected to be rolled out from 2025 - the Japanese currently have the Chademo standard.

4. Whilst the Alternative Fuels Infrastructure Regulation mandates CCS charge points for EVs, how will you achieve the level of V2G which at present only works with CHADEMO chargers?

FES is intended to show a broad range of credible future outcomes. To the best of our knowledge, CCS is intended to be standardised by 2025 but manufacturers will have agreed this standard a few years before and will have prepared for this date. In the scenarios, Vehicle to Grid adoption begins in 2025 and gets to scale in the scenarios in the 2030s and beyond. 2050 is 30 years away so the FES headline V2G numbers show a possible view of outcomes. Data on this is shown in workbook table ED1. We would welcome your views and any information you have on this.

5. You have much higher engagement of V2G compared with FES2019. What is the reasoning behind this? I understand there are multiple scenarios but is this coming from fleet vehicles or personal use vehicles?

FES is intended to show a broad range of credible future outcomes. Following stakeholder feedback from FES2019 and our "Bridging the Gap" workshop, it was generally felt that the range should be wider (higher and lower) in FES 2020. This reflects future uncertainty. We have modelled V2G in personal use vehicles as we have information to support the modelling. Further information on engagement is shown in Data

Workbook Sheet ED1, and more transport data is in Workbook Sheet ED5. Fleets also have V2G potential and we would welcome any information you have which may help to create projections.

6. 5.5m vehicles V2G - have car manufacturers agreed to their vehicles being used this way without affecting their warranty

V2G is seen by the car industry as an interesting technology and there are a broad range of opinions, and states of technological readiness in different companies. In FES, we see consumers and energy companies using V2G as a potential asset to reduce customer bills, generation build and network investment. So, customer "pull" might encourage this facility to be made available, as a competitive feature. Leading the Way assumes a high level of societal change with 5.5 million vehicles by 2050 whereas Steady Progression assumes 1.0 million vehicles by 2050, reflecting a broad range of possibilities. New: On warranties, manufacturers are currently cautious as their current priority is to ensure the battery lasts the lifetime of the vehicle. Some manufacturers are further ahead in development and are assuming V2G in future. The scenarios assume all manufacturers will allow V2G in future. We would welcome your views and any information you have on this.

7. Why is rail not included in consumer demand chart, when shifting to public transport by rail is a key consumer led change?

We model hydrogen and electricity demand from rail transport, but not diesel. As we do not have a complete dataset, it was decided not to include rail in the "CV" charts for consistency. Further data on rail many be found in the data workbook ED1 (Electricity) and SV sheets (hydrogen)

8. Can the grid sustain an early banning of the sale of ICE vehicles. E.G. 2025?

FES is intended to show a broad range of credible future outcomes, unconstrained by network limitations, in order to show potential customer needs. The UK Government is in talks with the car industry on bringing forward the 2035 petrol/diesel car ban to 2032. There are historic parallels where manufacturing has rapidly up-scaled to meet demand. Additionally, a 2032 date might have impacts on second hand values which would accelerate adoption of electric cars by consumers. Leading the Way assumes 2030, Consumer Transformation and System Transformation assume 2035, and Steady Progression 2040. We would welcome your views and any information you have on this.

9. Do I get this right 28m EVs by 2050 but only 5.5m V2G enabled?

This is the second year we have added significant figures for V2G into the scenarios, so industry thinking is still evolving in this space. Further data is available in the Data Workbook: Sheets ED1 (Demand) and ED5 (Road Transport). We assume V2G chargers are higher cost than standard chargers. Car manufacturers are currently cautious about Vehicle to Grid. Vehicle to Grid depends on the right customer tariffs, correct market framework and most importantly customer buy-in. V2G also has to compete in the market against other technologies like grid scale storage and dispatchable generation. We would welcome your views and any information you have on this.

10. Please advise your latest thoughts on "propulsion ratio". Last year 0.25 was totally unacceptable. Plus, you did not allow in the generation figure the 15% battery losses and 8% transmission losses.

We have used the latest DfT data on kWh/mile. We add distribution and transmission losses later in the process (~8%) - losses data is included in "System Demand" and is a separate line item in data workbook ED1.

11. Charging EVs at forecourts is something people would only ever want to do on long journeys:

(a) it takes a long time, much longer than petrol or hydrogen;

(b) very expensive as you'd have to pay retail electricity costs at peak times;

(c) inconvenient, far from home; and

(d) not available for V2G, which isn't accounted for in the modelling.

At forecourts, we assume rapid chargers are installed which keep the average forecourt visit to 7 minutes (e.g. connect, browse the shop, queue to pay…).

12. Similar to the ban on petrol and diesel cars from 2035, do you consider a ban on plug-in hybrid vehicles?

Yes, we consider a ban on Petrol/diesel plug-in hybrids similar to non-hybrid vehicles. However, there is a current debate on whether biogas or hydrogen hybrids should be allowed to continue to 2050.

13. Add to my comment on forecourt charging: fast charging is the fastest way to destroy a battery.

Manufacturers are currently investing in R&D to ensure that the battery will last the lifetime of the vehicle e.g. cooling, needs based charging per cell etc. Fast charging considerations are included in this.

14. How does NGESO envisage V2G at a scale that would assist with system operation could be implemented in practice?

There is plenty of development, design and R&D work going on in this area. The exact implementation is yet to be formulated. In addition, the "Power Responsive" program run by NGESO is actively working in this space.

15. You have 45% vehicle to grid update for LW at 2050 but say this is 5.5m vehicles. I thought you model EVs around 30m, so the 45% seems too high. What am I missing?

There are less vehicles in LW due to autonomous, self-driving vehicles, and greater use of public transport.

16. What is the impact of clustering of EVs and heat pumps on demand and do we know those regional clusters?

This is explored in National Grid Documents which build on the FES - specifically the Network Options Analysis (NOA), Electricity Ten Year Statement (ETYS) and Gas Ten Year Statement (GTYS). The electricity and gas distribution companies also produce investment plans and scenarios, some of which are closely aligned to FES, and clustering is examined in more detail by the distribution companies

17. I am curious about systems for charging for EV use. How do you envisage this developing? In my mind is people coming to my house and wanting to plug in their EVs, like they do with their mobiles.

Public chargers have a payment system attached. Private chargers are installed by homeowners but if the right mobile phone apps develop there is nothing stopping things developing as you imply, they might.

18. You mentioned as an uncertainty, people working from home. I appreciate that your detailed analysis may not have had time to model this rapid Covid-induced societal change, but do you have a sense as to how it might affect your scenarios if say a majority of office workers spent 2-3 days wfh?

Electricity demand seen to date can help here. The government 'rules' put in place in response to COVID, resulted in a significant drop in demand (roughly 10-20% depending on the time of day/week). More recently (early August) the overall reduction is about 5%. Beyond that, we will be further analysing a wider range of data to assess the shorter-term impact on peak demand and will be building more analysis into FES21.

19. Did I understand correctly that it is forecast all petrol/diesel vehicles will be removed from the fleet by 2050? If so, this may require the scrappage of ICEs purchased between 2030-2040 ahead of their normal end of life. Does the team think this will happen?

Banning new petrol/diesel car sales by 2035 will mean that most vehicles will have reached "end of life" by 2050. Government policy is developing in this area with this aim. Commercial vehicles are more challenging, and the Department for Transport is developing policy in this area.

20. What power consumption have you assumed for the sensors/computational power etc in autonomous vehicles?

We would welcome more information and views in this area - currently we have assumptions for kWh/mile which are assumed to capture this. Much also depends on where the computation power / sensors are based. If all on the vehicle then this will be a noticeable demand, but roadside sensors and computing is also being considered.

21. PHEV is banned in 2035 for both Consumer Transformation and System Transformation - why is there a big gap in number of cars between in 2035 between these two scenarios?

Consumer Transformation is higher on the societal change axis - more people are assumed to use public transport or autonomous self-driving taxis than in System Transformation.

22. You say that autonomous vehicles reduce number of vehicles in service: correct. But then you reduce energy consumption proportionately: wrong. AVs actually increase energy consumption owing to journeys between rides. (They also increase road use correspondingly.)

On page 46 of the FES2020 main document, table CV1 shows our assumptions for autonomous vehicles. In All scenarios, autonomous vehicles are shown to cover more miles than the average car today (around 8000-10000 miles per year).

23. Most people don't have somewhere to park cars for charging: they live in flats or other places with on-street or unassigned off-street parking, making EVs impractical: better to use hydrogen, filled up at forecourts.

According to this BBC "in depth article", 56% of homes are detached or semi-detached. 26% of homes are terraces and 12% of homes are flats. Detached and semi-detached homes are assumed to have access to off road parking, and around half of terraces or flats are assumed to have access to off road parking in the higher societal change scenarios (shared private car park or off road garages). The FES method document shows our assumptions for where people charge (e.g. charging forecourts, at work/public places or at home) and the range used reflects the uncertainty (around 40% to 75% of charging may occur at home across the scenarios). We agree that charging forecourts make a lot of sense in densely populated urban areas and for drivers without a drive. Hydrogen cars and heavier vehicles are featured in the scenarios, particularly from 2030 when hydrogen may be available at scale. (http://news.bbc.co.uk/1/shared/spl/hi/guides/456900/456991/html/#:~:text=There%20are%20about%2025%20million,with%20one%20in%2010%20now)

24. Your assumptions about charging do not take into account the large number of car owners who cannot charge from home and will cause a huge surge in demand in the owners only free time in the evening. Why do you continue to ignore this?

Peak electric charging demand scenarios were covered in the presentation (see website for recording) and are shown as charts in the FES main document, page 109. The data and charts are in the Data Workbook, sheet SV42. The charts show that electric vehicle charging demand is significant and the range of outcomes is wide across the scenarios. Peak electricity prices are significantly higher than off peak electricity prices, and price signals already exist which encourage drivers to take advantage of cheaper off peak electricity or periods of high renewable generation (windy sunny afternoons). This trend is expected to continue (and will impact both home and public charging) and is key to achieving Net Zero at lowest cost to UK households.

25. Why is digging up the road mentioned for home charging of EVs but not mentioned for electric heat?

Mass adoption of electric vehicles will require upgrades to the local electricity networks - much of this work is expected have started or be complete by the time the UK begins mass decarbonisation of heat (potentially future-proofing for further electrification). In addition, with heat there is uncertainty on the fuel which will be used. For example, a hydrogen economy would reduce the need to invest in the electricity network in order to meet heat demands.

26. Why does the benefit of V2G on peak power demand reduce from 2045 to 2050?

This occurs due to the adoption of automated, self-driving taxis. In the high societal change scenarios, people choose to use self-driving taxis instead of owning a car, which reduces the number of vehicles available for V2G. As these vehicles tend to be in use at peak time, they are not available for vehicle to grid at that time.

27. Why do you assume so much V2G? On average, vehicles would be less than half charged in the evenings. People wouldn't want their vehicles to be left without charge, again halving available energy. Most vehicles (say, half of cars) would have to be hydrogen. Therefore under 1/8 of vehicle battery capacity is available. But battery life is proportionate to the number of charge/discharge cycles, so you'd have to pay them for this.

The current average EV has around 60-100kWh of battery capacity. The current average commute is around a 40mile round trip each day. If efficiency is 0.25kWh/Mile then only 10kWh will have been used. Even at

0.33kWh/Mile only 13.2kWh used. This means the vehicle arrives back home with at least 50kWh of charge remaining.

As an average house charger is 7kWh, even exporting as V2G over 3 hours the vehicle can only export a maximum of 21kWh; leaving over 20 kWh remaining (equivalent to between 60 and 80 miles). The expectation would be that the vehicle would then smart charge outside of peak periods.

28. The modelling seems to expect battery powered cars and hydrogen powered HGV. What about Hydrogen powered cars?

Numbers are low across the scenarios due to saturation of the market by electric cars, higher costs associated with hydrogen fuel cell cars and lower technology maturity. There is some variance across the scenarios and in System Transformation where a hydrogen economy has developed, there are over 1million hydrogen powered cars by 2050 (see p47 of the main document for more information). We welcome any views or information you have in this area.

29. What % of charging demand is supplied by public charging and how does it impact peak demand?

A table with this information is in the "transport" section of the FES method document. Public charging and forecourt charging is expected to be rapid and high power, in order to quickly facilitate journeys to and from a destination. This may be moderated by mobile phone apps which inform drivers of the cheapest time to charge, or other mechanisms used globally such as hourly petrol price charging. Home charging on the other hand is expected to enable reduction of peak demands by spreading charging overnight and onto weekends.

30. Lithium shortages are NOT fundamentally due to mines shutting. They're due fundamentally to a global shortage of lithium. Currently prices are below where they should be because miners and refiners ramped up production faster than demand.

Third Party reports indicate that lithium is a commodity, subject to supply and demand. As prices increase, other costlier extraction methods become available or other materials and battery technologies may become viable. Many different battery technologies are being researched, and in the next 30 years, it is likely that they will become available (e.g. sodium-ion batteries).

31. For the cost modelling, how have you assumed the government taxes vehicles to replace the current billions from petrol and diesel fuel tax?

FES seeks to illustrate a range of credible outcomes, for the purposes of operating and planning the GB energy system. Our analysis involves total cost of ownership modelling of different types of vehicle (e.g. ICE and battery electric) and, whilst we appreciate that fuel duty is an element of the cost of running an ICE vehicle which is not present for EVs, we don't make any adjustment for this. Instead, we assume that how government tax revenue is replaced as part of the road to net zero is a fiscal policy decision for the UK Government, and will likely evolve over time.

32. Are trains more likely to be using Hydrogen than more electrification?

Trains are largely electrified across the scenarios although there are some hydrogen trains in System Transformation.

33. It is assumed heavy road vehicles will be hydrogen or gas. Page 49 mentions high costs for catenary charging and doesn't mention other forms of electric roads which give greater benefits by allowing cars to reduce battery capacity. Current estimates for electric road system installation costs are several times lower than the system costs of H2 when increased generation capacity is included. Why have electric road systems been dismissed in this way? Is this simply because more stake holders have a hydrogen interest or are there technical reasons?

Within FES we try to illustrate credible economic and efficient worlds, and this involves trading off investment in decarbonisation (usually zero carbon generation and networks) against reuse of existing assets and infrastructure (sunk costs, potentially allowing hydrogen reuse). Our team looked at catenary solutions but most reports indicated high costs.

In assessing "credible" we assess FES elements against PEST (Political, Social, Economic and Technology). Catenary systems are credible from a technology perspective. For inclusion, such systems would also require widespread political interest, social awareness and backing from business stakeholders (vehicle manufacturers and infrastructure providers like the network companies).

If you have any information or data on catenary systems it would allow us to assess these systems for possible inclusion in our analysis.

34. You had a much higher engagement of V2G compared with FES2019. What is the reasoning behind this? I understand there are multiple scenarios but this is coming from fleet vehicles or personal use?

Numbers have been revised to reflect stakeholder feedback and growing manufacturer confidence since FES2019 was produced. V2G is assumed to come from both personal and fleet vehicles. The modelling takes into account the vehicles parked during peak time. If you have any further information it would be welcomed.

35. What are your projections of no of EVs by 2050? Does this align to the CCC numbers?

Data for the number of road vehicles is contained within sheet ED5 of the FES Data Workbook. Electric road vehicles of all types (cars, vans, buses, heavy goods vehicles, motorcycles) reach the following levels by 2050:

Consumer Transformation 34.4 million,

System Transformation 35.9m,

Leading the Way 26.5m,

Steady Progression 37.6m.

Differences between the scenarios are scaled on the "Societal Change" axis - in low change scenarios there are more vehicles, and less use of public transport / autonomous self-driving cars. Leading the Way has the highest levels of public transport/self-driving taxis, so has the lowest number of road vehicles.

The CCC's road transport assumptions are detailed at high level in their May 2019 Net Zero Report - the UK's contribution to stopping global warming. At a high level, the assumptions in FES 2020 for Consumer Transformation and System Transformation are the same - running costs achieve cost parity in the early 2020s, and sales of petrol/diesel cars are banned in 2035.

Bioenergy and natural gas supply

1. We've increased bioenergy imports 400% in last 10 years and FES 2020 says that "Imported feedstocks are critical" to scenarios. There is no value in reducing UK emissions if this doesn't impact global emissions. Is dependence on bioenergy imports compatible with global net zero?

Although import has increased dramatically in the last 10 years, but it was based on a low number of 11TWh in 2008, and the increase is driven by wood pellet imports from North America for use in power generation. We don't see this trend continuing, and the import rate will not continue at this speed. Our 2050 import number is aligned with that in the CCC net zero report, which assumes that UK uses a fair share of global sustainable, harvested bio resources. In Consumer Transformation and System Transformation scenarios they are about 30TWh; Leading the Way scenario assumes the size of this import is doubled.

2. Do you publish biomass fuel price assumptions? Can't see them in the workbook at a cursory glance...

We don't publish biomass fuel price assumptions.

3. What proportion of the biomass availability in the three net-zero scenarios is imported?

In the System Transformation and Consumer Transformation scenarios the proportion of the biomass import is 16% and in Leading the Way it is 25%.

4. Biomass availability assumptions in the net-zero scenarios are high. Have you tested these assumptions against the UK's "fair share" of sustainable biomass (as per the CCC analysis)?

Yes, through our Bridging the Gap to net zero work undergone last year we have communicated with CCC on our biomass availability assumptions. Our 2050 import number aligned with that in the CCC net zero report, which assumes that UK uses a fair share of global sustainable, harvested bio resources.

5. What bioenergy is imported in the scenarios - is it mainly biomass (wood pellets)?

Yes, it is mainly biomass wood pellets.

6. Where will domestic bio resource be sourced from? Was land and water use taken into account in this analysis?

We don't have a breakdown of the sources of domestic bio resources. The total number has taken into account land use details from the CCC land use report. England's Forestry Commission identify 5 million hectares of low risk areas for afforestation which signals that there would be enough suitable land to meet a much higher level of afforestation. For the energy crops the planting area reaches 1.2 million hectares under the high level by 2050.

7. Do you envisage LNG terminals to handle imported Hydrogen - if so, what technical changes would be required to make this feasible?

We have assumed that the import infrastructure in Leading the Way changes from natural gas to hydrogen. However, we have not constrained how the infrastructure transitions.

8. Have you considered the CO2 intensity of the biomass import value chain in your net zero scenarios?

We have done the carbon accounting at point of consumption so does not include emissions in other countries.

9. Has the fertilizer CO2 been taken account of?

Yes, this part of emissions is included in 'Other' category in the emissions tables in the FES document and in the Data Workbook.

10. What is your assumption of the unabated biomass CO2 rate?

In our scenarios, we assume the unabated biomass is carbon neutral considering the life cycle. It is a simplified modelling assumption given the complexity of the supply chain.

11. Is the split between the biomass and biomass with CCUS provided in the databook? I could not straight away see it.

Total Bio resources in the System Transformation scenario is 212 TWh (out of which 158TWh is BECCS); Total Bio resources in the Consumer Transformation scenario is 215TWh (BECCS =152TWh); Total Bio resources in the Leading the Way scenario is 271TWh (BECCS=177TWh).

12. What does National Grid assume to be a "fair share" of global resources of biomass?

Our 2050 bio resources import number aligned with that in CCC net zero report, which is based on the assumption that UK uses a fair share of global sustainable, harvested bio resources.

13. Can you clarify how different scenarios blend bioenergy with hydrogen?

We only have Steady Progression scenario with hydrogen blending with green gas in the natural gas network.

14. In bioenergy and CCS carbon removal did you consider that Chatham House and former govt chief scientist have both raised concerns that they are not zero or even low carbon?

In our scenarios, we assume biomass is carbon neutral considering the life cycle. It is a simplified modelling assumption given the complexity of the supply chain. We haven't got the breakdown of the carbon footprint of each step in the supply chain however they are accounted for in the "other emissions" category in the document. We recognise that this is an important assumption across our analysis and so would welcome any further information or evidence on this topic as it develops.

15. What is your (NGESO) definition of green gas - how will it be made?

In our scenarios, "green gas" is a term used to cover both biomethane and bioSNG (i.e. biomethane which is created by larger, more industrial processes). It is made from a variety of different organic materials.

16. It looks like none of the net zero scenarios have any biomethane production. Is that right? I think you said that scarce bioresources would be deployed elsewhere? What happens to the current methane-carrying gas network under those scenarios?

There is no biomethane assumed in the gas system in 2050 in the net zero scenarios and this is because bio resources are used in other sectors in the lead up to 2050 to allow us to transition to net zero. Depending on which scenario is being looked at, the impacts on networks will be different. For example, in System Transformation the natural gas network could be used for carrying hydrogen.

17. What are the implication of the different gas scenarios for the future viability of the NTS?

FES analysis is not constrained by networks and looks at an unconstrained market when we consider future demand and supply. Across different scenarios, there are different levels of natural gas and hydrogen demand that have to be met at end consumer level and this feeds into downstream analysis carried out by the Gas System Operator such as the Gas Ten Year Statement (GYTYS) to inform potential future developments in relation to the NTS.

18. It's fascinating and positive to see the reliance on hydrogen being called out here. To clarify, is the analysis saying that only by removing all natural gas from our transmission and distribution system will we achieve net zero in the ST, LtW and CT scenarios?

In general, unabated use of natural gas is not consistent with net zero and CCUS is assumed to be a centralised technology. Therefore, whilst details relating to gas network development are covered in publications like the Gas Ten Year Statement (GTYS), some changes are likely to be required to meet net zero.

19. Regarding natural gas, across all the scenarios with large import levels, how are the assumptions aligned with Europe's net zero assumptions and hydrogen uptake?

We only do detailed analysis of UK energy supply and, as such, we don't make any detailed assumptions about what other countries in Europe are doing. We take a very high-level view that, generally speaking, Europe will be doing something similar to the UK with regards to decarbonisation and hydrogen uptake.

20. Do you consider that gas is a depleting resource? When do you see supply running out, or becoming economically unviable to extract?

Obviously, fossil fuels are finite resources and UKCS is clearly depleting over the period out to 2050. Globally however, we don't see natural gas running out within the timescales of our analysis although it may mean greater reliance on imports as indigenous production falls.

21. With the long-term availability of imported LNG embedded in our gas supply systems so far, do we not see the continued use of that but for generation of blue hydrogen coupled with CCUS... as being worked on by Acorn Project?

The conversion of natural gas into hydrogen (blue) using CCUS technology is considered in the System Transformation scenario.

22. How many proven reserves of gas remain in the UKCS in 2050 under the different scenarios?

It is not assumed that any currently proven gas reserves will be producing in 2050 in any of the scenarios.

23. Is using the GB network to import LNG and export to the continent through IUK and BBL considered in FES?

While we don't specifically model transit gas flows as part of the FES analysis, we do recognise the potential for taking delivery of LNG cargos in the UK and then exporting the gas to the continent via the interconnectors. This is further considered in downstream network analysis carried out by National Grid Gas.

24. On gas supply, your scenarios have very different mix of supply sources (particularly on LNG + generic imports). How have you treated the security of supply risks related to the imported vols. under the ST and SP scenarios?

We have assumed in these scenarios that there is still a very fluid international gas market and that the required gas would be available.

25. How do you see existing gas storage operators playing a part in each of the different scenarios? Do you see them shifting to blending and then hydrogen, cliff-edging from one to the other, or would new hydrogen storage sites be developed?

We have not modelled the transition of the natural gas storage sites to hydrogen and only concentrated on what hydrogen storage would be required in the year 2050.

26. Why don't we have more green gas injected into the gas system

This is restricted by the total bio resources supply in each scenario and how much bio resource is needed in other sectors to provide negative carbon or to meet demand where there is no alternative decarbonisation solutions.

27. What are you assuming happens to the NTS in CT and LW?

The impacts on the NTS are likely to vary across the scenarios. More detail can be seen in related documents like the Gas Ten Year Statement (GTYS) that can be found on the National Grid Gas website.

28. What fuel reserves does the UK require for energy security? How are these provided when fossil fuels have been phased out?

In FES 2020 we have focused more on flexibility (at a whole system level as well as just for electricity) than on fuel reserves specifically. However, as part of this we have established a need for significant levels of hydrogen storage across the scenarios to ensure security of supply.

Hydrogen supply

1. Most of the talk has been about h2 generated locally. is there any imported h2 being considered? The cost of desert solar electricity would be much cheaper and has a high capacity factor.

Leading the way considers imports of hydrogen (47TWh by 2050).

2. What is your assumption for the amount of H2 blended in the gas network in SP scenario?

We have assumed a roughly 2% blending of hydrogen into the natural gas network in Steady Progression in the year 2050

3. Is the existing gas infrastructure in the North Sea and onshore seen as a driver for using hydrogen as an energy carrier?

There are multiple drivers for hydrogen as an energy carrier. In System Transformation where there is the highest demand for hydrogen, it is seen as being the least impacting way of decarbonising heat on the consumer. To change the current infrastructure to hydrogen will be a key challenge for this scenario.

4. Do you see hydrogen being rolled out uniformly across the country, or to be used in specific areas?

We would expect the initial development to be in specific areas and in the case System Transformation this would grow to be more uniform across the country.

5. In LW, why is there a lower hydrogen shipping demand compared to the other scenarios?

In Leading the way, we have more bio energy available and some of this used in shipping resulting in less requirement for hydrogen in shipping when compared to the other net zero scenarios.

6. With the predicted 70TWh hydrogen demand for shipping does your modelling see this as being used as hydrogen, or as a hydrogen derived fuel such as ammonia, methanol, or DME?

We have assumed that it is likely to be a hydrogen derived fuel. Likely ammonia.

7. Are you exploring or aware of anyone else who is, whether that offshore hydrogen could be stored in existing gas fields - helping store and also forming a blend at source, while making continued use of piping infrastructure (where H2 compatible)?

We have only included a blend of hydrogen in Steady Progression. The hydrogen would be blended directly into the natural gas network in this scenario.

8. With the modelling of electrolysis using curtailed electricity, are there any assumptions made about the commercial viability of electrolysers used at sub-optimal capacity?

We have assumed that electrolysers will be commercially viable at a minimum utilisation factor of 7% when using curtailed electricity.

9. **In ST, do you assume the CO2 captured from blue H2 is stored or used in industry?**

Our assumption is that the majority will be stored.

10. Is "blue" hydrogen (hydrogen produced via emission creating sources) seen as an important interim step to reaching a full hydrogen economy, or will the focus be on achieving 100% "green" (hydrogen created from zero-emission sources) hydrogen production as soon as possible?

Our scenarios capture a range of hydrogen production with System Transformation and Consumer Transformation both with a mix of blue and green hydrogen. With the former favouring blue and the latter favouring green. In Leading the way, the focus is on 100% green hydrogen.

11. Does your 'Leading the Way' scenario factor in the massive offshore wind potential for the UK? Very surprising that you see the need to import H2.

In our stakeholder engagement, there was evidence that there is strong potential for international hydrogen trade and that the UK could be part of this. Because of this we felt that it was important to include imports in FES 2020 and more specifically Leading the way, where we are trying to decarbonise as fast as possible. Imports would allow for a flexible source of hydrogen potentially reducing the volume of storage required.

12. What is the point of the steady progression analysis given that it fails to get to the desired target?

When we carried out our stakeholder engagement on the scenario framework, we explored the possibility of having all scenarios meet net zero. However, our view, supported by stakeholders, is that when trying to capture the credible future of energy it is important to consider a scenario which doesn't meet the target. The Stakeholder Feedback document (see website) provides more detail on this.

13. If need to import hydrogen, is linking to European Hydrogen Backbone a possibility. Are we including that in BREXIT thinking?

We have assumed that trade with the EU would still be possible in the future.

14. Do you assume that H2 or natural gas will be used across the gas interconnector?

This varies across the scenarios. In ST and CT, we have presumed Natural gas would be available from the continent in 2050 and in LW we have no Natural gas coming from the continent however we do have hydrogen imports and this could be in the form of shipped in or piped from the continent.

15. H2 burns much hotter than natural gas. Are you assuming the collection and distribution of O2 from electrolysis to avoid excess NO2 production in boiler combustion?

Development of hydrogen boilers is already well underway. We have not modelled any specific O2 distribution to manage NOx and have assumed that that any technical difficulties with hydrogen boilers will be able to be overcome.

16. Is 20 TWh storage enough to meet the winter heating peak demand?

20TWh is the minimum storage we think is required in System Transformation to meet demand across a year and does not take into consideration deliverability rates to meet peak winter demand.

17. Has hydrogen blending above 2% within the NTS been considered?

We have modelled a switch from Natural gas to hydrogen without blending on the way. Where blending is enduring, it is only in steady progression and we did not go above 2%.

18. Do the scenarios assume we export any hydrogen post 2030, and is this in line with the European Hydrogen Backbone work?

We do not assume any exports in our scenarios for hydrogen however in Leading the Way we have identified that there is potential for this and we will be looking into this more in the future.

19. What are the pros and cons between generating electricity from hydrogen from fuel cells and being burnt? What assumptions are made for the link between this and power flexibility?

Generating electricity from hydrogen provides great source of flexibility in a high renewable world, it replaces natural gas in the peaking plant as a clean energy. How much hydrogen goes into power sector and burnt directly in heat or transport are modelled separately in our scenarios and there is no direct link between them.

20. Given the energy density of H2 do you anticipate using the existing gas networks or having a duel system to affect the transition?

Our modelling is done on an unconstrained network, so the physical aspects of the transmission network do not impact our modelling. However, we have presumed that some of the natural gas network today would be repurposed to carry hydrogen across the net zero scenarios.

21. I recently attended a series of webinars hosted by National Grid ESO on the future energy scenario publication. I found the presentations both informative and thought provoking, which are very useful to my PhD in the modelling of hydrogen storage at Edinburgh Napier University. In Rob Gibson's presentation on Hydrogen, he stated that the current UK natural gas capacity was 14TWh. I was curious if you had information on the breakdown of this storage capability i.e. pipe network storage capacity, cavern storage, depleted gas fields? It would be greatly appreciated if you could help to pass on some information for my PhD.

Natural Gas Storage information we refer to Ofgem's published document:
https://www.ofgem.gov.uk/publications-and-updates/gb-gas-storage-facilities

22. On pages 20 and 20 of FES in 5 mins (the Key Statistics page), hydrogen demand and supply is balanced for CT, ST and SP, but for LW there is a supply gap of around 47 TWh. Please can you explain?

This gap corresponds to the level of imported hydrogen in the Leading the Way scenario.

23. System Transformation scenario highly relies on SMR-CCS, instead of electrolysers. Is this assumption based on existing CCC analysis?

We try to capture different credible hydrogen pathways across the scenarios rather than favour one specific method of hydrogen production. We also try to align the different options with our scenario framework. For System Transformation, the majority of hydrogen is produced from methane reforming plus CCUS as the total hydrogen demand is very high, nearly 600TWh. The level of renewable generation is also relatively low compared with Consumer Transformation and Leading the Way in which the majority of hydrogen is produced by electrolysis.

24. What modelling have you done on the balance of H2 from hydrolysis and CCS/CCUS in the scenarios? Which are the different barriers to uptake for each of these?

The production of hydrogen is largely derived from the scenario framework assumptions. The balance between the different production methods largely depended on the availability of curtailed electricity, imports and dedicated electrolysis.

25. What are the barriers to increasing the amount of networked off-shore wind hydrogen generation? Why is there not more of this H2 in some scenarios?

Across the scenarios, we have varied the methods of hydrogen production to provide a range. In Leading the Way, we have utilised non-networked electrolysis, assumed to be electrolysers co-located with dedicated offshore wind farms, and imports which don't feature in the other scenarios. Across all three net zero scenarios there is off shore wind and electrolysers connected to the electricity network that would be able to flex when there is an oversupply.

26. Blue hydrogen assumes 95-97% carbon capture, but CCS equipment becomes exponentially more expensive as it approaches that. It also imposes inefficiencies of up to 30% on the parent plant, which again becomes exponentially more expensive as efficiency increases. This will make it much more expensive. Why haven't you factored that in?

Carbon Capture Usage and Storage development requires support and coordination across policy, regulation and industry. Current market signals do not provide strong enough investment signals to significantly scale the technology, however we assume policy support will be there to deliver the large-scale hydrogen presented in the System Transformation scenario.

27. Is there a different burn rate of nat gas and nat gas/H2 mix? If so how do you assume that boilers deal with it?

In Steady Progression, we are mixing in low levels of hydrogen to the natural gas network which would change the calorific value of the gas flowing through the pipes which could the change the efficiency of boilers. As the boiler replacement takes place, and as the blending increases, the boiler may have to be altered slightly to increase efficiency. In System Transformation, where we plan to change to pure hydrogen boilers, we expect to install boilers that are hydrogen-ready.

28. Will hydrogen replace natural gas as commodity?

Yes, in all net zero scenarios hydrogen as a clean fuel will largely replace natural gas as a commodity to deliver decarbonisation in heat, power generation etc.

Natural gas will still be required to supply energy to small amounts of users and to produce hydrogen. The level of hydrogen and natural gas required is different in each scenario as electrification is another important route for reaching net zero.

29. What are the key differences assumed among the different scenarios that mostly affect the electricity and gas demand for hydrogen production?

In System Transformation, total hydrogen demand is very high, nearly 600TWh, and the renewable generation level is relatively low compared with Consumer Transformation. Therefore, the majority of hydrogen is produced through methane reforming plus CCUS. In Consumer Transformation, the total demand of hydrogen is lower, about 150TWh, and the level of renewable generation is much higher. Therefore, the majority of hydrogen is produced by electrolysis in this scenario. This helps to provide the flexibility required in a high renewable world.

30. Could you expand further on why it is assumed that methane steam reformation would be the optimal means of production for hydrogen used in shipping compared to network/non-network electrolysis?

There is a mix of blue and green hydrogen supplying shipping across the scenarios. In System Transformation, it is blue and, in Leading the Way, it is green hydrogen.

In Consumer Transformation, where there is less of a hydrogen economy across the other sectors, it is presumed that some of the hydrogen will be produced by electrolysis, taking advantage of what would otherwise be curtailed electricity, and the rest would be made up of dedicated blue hydrogen production for the shipping sector. This is deemed more economical than building more power generation purely for the shipping sector.

31. Do you assume hydrogen imports in the form of liquid hydrogen or ammonia?

Both liquid hydrogen or ammonia are potential energy carrier for hydrogen imports and we do not restrict use of either.

32. Hydrogen storage - in m3 what is the likely volume of storage required in the UK by 2050?

Hydrogen storage volumes are published in the FES20 Workbook, please see Tab 'SV.37' and 'SV.38'.

33. Can you confirm that hydrogen production in GB is from sea water, not potable water sources.

We talk about this topic in relation to electrolysis use in Leading the Way. With reference to the water that is used in offshore electrolysis, we assume that this is sea water and that there is desalination equipment at the location where it is electrolysed. We take into account where the extra energy in our hydrogen efficiency numbers. There is water used in some onshore electrolysis where it has smaller volumes and this is not necessarily assumed to be sea water.

34. How is hydrogen stored now and how do we need to ramp up the infrastructure for 2050?

Hydrogen used in road transport today tends to be stored in pressurised tanks. Hydrogen storage in the future is expected to largely be salt caverns.

35. Domestic boilers can be manufactured hydrogen ready but can power station turbines be used / modified for hydrogen?

We assume that hydrogen can be combusted in new gas turbines or that some existing CCGTs can be retrofitted to burn hydrogen for power generation.

36. Why use H2 in a fuel cell and not a combustion engine in transport but, for general electricity production, central combustion is the method rather than home fuel cells where the electricity and heat could be used?

In the scenarios, we have both hydrogen-fired generation and fuel cells; depending upon both the scale of generation and the location.

37. How are electrolysers connected to the electricity network (distribution, transmission, a mixture, or scenario dependent, what you see as the typical capacity of electrolysers (in MW) and where do you expect these electrolysers to be located (presumably near the gas network for injection, but does a viable source of fresh water also constrain the potential locations?)

In terms of how networked electrolysis will be connected to the electricity network, a mix is applied across the scenarios.

There are several factors impacting the size of the electrolyser, such as the location of the electrolyser, availability of renewables nearby and the hydrogen network availability in the region. The size of the electrolyser will also impact the electricity network flow. Therefore, we don't have the answer now but these would be looked at in downstream analysis carried out by the ESO and other network companies (e.g. the Electricity Ten Year Statement or ETYS).

The location of the electrolysers has been scenario-driven in our analysis. In Leading the way and Steady Progression we have sited them near generation and, in System Transformation and Consumer Transformation, we have sited them near to demand. We model on unconstrained networks so we do not take into account network constraints.

38. Regarding the hydrogen generation replacing gas-fired generation in Consumer Transformation, is this envisaged as generation from hydrogen that was earlier electrolysed, so it is re-generation where hydrogen was used as the interim storage vector?

Hydrogen would have been created from electrolysis in Consumer Transformation (unless used directly in the shipping sector). Hydrogen here would be playing a key role in the whole system flexibility being able to store energy over a longer period of time.

39. What are your assumptions for renewable growth / electrolysis etc in Europe and does the rest of Europe achieve net zero in 2050?

In our scenarios, we assume our nearest trading partners move with us. Where we achieve net zero by 2050 that forms part of a background of our trading partners moving at the same rate. With regards to hydrogen in Europe, we would assume them to be moving to a similar solution as we are, in System Transformation for a more hydrogen-based economy for heat and, in Consumer Transformation, more electrification of heat.

40. What hydrogen storage capacity is expected for 2050? As Hydrogen offers excellent long-term storage duration compared to batteries, is this also considered?

We reach our maximum of 20 TWh for hydrogen storage requirement in System Transformation. However, our analysis is the minimum requirement for storage. This is more phase shifting of energy supply and demand rather than looking for any security for supply scenario. We could potentially see that number going higher if we were to look at making peak hydrogen storage a security of supply measure.

41. In your scenarios, when do you see hydrogen starting to make a significant impact (i.e. when would you envisage this technology rolling out in a meaningful way)?

Hydrogen starts to develop into large scale production from around 2030 in all net zero scenarios. Chapter 'Hydrogen Supply' in the FES20 document provides more details about how different technologies are rolling out in each scenario.

42. Is the hydrogen produced from electrolysis all from renewables that would otherwise be curtailed? Are there figures for the level of this output?

In System Transformation, all hydrogen produced through electrolysis is from renewables that would otherwise be curtailed. In Consumer Transformation, 73% of the networked electrolysis is from curtailment. In Leading the Way, 53% of the networked electrolysis is from curtailed generation.

43. Why do you not use blue hydrogen in Leading the Way?

We have a range of scenarios where we try to push the envelope in different directions. In Leading the Way, this is a scenario where we try to minimise emissions as early as possible and try to stop using natural gas to produce hydrogen as it does have emissions associated to it. When we started this analysis a lot of Europe favoured green hydrogen and there were discussions (e.g. in the press) that Europe only wanting green hydrogen. We felt to have a scenario where we were importing and potentially exporting hydrogen which meant markets would have to remain at green hydrogen. Since this time last year when we produced our net zero sensitivity, there have been further developments electrolysers and these have led to falling costs. One of them leads onto our assumption this year around the mid 2030's of green hydrogen becoming cost comparable with other production methods.

Electricity supply

1. Given the new Imperial College research published today suggesting that the currently being constructed offshore wind farms are very likely to pay a negative subsidy back to government, does this mean the electric heavy scenarios more likely than the H2 heavy scenario?

We use scenarios to assess the credible pathways for future supply and demand in GB. Rather than trying to decide which scenario is likely to most closely represent the 2050 energy system, the scenarios are designed to represent the "credible range of uncertainty" that this 2050 energy system could fit into.

2. Do you expect other countries in Europe to be net zero by 2050?

In FES, we do not make explicit assumptions about whether other countries meet net zero or not. However, in our electricity dispatch modelling we utilise information from EU Transmission System Operators (TSOs) and the European Network of TSOs for Electricity (ENTSOE) to inform our analysis and this includes selecting the most appropriate future scenarios for different countries against our scenarios. Similarly, we try to consider how decarbonisation in other countries might impact our gas supply modelling.

3. How will the variable renewable energy be handled by the ESO in the future from the day ahead and real time? Will this involve a separate team to coordinate with the offshore TSOs and Wind/Solar park operators?

As ESO we already handle variable renewable generation although, as FES shows, this will increase in all scenarios in the future which is why we continue to focus heavily on future operability (see System Operability Framework section of the website). In our role as ESO we currently coordinate with different onshore and offshore TSOs and generators.

4. What efficiency do you assume for hydrogen generation?

This is entirely down to the generation type itself; for a hydrogen fuelled CCGT, we assume the same efficiency as the current average CCGT plant. The same for a CHP and so on. Therefore, efficiency can be between ~45%-80% depending upon the technology (if you include the heat captured for other processes).

5. What is the definition of "zero marginal cost generation"?

A technical definition is that zero marginal cost generation has no cost short run cost such as fuel costs. However, as an example, generation like wind and solar is zero marginal cost whereas other generation such as gas or coal have fuel costs which have to be considered when deciding if it is profitable to generate for a given time period. Marginal cost doesn't include the capital costs of building the generation in the first place.

6. Fascinated by the wildly different roles for Natural Gas. The Utilities push natural gas in generation as a key technology for net zero - is that compatible with the new models?

In a net zero world, natural gas should not be burnt unabated. Across the scenarios, we have tended to favour hydrogen generation over natural gas with CCUS in most instances by 2050 due to the use of this type of generation as low load factor peaking plant (rather than baseload) and also the higher capital cost of e.g. natural gas CCGTs with CCUS over hydrogen generation.

7. So you assume hydrogen beats gas with CCS for power generation in all Net Zero scenarios on economic grounds? Do you vary capex / opex cost assumptions between scenarios? If not, isn't this attaching too much certainty to them?

We do vary our assumptions between scenarios to give a range of outcomes. One of the key observations was that as the running hours of dispatchable plant reduce. This is because of the increase in renewables and also the need for Biomass CCS to run near to baseload to provide negative emissions. At low load factors, the upfront capital cost becomes more important. A review of potential capex costs continued to highlight Hydrogen over Gas with CCS.

Furthermore, we examined the carbon cost of Gas Generation with CCS and the ability to meet net zero across the whole system. Part of that required residual carbon in generation to be removed where possible. As Gas CCUS does not capture all the carbon emissions the more it runs the more that has to be done elsewhere to offset the carbon that is emitted. This combined with the downward pressure on running hours due to an increase in renewables has led us to our conclusions that for low load factor plant Hydrogen Generation will be more economic that Gas CCS.

8. Following from your chart on net interconnector flows, please can you advise general trends of anticipated net flows by border and to what degree you think your assumptions regarding carbon pricing support influence this?

Due to the confidential nature of projects we would not be able to provide a boarder by boarder breakdown of flows. We can say that carbon prices, and how they feed into the generation marginal prices, do have an impact on flows between countries.

9. As all countries converge towards a greener future, what is the likelihood we all become net exporters of energy? Would this not cause more constraints on our system?

For electricity, we run our generation mix through a pan-European power dispatch model. This has shown that there is sufficient variation between each market such that electricity is still being traded across the interconnectors in large volumes. As shown in the Flexibility presentation, the volume and number of times that the flow direction changes increases as we move towards 2050. This indicates that the interconnectors will help balance large volumes of renewable electricity between markets. In addition to this we have also included electrolysis to convert excess renewables to Hydrogen. In effect this aids with seasonal fluctuations but also creates more links between the electricity network and other sectors.

10. We do not seem to be seeing any role for blue hydrogen being used to provide fuel gas to power stations. Is that not even a consideration even as a transition or a fall-back if offshore wind doesn't take off as hoped for?

We have some hydrogen being used to produce electricity however this is minimal (e.g. peaking plant) due to the efficiency losses incurred. Whether the hydrogen used here is "Blue" or "Green" depends on the scenario - there are large volumes of blue hydrogen in System Transformation.

11. Tidal range generation of up to 10GW by 2050 is included in this year's FES. Can you provide more detail on your thinking and its value to the Grid please?

GB is fortunate in both its natural wind and tidal resources meaning that tidal, being very predictable, is one amongst several technologies we see as being able to provide zero carbon energy into the electricity network in order to meet net zero. We continue to explore a range across our scenarios.

12. Do you know which scenario will be put forward to Entso-E for TYNDP20, or will it be some form of averaged scenario?

Due to the timing of the analysis, TYNDP 2020 is based on previous FES results. We have not yet decided how to map our scenarios to future ENTOSO work.

13. Can you provide more information on the near term and long term assumptions or sources used to determine the various generation technology capacity factors and therefore the annual generation output figures?

We utilise an economic dispatch model to determine the generation output in relation to the demand. This utilises fuel prices, generation plant efficiencies, weather patterns and demand patterns to calculate what plants (in ascending price order) are required to run. Whilst this is calibrated against the current network, one thing to note is that we run the dispatch analysis without any network constraints as today's network will not be reflective of the network in future years. We do this so that FES considers the generation mix that the market may bring forward if unconstrained. Our colleagues working on the Electricity Ten Year Statement (ETYS) and Network Options Assessment (NOA) can then assess what network changes will be required to deliver this.

14. Doesn't the Grid Network need to be changed for massive renewable generation? In percentage terms, how ready is it, and how are we expecting to make the further changes? Is it through further renewables paying for it and when they are hooked up?

Being able to assess how the network will need to change is one of the main reasons why we undertake the Future Energy Scenarios analysis. The results are passed to our colleagues working on the Electricity Ten Year Statement (ETYS) and the Network Options Assessment (NOA) in order to determine what changes may be required. We encourage you to read the next versions of both of these publications when they are released later in the year as they will reflect the latest thinking from FES 2020.

15. Why is there just one scenario reaching 40 GW of offshore capacity by 2030 taking into account that the target is supposed to increase from the 30 GW of the Sector Deal to 40 GW?

We generate a series of scenarios to cover a range of probable outcomes, including hitting the 40GW by 2030 ambition as well as the 30GW by 2030 sector deal target; as well as missing those targets in some scenarios. The 40 GW target is particularly challenging and as such we believe it is appropriate to have a range of scenarios, some of which do not achieve this by 2030.

16. It would be useful to know how much floating wind and bottom fixed (separately) have been assumed.

Beyond current known projects we have not specifically selected between floating wind and bottom fixed within the scenarios. We do assume that floating wind will be included within the offshore wind capacity we have used however we have not gone so far as to specify exactly how much due to the speculative nature of some of the projects that appear closer to 2050.

17. Do you get curtailment in your models and how much (in terms of percentage of the demand)?

We do have curtailment in the models. The maximum annual curtailment as a percentage of annual demand is: LW:2%, CT:5%, ST:16%, SP:1%.

18. How is hydrogen used to create electricity? Is it mostly burnt or used in fuel cells?

In our scenarios, we have turbines burning hydrogen for transmission-based hydrogen generation, we also have fuel cells being used in distributed generation. (See data workbook ES1)

19. Net interconnector flows from 2035-2050 are notably much more export-focused in the System Transformation scenario in comparison to the other three scenarios. What do you think is the key driver for this?

The relative price of generation between countries are the drivers for interconnector flows; with flows going from lower price regions to higher price regions. There is a large amount of wind and solar generation in ST in relation to demand, allowing more flows to occur during periods of lower demand and higher renewable generation.

20. The CCC report from last year talked about the need for around 40-120GW of backup gas plant by 2050, the FES scenarios have a lot less back-up plant but do include more storage. Does the storage provide as much security of supply as a back-up gas plant would?

In the scenarios, we do have less back up generation and more storage, but this is just one aspect of the flexibility requirement. There are also other technologies such as hydrogen-based generation, interconnectors and smart demand; together these help to meet the Loss of Load Expectation (LOLE); therefore reducing the reliance on backup gas plant.

Our scenarios all meet the security of supply standard (3 hours LOLE pa) and this is ensured through the capacity mix we produce. We then test the ability of this generation mix via our pan-European dispatch model analysis. As we move closer to the forecast year, the analysis undergoes further stress tests to ensure security of supply can be continued to be met under a wide range of situations.

21. I note that the height of the purple "storage" element in all four of your 2050 scenarios is less than the heights of the elements of offshore wind, on-shore wind, solar and interconnector elements, and thus below the critical diamond if these are not present. How then on a cold winter's night, having had a cloudy day and several days and nights with no or very little wind, as is common in winter all over Europe, will the system cope with peak demand?

All our scenarios meet the reliability standard of 3 hours LOLE per year. In GB, this is delivered through the Capacity Market. As we get closer to real-time, we carry out detailed modelling with a wide range of stress tests in both GB and Europe to determine the capacity to secure in the auction. This analysis includes the consideration of a variety of historic weather years to look at variation for peaks and outliers. It is published annually in the Electricity Capacity Report and scrutinised by BEIS' Panel of Technical Experts.

22. Following several surveys, each study has concluded that there are no sites in UK suitable for any other further pumped storage schemes on anything like the same scale as Dinorwig. You should therefore cross off any statements of intent for further pumped storage by this means.

You are correct that geographical restrictions mean that the construction of a single site on the scale of Dinorwig is not possible in GB. We have taken such survey evidence into account within the scenarios.

Smaller pumped storage sites are still possible within GB as you will see on examining the TEC (Transmission Entry Capacity) Register (https://www.nationalgrideso.com/connections/registers-reports-and-guidance). There are multiple sites that have been proposed for new pumped storage; each individually on a smaller scale than Dinorwig.

23. On page 91 it states that 'System Transformation and Consumer Transformation have high levels of tidal generation capacity, with up to 10 GW installed by 2050'. Please can you let me know if this 10 GW of tidal is tidal stream energy projects, tidal range projects, or a combination of both.

It is a mixture of projects that include both tidal range and tidal stream. The split between tidal stream and tidal range is entirely dependent upon the scenario. For the scenario with the highest amount of tidal capacity the split is 14% Tidal Stream and 86% Tidal Range.

24. In chart SV.24 I'm interested to know the assumptions behind the drop in load factors for onshore wind to 18% in the System Transformation scenario?

From 2032 the onshore wind load factor (LF) begins to decrease from 28% to 18% by 2050. We see similar patterns across the renewables for offshore wind, solar, marine and hydro. This drop in LF corresponds with an increase in the levels of curtailment so we can assume that it is the curtailment that is causing the drop in LF.

In 2032 the levels of BECCS generation rapidly increases. As BECCS is used to offset CO_2 emissions it has a negative price and will run constantly at maximum availability. This means there would be times where BECCS would run instead of renewables, causing renewable curtailment to increase.

In Customer Transformation and Leading the Way there are much higher levels of electrolysis than in System Transformation. This results in lower levels of renewable curtailment. In these scenarios, the onshore wind load factor stays above 25%.

In System Transformation, the rate of growth of onshore wind slows down in 2025 and again in 2035. By 2050 there is around 29GW of onshore wind in System Transformation vs around 48GW in Consumer Transformation.

25. In the data workbook for FES 2020, on sheet ES1 there is no type (within the Storage category) of "Vehicle to grid" as there was in FES 2019. Has this option for generating electricity been removed?

Although it is not included within the ES1 worksheet, it is included as a form of generation, but we have only included the data on Vehicle to Grid as part of the transport demand section (ED5).

26. What role do you see offshore wind playing in the scenarios?

We see a significant role for offshore wind in the scenarios with between 64.7GW and 107.5GW, both directly onto the grid but also, later in some of the scenarios, to power electrolysis to produce hydrogen.

27. Leading the Way has 160TWh of nuclear generation by 2030, up 160% from this year. Only Hinkley C is under construction and it's taken over 10 years so far. How credible is this assumption?

We assess on a project by project basis. Whilst there is a high degree of uncertainty in many areas of the analysis, including nuclear, we believe that there is scope for increases and hence we continue to model a range of nuclear outcomes across our scenarios.

28. How much extra pump storage do we see in the scenarios? Is it even possible?

We see pumped storage increase to between 4 and 4.7GW in our scenarios. This is shown in the Data Workbook (ES1), a table containing both capacity (MW) and Storage Capacity (GWh) for Pumped Hydro, Compressed Air, Liquid Air and Battery.

We work with our stakeholders, and in particular the network organisations, to identify where projects may come forward. Our projection is based on known plants.

29. DSR includes heat pumps with thermal storage, smart charging and V2G. Can you give any other significant examples?

A lot of DSR is enabled by smart building controls with a lot of interest in this with consumers and combined with mobile phone interactions. There are two types of DSR: pure demand side response which is somebody changing their demand. Examples include refrigeration, lighting, heat, air con, industrial processes, water pumping. We have talked with supermarkets, warehouses and hotel chains on this topic. You may have seen a dim supermarket at 5 o'clock- guess what they are providing a service. We have demand turn up which includes vehicle charging, industrial processes and storage charging. Other types of demand side response we refer to as behind-the-meter generation. We have in-home storage or commercial storage with a lot of buildings that do have their own storage and also behind meter generation predominantly with diesel backup currently but other sites have storage, solar and wind.

30. Please explain the difference between the National Grid ESO figure for 2019 electricity generation of 167g/kWh and various BEIS published figures (latest GHG reporting factor is 267g/kWh).

The different values are determined by what is and isn’t included within the calculations, the sources used and how the calculations are done. In the Future Energy Scenarios, we only include Great Britain and not the whole of the UK.

- carbon intensity in 2019 is around 170 gCO2e/kWh

This is from our economic dispatch model where we utilise an unconstrained system, therefore this will be lower than actual 2019 carbon intensity. E.g. no renewables are constrained off and no additional carbon based generation is brought on to compensate in a different part of the country.

- 215g CO2/kWh in 2019

This is the average carbon intensity form the National Grid ESO carbon intensity app for the period 01-01-2019 to 31-12-2019. (https://www.carbonintensity.org.uk/)

- 255.6 gCO2e/kWh

Unfortunately, it is not possible to comment on the BEIS number without knowing exactly what is and isn’t included within it; although it does state UK, so can maybe assume that this data includes both Great Britain and Northern Ireland.

31. FES suggests that BECCS will operate as baseload while other biomass generation will be used for dispatchable power. Does the capital cost of carbon capture preclude it's use in dispatchable power plants?

The capital costs of CCS do not necessarily preclude BECCS running for dispatchable power, but to meet net zero, the maximum output of BECCS is required. This means that BECCS should run as baseload for the maximum impact on carbon.

32. How do you expect BECCS to be subsidised, will it be incentivised to flex down in times of high renewables / low demand?

In the scenarios, we assume that the UK carbon price will be paid to any generation that produces negative carbon. To meet the negative carbon requirements for net zero this requires BECCS to run almost continually; we therefore do not expect it to regularly turn down.

33. You have provided Base Case assumptions for the natural gas, coal and CO2 prices; what is the biomass fuel price assumed?

We receive the Biomass price from an external company in confidentiality and so unfortunately cannot share the exact price we utilise in our model.

34. In the ES1 (ES1: Electricity supply data table), under the renewables category, I can see the total installed biomass capacity and generation for different scenarios. When I compare the generation and installed capacity, there is a discrepancy in the medium term.

The biomass generation is reduced dramatically in all 3 scenarios after 2027 (after the subsidies expire as you have mentioned) but the capacity stays at the same level until 2033 in LW, 2036 in ST and 2037 in CT. Can you please help me understand this result? Are you saying that these biomass plants will still be on the system (counted in as high firm capacity) but will not generate (and why)?

Yes, the generation output drops significantly post 2027, due to the loss of biomass subsidies. The plant however remains on the system to meet security of supply (the LOLE Reliability Standard). We run an economic dispatch model to determine which plants generate, based upon marginal costs from lowest to highest; with the loss of the subsidy, the marginal cost of the biomass generation becomes higher than various other forms of generation and therefore generates less in our dispatch model.

35. Across the three scenarios, what date(s) do you anticipate that unabated natural gas is phased out in the power sector?

The date are as follows:

LW - 2036 for transmission and 2045 for distribution

CT - 2046 for transmission and 2050 for distribution

ST - 2049 for transmission and 2050 for distribution

There may be some tiny volumes of unabated gas and biogas still being burned on the distribution side in these years, relating to micro-CHPs and biogas CHPs, but virtually all has been phased out by these dates.

System flexibility

1. How big a role do you see conventional hydroelectric generation (not pumped storage) playing in the future energy scenarios? With ROC's ending in 2027 do you see future market opportunities for this technology?

We expect to see existing hydro generation schemes continue to operate but the capital costs and geographical limitations of large hydro schemes makes it difficult to see how new schemes would be developed without significant financial or political support. Smaller hydro schemes are less capital intensive and have fewer geographical limitations but we still expect a lot of these issues to remain. In short, we would expect financial or political support to be required for new hydro generation schemes to enter the market.

2. Please could you explain the key drivers for the dramatic increase in GWh for electrical energy storage (Fig SV.46)? What assumptions drive the different timings of such spike under each scenario? Why is the spike so severe?

If you examine the data within ES1, which breaks down the GWh for storage into different storage types, you can see that the large increases (for example Leading the Way in 2028) are due to high duration storage (in this case Pumped Hydro) coming on line.

The addition of long duration storage causes spikes in the scenario, due to the amount of capacity that comes on line at that moment.

3. What are the incentives to build H2 plants with such low load factors?

We acknowledge that the low load factors for Hydrogen power stations will make their economics more challenging. The economics of these stations will be increasingly reliant on their ability to provide flexibility to back-up renewables and network services. In addition, the ESO has an ambition to operate the system with zero carbon by 2025, and this may affect the services we require, as we respond to the changing market.

4. When there are extended periods of high demand and low wind will there be enough electricity generation and storage to meet demand?

All our scenarios meet the reliability standard of 3 hours loss of load expectation (LOLE) per year. In GB, this is delivered through the capacity market. As we get closer to real-time, we carry out detailed modelling with a wide range of stress tests in both GB and Europe to determine the capacity to secure in the auction.
This analysis includes the consideration of a variety of historic weather years to look at variation for peaks and outliers. It is published annually in the Electricity Capacity Report and scrutinised by BEIS' Panel of Technical Experts.

5. The presentation slide showing generation mix on a typical day in 2025 does not appear to show any nuclear, why?

The nuclear generation output is included within the thermal aggregate grouping within the graph.

6. In relation to the "interconnector flows by years chart", what assumptions have you made about European markets to get the graph (LW) where UK supply>demand for next 15 years (or so). What evidence is there that UK will expand energy supply faster than European countries?

Leading the way is our most ambitious decarbonisation scenario, which also includes significant societal change. This leads to periods where supply exceeds demand, and where our generation is cheaper than some European countries which will cause interconnectors to export. It is not so much about expanding supply faster, more about what time that GB supply exceeds GB demand and is available for export; as well as what the price difference is to European supply that would be utilised to meet their demand.

7. I'm curious about why imports / exports reverse in the mid-2020s. Are you making consistent assumptions for interconnected countries? We know that the Net Zero target will be reviewed in light of international commitments (i.e. it doesn't make sense for UK to have high growth of zero carbon technologies if neighbouring countries don't).

We have used the ENTSOe scenarios (or TSO specific information) in our analysis of interconnector flows. Not all EU countries decarbonise at the same rate or using the same technologies. These differences, plus peak demand time differences across the continent, help encourage interconnector flows; especially where we have excess renewables at times where we have low demands. This moves GB from a net import in the early 2020's to net export in the late 2020's in Leading the Way.

8. Do the price differentials and utilisation of interconnectors derived in the BID3 model justify the capital expenditure on all these new projects?

We develop the interconnector capacities within FES by examination of the evidence, including the work done as part of the Network Options Assessment (NOA).

9. Am I correct in assuming that electrolysis contributes to both demand and supply side flexibility - electricity demand for the demand side and hydrogen for the energy system flexibility?

Yes - this is correct.

10. Is there any intention to break down battery storage asset classes for future FES studies (specifically in the data workbook)? e.g. grid scale standalone storage plants (c.50MW) vs domestic wall-mount batteries (c.7-10kW)?

Not currently but, if stakeholders will find this information of use to them, then we can look at how we can provide it in future issues of the FES.

11. How do you meet the winter peak?

Winter peak is met by a mixture of technologies from both supply and demand positions. All our scenarios meet the reliability standard of 3 hours LOLE per year. In GB, this is delivered through the capacity market. As we get closer to real-time, we carry out detailed modelling with a wide range of stress tests in both GB and Europe to determine the capacity to secure in the auction. This analysis includes the consideration of a variety of historic weather years to look at variation for peaks and outliers. It is published annually in the Electricity Capacity Report and scrutinised by BEIS' Panel of Technical Experts.

12. Do you change the renewables build out assumptions in in Europe each FES 2020 scenario? Or are they always kept the same?

Yes, we vary key input assumptions like generation, storage, demand, fuel and carbon prices and non-GB interconnectors. We model Europe using scenarios developed by ENTSO-E and other European TSOs. We include a full list of our sources in the Modelling Methods document.

13. Could you provide insights into the reasons behind the differences in forecasted connection capacity for different storage technologies. It looks odd that pumped hydro, a non-locatable technology, has a larger connection capacity compared to LAES. LAES is locatable and is suitable for sector coupling transport, heating and cooling. The value that storage provides greatly derives from its temporal and locational flexibility so it would be interesting to understand how you allocate cost and value.

When we look at capacity for any technology, we first look at live projects on the TEC or Embedded registers and what their expected connection dates are. We also speak to a range of stakeholders about how they consider the various technologies will advance.

We always enjoy speaking to any stakeholder who will be able to improve our knowledge of technologies and deployment. Please consider taking part in our FES call for evidence later in the year.

14. How do interconnectors contribute under peak circumstances? Are they importing or exporting or somewhere in between?

In our analysis, we assume that interconnectors are price driven and look at price differentials between Europe and the UK to inform their contribution at peak times. Imports are assumed in most scenarios with highest peak flows seen in Leading the Way and Consumer Transformation which have the highest interconnector capacities.

15. Flexibility seems to come from undeliverable technologies, e.g. interconnectors (can't rely on them), hydrogen generation (much costlier and less efficient than CAES), flexing electrolysis (needs too much investment in equipment) and V2G (you've overestimated both vehicles and their availability). It would be much more cheaply delivered by large-scale long-duration storage which also (1) has inertia and so provides system stability and (2) would halve (or better) the investment in grid capacity by balancing intermittency at source. Why do you insist, every year, on underestimating the benefits of large-scale long-duration storage?

We see a range of technologies supporting flexibility, including significant growth in long duration storage technologies such as CAES. When we undertake our analysis, we ensure that all scenarios are compliant with the security of supply standard which is the Loss of Load Expectation (LOLE) of 3 hours. We test our generation mix in a pan-European dispatch model to assess the ability to meet this standard but also to examine extreme events such as a sustained period of low wind. Further stress tests are undertaken covering a period several years ahead and this analysis is scrutinised by the BEIS Panel of Technical Experts (PTE). When we examine the results of our pan-European dispatch model we are satisfied with the response we see from the mix of flexibility technologies we have.

Whist we continue to monitor and assess the developing market, and in particular cost projections for each technology, the reality of a renewables dominated market is that load factors of dispatchable generation along with other technologies supporting security of supply will decrease. This creates challenges for the economics of these plant many of which will also be looking to stack revenue via ancillary services.

16. Given the increasing operating costs to the ESO of meeting increasing variable renewable energy (VRE) during the operational phase, what does the ESO expect to have to change in order to obtain better operating timescale forecast of VRE capacity. I understand Eirgrid has been working closely with windfarm operators to improve their inputs.

We continue to invest in our short-term forecasting capability as set out in our Forward Plan. This work is supported by the ESO Lab who investigate and deploy new forecasting techniques using Artificial Intelligence (AI) and Machine Learning (ML). We have worked with a number of partners across a wide spectrum of the industry in this work.

17. In addition to market led flexibility, flexibility can also be delivered by (electricity) network operators to alleviate constraints on their local network. Do the flexibility figures in FES 2020 account for both of these types of flexibility? If so, what do you think will be the proportional split between these two ways to deliver flexibility?

The flexibility figures account for all flexibility regardless of where it is located. However, the flexibility we have included is for energy balancing and security of supply only. We undertake FES analysis on an unconstrained network as we are wanting to assess what the market may look like if it had free choice without being limited by the current network constraints. The reason we do this is partly because today's network constraints may not be reflective of the network constraints in future years, and also because we use FES to assess where network constraints may appear and how to resolve this. This is the work that our colleagues undertake as part of the Electricity Ten Year Statement (ETYS) and Network Options Assessment (NOA). Consequently, additional flexibility may be required unless our projected flexibility can also be utilised for network constraint flex use cases.

18. How can "interconnectors balance large volumes of renewable generation"? Usually when it's windy here, it's also windy at the other end of the interconnector. Ditto solar.

We populate a pan-European power dispatch model with the equivalent of FES from the other European TSOs. The results of this dispatch model show that there is sufficient opportunity to balance large volumes of renewable output across each interconnected market. This suggests that there is sufficient variability between markets (e.g. of generation mix, demand profile, cost differential) even as all markets transition towards net zero.

19. 50% availability of V2G is a gross exaggeration. They will be at different states of charge, so assume 50%. Travelling capacity will need to remain in the vehicle, so halve that to 25%. AVs are almost never available, so reduce this to 20%. About 2/3 of vehicles must be hydrogen / fuel cell because there isn't enough lithium in the earth's crust, so actual availability is ~7%.

The current average EV has around 60-100kWh of battery capacity. The current average commute is around a 40mile round trip each day. If efficiency is 0.25kWh/mile then only 10kWh will have been used. Even at 0.33kWh/Mile only 13.2kWh used. This means the vehicle arrives back home with at least 50kWh of charge remaining.

As an average house charger is 7kWh, even exporting as V2G over 3 hours the vehicle can only export a maximum of 21kWh; leaving over 20 kWh remaining (equivalent to between 60 and 80 miles). The expectation would be that the vehicle would then smart charge over night outside of peak periods.

If we look at autonomous vehicles, at the moment there is no reliable evidence of how they will operate. Comparable evidence (such as Taxi's) would indicate their busy periods are during peak demand times. i.e.

they are ferrying people during peak times. Customer owned electric vehicles are likely to be parked after the end of the evening journey, and might be charging or offering V2G.

20. Do you have maps of where the storage is required?

As part of the FES we do not produce maps of where particular technology types are required; we do produce a piece of work that does down into more detail than the FES document itself as part of our data workbook. The bit that may be of help to yourself is the building blocks section (sheets BB1 & BB2), this will give you the storage capacity for the FES scenarios by network.

21. Will the delays in the smart meter rollout impact the contribution to flexibility of residential demand side response?

We see a low level of engagement in smart meters in the early years in the 2020's. However, smart meters are crucial for residential flexibility to enable the time of use tariffs. We see the uptake of EVs and heat pumps by consumers acting as a gateway to them adopting the time of use tariffs by the point that they have a smart meter, EV and heat pump. We see a lag in the scenarios for the adoption rate of these tariffs and technology.

22. How do you see the proportion of consumers with tariffs which change with renewable output (to incentivise flexibility) increasing over time. Will it reach 100% and, if so, when?

We don't explicitly model particular types of tariff. What we do model in the scenarios is how many consumers are engaged in smart charging or smart time use of tariffs. This information is held in the Data Workbook in the Flexibility and demand sections. We have a range of engagement figures which is shown in the Consumer View chapter of the document. Therefore, it's not necessarily 100% renewable, but more smart use tariffs and usage. This is backed up by automated devices telling consumers when energy is more expensive or cheaper.

23. What do you think of consumer resistance to V2G on the grounds of cost of the meter, loss of control of range, and degradation of the batteries? In my opinion these mean that no one will be willing to partake.

We assume battery technology improves (e.g. degradation and range) and that control will be retained by the consumer. Whilst there are likely to be reductions in the cost of bidirectional chargers, we do assume they cost more than unidirectional chargers which is why uptake varies in the scenarios and represents a relatively small proportion of total drivers by 2050.

24. Can I ask how many cars or what kW per car is assumed to make up the total 19GW of V2G in 2050 in Leading the Way in 2050, please?

Currently we assume 7kW power/demand per V2G vehicle. In LW, 5.5m vehicles have V2G by 2050 but only 50% of these are parked at peak time (5pm-6pm).

Further data is available in Data Workbook tables ED1 (Electricity Demand, V2G assumptions) and ED5 (Transport) and further details on modelling assumptions are in the FES Modelling Method document.

25. Why would consumers change their consumption patterns when even the Smart Meter advertising claims only up to 2% (~¬£20-40/year) savings?

We see automated appliances and consumer engagement being key. For instance, some suppliers are experiencing successful results via mobile phone apps, well designed tariffs and engaged consumers. In addition, we expect the incentives on consumers to change their behaviour (e.g. indirectly via their supplier) to increase as the penetration of weather-dependent generation increases as this is likely to impact the volatility of wholesale prices.

26. Have the combined needs for short duration storage (on the demand side) and long duration storage (on the supply side) been costed to optimise to best mix of short and long duration storage to maximise the utilisation of intermittent renewables (e.g. wind) at least cost, or is this outside the FES brief? If not, has the ESO any plans to do so?

Our analysis optimises at a high level between the different types of flexibility that are available at a whole system level (i.e. demand-side technologies like VtG for short term and more supply-side technologies like hydrogen storage for longer term) to ensure security of supply criteria can be met. More information on this can be found in the Energy System Flexibility chapter of the FES Document (p99). Specifically in relation to costing the scenarios, we are in the process of completing this work and hope to share our results later in the year.

27. What build-out of storage capacity (and of what type) do the scenarios require?

In the scenarios, we see a wide range of storage types and associated capacities, from large pumped hydro storage sites to small micro batteries and everything in between.

This is shown in the Data Workbook (ES1), a table containing both capacity (MW) and Storage Capacity (GWh) for Pumped Hydro, Compressed Air, Liquid Air and Battery.

General[1]

1. I am trying to understand the different demand figures published in the FES In 5 document and the data workbook. The FES in 5 has different 2050 demand figures for the consumer end annual electricity demand, compared to the data workbook. What assumptions have been used for both? As the different demand figures is confusing.

FES in 5 (footnote 5) defines demand as being customer demand, plus system losses, plus on grid electrolysis. This is also called "System Demand" in FES, and in the data workbook Sheet: ED5. CV1 is on a different definition as we're trying to compare all fuels (where we have full data for diesel, gas, electricity etc) showing consumer demand, without aviation, marine and losses. There are notes below on why it differs but I will highlight them in the next version of the workbook. Data Workbook sheet ED5 also lists "end use" or "total consumer demand" which I may rename as "Final" demand in a workbook revision. This is all sectors end user demand but excludes system losses. Interconnector exports are not discussed in the demand section - they are discussed in the supply section and contribute to the electricity demand numbers on the Sankey diagrams.

2. FES is fairly light on the required evolution of the electricity and gas grids to accommodate net zero pathways. What's the thinking, and have you consciously avoided getting too far into this?

As FES is used as a starting point for a lot of downstream network development analysis in relation to both gas and electricity (e.g. ETYS and GTYS etc) we are very conscious of the need to ensure that FES is based on intact and unconstrained networks so as not to adversely impact this downstream analysis. This is why there is less focus on network evolution.

3. Is FES in 5 available as a download?

FES in 5 is available on our website as an interactive and a pdf version.

4. Do you have costs associated with each of the scenarios?

We are undergoing a process to cost the scenarios across whole energy system. We will be looking to share the findings of this work in the Autumn.

5. How does FES fit into the ESOs 2025 goals and RIIO plans?

The FES 2020 analysis, our 2025 ambitions and our RIIO2 business plan are all consistent with each other. In particular, FES provides a long-term over-arching framework for how we see the industry and sector developing. We then use that to inform what we need to do in the short term and that's what you see reflected in our RIIO2 business plan that we submitted and also informs our ambitions in particular around enabling an electricity system that can operate at zero carbon plan. The FES 2020 framework also supports alignment across the industry more broadly.

6. How do you define Consumer Whole Energy Demand - is this the same as final energy consumption?

Consumer whole energy demand is at the end user level so, yes, it's the amount that end users consume. We also publish our system level of demand which is the demand on the energy system and includes losses and energy conversion losses. Please refer to the FES 2020 Data Workbook which includes footnotes that give a full definition of the measure of demand that we use.

7. Are the [electricity] demand calculations based on ACS, do we know the winter peak demand for each of FES scenarios?

Yes, the electricity peak demand calculations are based on ACS. Winter Peak Demand is in the following parts of the FES Data Workbook:

1) Underlying System Demand (FES Peak Demand): SV4
2) ACS Peak Restricted National Demand: Ex2

[1] This section is for questions that are not obviously aligned to any of the individual topic areas.

3) Demand Components for peak and other times in Sheet: ED1

4) National and System Demand at Summer Minimum 6am and 2pm: Ex4

8. How is National Grid ESO viewing the functioning of the current wholesale and balancing market in the more aggressive decarbonisation scenarios for a net zero world? Will the merit order dispatch system for price setting in particular in the wholesale market still be fit for purpose or will that require a complete overhaul?

We will also be carrying out our Bridging the Gap to Net zero programme again this year and one of the key areas we will look at is how markets need to evolve in the future and working with stakeholders to consider the peaks and troughs that we will be seeing on our energy system.

9. How do your scenarios compare with those developed elsewhere?

Our scenarios are used in decision-making in network investment and planning and so robust evidence and stakeholder engagement is required. We work closely with industry stakeholders and other organisations that produce scenarios to ensure that any differences in our comparisons are made for the right reasons and clearly understood. Examples of organisations engaged include BEIS, Ofgem, CCC and the Energy Networks Association. In general, our scenarios broadly align with others carried out by different organisations and we are always keen to identify any differences so that these can be clearly understood and any necessary changes made.

10. What is the ESO's role in climate change?

One of our ambitions as a legally separate ESO is to enable an electricity system that could operate carbon free in 2025. This is consistent with a move towards net zero and is also consistent with delivery of energy and electricity to our consumers which enables us to use renewable generation when it is available. Our role is to ensure we facilitate that transition of the energy system.

11. How "sustainable" is CCS? There must be a limit in how much CO2 you can store.

CCS development requires support and coordination across policy, regulation and industry to ensure that it is utilised sustainably. We have not put a limit on the amount of CCUS in our scenarios as stakeholder feedback has indicated that there is more than enough UK potential (e.g. storage availability). System Transformation is the scenario with the highest CCS level, which is similar to the CCS level in CCC's net zero scenario.

12. CCUS is clearly seen as essential for the achievement of Net Zero by these scenarios. What timescale is assumed for these achieving wide-scale deployment?

The deployment of CCUS varies in scale and time across the scenarios. Leading the Way relies on BECCS (Bioenergy with CCS) to reach net negative emissions in the power sector by 2030 whereas the other scenarios are a few years later. System Transformation is the scenario that uses CCUS the most due to the large quantities of blue hydrogen (i.e. produced using methane reformation with CCUS). This technology begins to scale up from the early 2030s so that around 200TWh is being produced by 2040 (see p78 of the FES document).

13. I am analysing the Data Workbook that has just been issued for 2020. I notice that although you still have the Five Year View in the detailed data, this is not pulled out as a separate table in EX2 amongst the four scenarios.

Can you confirm:

- Whether the five year view data is still maintained (the data in the detail tab is reliable).

- Was there a conscious decision to remove this (and if so why)?

Several of the sheets only show the 4 main FES scenarios; this is deliberate as these are ones which appear within the FES document. All the data, including the 5 Year View, is included in the detail tabs for each section of the Data Workbook.

14. Does the FES data have annual demand split between Scotland and the rest of the network? If so which document should I be looking at?

This information can be found in the "Regional Breakdown of FES data" supporting document on the website.

15. How do the scenarios take account of climate change related effects on power production, transmission and distribution? e.g. extreme weather events?

We don't currently flex these types of effects between the scenarios (i.e. for consistency given global nature of climate change) although we do reflect some high-level changes caused by climate change across all the scenarios. In addition, we are involved with an innovation project which aims to use the latest climate change science, published by the Met Office within UKCP18. This project will give us quantitative data on the effects of climate change on the energy system and may allow us to start scientifically including the impact of climate change in future scenarios. We would welcome any information on modelling or data in this area which you are aware of.