Committee on Climate Change

Independent advice to government on building a low-carbon economy and preparing for climate change

The Sixth Carbon Budget and Welsh emissions targets – Call for Evidence

Background to the UK's sixth carbon budget

The UK Government and Parliament have adopted the Committee on Climate Change's (CCC) recommendation to target net-zero emissions of greenhouse gases (GHGs) in the UK by 2050 (i.e. at least a 100% reduction in emissions from 1990).

The Climate Change Act (2008, 'the Act') requires the Committee to provide advice to the Government about the appropriate level for each carbon budget (sequential five-year caps on GHGs) on the path to the long-term target. To date, in line with advice from the Committee, five carbon budgets have been legislated covering the period out to 2032.

The Committee must provide advice on the level of the sixth carbon budget (covering the period from 2033-37) before the end of 2020. The Committee intends to publish its advice early, in September 2020. This advice will set the path to net-zero GHG emissions for the UK, as the first time a carbon budget is set in law following that commitment.

Both the 2050 target and the carbon budgets guide the setting of policies to cut emissions across the economy (for example, as set out most recently in the 2017 Clean Growth Strategy).

The Act also specifies other factors the Committee must consider in our advice on carbon budgets – the advice should be based on the path to the UK's long-term target objective, consistent with international commitments and take into account considerations such as social circumstances (including fuel poverty), competitiveness, energy security and the Government's fiscal position.

The CCC will advise based on these considerations and a thorough assessment of the relevant evidence. This Call for Evidence will contribute to that advice.

Background to the Welsh third carbon budget and interim targets

Under the Environment (Wales) Act 2016, there is a duty on Welsh Ministers to set a maximum total amount for net Welsh greenhouse gas emissions (Welsh carbon budgets). The first budgetary period is 2016-20, and the remaining budgetary periods are each succeeding period of five years, ending with 2046-50.

The Committee is due to provide advice to the Welsh Government on the level of the third Welsh carbon budget (covering 2026-30) in 2020, and to provide updated advice on the levels of the second carbon budget (2021-25) and the interim targets for 2030 and 2040. Section D of this Call for Evidence (covering questions on Scotland, Wales and Northern Ireland) includes a set of questions to inform the Committee's advice to the Welsh Government.

Question and answer form

When responding, please provide answers that are as specific and evidence-based as possible, providing data and references to the extent possible.

Please limit your answers to <u>400 words</u> per question and provide supporting evidence (e.g. academic literature, market assessments, policy reports, etc.) along with your responses.

A. Climate science and international circumstances

Question 1: The climate science considered in the CCC's 2019 Net Zero report, based on the IPCC Special Report on Global Warming of 1.5°C, will form the basis of this advice. What additional evidence on climate science, aside from the most recent IPCC Special Reports on Land and the Oceans and Cryosphere, should the CCC consider in setting the level of the sixth carbon budget?

ANSWER: n/a

Question 2: How relevant are estimates of the remaining global cumulative CO_2 budgets (consistent with the Paris Agreement long-term temperature goal) for constraining UK cumulative emissions on the pathway to reaching net-zero GHGs by 2050?

ANSWER: n/a

Question 3: How should emerging updated international commitments to reduce emissions by 2030 impact on the level of the sixth carbon budget for the UK? Are there other actions the UK should be taking alongside setting the sixth carbon budget, and taking the actions necessary to meet it, to support the global effort to implement the Paris Agreement?

ANSWER: n/a

Question 4: What is the international signalling value of a revised and strengthened UK NDC (for the period around 2030) as part of a package of action which includes setting the level of the sixth carbon budget?

ANSWER: n/a

B. The path to the 2050 target

Question 5: How big a role can consumer, individual or household behaviour play in delivering emissions reductions? How can this be credibly assessed and incentivised?

ANSWER: n/a

Question 6: What are the most important uncertainties that policy needs to take into account in thinking about achieving Net Zero? How can government develop a strategy that helps to retain robustness to those uncertainties, for example low-regrets options and approaches that maintain optionality?

ANSWER: Development of a transport and storage network for offshore deep geological storage of CO2 is a least-regrets option for the UK.

A current barrier to more rapid carbon capture and storage (CCS) implementation is the lack of this transport and storage infrastructure. Providing this transport and geological CO2 storage infrastructure is therefore a least-regrets option because it will enable wider and more rapid capture deployment from large emitters. Developing this infrastructure as an integrated and strategic service, which may be operated independently from the capture businesses, provides a robust network that will provide confidence that investments in capture facilities will be supported. Research in progress in the ALIGN-CCUS project (http://www.alignccus.eu/) illustrates understanding of UK prospective storage sites is well advanced, relative to other North Sea countries, despite not yet operating a CO2 storage project. The UK's strategic approach to site appraisal, by the UK SAP (https://www.eti.co.uk/programmes/carbon-capture-storage/uk-storage-appraisal-project), Strategic-SAP (https://www.eti.co.uk/programmes/carbon-capture-storage/strategic-uk-ccs-storage-appraisal) and FEED studies of industry CCS demonstration and commercialisation competition projects, has achieved at least four sites at 'contingent storage resource' level.

Furthermore, the development of a transport and geological CO2 storage network would enable the wider use of hydrogen for space heating and industrial use. CO2 capture is required for hydrogen to be a low-carbon fuel where it is produced from steam methane reforming of natural gas. This in turn, may also enable the wider use of clean hydrogen in the transport sector.The capture of CO2 from large emitters is a focused and effective technology for emissions reduction that has been widely demonstrated as a practical technology to reduce emissions in several key industrial sectors (fossil fuel-based power, petrochemical, fertiliser, steel, cement etc.). Current policy is to initiate industrial capture in areas where multiple industries are co-located. However achieving Net Zero will require deep decarbonisation of many emitters, including those not co-located in industrial clusters. To progress beyond initial capture operations in these industrial clusters will require a transport and CO2 geological storage network that enables the efficient compression, transport and geological storage in an integrated system.

Question 7: The fourth and fifth carbon budgets (covering the periods of 2023-27 and 2028-32 respectively) have been set on the basis of the previous long-term target (at least 80% reduction in GHGs by 2050, relative to 1990 levels). Should the CCC revisit the level of these budgets in light of the net-zero target?

ANSWER: n/a

Question 8: What evidence do you have of the co-benefits of acting on climate change compatible with achieving Net Zero by 2050? What do these co-benefits mean for which emissions abatement should be prioritised and why?

ANSWER: n/a

C. Delivering carbon budgets

Question 9: Carbon targets are only credible if they are accompanied by policy action. We set out a range of delivery challenges/priorities for the 2050 net-zero target in our Net Zero advice. What else is important for the period out to 2030/2035?

ANSWER: n/a

Question 10: How should the Committee take into account targets/ambitions of UK local areas, cities, etc. in its advice on the sixth carbon budget?

ANSWER: The committee will require evidence that the subsurface geologies are appropriate to support the ambitions of different regions in the UK. This includes rocks suitable for several applications including those suitable for:

• Geological CO2 storage offshore;
• Onshore energy storage, which could include compressed air storage and hydrogen storage;
• Onshore heat storage.

The British Geological Survey holds much data (see for example www.co2stored.co.uk for the ULK's publicly-available atlas of offshore geological storage capacity) and the expertise to interpret this data that could provide evidence to satisfy this requirement. However a comprehensive study to determine those areas most appropriate for the subsurface applications to meet Net Zero targets should be a priority.
Whilst hydrogen storage is expected to be mainly onshore in engineered salt caverns, other forms of storage including offshore storage in salt or storage in porous sandstones may also offer future benefits, although these options are currently very much at the research stage. Benefits of these options might include co-location with offshore wind power for compression, reductions in barriers from the planning process and economies of scale.

Question 11: Can impacts on competitiveness, the fiscal balance, fuel poverty and security of supply be managed regardless of the level of a budget, depending on how policy is designed and funded? What are the critical elements of policy design (including funding and delivery) which can help to manage these impacts?

ANSWER: n/a

Question 12: How can a just transition to Net Zero be delivered that fairly shares the costs and benefits between different income groups, industries and parts of the UK, and protects vulnerable workers and consumers?

ANSWER: n/a

D. Scotland, Wales and Northern Ireland

Question 13: What specific circumstances need to be considered when recommending an emissions pathway or emissions reduction targets for Scotland, Wales and/or Northern Ireland, and how could these be reflected in our advice on the UK-wide sixth carbon budget?

ANSWER: Recommendations for emissions pathways/reduction targets for Wales, Scotland, Northern Ireland should include consideration of the subsurface geology, which is different in each region and therefore provides opportunities for different pathways in each region.

For example, underground energy storage options are limited due to the absence of key geological formations in certain areas, including an absence of rock salt (halite) formations suitable for cavern storage in Wales and Scotland. Halite in N Ireland is present, but to date unexploited for storage purposes. Natural gas is stored within depleted gas fields, a possible opportunity also for hydrogen storage, although not yet tested in the UK. Gas fields occur offshore north-west and eastern England and offshore eastern and northern Scotland. Gas fields closest to shore, off north-west and eastern England, might be considered for seasonal storage of hydrogen.

Opportunities exist in different regions to co-develop carbon capture and storage infrastructure. For example, South Wales could explore opportunities to link with the Cork CCS project which seeks to develop a CO2 storage project in the depleted Kinsale gas field. Similarly, Northern Ireland may be able to benefit from CO2 storage projects currently being proposed for the Hamilton depleted gas field in the East Irish Sea. In Scotland, the ACORN CCS project is one of the most advanced in the UK and if fully implemented, will provide the starting point for Scotland's CCS pathway.

Furthermore, whilst in the long-term CO2 transport in pipelines is expected to be most cost-effective, in the shorter term transport by ship may be more cost-effective and therefore coastal regions could benefit from developing appropriate harbour facilities, as assessed by Scottish Enterprise for the port of St Fergus, eastern Scotland.

Techno-economic appraisal of CO2 transport and storage has been assessed for the East Coast Network including co-operation and sharing of infrastructure between industrial sites at Grangemouth, Scotland, and Teesside, north-east England. Techno-economic modelling of infrastructure components for Grangemouth and Teesside, as proposed by the East Coast Network, including storage options, is in progress by the ALIGN-CCUS. The modelling assesses infrastructure costs for different transport and storage networks to correspond to a range of ambitions for CCS deployment. Modelling is in progress and to be completed summer 2020 to inform the UK.

Question 14: The Environment (Wales) Act 2016 includes a requirement that its targets and carbon budgets are set with regard to:

- The most recent report under section 8 on the State of Natural Resources in relation to Wales;
- The most recent Future Trends report under section 11 of the Well-Being of Future Generations (Wales) Act 2015;
- The most recent report (if any) under section 23 of that Act (Future Generations report).

a) What evidence should the Committee draw on in assessing impacts on sustainable management of natural resources, as assessed in the state of natural resources report?

b) What evidence do you have of the impact of acting on climate change on well-being? What are the opportunities to improve people's well-being, or potential risks, associated with activities to reduce emissions in Wales?

c) What evidence regarding future trends as identified and analysed in the future trends report should the Committee draw on in assessing the impacts of the targets?

d) Question 12 asks how a just transition to Net Zero can be achieved across the UK. Do you have any evidence on how delivery mechanisms to help meet the UK and Welsh targets may affect workers and consumers in Wales, and how to ensure the costs and benefits of this transition are fairly distributed?

ANSWER: n/a

Question 15: Do you have any further evidence on the appropriate level of Wales' third carbon budget (2026-30) and interim targets for 2030 and 2040, on the path to a reduction of at least 95% by 2050?

ANSWER: n/a

Question 16: Do you have any evidence on the appropriate level of Scotland's interim emissions reduction targets in 2030 and 2040?

ANSWER: n/a

Question 17: In what particular respects do devolved and UK decision making need to be coordinated? How can devolved and UK decision making be coordinated effectively to achieve the best outcomes for the UK as a whole?

ANSWER: n/a

E. Sector-specific questions

Question 18 (Surface transport): As laid out in Chapter 5 of the Net Zero Technical Report (see page 149), the CCC's Further Ambition scenario for transport assumed 10% of car miles could be shifted to walking, cycling and public transport by 2050 (corresponding to over 30% of trips in total):

a) What percentage of trips nationwide could be avoided (e.g. through car sharing, working from home etc.) or shifted to walking, cycling (including e-bikes) and public transport by 2030/35 and by 2050? What proportion of total UK car mileage does this correspond to?

b) What policies, measures or investment could incentivise this transition?

ANSWER: n/a

Question 19 (Surface transport): What could the potential impact of autonomous vehicles be on transport demand?

ANSWER: n/a

Question 20 (Surface transport): The CCC recommended in our Net Zero advice that the phase out of conventional car sales should occur by 2035 at the latest. What are the barriers to phasing out sales of conventional vehicles by 2030? How could these be addressed? Are the supply chains well placed to scale up? What might be the adverse consequences of a phase-out of conventional vehicles by 2030 and how could these be mitigated?

ANSWER: n/a

Question 21 (Surface transport): In our Net Zero advice, the CCC identified three potential options to switch to zero emission HGVs – hydrogen, electrification with very fast chargers and electrification with overhead wires on motorways. What evidence and steps would be required to enable an operator to switch their fleets to one of these options? How could this transition be facilitated?

ANSWER: n/a

Question 22 (Industry): What policy mechanisms should be implemented to support decarbonisation of the sectors below? Please provide evidence to support this over alternative mechanisms.

a) Manufacturing sectors at risk of carbon leakage
b) Manufacturing sectors not at risk of carbon leakage
c) Fossil fuel production sectors
d) Off-road mobile machinery

ANSWER: n/a

Question 23 (Industry): What would you highlight as international examples of good policy/practice on decarbonisation of manufacturing and fossil fuel supply emissions? Is there evidence to suggest that these policies or practices created economic opportunities (e.g. increased market shares, job creation) for the manufacturing and fossil fuel supply sectors?

ANSWER: In the USA, the provision of the “45Q” tax credit for CO2 storage projects provides a clear financial incentive to companies that can use captured CO2. The 2018 US

Budget Bill increased the level of support to US$50 per tonne of CO2 that is permanently geologically stored. IEA analysis (https://www.iea.org/commentaries/us-budget-bill-may-help-carbon-capture-get-back-on-track) indicates this measure could lead to between 10 and 30 million tonnes of additional CO2 capture capacity (but will also lead to increased oil production of between 50 000-100 000 barrels per day). It should be noted that the credit is for the storage of CO2 and geological storage without EOR receives the highest benefit (https://carboncapturecoalition.org/primer-section-45q-tax-credit-for-carbon-capture-projects/) . Similar tax incentives may also stimulate investment in the UK.

In Canada, the Alberta Carbon Trunk Line (https://enhanceenergy.com/actl/), provides an example of an integrated infrastructure project that is designed to provide a transport and storage solution for Alberta's industry, with enhanced oil recovery and permanent geological storage. Whilst we do not advocate enhanced oil recovery, as it may be incompatible with the UK's net zero target if CO2 emissions from oil consumption are not captured, the Alberta project does provide a model for enabling multiple emitters to benefit from a trunk line that will lead to permanent geological storage. The ACTL project proponents, Enhance Energy, estimate up to 14.5 million tonnes of CO2 will be permanently geologically stored by the project.

Question 24 (Industry): How can the UK achieve a just transition in the fossil fuel supply sectors?

ANSWER: n/a

Question 25 (Industry): In our Net Zero advice, the CCC identified a range of resource efficiency measures that can reduce emissions (see Chapter 4 of the Net Zero Technical Report, page 115), but found little evidence relating to the costs/savings of these measures. What evidence is there on the costs/savings of these and other resource efficiency measures (ideally on a £/tCO2e basis)?

ANSWER: n/a

Question 26 (Buildings): For the majority of the housing stock in the CCC's Net Zero Further Ambition scenario, 2050 is assumed to be a realistic timeframe for full roll-out of energy efficiency and low-carbon heating.

a) What evidence can you point to about the potential for decarbonising heat in buildings more quickly?

b) What evidence do you have about the role behaviour change could play in driving forward more extensive decarbonisation of the building stock more quickly? What are the costs/levels of abatement that might be associated with a behaviour-led transition?

ANSWER: n/a

Question 27 (Buildings): Do we currently have the right skills in place to enable widespread retrofit and build of low-carbon buildings? If not, where are skills lacking and what are the gaps in the current training framework? To what extent are existing skill sets readily transferable to low-carbon skills requirements?

ANSWER: n/a

Question 28 (Buildings): How can local/regional and national decision making be coordinated effectively to achieve the best outcomes for the UK as a whole? Can you point to any case studies which illustrate successful local or regional governance models for decision making in heat decarbonisation?

ANSWER: n/a

Question 29 (Power): Think of a possible future power system without Government backed Contracts-for-Difference. What business models and/or policy instruments could be used to continue to decarbonise UK power emissions to close to zero by 2050, whilst minimising costs?

ANSWER: Energy storage is subject to 'double charging' of network charges, as outlined in the Energy Storage in the UK House of Commons briefing paper (Grimwood, GG & Ares, E. 2016. Energy storage in the UK. House of Commons briefing paper No. 07621, 21 July 2016.), that could be addressed to improve commerciality of energy storage.

Question 30 (Power): In Chapter 2 of the Net Zero Technical Report we presented an illustrative power scenario for 2050 (see pages 40-41 in particular):

a) Which low-carbon technologies could play a greater/lesser role in the 2050 generation mix? What about in a generation mix in 2030/35?

b) Power from weather-dependent renewables is highly variable on both daily and seasonal scales. Modelling by Imperial College which informed the illustrative 2050 scenario suggested an important role for interconnection, battery storage and flexible demand in a future low-carbon power system:

i. What other technologies could play a role here?

ii. What evidence do you have for how much demand side flexibility might be realised?

ANSWER:

a) Hydrogen could play a greater role in the 2050 generation mix. Commercially viable technology with production from stream methane reformation is viable to play a role now and in 2030/35, although to reduce the carbon budget, would need to be allied with CO2 capture and stroage at scale. Storage of hydrogen would likely require additional subsurface storage facilities including cavern storage (and potentially aquifer storage if the technology is proven to be viable). If hydrogen production by electrolysis were to be commercially viable, then there would be no requirement for CO2 capture associated with hydrogen production. Compressed Air Energy Storage (CAES) could play a greater role in the 2050 generation mix. To improve carbon emissions, adiabatic energy storage (where heat of compression is captured) would be necessary, requiring adoption of technical advancements from the existing schemes. If diabatic storage is adopted, then there is a necessity to heat air on decompression, likely requiring input of heat from fossil sources. Diabatic CAES is technically viable and could therefore play a role in the generation mix of 2030/35. Other technologies such as Liquid Air Energy Storage, molten salt energy storage, or subsurface pumped hydro could potentially play a role in the future generation mix up to 2050.

b) Large-scale decarbonisation via renewables will require grid-scale subsurface energy storage, in addition to battery storage and flexible demand, to address issues of intermittency principally from wind and solar. This could include storage of compressed air and hydrogen in solution-mined caverns, and potentially storage also in aquifers (the latter would allow subsurface energy storage across a greater area of the UK, as the halite suitable for cavern development is regionally restricted to 3-4 areas of the UK). Research estimating demand side flexibility is active, with initial results estimating a potential capacity of 10 caverns as 25.32 GWh exergy (Dooner M & Wang, J. 2019. Potential exergy storage capacity of salt caverns in the Cheshire Basin using adiabatic compressed air energy storage. Entropy21, 1065. Doi: 10.3390/e21111065) at a cost of $1-5/kWh for solution-mined cavern storage (Parkes, D, Evans, DJ, Williamson, JP & Williams, JDO. 2018. Estimating available salt volume for potential CAES development: A case study using the Northwich Halite of the Cheshire Basin. Journal of Energy Science 18, 50 – 61).

Question 31 (Hydrogen): The Committee has recommended the Government support the delivery of at least one large-scale low-carbon hydrogen production facility in the 2020s. Beyond this initial facility, what mechanisms can be used to efficiently incentivise the production and use of low-carbon hydrogen? What are the most likely early applications for hydrogen?

ANSWER: Detailed plans for large-scale hydrogen production via steam methane reforming have already been prepared: Northern Gas Networks for north and north-east England within the H21 North of England project; Cadent for north-west England within the HyNet project; Scottish Gas networks. The industry aspiration for up to 100% natural gas replacement by hydrogen for domestic and commercial customers can only be achieved with geological storage of the emitted CO2. UK research in two BEIS-funded Accelerating CCS Technologies projects (ALIGN-CCUS1 and ELEGANCY) has estimated the additional CO2 produced by large-scale hydrogen production to significantly increase the mass supplied for permanent storage. Industry estimates of the annual mass of CO2 captured from hydrogen production at Teesside and Grangemouth increases over a period of ten years from less than 2 million tonnes to more than 20 million tonnes CO2 per year. Incentives for the production and use of low-carbon hydrogen could include:

• Provision of publicly-accessible database and knowledge of prospective subsurface suitable for hydrogen storage, and the potential volumes that could be stored. This will enable strategic planning of production and transmission infrastructure, and downstream uses of hydrogen.

• Potential conflicts in subsurface use, e.g. solution-mined caverns for methane, natural gas or compressed air energy storage, could be avoided by implementing policy that encourages hydrogen storage over methane. As methane has a higher calorific value than hydrogen, methane storage may represent a more commercially attractive gas to store.
• The development of commercially viable production of hydrogen by electrolysis rather than from natural gas would reduce its carbon footprint. The current commercially available technology of steam methane reformation should not dis-incentivise the development of lower-carbon production and incentives could be developed to ensure this does not occur.

The ALIGN-CCUS research indicates the UK has sufficient CO_2 storage capacity for the most optimistic adoption by industry of large-scale reformation to produce hydrogen in two UK regions for heating, to achieve the UK's Paris Agreement commitments in those areas (see response to Q38). Hydrogen usage for transport or other use is noted as possible but this was not quantified. A strategic approach is being assessed in ALIGN-CCUS1 to optimise the UK's CO_2 storage capacity.

Question 32 (Aviation and Shipping): In September 2019 the Committee published advice to Government on international aviation and shipping and Net Zero. The Committee recognises that the primary policy approach for reducing emissions in these sectors should be set at the international level (e.g. through the International Civil Aviation Organisation and International Maritime Organisation). However, there is still a role for supplementary domestic policies to complement the international approach, provided these do not lead to concerns about competitiveness or carbon leakage. What are the domestic measures the UK could take to reduce aviation and shipping emissions over the period to 2030/35 and longer-term to 2050, which would not create significant competitiveness or carbon leakage risks? How much could these reduce emissions?

ANSWER: n/a

Question 33 (Agriculture and Land use): In Chapter 7 of the Net Zero Technical Report we presented our Further Ambition scenario for agriculture and land use (see page 199). The scenario requires measures to release land currently used for food production for other uses, whilst maintaining current per-capita food production. This is achieved through:

- A 20% reduction in consumption of red meat and dairy
- A 20% reduction in food waste by 2025
- Moving 10% of horticulture indoors
- An increase in agriculture productivity:
  - Crop yields rising from the current average of 8 tonnes/hectare for wheat (and equivalent rates for other crops) to 10 tonnes/hectare
  - Livestock stocking density increasing from just over 1 livestock unit (LU)/hectare to 1.5 LU/hectare

Can this increase in productivity be delivered in a sustainable manner?

Do you agree that these are the right measures and with the broad level of ambition indicated? Are there additional measures you would suggest?

ANSWER: n/a

Question 34 (Agriculture and Land use): Land spared through the measures set out in question 33 is used in our Further Ambition scenario for: afforestation (30,000 hectares/year), bioenergy crops (23,000 hectares/year), agro-forestry and hedgerows (~10% of agricultural land) and peatland restoration (50% of upland peat, 25% lowland peat). We also assume the take-up of low-carbon farming practices for soils and livestock. Do you agree that these are the key measures and with the broad level of ambition of each? Are there additional measures you would suggest?

ANSWER: n/a

Question 35 (Greenhouse gas removals): What relevant evidence exists regarding constraints on the rate at which the deployment of engineered GHG removals in the UK (such as bioenergy with carbon capture and storage or direct air capture) could scale-up by 2035?

ANSWER: To date, we have not included estimates of the capture rates from engineered greenhouse gas removal technologies in our assessments of future storage capacity requirements (see responses to Q35 & Q37). This is a priority for future evaluation. Given the large theoretical storage capacities present on the UKCS , we do not anticipate that this theoretical storage capacity will place limits on the rate of scale-up. However, the blueprints being formulated for strategic development of specific stores will need to be revised to accommodate the higher rates of CO2 injection required to meet additional CO2 'supply'. Depending on the region where bioenergy or direct air capture with CCS might be deployed, we expect revisions to include the need for an increase in the number of storage sites being developed. Particularly, there will be an increased need for pressure management in some storage formations and an increased need for an integrated approach to optimising injection rates within, and between, storage sites to optimise the UK storage resource. Multi-year timescales are required to develop a storage site, and operator estimates suggest between 5-10 years may be required in some cases. Therefore, early and significant investment is needed to appraise, design and construct storage sites. To achieve scale-up by 2035, detailed storage site appraisal is required to accelerate rapidly by 2025 and assessments of the scale of the required storage provision must be made before 2025.

No sources of CO2 for geological storage from the combustion of waste or direct capture from air were included in the UK industry estimates reviewed by the ALIGN–CCUS and ELEGANCY projects. The industry approach to CO2 capture is one of feasible, practical and familiar technologies. Once a CO2 transport and storage network has been established other sources, implementing developing and prototype low-carbon technologies, would be attracted to the CCS network. The increased volume of CO2 supplied to the storage network should reduce the cost per tonne of CO2 transported and stored.

Question 36 (Greenhouse gas removals): Is there evidence regarding near-term expected learning curves for the cost of engineered GHG removal through technologies such as bioenergy with carbon capture and storage or direct air capture of CO_2?

ANSWER: n/a

Question 37 (Infrastructure): What will be the key factors that will determine whether decarbonisation of heat in a particular area will require investment in the electricity distribution network, the gas distribution network or a heat network?

ANSWER: Key factors determining whether decarbonisation of heat will require additional investment will include the status and condition of existing infrastructure; for example, will pipelines be suitable for hydrogen transmission in areas where its roll-out to decarbonise heating is proposed. Additionally, decarbonisation of the domestic heat market by use of hydrogen would require regional up-take of boilers and cookers capable of running on high-hydrogen mixes. A major barrier to the uptake of hydrogen in domestic heat schemes may be the public perception of using hydrogen in the home; this should be addressed by information campaigns and initiatives.

Research on infrastructure network development for large-scale low-carbon heating by hydrogen and CCS in the UK by the ELEGANCY project has noted a marked sensitivity to the provision of key technical components. Technical constraints to network development include the provision of permanent geological storage of CO2 and seasonal storage of hydrogen. CO2 storage is well known from decades of offshore operations in the Norwegian sector of the North Sea and the UK has a very significant theoretical storage capacity (CO2 STORage Evaluation Database (CO2Stored). The UK's online storage atlas. Energy Procedia 63 (2014) 5103 – 5113). Hydrogen storage within subsurface salt caverns is also very well-known from many decades of onshore UK operations. However, geological formations suitable for the construction of salt caverns storage resources are not widespread across the UK. Research within the ELEGANCY project indicates the development of hydrogen and CCS infrastructure is very sensitive to the distribution of storage caverns in salt or the geological formations in which caverns may be constructed. Hydrogen storage capacity within sandstones is being investigated at research project level but has not yet been operated as a proven industrial operation in the UK. Currently, hydrogen storage capacity for seasonal storage remains a technical constraint on the development of an infrastructure network for large-scale hydrogen production.

Question 38 (Infrastructure): What scale of carbon capture and storage development is needed and what does that mean for development of CO_2 transport and storage infrastructure over the period to 2030?

ANSWER: Recent BGS research for the ALIGN-CCUS and ELEGANCY projects addresses this question to meet the UK's targets for the Fifth Carbon Budget. This provides partial estimates of the scale of CCS in specific UK regions and is summarised below. Specifically, the research has addressed the storage requirements for the Teesside and Grangemouth industrial clusters and their wider 'catchments'. The research does not consider storage requirements for: all five clusters identified by the UK Clean Growth Strategy; the whole UK; or a Net Zero target. It does, however, consider requirements to 2050 and extrapolated to 2100, to indicate the scale of likely demand.

Estimates of future CCS deployment are based on industry predictions of CO2 capture from industrial sources and hydrogen production. These estimates allow CO2 supply curves to be defined, and a portfolio of suitable storage sites to be appraised. Regional CCS deployment concepts were integrated and mapped onto a low-carbon development pathway at Teesside and Grangemouth. To reflect different rates of deployment, three variants were defined: 'initial projects'; 'growing projects'; and 'maturing projects'.
During initial projects, annual capture rates at Teesside of 0.7 million tonnes (Mt) and at Grangemouth of 1.7 Mt are estimated based on existing plant. Storage capacities required for these initial projects are approximately 23 Mt and 61 Mt by 2055, respectively. During growing projects, the number and rates of industrial capture would increase, together with increasing hydrogen production. Annual CO2 capture rates would increase to approximately 14 Mt per year at Teesside and 8.6 Mt per year at Grangemouth. Growing projects would require a total CO2 storage capacity of 309 Mt for Teesside and 267 Mt for Grangemouth and Central Scotland, including the Acorn project, by 2055. Assuming constant capture thereafter, the combined required storage capacities would increase to 1248 Mt at 2100.

During maturing projects, the average rate of CO_2 captured for storage in England would be 59 Mt per year. The CO_2 storage capacity required in 2050 would be approximately 852 Mt. Assuming constant capture rates thereafter, the required storage capacity would be 2557 Mt by 2100 for northern England.

Early reliance on a single storage network catering for both clusters would be insufficient for the growing projects scenario.