House of Commons

Environmental Audit Committee

Oral evidence: Technological Innovations and Climate Change: Negative Emissions Technologies, HC 738

Wednesday 5 January 2022

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Watch the meeting

Members present: Philip Dunne (Chair); Duncan Baker; Barry Gardiner; Sir Robert Goodwill; Ian Levy; Dr Matthew Offord.

Questions 99 to 180

Witnesses

I: Jonny Gallagher, Senior Public Affairs and Policy Manager, National Grid Electricity System Operator; Dr Amy Ruddock, Vice-President Europe, Carbon Engineering; Professor Benjamin Sovacool, Director, The Sussex Energy Group (University of Sussex); and Dr Cheng-Gong Sun, Associate Professor of Clean Energy Technologies, Faculty of Engineering, University of Nottingham.

II: Michael Grubb, Professor Energy and Climate Change, University College London Institute for Sustainable Resources; Dr David Joffe, Head of Carbon Budgets, Climate Change Committee; and Professor Duncan McLaren, Research Fellow, Lancaster University.

Written evidence from witnesses:

- National Grid Electricity System Operator
- Carbon Engineering
- Sussex Energy Group
- Professor Duncan McLaren

Examination of witness

Witnesses: Jonny Gallagher, Dr Amy Ruddock, Professor Benjamin Sovacool and Dr Cheng-Gong Sun.

Q99 **Chair:** Welcome to the Select Committee's first session of 2022. We have two panels today in our inquiry into negative emissions technologies, which is our final oral evidence session. We are very pleased to welcome today three panellists present in the room for the first panel, and one virtually. I invite each to briefly introduce themselves before we kick off with this session. First, Dr Amy Ruddock from Carbon Engineering.

Dr Ruddock: I am the VP of Europe for Carbon Engineering. We are a direct air capture company, founded in 2009. We license our technology to a global network of plant developers and we are focused on the deployment of megatonne-scale direct air capture. In the USA, we are busy engineering our first plant and targeting 2024 operations for a megatonne-scale plant. In the UK, we are working with Storegga.

I have extensive experience in aviation, previously at Virgin Atlantic. I also have a PhD in chemical physics. Thank you for inviting me today. I think direct air capture is a very important tool to get us to net zero, both for the UK's own goals and for export opportunities so I welcome the opportunity to be here.

Chair: Thank you very much, Amy. We will get into the detail later. The first panel is focused on direct air capture technologies. We are also joined, virtually, by Professor Benjamin Sovacool.

Professor Sovacool: I am Professor of Energy Policy at the University of Sussex where we have the Science Policy Research unit, which examines new, cutting-edge technologies from a social and political perspective.

I direct the Sussex Energy Group, which is the largest interdisciplinary group of social scientists looking at these topics. I am also the principal investigator for a large ERC grant that is looking at the governance of negative emissions technologies, including direct air capture, as well as BECCS and some of the other options.

I am also a lead author of the Intergovernmental Panel on Climate Change's Sixth Assessment Report AR6, where I am in chapter 4, which is looking at mitigation pathways in the near-term and the mid-term.

Lastly, I am Research Co-director of the Industrial Decarbonisation Research and Innovation Centre, or IDRIC, which is looking at net zero industry for the UK by 2030 and 2040.

Chair: Thank you very much. You were coming through a little faintly there so I hope we can either increase your amplification in the room or you might be able to raise the volume slightly on your device. Thank you.

Back in the room, Dr Cheng-Gong Sun is Associate Professor of Clean Energy Technologies in the Faculty of Engineering at the University of Nottingham.

Dr Sun: I have been undertaking research, along with my colleagues, in carbon capture storage technologies for over 20 years now. You will probably know that Nottingham University is one of the UK's leading international centres for excellence in energy research. It is a part of the UK Government-funded Energy Research Accelerator and also part of the UK Carbon Capture Storage Research Centre.

Currently, we are developing and trying to demonstrate new direct air capture technology in partnership with Sizewell C and Strata Technology with the guests behind me and also other industry partners, including Doosan Babcock and Atkins.

Chair: We are also joined in the room by the other operator, Jonny Gallagher of the National Grid Electricity System Operator.

Jonny Gallagher: Thank you very much for inviting us to this session.

I am head of Public Affairs and Policy for National Grid ESO. That is the part of National Grid that manages the electricity system in GB, balancing supply and demand on a second-by-second basis, keeping the lights on throughout the country. We also do a lot of work on the future of energy, looking at pathways out to 2050, how the Government can deliver commitments to 2035 and 2050, and the different technologies that might be in that mix.

Q100 **Chair:** Moving straight to one of the technologies, I would like Amy Ruddock, if you would, please, to describe to the Committee how the direct air capture technology that you are promoting works.

Dr Ruddock: Direct air capture is an important tool in the toolbox against net zero, alongside reduction. We are removing carbon dioxide directly from the atmosphere. Our product is pure, highly-concentrated CO_2 and that CO_2 can be sequestered permanently, securely, safely, underground, creating a negative emission or it can be used in drop-in compatible products, for example aviation fuels.

With our technology, we draw in CO_2 at the 420 parts per million using air contactors. Those are based on industrial cooling towers. The philosophy around our technology is that we use equipment that has been used in existing industries for decades but we are repurposing it for direct air capture. We are pulling CO_2 in and then we have a solvent, potassium hydroxide that is effectively acting as a sponge. We soak up the CO_2 and the rest of the process is about releasing it again and regenerating the solvent.

Q101 **Chair:** What kind of scale has this been tested at and are there plans to commercialise it?

Dr Ruddock: At the moment, we are focused on deployment at commercial scale, which we see at megatonnes. When I say megatonnes, we are talking a million tonnes of CO_2 removed from the atmosphere per annum. We are currently engineering our first plant, in collaboration with 1PointFive, our plant development company in the USA. That is targeting operations in 2024 and we see that as a blueprint for global commercialisation.

We were founded in 2009. Since 2015, we have been running a pilot plant in Squamish, British Colombia, where the company is headquartered.

Next door to that, we have recently built an innovation centre that will be commissioned very soon. The idea for the innovation centre is that we do not stop with our technology. We have a first generation, which we are commercialising, but we want to look at the next generation and where we go next, so we have a dedicated R&D centre for direct air capture.

Q102 **Chair:** At what kind of scale is have you proven that the technology works?

Dr Ruddock: The innovation centre will be capable of removing around 1,000 tonnes from the atmosphere per annum. It is testing each of the individual pieces of equipment at close to commercial scale.

Q103 **Chair:** In relation to the UK, do you have any projects underway at the moment that would contribute to our net emissions targets?

Dr Ruddock: Our plant development partner in the UK is Storegga. You might know Storegga as one of the lead developers of the Acorn project in north-east Scotland, previously known as Pale Blue Dot Energy.

As well as developing that transport and storage in north-east Scotland, Storegga has looked at the cluster and has the ambition to take that to net zero, not just to address those industrial emissions, but also to look at hard-to-abate sectors. Storegga has become interested in direct air capture.

The projects that we are doing with Storegga entered pre-feed—that means the first detailed engineering stage—in August 2021. We are looking at deploying a plant of 500,000 to 1 million tonnes of CO_2 capture per year and are targeting operations in 2026.

Q104 **Chair:** Based on what Dr Ruddock has just said about 500,000 to 1 million tonnes per plant, can I ask you, Dr Sun, whether you think that direct air capture in its entirety, including the business opportunities we have just heard about, have a contribution to make towards negative emissions technologies? Is this a meaningful contribution in the UK, where we are currently emitting about 500 million tonnes a year?

Dr Sun: Yes, clearly. Direct air capture is no longer considered as an option but as something that we have to do to deliver our climate targets, particularly the UK's net-zero target. Even if we used all existing technologies to the maximum potential, we would still have a quite considerable remainder to decarbonise because of the wider range of harder-to-decarbonise sectors.

Regarding direct air capture, all these technologies currently work on a similar principle, which involves the use of a solvent to react with the CO_2 and then the solvent is regenerated to release the CO_2 and the solvent is recirculated back into the system.

Using similar principles, however, the performance of different existing technologies vary quite considerably, leading to one of the major performance variances, which is the cost for large-scale deployment. The technology that we are currently developing at Nottingham in partnership with our industry partners is aimed to address one of the major performance variances, which is the high energy demand, particularly the need for electrical energy.

We all know that electrical energy is much more costly than heat. The technology we are currently trying to demonstrate, with the support of BEIS, is a heat-driven direct air capture system which would be able to use essentially any low-grade or wasted heat above ambient temperatures. The overall principle is quite similar to, if not the same as, other technologies, but with our own absorbent and process technologies.

Probably the Committee members here will already know that the UK has been a leader in developing CCUS technologies but not in direct air capture technology development. Nottingham is one of the few universities or research institutes to develop direct air capture so we feel quite privileged that our project has been selected by BEIS in its recent call to further develop and demonstrate.

The capacity with Sizewell C, with heat, low-grade heat, with very low cost, is able to capture 1.5 million tonnes of CO_2 from the atmosphere, which is something quite similar to the total CO_2 emissions of the whole UK railway network. That is the scale. By 2030, the full integration of our DAC technology with Sizewell C has this potential to deliver a change or difference to the net-zero target.

Q105 **Chair:** You mentioned that all systems use one form of solvent or another. Have you identified any systems as being more effective than others or more cost-efficient?

Dr Sun: Each technology has its own characteristics, advantages or disadvantages but some have the effect of applicability to different areas. For example, if you use a lot of electrical energy, that is a limitation in some places or areas. Some technologies need higher temperatures. For example, Carbon Engineering requires high temperatures for some processes but some technologies, for example, Climeworks and Global Thermostat use a lower-temperature process and are able to make effective use of low-grade heat.

Our technology is different from the others in that it is an extremely low-temperature process with an operating temperature typically below 100 degrees centigrade. That could be particularly suitable for applications where low-carbon waste heat, or low-cost heat is available. On top of that, we can make potentially effective use of wind to drive the direct air capture process directly, or solar heat where possible. Currently, we are developing waste heat from Sizewell C.

Q106 **Chair:** Can I ask Jonny Gallagher to come in now and explain what part net emissions technologies play in the Energy Systems Operator business for the future?

Jonny Gallagher: I am happy to do so. Importantly, there are two parts to it. There is the BECCS element, the bio-energy of carbon capture and storage, and there is direct air carbon capture. We see a big role for net emissions technologies as a whole out to 2050 and they form a core part of our pathways that are net-zero compliant and we cannot get there without them.

Bio-energy carbon capture plays maybe the largest role across the various scenarios. We see that broadly in line with where the Government are at in their ambition for the future, scaling up through 2030 out to 2050.

Direct air carbon capture does not feature very prominently in our scenarios; it only features in one of our four scenarios and that reflects the fact that it is quite a nascent technology. We iterate our scenarios every year and when we have further information about technologies, they come into the mix and that is very much about making sure that our pathways get us to those targets using the technologies available today. In the future direct air capture may feature more prominently.

Q107 **Chair:** Have you been in discussion with either of these proposals that we have been hearing about?

Jonny Gallagher: Our future energy scenarios are based on inputs from 1,500 stakeholders every year. We talk to academia and industry and we make sure that we are basing them on the latest information. All parties have the opportunity to input into them and then we undertake some modelling, which brings in all those expert views and comes up with plausible, credible pathways out to 2050.

Q108 **Chair:** Thank you. Jumping back up the academic chain, could I ask Professor Sovacool for his view on where he sees this sitting within the net-zero mix for the future, if it is not quite ready to get into the design plans for the grid?

Professor Sovacool: I am happy to do that and I hope you can hear me a bit better now.

You are absolutely right that the scaling issue is a significant barrier. Amy Ruddock is correct that Carbon Engineering is one of the two market leaders. The other one is Climeworks, and to put all of this into perspective, their biggest facility, Orca, which just came online last year, is only 4,000 tonnes per year. Climeworks can claim that they are the world’s largest direct air capture facility and they are coupled to a geothermal source of energy and have to truck their carbon to a reservoir. Climeworks does not even have a pipeline.

So that gives you a sense of where the world-leading market is.

Q109 **Chair:** Where are those places in the world?

Professor Sovacool: Climeworks has one facility in Switzerland and I think their only other one is in Iceland, so different markets and countries compared with where Carbon Engineering is but Dr Ruddock may be able to tell you more about where all the other locations are.

The only other thing I want to add is that we did do a very large expert elicitation exercise just a few months ago. This is where we talked to more than 70 experts intimately familiar with DAC, BECCS, CDR and GGR and I have the data in front of me.

When we asked them the question of when they thought direct air capture would achieve scale, the range of answers was quite interesting. The earliest was 2030; the latest was 2090. The average, the median, was 2047. That sounds really bad, 2047, but to put it into perspective, BECCS is almost the same. Those experts also predicted BECCS would not achieve scale until about 2040. It looks, therefore, as if the experts are telling us that from now these options will only achieve significant scale by mid-century.

Q110 **Chair:** Amy Ruddock, would you like to come back on that as you have been named?

Dr Ruddock: Yes. It probably is in contrast to what I was saying about our first commercial-scale facility targeting 2024. For our technology, our focus has very much been on using what is available today and that gives the advantage of that supply chain that exists and that we can transition to a new, green use. It also means that there is competition in the supply chain. While we talked about the cost of energy, it is part of the problem that when we are looking at the costs in the USA, one-third of the cost is energy, another third is capex and another third is financing. A large part of the equation is whether you have those supply chains and is there competition and therefore can you lower the capex, which was extremely important in designing our solution.

For us, the technology is ready and that is why we are engineering those commercial-scale plants. The question is the market. The highest risks we see are market and financeable revenue streams. We have a technology that is ready and we have large-scale-infrastructure investors who are very interested in funding these types of facilities, but those infrastructure investors are used to airports and utilities. They are used to that almost-guaranteed revenue stream and they look at something like direct air capture and ask where is the reward for cleaning the skies.

We pay for waste disposal, we pay for collection from the streets, we pay for cleaning up water but we are not paying for cleaning up the skies. The establishment of that policy that says that there will be a revenue stream for this will attract the private investment and will mean that we can deploy very quickly. Technologically we are ready. For a project end-to-end, today you are talking in the regions of four years. We are looking at megatonne-scale plants today.

This is an economies-of-scale problem, so the bigger you can build those plants, the better. We would do 5 to 10 megatonne-scale plants with the technology but the question is, is the market there. If the market can be developed, if there is clear policy that says there is a reward, it is very easy to see the faster build-out rates that we need.

Chair: Thank you. We will move on now to Robert Goodwill.

Q111 **Sir Robert Goodwill:** If I could start with Dr Ruddock, looking at the energy requirements—because this seems to be the key element of what it is going to cost to power the facilities up—how does your technology differ from Dr Sun's technology—I will come to Dr Sun next—in terms of the energy requirements, the intensity of the energy, whether it is waste heat or whether you need to plug into the grid?

Dr Ruddock: I can comment on our technology and then maybe pass over to Dr Sun for his comment.

First, I would reflect that the cost of energy is one-third of the consideration of cost. The rest is capex and financing, which are important, but there are other, larger considerations when it comes to cost.

We published a peer-reviewed paper in 2018 in "Joule", the journal, and we spoke about the energy needs of the system. We talked about a range of 80 to 370 kWh per tonne of CO_2 of electrical energy and about 5 GJ of thermal energy needed per tonne.

To put that into some kind of perspective, for a megatonne-scale plant, you are talking about a typical-scale wind farm to support it.

Those energy needs will depend on where you deploy the plants. For example, climate plays a part. You do have some trade-offs to make in your design on capex versus opex, but roughly that is the kind of range that you are talking about and that will reduce over time, with research and development.

You do have those trade-offs and our philosophy was that capex and financing are going to be such an important element that if you can have the competition in your supply chain, your capex lowers and if you have proven your equipment over many decades, your cost of financing reduces. We do therefore need to focus on the energy part but also those other two-thirds of the costs.

Q112 **Sir Robert Goodwill:** Does that capex include building the wind turbines or the nuclear power stations, or whatever else, or will you be going along to Mr Gallagher asking to buy energy from the market through his system?

Dr Ruddock: The capex cost does not include building the energy source; it is for the direct air capture plant alone. However, I would say that it is a very clearly offtake market for private investors in wind farms so we probably would not be going to ESO but to developers of wind farms, saying, "Can we be an offtake customer? Can we generate your projects more quickly?".

Q113 **Sir Robert Goodwill:** Dr Sun?

Dr Sun: If you look at the existing technologies, the energy costs are quite comparable. Around 20% to 30% or 50% is electrical. The rest is heat. That is the general situation. The key thing is the grade of heat; what quality of heat you need to drive your technology. That essentially also affects the capital investment and operational cost.

I would say some of the existing technologies could find themselves in a difficult position in trying to bring down the cost any further because of the high grade of energy, and therefore the capital investment, required. Some technologies therefore clearly are moving very-low-grade heat—waste-grade heat, which mostly exists where there is waste, or where it can be easily available, for example by harvesting from the natural environment, so solar or wind. So that will determine the cost as well.

Overall, for us, the technology we are currently developing aims to bring down the cost through our two projects to something below $200 per tonne of CO_2, through larger-scale integration and optimisation, to close to something close to $100, or even lower than $100—that is the overall cost—but also bearing in mind that if you can make use of low-grade heat, the capital investment and the maintenance could also be reduced.

We are pretty much confident that if the carbon cost can be reduced to something between £100 and £200 per tonne of CO_2, we will become economically feasible with the carbon price in a similar range. That is what will attract the private investor to engage in this sector.

Q114 **Sir Robert Goodwill:** It does seem that every new technology that we hear about in this Committee, whether it is about electric cars or generating hydrogen or heat pumps in the home, will require lots of people to buy a lot more electricity. Have you factored that in? Where are you on the hierarchy? If the price of electricity goes up, will your technology possibly be like some of the bio-diesel plants or bio-ethanol plants in our area, in Yorkshire, and become non-viable? Are you right on the margin of cost or are you comfortable that you will come in more cost-effectively than, say, producing hydrogen to put in the grid or to power vehicles?

Dr Sun: I would say so. If you think about the capital-investment requirement for electric cars or any other low-carbon industry or direct air capture. The costs are in a pretty much comparable position.

At the same time, we need to think about the fact that even though we deliver all these low-carbon tools, for example electric cars, solar or wind, we are still a considerable way away from the net-zero target. We still need direct air capture to deliver on the net-zero target. It is highlighted in the report of the American Academy of Science and the report of the

Climate Change Committee as well as that of the Royal Society. Even if we use all the options available, we still have something around 130 million tonnes of CO_2 by 2050 that has to be dealt with using negative emissions. So we see DAC as additional to electric cars or any other low-carbon solutions.

Q115 **Sir Robert Goodwill:** Dr Ruddock, do you agree with that—that in terms of your technology, you will be able to pitch into the energy market and still be viable?

Dr Ruddock: Yes. I would echo that this needs to be alongside what is being done by reductions. Scientists in multiple committees—the IPCC, the CCC—talk about the need for negative emissions alongside reduction. The prediction of the CCC was 60 to 100 megatonnes per year by 2050 alongside reduction.

I would also say that those would be targeted at hard-to-abate sectors, such as aviation. Coming from the industry, I think it is certainly a punt and it is by no means certain, that electric or hydrogen planes would be available for mid-haul, let alone long-haul, flights by 2050 so we still need to deal with those emissions. Also, no amount of renewable power—changing to electric vehicles; changing to hydrogen—is going to deal with legacy emissions. We talk about net zero, but we are at 420 parts per million now and scientists debate it but roughly come in at 350 parts per million being safe. We have a global responsibility to bring down the carbon budget and for that you need negative emissions technologies.

I would also just touch on cost because it is being discussed. The "Joule" paper that I talked about was very much targeted at showing that our technology, based on what we knew in 2017, could come in at under $100 per tonne. That paper sets out how it could be $94 to $232 per tonne at large scale but just to offer a sense of where we are today, with the first US plants that I have talked about you are able to create a revenue stack for those plants that gets to about $260 per tonne and from that, you can build a commercial plant; that includes returns and so on.

The final point in this theme is that when you look at all the solutions together, I point to Goldman Sachs' abatement curve. Goldman Sachs has taken each of today's global emissions—53 gigatonnes or so—and have said, "What is the cost to abate that?". If you stack it up, I think I remember correctly, there are around 5 gigatonnes that are over $300 per tonne. There are around 15 gigatonnes that are over $100 per tonne. So you can think about a solution like direct air capture and sequestration effectively capping that cost. I am not saying it is necessarily the route that you would take to decarbonisation, but it gives you a benchmark of how it compares to other solutions that we are investing in.

Q116 **Sir Robert Goodwill:** Is it any more expensive than planting a tree, for example, and doing it that way?

Dr Ruddock: It is a very different impact. If you look at the permanence of the solution, planting a tree is fantastic for drawing down immediately but you are probably talking in the region of hundreds of years of that storage versus millennia for direct air capture and sequestration.

Another point is land area and water usage. A 1-megatonne-scale direct air capture plant does the work of about 40 million trees but hundreds of fewer times land area and water usage.

Q117 **Sir Robert Goodwill:** And no biodiversity?

Dr Ruddock: They can support biodiversity because of the need for less land and water. You do not have identikit-planted forests but, if you are trying to do a carbon problem and you can do it with less land, you have more land to achieve your other aims, such as biodiversity.

Q118 **Sir Robert Goodwill:** I will turn to Dr Gallagher, if I may.

Obviously you will be planning ahead, I suppose, certainly for the next decade, I guess, but perhaps looking further afield. Do you feel that this is a market for power that you need to accommodate? Where in the hierarchy of demand do you feel that direct air capture would be?

Jonny Gallagher: We do not see sources of demand as being a hierarchy. You connect to the grid through a process and there are certain factors that influence where things connect on the network but there is no hierarchy in that sense. We would very much expect that it would be through the commercial market that the requirement for energy for direct air carbon capture would be met. As Dr Ruddock alluded to, you may see wind farms building their business case around supplying the power directly to those plants and so on. From a system-operator perspective, we do not see such a hierarchy.

Q119 **Sir Robert Goodwill:** Could I now turn to Dr Sovacool?

We have heard that there are very high potential energy demands, whether it is residual heat from a nuclear power station or connection to the grid or having your own wind farm to supply you. Are you aware of any other concerns about betting the farm on this technology?

Professor Sovacool: All the technologies have different risks and benefits. Two that have not come up yet strike me as interesting. The first one, and you kind of hinted at it, is the notion of reversibility. How can we guarantee that a tonne that we put below ground stays there?

Dr Ruddock is right that direct air capture can put it in places where storage is potentially feasible for thousands of years, not prone to wildfires or pests or things like that, but what is interesting is that also increases the security risks. In some of our research, we have identified concerns that terrorists or hackers could target these types of carbon reservoirs to release large amounts of carbon as a threat or to get money or to get some sort of concession. This is the tension. It is like the more you concentrate and create economies of scale, the more you create potential security risks, no matter whether it is DACCS or BECCS.

The second thing that has not come up yet is social acceptance. Dr Ruddock and the others are right that direct air capture has to be coupled with CCUS. That is the C, right? And then the CCS in DACCS. Yet we have had horrendous experiences in the past 15 years of trying to get various types of CCS socially accepted.

People are afraid of earthquakes; they are afraid of leakage; they do not understand the technology. Very recent experiences here in the UK with shale gas and geothermal energy raised similar concerns about underground permanence so I think social acceptance, knowledge and awareness could also be very frustrating. We can identify very strong geological depositories that are not socially viable and that will create a nightmare for politicians and Members of Parliament who have to contrast security and climate change with social legitimacy and acceptance.

Q120 **Sir Robert Goodwill:** Would you say that these technologies are a last resort? Or ones that should be seen as one of the front runners in terms of achieving net zero and generally reducing the concentration of carbon dioxide in our atmosphere?

Professor Sovacool: In the near term, I think that similar to those Goldman Sachs abatement curves, you have a merit order of things you should do to improve net-zero chances, improve resilience; those to me are things like energy efficiency, demand-side management, solar, and so on. But Dr Ruddock is absolutely right that we will reach a point in 2040 or 2050 where we have to draw down emissions. Even if we mitigate, PPM levels are already so dangerously high that we have to deploy negative emissions technologies.

In my work on the IPCC, I can tell you that almost every scenario we run depends on a very significant deployment of NETs by mid-century. I think it is definitely a technology that we have to invest in as a safety measure and even just to stabilise the climate. The key for this Committee is whether the UK is where we should invest and be a frontrunner or is it an area where we can continue to draw on and learn from the US, Japan, Switzerland and Iceland? We are literally now setting the goalposts for who will dominate the next energy transition mid-century. Those are the stakes and the technologies can be so huge.

We have seen estimates that say that BECCS could occupy 80% of arable land or that DACCS could consume 80% of heat or electricity. Those are the numbers that are around the corner for the viability of this market. There is a huge opportunity there but I guess there is also a series of risks.

Q121 **Duncan Baker:** This is a question first of all for Dr Ruddock.

Carbon Engineering has said that direct air capture technology offers the ability to produce sustainable fuels in the UK for transportation, aviation, which I think we all agree is extremely important. Certainly we have heard that in other evidence sessions.

Can you elaborate a bit further on what plans Carbon Engineering has to develop sustainable fuels? How will the energy for that production be sourced?

Dr Ruddock: Our product is that highly concentrated, pure CO_2. We have been talking about negative emissions by storing it underground but we also focus on drop-in compatible products and we see one of the largest markets for that as being sustainable aviation fuels.

We have started work engineering our first commercial-scale fuels plants in Canada, in British Columbia. We announced that about two and a half months ago. It will be a commercial-scale plant producing 100 million litres per year. To put that into context, it would be about 1% of the aviation needs in the UK if everything was covered by e-fuels.

Our role in that is the direct air capture and we are partnering with experts in green hydrogen production and fuel-synthesis production. In the UK, we are working in the DfT's competition Green Fields, Green Skies. We are working with LanzaTech. LanzaTech are experts in the fuel-synthesis step.

For comparison with what we were talking about before, the direct air capture portion of one of those 100-million-litre plants is about one-quarter of the size of what we are doing for sequestration so about 250,000 of CO_2. Why? Because we need green hydrogen to be able to scale, to be able to build bigger and bigger plants.

When I was in aviation, we almost had the thought of if you burn fossil fuels and then remove the CO_2 afterwards for something like direct air capture, so 1 + -1 = 0? Or do you use sustainable fuels in your supply chains so the combustion is less in the first place? For one of those, you are capturing the CO_2 and sequestering it underground; for the other one, you are capturing, creating green hydrogen, combining them and you are combusting again. That is obviously a more energy-intensive process, the second one, because of the green hydrogen needs.

I would say that there are more uncertainties on the energy needs of that second step because there are different ways of producing the green hydrogen, different ways of doing the fuel synthesis, but as a rough, rough order of magnitude, if you look at a 100-million-litre facility, about 20% of your power needs come from the direct air capture side and about 80% is from the rest; the majority is coming from green hydrogen. So it comes down to if we have a green hydrogen strategy, we want to produce that volume of green hydrogen, the questions become what is your offtake market and does the infrastructure exist to create demand for that supply. I think something like e-fuels, sustainable aviation fuels from direct air capture and green hydrogen, gives you that initial offtake market.

Q122 **Duncan Baker:** If you are saying that in Canada you are producing 100 million litres and that is 1%, effectively, of what worldwide consumption would require, if you were doing the same in the United Kingdom, would we have the energy infrastructure to produce that amount?

Dr Ruddock: It is about 1% of the UK's aviation needs as opposed to global. I think that what you will see is that plants will get larger and larger as green hydrogen is able to scale more. The bottleneck to it is not the direct air capture; it is the green hydrogen.

The feasibility study that we are undertaking as part of this DfT competition is exactly looking at that question of how could you source those energy needs in the UK. I am a little bit early to have an exact answer, but I think my answer, as with everything, would be that it is critical that the energy source is additional. You cannot claim that you are providing an additional environmental benefit unless there is that additionality. You cannot be taking from the grid; you cannot be taking from homes.

So where you look at locating that plant is going to be critical and I think Jonny Gallagher might have something to say about that. Where you have remote locations—I think of somewhere like the Shetland Islands, where you have perhaps a lot of capacity for renewable energy but less ability to use it there—I don't know if you have—

Q123 **Duncan Baker:** I will come on to you, Mr Gallagher. I have had various dealings with National Grid ESO because I am the MP for North Norfolk where we have the highest concentration of wind turbines being built off our coast and your organisation is one that obviously fits very nicely with us and I want to understand what the future role is and how we bring that energy properly into the National Grid. From your point of view, how can energy produced through NETs, such as carbon capture and storage, be integrated with the future GB necessary energy that we need to produce?

Jonny Gallagher: There are two elements to that. On the BECCS side, that is a source of generation so you are putting the capture on a power plant so that is producing power for the grid. On the direct air side, that is a source of demand. There is a myriad of factors that will influence where a direct air carbon capture plant locates itself, but it is very possible that the requirements of the grid might be one of them so we may see them where they are able to respond to peaks and troughs in the production of energy, as dictated by how windy it is. There may be areas on the grid where it is more convenient for them to locate because there are particular bottlenecks in those places and they can effectively soak up that electricity. At this stage, however, we simply do not know exactly how that is going to play out.

Q124 **Duncan Baker:** If we take my experience of trying to work with the Government and yourselves with that offshore wind, the legislation and the regulatory framework to put in an offshore transmission network is way behind where I would like it to be. Are there similar barriers and regulatory issues with what we are trying to propose here?

Jonny Gallagher: I don't think there are exactly the same issues that we have in the offshore-wind space and certainly the experience of that is changing how we think about the deployment of infrastructure as a whole. We are moving within the ESO to a much more holistic view about where you locate infrastructure and how you approach that.

Whereas traditionally we evaluated primarily the economic criteria, we are now evaluating the social impact, the environmental impact, and thinking about what it does to local communities. I would expect, therefore, across the entirety of the energy sector as we move forward that will become more and more of an issue.

Q125 **Duncan Baker:** So we are not being blocked, in effect, in the integration of NETs by a legislatory framework as we are with the first example I gave you. That is not going to be an issue here?

Jonny Gallagher: It is not one that I am aware of but maybe those who are closer to the development and deployment can speak more to that.

Q126 **Duncan Baker:** Thank you. If I could turn to Dr Sun now, we heard in a previous session that there is a huge and high demand for outputs from DAC and the like, both to support a supply chain for CO_2 and from businesses looking to reach net zero and I think that is where the demand is predominantly going to continue to come from. Do your projects plan to offer CCS outputs in this way and have you factored the demand into your plans going forward?

Dr Sun: I don't think this will have any kind of impact on the demand. According to our calculations and also Sizewell C's planning, we can easily make available around 400 megawatts thermal hour nuclear heat, which is around only 5% of the total Sizewell C thermal capacity and that will be enough to power 1 million tonnes of CO_2 per year. That impact on the demand would be quite minimal, if I understand your question correctly.

Bear in mind also that—and I am not a nuclear scientist—based on the report conducted recently by Manchester university and also Glasgow university, nuclear is clearly the least costly and the most reliable source of low-carbon heat, whether you like it or not, to power direct air capture in a more secure way. Compared with the others, clearly we developed this technology through use of low-grade heat generated from nuclear.

We are now seeing with these technologies we are developing currently you can only use nuclear heat, there is no denying that. However, compared with DAC driven by the other heat or electrical power, nuclear at this moment looks a quite favourable option with very minimal impact on the electricity demand that we expect from Sizewell C.

Duncan Baker: Thank you very much.

Q127 **Barry Gardiner:** Dr Ruddock, the UK Government's net zero strategy requires that GGRs result in a permanent net reduction in atmospheric carbon. I want to focus on permanence and accountability in my questions to you.

I was struck by your metaphor that we pay for cleaning up our communities, our streets and so on, but we do not pay for cleaning up the skies. The trouble is that at the moment DACCS and GGR are not doing that, are they? What is actually happening is that we are using the CO_2 that has been captured to turbo-charge increased fossil fuel usage through enhanced oil recovery. Do you see that as a problem? Do you see it as a tarnishing of the brand? It certainly rather undermines any claim that this is leading us to net zero because it is not fulfilling that ultimate goal of permanence that is established in the government strategy, is it?

Dr Ruddock: What I look at is the premises we have in energy transition. Today we do rely on fossil fuels that we cannot switch off overnight. Of course, the ultimate goal is that we should work towards defossilisation, but they are not going to be turned off overnight.

One of those ways that we get fossil fuels today is through enhanced oil recovery. To meet the volume demand you effectively have a choice of enhanced oil recovery, which is undertaken in some jurisdictions, or new exploration. The question should be: given that we have that fossil fuel need today—we cannot switch off overnight—can we decarbonise that process as far as possible? I think that using direct air capture to decarbonise—so effectively you are sequestering from the atmosphere for the crude you produce—is a sensible step to take.

Q128 **Barry Gardiner:** Would it not be better just to sequester that CO_2 right from the beginning and not use it to turbo charge fossil fuels?

Dr Ruddock: From a carbon removal perspective, absolutely. The more NETs you can store underground, the better for our climate goals, but I come back to the market for it. We need to have a carbon price that supports plants to be built to do that. In the meantime, we need to start on the deployment curve. We have seen solar and wind decrease in cost over time through deployment. I think it is incredibly important that we start on that journey. The sooner that we can get a market price that supports direct air capture to sequestration and supports that deployment at scale I think you will start to see those sequestration-only plants develop quickly.

I point to the US as a blueprint for this. Obviously, the Build Back Better Bill is currently going through Congress. There are discussions still going through Congress on the 45Q tax credit, but the federal government are saying that for permanently storing CO_2 underground, currently you can achieve about $35 per tonne if it is used for EOR. There is discussion about that going to $180 per tonne for direct air capture, and I think initiatives like that create the market for doing direct air capture sequestration only. Then you have the market demand and the supply will go there.

Q129 **Barry Gardiner:** Is there not a danger that direct air capture is going to be used by the private sector to offset emissions rather than focusing on the need to reduce those emissions in the first place?

A recent example would be Ocado and the deal that it struck with the operator in Iceland, in Climeworks, where it is saying that it is going to go as a net zero company because its entire headquarters is now going to be offset against this direct air capture. Have you no sympathy with the argument that what is happening here is that the real value of direct air capture would be in permanent sequestration, as the Government's net zero strategy says it ought to be, but what is happening is that it is being used as a means of reducing the price of the oil that is then ultimately going to create even more CO_2 emissions than have been used in its production and as a means of avoiding taking the real action that is required now to reduce emissions by companies like Ocado and just as a way of getting around the problem to be able to create a headline that says, "Aha, we are a net zero company"?

Dr Ruddock: No, absolutely, it should not be used in place of reductions. I point to what IPCC scientists are saying: you need to do reductions and removals. We are unfortunately at a position in time now where we cannot rely on reduction alone; we need to reduce that carbon accumulation and that carbon budget.

Q130 **Barry Gardiner:** Twenty of the 26 global operating CCS facilities are using CCS as a means for enhanced oil recovery, aren't they? Twenty out of the 26 global production facilities?

Dr Ruddock: I am not sure about broader CCS; I can only comment on direct air capture to date. I would say that the focus industries should be hard-to-abate sectors. We should follow science-based targets. Hard-to-abate sectors include aviation, shipping, agriculture, those for which there is not a technological means of reduction to zero by 2050, to 100%, recognised. Long-haul aviation, something that I used to work in, is a prime example. That is what direct air capture and sequestration should be focused on in the near term. In the long term, we should be thinking about legacy emissions and reducing the carbon accumulation that we have out there today.

Q131 **Barry Gardiner:** How long is your long term? According to the IPCC, we have very limited time to do this, haven't we?

Dr Ruddock: I agree.

Q132 **Barry Gardiner:** If we are going to get to 1.5 the window closes in about 10 years or less.

Dr Ruddock: I agree. The sooner we can start thinking beyond net zero and start thinking net negative the better.

Q133 **Barry Gardiner:** So how long is your long term?

Dr Ruddock: I think that is really a question for the Government to decide on where net zero starts.

Q134 **Barry Gardiner:** You were the person who used the term. You said in the near term we need to be doing this, we need to be focusing on aviation fuel and so on, but in the long term then we talk about the real emissions reductions, the permanent emission reductions.

Dr Ruddock: What I meant was when we are looking at the transition to net zero we are then going to have to go net negative. In that transition to net zero, the focus for negative emissions technologies like DAC should be the hard-to-abate sectors where we do not have technological solutions. Net zero is not enough. We will have to go net negative, so my only comment on saying long term is that the question of net negative will come after net zero. Other people—and I can see that Benjamin has his hand up—will have a view on when that net negative should come.

Q135 **Barry Gardiner:** I will come to Benjamin in a moment. I just want to pursue this with you a little bit further. Currently, there are no accounting rules for DACCS, are there, like, for example, albeit imperfectly I would argue, the rules for BECCS? How does your technology guarantee that the CO_2 you take out from the air is going to be sequestered permanently?

Dr Ruddock: Accounting rules do exist under the Californian low carbon fuel standard. Where we are looking in the US in the first facility we are generating LCFS credits, $200 per tonne. We have to adhere to the California Air Resources Board standards for that direct air capture and sequestration. I talked about the 45Q—

Barry Gardiner: They do not apply in the UK, though, do they?

Dr Ruddock: No, they apply in the US. The standards do exist globally. They exist in California. They exist at US federal level. The UK needs its own standards. The EU is also looking at a carbon removal certification mechanism. It is a barrier. It is something we need to work on. It is something that BEIS has started working on.

For the voluntary market beyond that, there is an initiative at the moment called the CCS+ Initiative. We are working with Verra to say what those standards should be. It is an extremely important call. They do exist globally but we need to make sure we have those standards in the UK, in Europe and in the voluntary market.

Q136 **Barry Gardiner:** Would it be helpful that that should form one of the recommendations of this Committee's report to Government that those standards should be expedited?

Dr Ruddock: Absolutely. I think we should recognise that we are not starting from scratch. BEIS undertook an exercise last year that started to look at the measuring, reporting and verification of this.

Q137 **Barry Gardiner:** Professor Sovacool, did you want to come in?

Professor Sovacool: Thank you, yes, just very quickly. There is, of course, this risk of what is called mitigation deterrence or moral hazard, but I am pretty sure Professor McLaren is going to talk to you later on about those things. It is also important to reflect that DAC is a tool and you can do it in certain ways where it does do enhanced oil recovery or it does not really cut emissions. You have centralised DAC. You could couple it to fossil fuels. You can make it high temperature. You also have distributed DAC, low temperature, coupled to wind or solar or geothermal. There is no such thing as a one-size-fits-all DAC design. You could steer that with policy very easily to make sure it gets you the emissions reductions that you want, and you avoid things like just shaving off a little bit or doing greenwashing or perpetuating fossil fuel consumption in the near term. I think it is a flexible tool.

Q138 **Barry Gardiner:** Give me some examples of how with policy one could do that. That would be extremely helpful.

Professor Sovacool: One of the things that the literature talks about is called splitting rather than bumping. You make sure your climate mitigation targets or your carbon budgets are separate from your negative emissions targets. That way they are not conflated. That way you do not have actors that get the perverse incentive to just think, “We will be able to use DAC later so we can invest in this new gas fuel”.

You can also do very clever things like set specific incentives for specific types of DAC. You could, say, have different levels of incentives for high temperature versus low temperature or you could disincentivise DAC from gas and incentivise DAC from offshore wind or hydrogen. Just like you could tailor a feed-in tariff, you could also tailor incentives and tax breaks and all these other instruments to the types of DAC you might want. You could also make sure that the DAC facilities are more in the UK. The last thing we want is to outsource this to some DAC facility in China or South America. You could also set restrictions on location, which I also suspect Professor Grubb is probably going to talk about later on.

Barry Gardiner: Thank you very much. It was slightly difficult to hear you, for me anyway, over the monitor, but perhaps you might put those in a note to the Committee. That is something, Chair, that we might take up in our recommendations—those different splitting elements that Professor Sovacool referred to.

Q139 **Chair:** He has just put his thumb up on the screen. I think that Dr Sun wanted to come back on that briefly.

Dr Sun: Yes. I think it is a good question. Currently, I would say that there is still a policy gap there, the policy for capture for storage and the policy for capture for utilisation or recycling. If we look at the recycling, the whole carbon cycle is only about a month, for example, carbon cycle to aviation fuel. The whole carbon cycle length is about a few months’ time. In the future, I think the carbon price should be defined differentially for capture for storage and capture for utilisation or recycling.

The policy should also be very clear for direct air capture operators. Do they need to buy or develop or even operate the CO_2 storage or transportation infrastructure? I think there are quite a few questions from the private sector regarding these uncertainties, so they will need the Government to step in as well regarding the transportation.

Q140 **Barry Gardiner:** Can I be clear that I understand what you are saying, Dr Sun? Is it that we should discriminate between CO_2 that is produced depending on the speed with which it is then returned to the atmosphere when we are setting the carbon price? That is what you are recommending?

Dr Sun: Yes. I think that it should be differentiated.

Q141 **Barry Gardiner:** Again, just for the Committee’s benefit, would it be helpful if that were one of the recommendations that we incorporate in our report to Government?

Dr Sun: I would say so. The whole purpose of direct air capture is to remove the CO_2 permanently from the atmosphere, but that is more costly. If we do so, we need to deliver the purpose we aim to. Therefore, I would recommend—

Q142 **Barry Gardiner:** If the CO_2 is going into short-lived plastics or if it is going into enhanced oil recovery, there should be a much lower price than if it were going for sequestration permanently into a geological formation?

Dr Sun: I would personally say so, yes.

Barry Gardiner: Thank you very much.

Chair: The final set of questions for this panel are from Matthew Offord.

Q143 **Dr Matthew Offord:** If we turn back to Professor Sovacool, one of the problems that I am aware of is that the direct air carbon capture and storage technology is relatively immature. How do you overcome that?

Professor Sovacool: We have this discussion a lot at the Science Policy Research Unit, what historical analogues can teach us about how to scale up DAC. Is the analogue solar photovoltaics, is the analogue genetically modified crops or is it some other scaling issue? I think it is learning from past innovation trajectories from similar products.

What makes it a bit difficult for DAC is, as I was saying earlier, there is no one-size-fits-all DAC. There is high temperature, low temperature, liquid absorbents, solid absorbents. It is questionable what that analogue is, but there is plentiful historical evidence that shows you how you take new innovations like DAC and push it through the innovation process so it successfully reaches commercialisation.

You may be familiar with this notion of the technology readiness levels or TRLs. They come from NASA, assessing on a scale of one to 10 or sometimes one to 15 how ready a technology is and how you avoid the valley of death. DACCS also, depending on the design, could be a two or a five or an eight, but I think there are plenty of assessment tools that we have to properly understand how you take something with a low TRL and move it to a higher TRL.

Q144 **Dr Matthew Offord:** Thank you. Mr Gallagher, your business model for both the bioenergy CCS and, indeed, the direct air CCS is based upon a premise of being able to not only transport but also store CCS. To achieve your net target by 2035 there will have to be greater development and capacity of that area. How will you achieve that?

Jonny Gallagher: We set out what the future might look like. We are not directly investing in any of these technologies, but we have a clear interest in delivering a zero carbon electricity system by 2035.

One of the keys to that is carbon capture. The Government are doing the right thing in that space at the minute in providing some certainty for the clusters that are developing to enable it to scale up, and we are aligned with the Government in the view that you need around five megatonnes by 2030 to demonstrate that you are on the right pathway for 2035. We very much see it as in this decade moving from targets to delivery, and the Government are doing the right thing in that space in bringing that forward.

Q145 **Dr Matthew Offord:** That is interesting. Dr Sun, I would like to come to you. What are the next actions you will be taking in the development of your direct air carbon capture and storage project? Do you see any problems that you will need to overcome as part of that process?

Dr Sun: Honestly, we are quite excited with our current technology. I think that all our project partners agree with me. As I mentioned earlier, the UK is a leader in developing CCS technologies but there is not much research in DAC, direct air capture, so we are one of them. We are very pleased that our project is selected in phase 1 of BEIS's recent GGR call for proposals. In phase 2, if we succeed, we will try to scale it up to 100 tonnes per year. This is still a small scale compared with carbon engineering and some other technologies.

Once we reach that scale and we learn to optimise this process, we are going to deliver it to around 50,000 tonnes by 2030. We are confident that by the time Sizewell C is fully commissioned we plan to scale it up to 1.5 million tonnes per year with approximately 5% of Sizewell C's heat output. That is our milestone plan to deliver; first, 100 tonnes to learn things and then next is 50,000 tonnes by 2030, to scale up once the nuclear power plant is fully operational, and then the integration will be performed to achieve around 1.5 million tonnes per year. That is our plan at this moment, having discussed with Sizewell C and other project partners, including Doosan Babcock, Atkins and Strata. That is our milestone.

Q146 **Dr Matthew Offord:** Thank you. Finally, Dr Ruddock, there is still greater capacity that is needed within direct air CCS and, indeed, the other neutral emission technologies as well. What would you like to see the Government introducing or making available in order for the Government to achieve their own net zero objectives?

Dr Ruddock: The number one ask is a financeable revenue stream so we can get those private infrastructure investors on board. I talked about their use to that almost certainty of returns through airports, utilities and so on. Ultimately, the aim should be a market mechanism, be that the ETS where the price is going to rise. There are other mechanisms we have in the UK today focused on hard-to-abate sectors that are already trading at very high carbon prices; think the RTFO, think the future SAF mandate. Ultimately, direct air capture could be supported through a market like that with the right certification mechanisms.

In the short term and for first-of-a-kind plants, they do cost more than what it will ultimately cost and I think the role of Government, if they see this as a strategic opportunity for the UK, is to provide some of that initial support. There are many different mechanisms. I know that BEIS is consulting at the moment.

One of the discussions is around whether it could be a contract for difference to the ETS. There are other mechanisms. If we look to Sweden, the Government are talking about auctions for BECCS. Government are effectively saying, "Look, we have our own footprint that we are going to need to do removals for". Take the RAF, for example, a hard-to-abate sector that there will need to be removals for in 2050. Could we think about that as direct Government procurement to get the first plants online?

There are other ways. I talked about the high cost of financing today due to the market risk; think about national infrastructure banks and how they can support with Government-backed loans, for example. I think there are several mechanisms, but the ultimate target should be that financeable revenue stream. That is strong ask number one.

Number two is the availability of CCS when we are talking about CCS clusters and the volume that is available if we want to build to this five megatonnes. Then, in the net zero strategy, the number for 2035 of 23 megatonnes is going to require storage. We welcomed the first two clusters being supported, but clarity on what it means to be a reserve cluster for Scotland and clarity on the second clusters to be supported is important so that we can see that storage will be available for what we are capturing.

Q147 **Dr Matthew Offord:** I think probably a reduction in acronyms would be—

Dr Ruddock: Yes, I am sorry.

Dr Matthew Offord: That is great. Thank you very much.

Chair: Acronyms are not a unique problem to this sector. That concludes our first panel this afternoon. I would like to thank Dr Amy Ruddock, Dr Cheng-Gong Sun, Jonny Gallagher and Professor Sovacool for joining us remotely. Thank you very much indeed. If you would not mind leaving the table, we will ask the second panellists to join us.

Examination of witnesses

Witnesses: Professor Michael Grubb, Dr David Joffe and Professor Duncan McLaren.

Q148 **Chair:** We have two witnesses on the screen and Dr David Joffe is joining us in person from the Climate Change Committee. David, welcome. We will go straight on now. Perhaps you could describe your role on the CCC relevant to this inquiry.

Dr Joffe: I am head of carbon budgets at the Climate Change Committee, the statutory adviser to the Government and to Parliament on climate change matters. I oversee our process for recommending carbon budgets. I led our process for recommending the sixth carbon budget at the end of 2020 and also the pathways for achieving net zero, so the five different pathways that we developed for that advice that reach net zero by 2050.

Chair: Thank you very much. We are also joined by Professor Michael Grubb from UCL and Professor Duncan McLaren from Lancaster University, two academics who can help set some context for us in our discussions today. Can you just explain, Michael, what your role is at UCL?

Professor Grubb: Thank you and good afternoon. I am professor of energy and climate change at University College London Institute for Sustainable Resources. I am also convening author on the mitigation report for the IPCC.

Chair: Thank you. Professor McLaren, what do you do at Lancaster?

Professor McLaren: I am a research fellow focusing on the justice implications of climate geoengineering, of which carbon removal is one technique. For clarity, I was previously the chief executive of Friends of the Earth Scotland, working on energy and climate issues there. I have worked on negative emissions technologies and techniques since about 2011 and most recently we conducted a research council-funded project looking at the mitigation deterrence risks associated with the pursuit of negative emissions.

Q149 **Chair:** Thank you. Duncan, you are coming through slightly fuzzy. Could you either move the mic closer to your mouth or increase the volume?

I will start with Professor Grubb. Both the UK Government assessment and the Committee on Climate Change assessment assume that there will be 5 million tonnes of negative emissions using BECCS by 2030. What is your academic assessment of the significance of NETs in that timeframe?

Professor Grubb: I think the significance of negative emission technologies overall, or to be more precise carbon dioxide removal, clearly has an important role in the long term and globally. We see that repeatedly in scenarios. There is enormous variation in the scale, and often, to be honest, the scale is derived back to front by making projections, working out what other things will do and saying, "There is a gap that needs to be filled", which is a technique that in the 1970s and 1980s used to be called "gapology" and was used to justify all kinds of things. It helps if it is complemented by a bottom-up understanding of the prospects and implications and constraints of the various things that people expect to fill the gaps.

More specifically, one thing that makes me hesitate about projections on CCS is that—I should stress I am not an expert on CCS or negative emission technologies per se and I made that clear when I was first invited—I am conscious, having worked in the broader field for a long time, that for at least two decades I have seen projections of CCS rapidly expanding and becoming a major part, which have yet to be realised on anything like the scale projected. I think that is equally true for BECCS. I learnt to view such projections with a degree of caution.

That said, the UK in two senses is relatively well placed: first, we have Drax as a major biomass consumer and, secondly, we have potential CCS storage within potential reach. There is certainly a case for the UK pursuing it, but whether we will see that 5 million tonnes from BECCS on that timescale I will be interested to see. I would not like to be more specific.

Q150 **Chair:** Thank you. Duncan, do you share the scepticism that Michael has just expressed about the feasibility in modelling terms of relying too much on technologies that are yet to be demonstrable?

Professor McLaren: Indeed. In our project, we not only looked at carbon removal technologies—am I clear and audible now?

Chair: Yes.

Professor McLaren: Great; I didn't want to go on and then be told. In our project, as well as carbon removal technologies we also looked at a series of historical analogues, including, as Michael has just mentioned, the CCS experience. Nuclear power was also another experience where typically much more was promised than was ever delivered. Yes, I have a scepticism particularly about large-scale centralised possibilities for future technologies.

In our project, we also investigated why the models seemed to like the idea of large-scale future technologies. Put very simply, it is because anything in the future, to a model with a discount rate in it, looks cheaper. Anything immediate looks more expensive and, at the same time as that dynamic, most models allow an overshoot of carbon dioxide levels so, therefore, when you put in a technology that can remove carbon dioxide in the future the models gobble them up, to put it colloquially. They will prefer doing carbon removal in the second half of this century to doing emissions reductions in the first half of this century. We need to be very cautious about that, especially as many of the benefits of doing emissions reductions for things like air quality or health are not very well quantified in the same models. Not only do those emissions reductions look expensive but the benefits of them look less than they would if we modelled them completely.

Q151 **Chair:** Thank you. We have had two views from observers of models and I would now like to hear from David, who is writing the model or is helping to produce the model that the Government are relying upon. How do you respond to those criticisms or concerns?

Dr Joffe: To some extent, I would share the concerns and the scepticism. I am a veteran; I have been at CCC for 14 years and I have been through the experience with the CCS demonstration programmes.

Clearly, there are multiple reasons why those failed, but it does not suggest that CCS will be easy or cheap and I think we need to bear that in mind.

On the other hand, as all the models show, whether you backend the trajectory or not in terms of emissions reduction, we do need carbon capture and storage and we do need greenhouse gas removals. Our approach is to say it is better if we have it sooner rather than later. It is better if we know. If it is not going to work, we would rather try it in the 2020s and know that it is not going to work and then say, "This is not going to work" and change course by 2030, rather than say, "Let's not try it until 2040" but we are still relying on that. We have built-in a certain amount of greenhouse gas removals during the 2020s and 2030s to ensure that government are focused on developing these options.

Of course, if we try and fail again—we have had two failures already at least, depending on how you count them in the UK—I think we can then say that this may be a non-starter and we will have to pursue other routes. What those routes are is very difficult to say. We are talking about taking some pretty important options off the table if we do take greenhouse gas removals and CCS off the table. It is not clear that we can meet net zero if we do take those off the table. That is why we think it is important to get on and prove that this is feasible. If we try properly and we fail, then that is important information and it will not have been for nothing to have tried.

Q152 **Chair:** You focus mostly on BECCS as opposed to other technologies that we have just been hearing about from our first panel. Is that because you see that is a more mature technology and, therefore, more deliverable more quickly, or have you not had the opportunity to look at much DACCS?

Dr Joffe: We have looked at DACCS. You are right that BECCS is more established in terms of at least people thinking about it. Since 2011 BECCS has been in our modelling and in our scenarios, whereas with DACCS it has only really been in the last two, three, four years that we have started to include it.

DACCS is so uncertain. We have heard from technology providers and clearly good progress is being made, but it is still highly uncertain. Therefore, we know that large-scale biomass power plants, yes, they come with problems and we can discuss some of those problems, but we know that that is feasible. We know that we can fit CCS to them. We know that we can do the removals that way. It just feels slightly more speculative in terms of exactly how much DACCS we can do and exactly what the costs are going to be. In our scenarios we tend to build in more from BECCS but we hope that a greater proportion of the greenhouse gas removals that we have in our scenarios can be from direct air capture of CO_2 because it comes without some of the problems that we have from biomass supply and ensuring that that is sustainable. Of course, direct air capture comes with its own challenges around energy supply, and I am sure we will come on to those.

Q153 **Chair:** When undertaking your advice to Government on your annual update, do you look again at all of your assumptions for negative emissions technologies or is this done only when you are producing a new carbon budget?

Dr Joffe: We do periodically review them. In our annual progress report to Parliament in June we will set out a set of indicators for how we monitor progress on a range of technologies and a range of sectors. That does not mean that annually we will review those pathways; I think we will do that more like on the next carbon budget or maybe in two or three years' time. Clearly, if progress is very good in, let's say, direct air capture and there are big problems on the BECCS side, of course we would acknowledge that and adjust our expectations accordingly.

Q154 **Chair:** You have touched on some of the challenges from all of these technologies. We have had evidence on the concerns about the sustainability of biomass as a source of fuel for BECCS. How concerned are you about that?

Dr Joffe: It is a key issue. The reason why we do not have more BECCS in our scenario is because of supply constraints globally and in the UK. One thing to point out is that in our pathways that underpin our carbon budget advice the vast majority of the biomass that we assume is UK grown, so we have control over the governance of that biomass supply chain to a very large extent there. I think that is really important. We need to build in governance and sustainability from the beginning, from the outset, before we incentivise any greenhouse gas removals, otherwise we are just storing up problems that we may not be able to resolve later on.

There are big challenges to ensuring the sustainability of biomass grown outside the UK. It is not impossible but it is very difficult. I am sure you have talked to Drax. It will tell you all the things that it is trying to do, but ultimately it is very difficult. It is not something that the UK should be relying on at large scale in terms of biomass imports for greenhouse gas removals. There can be a small contribution but no more.

Chair: I think that other colleagues will pick this up, but I might just turn to Matthew Offord.

Q155 **Dr Matthew Offord:** I will return to Professor Grubb to ask about projects in their infancy, particularly early-scale NETs, the first-of-a-kind projects, those innovations that we are looking at. How can the Government not only encourage them financially, because it could always be said more resources would assist, but what other conditions need to be created for these start-ups to emerge to bring forward innovation in the NETs?

Professor Grubb: It is a pretty big and broad question in its way. Obviously, the history of technology policy is littered with both failures and successes, often contrary to expectations. It is worth starting by making a couple of points about characterising different technologies. This has been a field of considerable academic interest in the last couple of decades and I think it was touched on briefly in the previous comments.

First of all, all technologies need to go through stages, generally obviously originating in some form of ideas creation, R&D, development and so on. You are probably familiar with the broad idea of innovation chains and obviously as technologies go through these various stages and move towards commercialisation, scaling up and so on. Real professionals would say it is more complex than that because there are feedbacks from learning at later stages, which pursue R&D to fix those problems and so forth.

The characteristics of technologies where we have seen radical improvements have tended to be fairly small and modular because that has enabled relatively rapid cycles of learning and improvement, and the modular because you then have scalability in terms of supply chain and so on. That is somewhat different from some of the large engineering of the previous century, which tended to go for economies of scale in a piece of kit. As we all know, that had big improvements early on and then ran into things getting so big and complicated it is very hard to learn anything, other than the fact that it is incredibly complicated and something went wrong in the construction. That is slightly caricaturing, but you get the point.

A really interesting area is wind energy, which started with some big companies trying to do really big wind turbines and success actually came through much more modest steps at smaller scales, improvements in understanding and materials and so forth, and developments of industries that would help to fund the innovation cycle.

That was not a direct answer, but it is a pointer about some caution before diving into gigawatt-scale efforts to do a BECCS or DACCS. We need if possible to think about incremental steps and also about areas of comparative advantage.

Where I am looking at these areas, these technologies, without being a specialist in them, is that clearly we have had major investment in biomass, we have had some big efforts in CCS. If this technology is going to work, we do need to move towards a modest-scale pilot programme in favourable conditions of a technology that we believe can be replicated and expanded. My guess is in UK conditions that that would involve Drax and that there are plans for that, notwithstanding obvious constraints that have been flagged. The incentives for doing so? Since it is fairly site-specific, technology-specific, if one does go down that route, there are various options.

It may not matter enormously whether you go for a fairly significant chunk of direct public finance or underwriting or more demand pull. In general, though, for technologies, the ones that succeed have a fairly strong mix of both. The reason for that is not hard. If all you try to do is subsidise demand for a technology that hardly exists, a lot of actors are going to be pretty wary and cautious and demand pull has to be pretty big and powerful and expensive in order to persuade them to put money into risky ventures. Conversely, if all you do is a Government-funded technology push, you will create a mini industry of technologies that depend upon Government finance and want more of it, but the big independent private financial players are likely to be pretty wary of coming in because they do not really see the market.

It is rarely one or the other. It is usually a combination. You have to do a base of R&D to know roughly what technologies you are playing with, take out some of the very high up-front risks, and that is not generally very expensive. I take your question as pitching a little bit towards the demand pull, or the finance for the output of the innovations we say rather than the innovation itself. I think that could well be an element in a BECCS pilot. DACCS: I am worried. I have not yet seen the clear and obvious case of frontrunners, and I think there are a lot of questions to be asked around DACCS and its relationship to other potential carbon dioxide removal approaches. I will pause there. That was a long answer; apologies.

Q156 **Dr Matthew Offord:** You focused very much upon the United Kingdom market, which is understandable. Would you have any indication of approaches being taken in other countries in the world that we could learn something from?

Professor Grubb: The CCS itself is very much a multi-country effort. We now have two decades of experience and we should learn as much from it as we can. I am sure all the big industries that might be involved would be doing so. I think you will have heard from others who would have more expertise than I about the exact lessons from those 20-odd plants.

One lesson I was not surprised to hear but I did not know that number, that 16 of them have used the CO_2 for enhanced oil recovery. That just underlines that industries want to minimise the risks and maximise the revenues from whatever they are doing. If they can earn revenues by pumping more oil out they will do so. Replacing that as an incentive is a very important part of the policy mix.

In terms of DACCS, let me step back about this because I do want to put a slightly broader question on the table about what seems to be a rush towards DACCS. When we think about carbon dioxide removal it is worth thinking about the various options around it. We have some big concentrated CO_2 streams coming out of existing facilities; steel plants, cement plants, and so on. We have distributed concentrated CO_2 streams and then we have proposals to suck CO_2 out of the air.

On the output side are the proposals for utilising the CO_2 in various ways, some of which may be locally specific, some of which may be going into transport fuels, which are highly mobile, and others may be just burying the CO_2. Then we also have nature-based solutions and talk about accelerating absorption in peatlands or other nature-based solutions. I get slightly unnerved by the tendency to rush towards assumptions that we are building something that will suck CO_2 out of the air and dump it underground.

In part, the physicist in me thinks, “Hang on a minute, if this is not economic with highly concentrated CO_2 streams coming out of cement or steel plants how can it be economic or why would it ever be competitive with those kind of concentrated CO_2 streams? Can’t we start there, if we have smart ideas, as to how to get rid of CO_2?”

Likewise, you then think about those other things, including when I talk about CO_2 going into other things, CO_2 going into construction materials, whether it is dressed wood or other things. I do feel, and I do not know the exact scope of your inquiry, but I hope that carbon dioxide removal is set in the wide context of all of those various approaches to carbon dioxide removal rather than just saying the only things that matter are BECCS and DACCS because that makes me feel we may miss things that ultimately are more promising or comparative.

The final remark: the cost of energy is going to matter. Location can matter but if all you are doing is taking CO_2 out of the air the location does not matter very much, in which case you would expect to look where the energy is the cheapest. That is likely to be in deserts with solar rather than in the UK, if you are in a situation where it does not matter where you are taking the CO_2 out of the air.

I just wanted to offer those broader thoughts as I reflected on the parameters around the inquiry.

Dr Matthew Offord: Professor McLaren, you indicated you wished to come in on that point.

Professor McLaren: There is a lot I could say; I will try to make a couple of brief remarks. First, I think it is very important, as Professor Grubb has suggested, that we look for a portfolio of carbon removal techniques. That is after saying the desirable outcome is to maximise emissions reduction so there is a minimum level of removal required. That has to be repeated because so often it just gets said and then ignored. A portfolio is right.

However, I do think it is important to recognise that direct air capture may be competitive because what you need to do to capture from the dilute CO_2 in the air is only to take a small proportion of it, whereas when you are trying to design a CCS system to capture the CO_2 from a power station, or something like that, you need to get virtually all of it. The aim is 90% capture. It is that difference between doing, say, 20% capture on a big flow and 90% capture on a concentrated flow that means the two may be competitive with one another energetically and economically.

Yes, there are plenty of reasons to be sceptical about DACCS but there are also reasons to think that again a more modular dispersed approach, which can work with that dispersed atmospheric $CO_{2,}$ might be better than the very concentrated big plant approach on concentrated sources.

Q157 **Dr Matthew Offord:** I am going to turn to Dr Joffe. While the other two members of the panel have made it very clear it would be more productive and efficient to remove CO_2 at the beginning of a process, you will have heard me say to Mr Gallagher about the ability for the industries to not only transport but also store CCCs. Where would you, as a member of the CCC itself, seek that the Government support the development of carbon capture and storage?

Dr Joffe: There are a number of things here. I would agree with Michael that we should not be doing greenhouse gas removals instead of industrial carbon capture from a cement plant or a steel plant. This is additional rather than instead. The number one priority has to be to develop the $CO_{2,}$ the transport and storage infrastructure so we have the capability then of taking the CO_2 and sequestering it. We then need to stimulate the market in terms of an incentive to capture the CO_2 and sequester it.

I do think there should be a mix of sources of CO_2 that go into that infrastructure and go into sequestration but it should be dominated by industrial carbon capture and, to some extent, CO_2 from the power sector. In the near term it should be a relatively small contribution from greenhouse gas removals on a 2030/2035 timescale for a number of reasons.

On the BECCS side of things, there is a question of we have some existing biomass powerplants, we could retrofit carbon capture and storage to those and that is what we have assumed in our scenarios. That makes sense, and that is the 5 megatonnes of CO_2 per year that was talked about for 2030, but there is a question then about the economics of building new biomass power stations with CCS during the 2030s and it may be that that is just very expensive.

On the direct air capture side, we heard earlier it is very energy intensive and there is a question about the hierarchy of if you have a certain amount of zero-carbon energy should you put that into displacing fossil generation from the electricity system into powering heat pumps and electric vehicles or should you divert it into greenhouse gas removals. It is very clear from the numbers that the priority has to be reducing electricity sector emissions and powering heat pumps and electric vehicles ahead of greenhouse gas removal.

I would be cautious about too gung-ho an approach on direct air capture in the next 10 years. I think we should be developing the option but at a sufficiently small scale that we can accommodate that demand for energy rather than going to such an extreme that we end up burning more fossil fuel to power the electric vehicles or achieve lesser decarbonisation of the electricity system.

It is a mixture of things. I do think we should be developing these options and proving that they can work but in terms of the large-scale deployment, that is something for the 2030s and 2040s, alongside then decarbonisation of industry, full decarbonisation of the electricity system, the electric vehicles, the heat pumps and all the other things that we talk about.

Q158 **Dr Matthew Offord:** Is that message being put across to Ministers by the Climate Change Committee?

Dr Joffe: It is very much part of our advice. We have limited the amount of greenhouse gas removals in our pathways exactly for these kinds of reasons. We have set out this thinking in our advice. I think it is clear in the net-zero strategy there is a greater reliance on greenhouse gas removals by 2050 and the Government's net-zero strategy compared to our numbers but the difference is our number is something like in our central pathway around 60 megatonnes of greenhouse gas removals in 2050 and the Government's number is 75 to 80. So it is not a huge difference. It is significant but it is not huge.

That has been taken on board at least in the analysis. What then needs to come through is in the design of the policy mechanisms to say how can we pull through these greenhouse gas removals to focus on counterbalancing just those areas where we are going to need the removals to balance the positive emissions in 2050. Whether that is aviation, agriculture, but a small number of sectors that are hard to reduce. We need to make sure that the policy design does not lead to a dash for greenhouse gas removals way in excess of our capacity to meet that demand. That is going to be key.

The final thing is we need public engagement, public acceptance strategy to explain to the public that this is only trying to do the last bit to get to net zero. It is not trying to displace the other solutions for reducing emissions, whether that is changing diets and flying this, or whether it is heat pumps and electric vehicles. What we learnt from the Climate Assembly is that people are intuitively very wary of greenhouse gas removals and particularly if that is in place of other solutions rather than as an add-on. I think there needs to be a strategy from the Government to make sure that people understand that strategy and that is what they are delivering.

Q159 **Sir Robert Goodwill:** Just when we thought this could not get more complicated I would like to ask you a bit about emission trading schemes and how these technologies could be incorporated into them. I think probably start with Professor Grubb. Should negative emission technologies be incorporated into the UK's emission trading system and, if so, how? An exam question.

Professor Grubb: A fine exam question. I think we first need to let the UK ETS settle in well and also establish its longer-term design and relationship to the European emissions trading system.

Obviously it is a system that is founded upon measuring emissions per se; there is no reason in principle why one could not include negative emissions as something that gets credit. Normally in an emissions trading system, they would be treated as a limited and specified category of offsets. In other words, various players that were not subject to emission caps could put forward accredited projects that would absorb CO_2 or reduce CO_2 elsewhere and sell those to participants in the EU ETS who were finding it a bit expensive to meet their emission caps.

In principle, if everything worked smoothly in the way, in theory, a market would, the price and the value of those carbon offsets would pretty much track the cost of emission allowances. It is an added complication and I think initially at least best thought of as a specific form of offsets related to negative emissions, carbon dioxide removal.

Q160 **Sir Robert Goodwill:** Do you think it might be simpler if, for example, Virgin Atlantic either offset its emissions or used synthetic fuels derived from these technologies as a way of keeping it within a very closed loop rather than going out into some big market?

Professor Grubb: Yes, broadly. Then the qualifying criteria and monitoring of those kinds of offsets would be ones accredited as legitimately linked with compliance in the emissions trading system.

Q161 **Sir Robert Goodwill:** Dr Joffe, do you have any comments on this topic?

Dr Joffe: Yes, in our advice on the sixth carbon budget we specifically said it would make sense for the engineered greenhouse gas removals—so depending on carbon capture and storage—to be included in the UK emissions trading scheme were it to come forward. At that time we did not know that we would have a UK scheme for definite. We have set out the numbers for what we think the cap of that scheme should be, whether including the removal or excluding as is currently the case.

The rationale there is that we are already doing things similar to many of the things that we would do to get greenhouse gas removals or have the potential to do similar things already within the scope of the emissions trading system. If we think about fossil fuel carbon capture and storage for power generation or CCS applied to industrial facilities, those would already be covered by the ETS.

Similarly, we have power stations that burn biomass and we have industrial installations that burn biomass. If we have a parallel system for incentivising greenhouse gas removals then there exists the potential to have distorting incentives to say the reward for doing greenhouse gas removals is much higher if we do it and put the carbon into aviation fuels than it is to do it, even if it would be logical, in an industrial facility where they are already burning biomass, for example. Just to put CCS on that.

In order to keep the incentives broadly aligned it would make sense to have all of these solutions within a single trading system. That is part of the reason why we have recommended that. I recognise, as Michael said, that there are complexities to inclusion but I think, broadly speaking, that ought to be the goal.

Professor McLaren: I want to offer the opposite opinion and this is based on the work we did around 70 stakeholders discussing how best to incentivise negative emissions and avoid problems of mitigation deterrents. Clearly, one could include them in a market as long as one was reducing the cap on the market in proportion to the amount of negative emissions allowed in. Otherwise they act directly to deter mitigation within that trading market.

Our stakeholders and our analysis, and you heard in the previous session the idea that different forms of carbon dioxide should probably receive different incentives because they are not directly equivalent. If we store something in a forest for 100 years compared to storing it underground for 1 million years or 10,000 years, or whatever, these are not easily equivalent and trading markets assume a flat level of equivalence.

Our view, and very widely supported by climate scientists as a research paper by Wim Carton and others has shown, is the idea that there should be very clear separate targets and accounting for negative emissions and mitigation emissions reduction, that you also heard a recommendation, I believe, in the last session.

We need to beware, as Professor Joffe has said, that this could lead us to a situation where there is perhaps a perverse incentive and make sure that we do not go that far but we should be aware that just putting these things into an emissions trading scheme itself releases a lot of potential for perverse incentives.

Q162 **Sir Robert Goodwill:** Returning to Professor Grubb, I must come clean that I do not understand how contracts of difference in the offshore wind sector operate, but would these contracts of difference be applicable in this sector?

Professor Grubb: Potentially yes, and let me make a couple of comments related to that previous exchange as well. I think it is right. Before one puts everything together under the same regulatory structure you need to be confident they are commensurate. They may be commensurate in terms of CO_2 itself to the atmosphere if everything works but other things can differ such as reversibility, other upstream or downstream impacts, or the potential for renovation.

One lesson: let us wind back and remember that only a decade ago a lot of economists said it was crazy to have these special feed-in tariffs for renewable energy because the cost per unit tonne was a lot more than in the European emissions trading system. The major benefit was launching new industries in this area, which would never have got a lift off if their only revenue stream was the value of European emission credits, which crashed.

I think we need to be careful before saying everything should be commensurate and therefore under the same regulatory structure. It is a nice economist's ideal but I do not think we are there yet in terms of the state of any of the DACCS technologies certainly. They could benefit from more targeted support measures, which help to address concerns and pull through the most promising technologies, as well as the point that Duncan offered.

The final thing is, bear in mind if you are taking those kinds of technology risks, the one thing you do not want on top of it is a lot of price risk. If there is one thing emissions trading systems have delivered it is a lot of price risk. To come to your question of contracts for difference, let me just underline that in the electricity sector you can think of it economically as a slightly complicated way of giving the fixed electricity price. That is basically what a contract for difference is: it defines you will receive the following price for the first 15 years of your operation. A fixed price for electricity. It does it by saying you will get some money from the wholesale price of electricity and if that is below the strike price we have agreed the Government will top it up. That is what a contract for difference is.

I believe we are now in a period where the opposite is occurring and the wholesale price is so high for electricity that those contracts are paying back to the Treasury; but that is another story.

In terms of carbon removal, we are not talking about an electricity price contract for difference. We are talking about a carbon price contract for difference. In other words, we might, for example, say, yes, the ETS price at the moment is pretty high but that is partly because of its conditions and the gas price and other things, and it could be fairly volatile. The Government will guarantee that your project is rewarded by 80 tonnes, rising to 100 tonnes, over the following timescale for every tonne of CO_2 that is monitored and verified when you take it out of the system.

You should earn what you can through selling credits into the UK ETS but the difference is guaranteed by the Government. That is basically what a contract for difference on carbon is. It is basically the same idea; it is just that you are fixing the carbon price that the project will receive rather than the electricity price that the renewables would receive. There is a lot of mileage in that. It reduces the cost of capital, providing funders are reasonably confident of the technology, because you have taken a large chunk of market risk out. For the formative commercialisation stages of these technologies, that is a very valuable thing to do.

Q163 **Sir Robert Goodwill:** Are there other parallels with offshore wind in terms of not only guaranteeing prices and underwriting some of the risk but also in the way that we have seen costs both in wind turbines and photovoltaics coming down dramatically? Are we likely to see these economies of scale and does that need to be factored in?

Professor Grubb: One should always factor in the potential for learning and I think in the previous session that was emphasised. In my first remarks, I did say we have learnt quite a lot about the kinds of technologies where we can reasonably expect a lot of economies of scale and learning. Replicability in learning cycles is important.

Offshore wind: the key was our commitment got big enough that it began to look a little bit more like solar and we could have several sequential rounds of large-scale industrial investment; not just in the piece of kit, but the in supply chain, the factor is the ships. If you look in detail at that experience there were a lot of things going on. The economic heart of it in the end was the contracts for difference but that only worked because we had built up supporting infrastructure, the offshore wind accelerator with the carbon trust, getting companies together to solve some of the technological problems of driving piles in deep water, various co-ordination mechanisms.

Finally, and this is a thorny one for Government—no easy answers—offshore wind benefited from initial contracts negotiated with Governments, which turned out to be fairly generous. That gave the companies a big incentive to play. It gave them some profits. Then when we moved to auction they had the capital and the expertise and the confidence to get into competition and manufacture down the costs.

For big innovation like that, if you start with too much competition you take out the incentive for the early players to put big money in because the risks are still quite big.

Q164 **Sir Robert Goodwill:** Thank you, that is very interesting. Have the other two witnesses anything to add to that?

Dr Joffe: Yes, I would like to come in and agree with a lot of what I have heard from both Duncan and Michael. Inclusion of removals in the UK emissions trading scheme is not mutually exclusive to having a contract for difference—in fact, that would be an eminently sensible thing to do. You absolutely do need to stabilise the revenue stream, particularly for newer technologies. That would be a reasonable way to do that. That would also enable, addressing Duncan's point, that you might have different incentive levels for different kinds of removal technologies because you could have different, effectively, strike prices of carbon that you are paying for a direct air capture project compared to a biomass project, for example.

To clarify, in terms of the point that Duncan made on mitigation deterrents, as he called it. One would absolutely have to have a tighter cap on the emissions trading system if we had greenhouse gas removals in order not to push out the other sensible things that we ought to be doing. I absolutely agree with Duncan on that. But that is also our advice, that we should have a tighter cap in that case.

Professor McLaren: If I may add a couple of things. The first is to emphasise that if we go down something like a contract for difference route, which I think is workable, as perhaps would be an auctioning route, the payments have to be for actual storage—the amount stored, not the amount captured.

We heard a lot in your last session of people talking about utilisation as though it was something equivalent to storage. It is not. That is another form of mitigation deterrent. If we capture it, having promised to do capture and storage, and then it ends up being burnt as additional fuel or whatever and put into fizzy drinks, ends up back in the atmosphere. The payments need to be for the storage end, not simply at the capture end.

Sorry, the other point I was going to make has gone out of my head.

Sir Robert Goodwill: Thank you very much. I now understand what contracts for difference is; it is like the old deficiency payment scheme we farmers got for lambs. The only difference is we did not have to give any money back when the lamb price was good.

Chair: Thank you for bringing us down to earth.

Q165 **Barry Gardiner:** You can always explain things to farmers in terms of sheep and cows, can't you?

Can I briefly come back and pick up Professor Grubb on a couple of things that he said? You talked about DACCS as perhaps being suitable for desert climates but that did not take account of the water requirements for DACCS, which I understand can be quite substantial, something like 7 tonnes a day, I think. I can see our previous panel waving at me furiously in the background here but, Professor Grubb, if you want to tackle that in the first instance.

Professor Grubb: I cannot see if they are giving you the thumbs up or the thumbs down.

Barry Gardiner: I was not sure; it was just a thumbs down.

Professor Grubb: My limited technological knowledge is there are still quite a few very different DACCS technologies at play. It does not surprise me if some have substantial water requirements. Obviously that would absolutely affect placement and may raise alternate concerns.

I was making the simple point that let's think about some of the fundamental physics of what is behind these different proposals as to which ones might make sense under which circumstances and which ones might it make most sense for the UK to be pushing forward. If the dominant determinant is just cheap energy, cheap electricity at large scale with very cheap land, that is probably not the UK. That is really the only point I was making.

Q166 **Barry Gardiner:** One needs to choose the location according to the sustainability of the resources required, which I think we agree on. The other point: you emphasised price risk around the ETS and of course the great thing about the ETS is that, yes, you have price risk but you do have, in terms of the trading caps, emissions certainty whereas if you go down the other route of having price certainty with the carbon tax, what you then have is emissions risk. I wondered if you wanted to consider that trade-off in respect of DACCS and BECCS.

Professor Grubb: It has been an old debate in economic price versus quantity and for many years I think there has been a lot of evidence and a growing amount of theory to say neither extreme is what you need. You need probably a system that has some price responsiveness, at least for the more flexible actors and the more mature technologies. But the kind of huge price durations we have seen with EU ETS made it almost irrelevant. It was a joke. To say it has achieved the cap, it is just much more cheaply, is useless when you knew you had the long-term dynamic objective of getting to net zero. You need a solid base of a minimum price in these systems, and I am glad the EU ETS has taken that on board.

Let me build on that a fraction. We may have got slightly confused about terminology but, in relation to David's remark, I would not see a contract for difference meaning that carbon dioxide removal was part of the UK ETS. To me, being part of the UK ETS is you are emitting stuff and you have to pay to buy the allowance to emit, and that price may be volatile.

We would not normally say our offshore wind contracts were part of the electricity market but obviously they are linked to it because that is their first source of revenue and the Government simply tops up the rest. That is a terminology difference. Let's not get confused about it.

Could I add in one other thing? It is slightly left-field, but it comes back to my earlier remark—partly it bears on this question about relationship between ETS facilities and air capture or carbon dioxide removal, but also my remark about let's think about all the various options. I do find myself coming back to the fact that first, setting aside global net negative, long before we get to any global net negative, we need some degree of carbon dioxide removal to offset things that are very hard to abate.

In the UK, when you look through the CCC and other analyses, you find a relatively limited number—a significant but limited number—of things that look hard to abate, and some of them are in locations where we think we can have solutions, big industrial clusters. Some are not. Linking the CDR discussion a bit to what problems are we trying to solve, which hard sectors are we trying to offset with the removal, could be productive.

One particular sector that I think about, aside from the distributed methane or whatever, is cement plants. Most of the analyses say they are hard to deal with but at the moment they produce incredibly concentrated large streams of CO_2 so if we have good uses for CO_2 that is a place to start or good disposal methods, but also of course they are producing materials for construction, which embody quite a lot of the carbon, and there are a lot of interesting ideas for carbon-absorbing materials or materials that have absorbed carbon from the air. I would still like to see a lot more thought around that interface because I suspect—I am not enough of a chemical engineer to know for sure—that there are stones not yet turned in that interface of carbon removal and cement or materials production.

That was slightly left-field, but it comes back to my opening comment: let's not get trapped into just assuming that carbon dioxide removal is just BECCS and DACCS.

Q167 **Barry Gardiner:** If I can turn to you, Dr Joffe, to get your response to that and ask you a specific question around it. Would it make sense for the CCC to be recommending to Government, and also of course for this Committee to be making it as part of its recommendations, that there is almost, as Professor Grubb is suggesting, a zoning or planning structure to the way in which we should be recommending that negative emissions technologies cluster around various areas, depending on the sort of specificities that Professor Grubb was saying?

Dr Joffe: Do you mean geographical areas?

Barry Gardiner: Yes.

Dr Joffe: Yes, I think that is going to happen anyway. The direction of travel of the CO_2 infrastructure, the pipelines and the stores, is that they are going to be around industrial clusters, whether it is in the north-east of England, the reserve one in Scotland, or north-west England, and so on. Once we have the infrastructure, we can start using the infrastructure not only to take away the industrial emissions but we can also site power stations there that are going to take advantage of it, and we can start greenhouse gas removals there. That will naturally happen as a function of the geography but also the fundamental economics of the challenge. I do not think we have to worry too much about that.

Q168 **Barry Gardiner:** I will turn to the questions I was going to ask but it has been a fascinating discussion, so thank you for the input.

Turning to Professor McLaren, you have used this phrase about mitigation deterrents, and I just would ask you to cash that out in a way that is relevant to negative emissions technologies because I believe part of the research that you have done—and I assume that this is looking at this at a global scale—would imply that the perceived saviour of negative emissions technologies in addressing the symptoms of the problem, if it were to deflect us from reducing our emissions, could produce the perverse outcome of raising our global target of 1.5 degrees by a further 1.4 degrees. If you could cash that out for us and explain it in lay terms, that would be helpful.

Professor McLaren: I will do my best. It is a technical paper that was published in "Climatic Change". Essentially what it does is take this perhaps a natural public response, as we heard earlier from Dr Joffe that the Climate Assembly was concerned that the use of negative emissions techniques might distract us from doing as much as possible to cut emissions. Through an analysis of the way these techniques are incorporated into integrated assessment models we came up with this calculation and we broke down the problem into three broad areas.

First, to say Governments could plan to do negative emissions and say it is rationale because it is very expensive to cut emissions otherwise, so we are going to put this in the plan instead of doing that emissions reduction. All well and good if the negative emissions do happen but, as we have heard, they have a lot of uncertainties technically and in commercial terms. So there is a risk there that they may not be delivered. That is one chunk of the calculation.

The second chunk of the calculation is to ask whether if you do these things there are unforeseen rebounds. One of those you referred to yourself earlier: the enhanced oil recovery idea. Yes, oil companies tell us that it is possible to shove more carbon dioxide down an old oil well than comes out in the new oil. But their incentive is to do exactly the opposite. It is to put as little carbon dioxide down as it takes to get as much oil as possible out. They also tell us that if we were not doing that we would be drilling new oil wells. I heard that the IEA said that if we are going to meet 1.5 there can be no new exploration for fossil fuels. Clearly, this is going—

Q169 **Barry Gardiner:** You have already identified five times as much as we can possibly use to keep to 1.5.

Professor McLaren: That is an example. The EOR is an example of how we can have a rebound effect from pursuing negative emissions.

Thirdly, is the rather more pernicious what we call imagined substitution. Some people have talked about this as a moral hazard but Dr Ruddock, in the last session, said, "Think about all those things that cost more than $100 a tonne to abate". That is the threshold we used. How much mitigation is said to cost more than $100 a tonne? If you, Dr Ruddock, are promising that carbon removal can do it for less than $100 a tonne why should any rational actor pay more than $100. So they will wait to see if this thing happens at the lower cost. That is that third chunk.

In the calculation, we take account of the fact that the more there is actual substitution by Governments, the less imagined substitution there would be left to do by companies and the corporate actors that will generally be doing that. We have seen so much of that; so many corporate actors are promising net zero based on very large negative emissions promises.

Q170 **Barry Gardiner:** Can I try to encapsulate what you have told us so that we are clear that I understand it and that the Committee can then incorporate it in its work? The first point that you are saying is that negative emissions should be separated from emissions reductions, there should be separate targets and redesigning and offsetting trading systems. Secondly, the point is about robust systems of accountability, monitoring, reporting and verification, avoiding double counting. Thirdly, is what you call the moral hazard part of this—where we do not wait for the perfect and, in the process, stop doing the stuff that we absolutely need to do now, which is the good. Is that correct?

Professor McLaren: Yes, all of those are conclusions that we drew and these were the product of the deliberations we held with a broad group of stakeholders in negative emissions technologies and carbon removal more generally. Our summary would perhaps be: we need to acknowledge the risk that these things can happen and, when we are looking at negative emissions technologies, undertake a risk assessment that includes this risk.

We need to understand the mechanisms and understand that they have a psychological, a cognitive appeal. It is very easy to procrastinate. Many of us will know that. This gives us an opportunity to do so. Then, yes, we can design these mechanisms, such as separate targets, strong verification, good monitoring, dedicated targeted support to make sure that we do develop greenhouse gas removal and negative emissions.

We are absolutely not saying do not do it. We are saying that there is a serious risk and some of it is just hidden away. We do not see it happening, for instance, in the modelling that I spoke about earlier.

It is just hidden away and we don't see it happening, for instance in the modelling that I spoke about earlier.

Q171 **Barry Gardiner:** Dr Joffe, on the discussion that we had earlier about contracts for difference, what is your understanding of the Government's position on contracts for difference at the moment? Is the Climate Change Committee recommending that they should be employing contracts for difference in this area?

Dr Joffe: I don't know exactly what the status is within Government. I know that they have been considering contracts for difference on the carbon price, for example, for industrial decarbonisation not just for greenhouse gas removals. Is it the CCC's position? Yes, something that looks like that. We certainly need the revenue stabilisation element of that to reduce the risk and the cost of capital to investors to make it an investable proposition.

Q172 **Barry Gardiner:** My understanding is that the Government have been reluctant to renew contracts for difference as a preferred methodology. Would some prodding from this Committee be helpful to push them down that road?

Dr Joffe: Very much so. Contracts for difference are not the only way of providing revenue stabilisation but, as Michael set out very clearly, it is a vital part of bringing forward particularly early stage technologies to give people the confidence to invest.

Q173 **Barry Gardiner:** This question is open to anybody but it may fall naturally to Professor McLaren. What steps need to be taken now and by whom to raise public awareness on the role of negative emissions technologies in reaching net zero? What should we be doing and who should be doing it?

Professor McLaren: That is a bit of a $64,000 question. If I were put on the spot, as you have done, I would say that we had a climate assembly that looked more generally at climate policy and this is something that also should be given consideration by such a body.

If I remember correctly, the EAC was one of the committees that helped initiate the UK climate assemblies. In many times and places, I would say that this is a job for politicians to lead on, but I am afraid I do not see the public confidence in our leading politicians at the moment to suggest that

that would work. I think it has to be done by politicians in collaboration with some representative body.

Q174 **Barry Gardiner:** I think you have just said that we should all be holding climate assemblies in our own constituencies and inviting you to give impartial evidence to them. Given that you have volunteered in that way, thank you very much, and I will pass back to the Chairman.

Dr Joffe: If I could come in on the public engagement side, I think that there are two important aspects of this. One is the technologies themselves—are we engaging with the communities where these things will be decided and making sure that they understand the rationale for them and so on—and the wider public engagement, "Here is our strategy; these technologies form an important but small last step in getting to net zero; we are not pushing out the electric vehicles, the heat pumps and all of the other things". I think that both levels are crucial otherwise we start to undermine the whole strategy.

Chair: I thank our panel for staying on a little longer than we indicated we would ask you to. We will conclude with some questions from Ian Levy.

Q175 **Ian Levy:** I want to touch on safeguarding and monitoring for the last group of questions. I will direct the first question to Professor McLaren and Dr Joffe. How should a monitoring or reporting and verification framework be implemented when it comes to negative emissions technologies? Dr Joffe, do you want to kick that one off?

Dr Joffe: That is a big question. I don't think that I have a comprehensive answer but there are various aspects to it. One is the monitoring and verification of the CO_2 flowing into the storage. We have to be absolutely sure that the right amount of CO_2 is going in there and that we are not paying for things that are not going in there.

We need to monitor the pipelines as well to ensure that there are not CO_2 leaks, particularly the onshore aspects. We have offshore storage in the UK and leakage of CO_2 is much less of a concern in this country than it is in Germany, for example, where if it was to do CCS it would all be onshore storage of CO_2. That means that if CO_2 leaks it is potentially in populated areas. CO_2 is an asphyxiant and that is a public health issue. We have much less of a problem in the UK but still the pipelines that pass overland need to be properly monitored.

There is an important question around biomass if we are talking about the BECCS side of things. Our preference is for most of the biomass to come from the UK where we can have proper governance of the sustainable supply of that. That means not using land that could otherwise be used to grow food, not using excessive water, not pushing people out of their land and so on. We have much more capability to do that for the UK than we have outside. We can still place criteria on imports but it is likely to be less effective.

They are some elements but I am sure that Professor McLaren can add to those answers. It is important to get this right in the next five years before we start deploying this stuff at scale and build in some problems.

Professor McLaren: I endorse pretty much everything that Dr Joffe said. Clearly, monitoring storage and flows is critical. The bigger challenges come with the techniques that are not generating a gaseous or liquid flow of CO_2 through a pipeline. DACCS and BECCS do that, so the central bit of monitoring and verification is possible. There are challenges with inputs particularly that need to be monitored for the biomass side. There are challenges with leakage in the process and from the storage, which have to be monitored, but for techniques such as enhanced weathering or soil carbon storage, there are much greater challenges even though these techniques might in the end prove more socially and environmentally desirable than the big, hard technology options of BECCS and DACCS.

For our monitoring challenges, we have to design a system that is good for a whole diversity of techniques, including those that have the risk of leakage from things like wildfires or drought. If we are going to account, for instance, for carbon stored by peatland rewetting and there is a drought that means that the carbon starts coming out, that has to be picked up. For a lot of those, the issue is perhaps not so much the monitoring method but the degree of what you might call redundancy that is allowed in the accounting so that we do not say we might think a forest will store 100 tonnes but we discount that. I am just taking a figure out of the air. We might say 80%, 80 tonnes, is accounted for in our reporting, in what we pay as support measures.

Similarly, to deal with these sorts of uncertain systems there need to be very clear accountability measures for the operators so that they are held liable where there are problems. That gives them the incentive to do the most transparent and precise monitoring and verification they can.

The final thing I want to emphasise is that a monitoring regime should be sensitive to the distribution of any side effects or side impacts. I hear that there are already concerns from farmers in Wales and Scotland about the way that potential carbon storage schemes are being set up and the levels of disadvantage in the communities that are now perceiving these as a greater imposition on their local environments. The justice aspects should be part of a broader monitoring scheme.

Q176 **Ian Levy:** You have touched on the second part of my question: what safeguards should the Government put in place if negative emissions technologies basically don't deliver on their targets? Does anybody want to add anything on that?

Dr Joffe: We have an economy-wide set of climate targets for exactly the reason that if one area underdelivers we have to overdeliver in the other areas. I know there has been discussion of separate targets for greenhouse gas removal versus reduction of emissions, but one of the advantages of having everything together, as long as you do it right, is that the Government are on the hook for reducing emissions by more in other sectors if they have to because greenhouse removals underdeliver now. By the time we know that they will underdeliver, some of the options to compensate might be off the tables in the timescale with which we need to compensate. If they were considering building three more nuclear power stations to compensate for underdelivery of greenhouse gas removals, that would take more than a decade and is not very useful.

It will have to be the demand side. If these things underdeliver and we still need to stick to our carbon budgets, it would have to be, "Let's find a way for people to fly less, let's try in a more concerted fashion to persuade people to change their diets away from red meat, dairy and so on". That ends up being the backstop. The things that you can do quickly tend to be on the demand side but ultimately we also need a monitoring framework, which we have under the Climate Change Act, to pick up these problems early enough so that direction can be changed within a year or two of the problems emerging rather than five or 10 years down the line and then it is more difficult to change course.

Q177 **Ian Levy:** Do you feel that we can rely on proven negative emissions technologies to reach that UK zero target by 2050? I know it is a big question.

Dr Joffe: It is a big question. I think we can rely on some contribution. I don't think it is a credible position to say that we can't do any. There is a question about how much we can do and there are certainly constraints on sustainable biomass and uncertainty about exactly how much we can get there. Clearly, direct air capture is not proven at scale yet, so it makes sense to consider uncertainty in the scale with which it can do it.

I will turn it round the other way and say that at the moment we don't know of any way to get to net zero in the UK without some contribution from those. I think we should be planning for some contribution. It should be as small as we can make it. We need to put in place mechanisms that start to develop it now rather than saying that we will have some greenhouse gas removals turning up in the 2040s and rely on it then. If we start to develop it now and it does not work at least we can change course. I think that is very much the implication of the question.

Q178 **Ian Levy:** Michael, do you want to add to that? I see your hand is up.

Professor Grubb: First, I would separate the BECCS from other CDRs. On the assurance side the position one wants to get to is where the absorption of growing the trees is monitored and credited and the burning of it is penalised as an emission in the ETS. Therefore, capturing and sequestering become part of avoiding payment for those emissions, which is the totality of giving you the net negative. That is a rather special case and it addresses the complication of upstream emissions, particularly if some of it is imported.

On the general CDR, yes, underlining the point that one needs whatever incentive system to focus on the actual sequestered carbon, but I want to touch on your question about safeguards in other respects and link it to another aspect of the discussion. Earlier David referred to the fact that we don't want to take options off the table. With the other CDRs, the challenge is getting options onto the table. Let's not pretend that they are on the table at present. They are in all of the models but that is only because the models say that we will need something like this.

One way of addressing the safeguards issue is to also ask the question: where and how do we get industries with real technological knowledge and financial muscle into this game? We saw how that was engineered through in the wind energy sector in the end. It is pretty obvious for BECCS; it is less obvious for much of the DACCS. I think that is one reason why it is worth thinking about what are the really hard-to-abate sectors that we are trying to offset. We will have some whether or not we get below net zero and hence my reference to some of the concentrated, hard-to-trace sources.

If one said that as a safeguard by year X—let's say 2040, which I think is when CCC said the cement sector should be net zero—anyone producing construction materials will be legally liable for making sure those materials are net zero carbon, in one way or another, which may include funding carbon dioxide removal that they are paying for as part of the monitoring system, at some point that becomes a legal liability. In effect, you get some of those industries involved much more materially in saying not just, "We want solutions" but "we will have to contribute to the solutions".

At the end of the day, if some of these things prove harder than the proponents hope, the answer is that we need to get more money into more varied solutions. I think that one way of doing it is to say that there will come a point at which companies become liable for these emissions more directly than just paying but getting to net zero.

I think that one of the most dangerous things in this area is the $100 number. We don't really have a clue whether that is right. It might be but, more to the point, it is not that big a number. If we go back only 10, 15 years the complaint about solar energy was it was $400 or $500 per tonne of CO_2 removal. Let's not underestimate the need for investment in technologies that help to reduce emissions that have a lot of potential for coming down the cross curve. I am thinking of things like hydrogen steel and other things. They may or may not be economic at $100, we don't really know, but I think there will be a real risk if we say that we are never going to bother investing in anything that currently costs more than $100 because in the end, negative emissions will arrive at that price.

I think that we have to accept that we don't know what the cost or the scale of these things will be in the long run. We should get on with finding out through these smaller-scale efforts to get things onto the table.

Q179 **Ian Levy:** Professor McLaren, I see you nodding.

Professor McLaren: I have a few comments on your question about safeguarding. I think that the critical thing to remember here is that even if they work, any negative emissions technology is limited in its total potential, whether that is by the amount of land we can dedicate to the feedstock or the amount of renewable or clean energy we can provide for it or the amount of rock we can grind up for enhanced weathering. We can't rely on any of them. I agree with Professor Grubb that that means investing in a wider portfolio offering.

I am hesitant to say this but Dr Joffe said that if we find these are not delivering we will have to accelerate the demand side. I am sorry, but if we can accelerate the demand side we should be doing that now. The commitment to reduce emissions as much as possible ought to be taken seriously. I think that what we are hearing there is that even with all the good things he said—I agreed with many of them—even in the CCC's modelling and budgets there is a little bit of mitigation deterrence going on, that if it could be done as a backstop but is not being done because negative emissions are in there instead, we should be doing it now. That is not to say that we don't do the negative emissions because then there is more capacity of negative emissions techniques for the legacy of too much carbon dioxide in the atmosphere that, as you heard in the earlier session, we will need to remove in the future.

That would be my safeguard: a portfolio that drives it forward but do what we can to cut emissions now, including things that might sound a little less popular. I go back to the climate assemblies where we heard much more support for more rigorous efforts to reduce emissions, to change behaviours, than we are seeing from politicians even in the UK, which is one of the leading countries in the world on this.

Ian Levy: Lovely. Thank you very much.

Dr Joffe: Chair, if I could come back in on a point that Professor McLaren made.

Q180 **Chair:** Yes, just very briefly because it has been a marathon session.

Dr Joffe: I absolutely agree that we should be doing the demand side things anyway, but there is a question of degree. The Climate Assembly was not comfortable with anything more than a 15% cut in aviation compared to 2019 levels before all of this happened. If we aim for that and we do greenhouse gas removals alongside and they don't work, we could go further than a 15% cut in aviation to compensate. That would not be popular but we could still do it, so there is a question of degree.

Professor McLaren is absolutely right to challenge me but we should be doing the demand side things alongside the greenhouse gas removals. We will have to do something else if the greenhouse gas removals don't deliver. The legally binding targets don't offer too many ways other than things on the demand side that deliver quickly.

Chair: Or other technologies. On that note, I thank our panellists, Dr David Joffe in the room, Professor Duncan McLaren and Professor Michael

Grubb on the virtual channels. Thank you much indeed also to Marc Geddes and Kirsty Macleod for preparing our brief and to members of the Committee for sticking with us for what has been for us quite a long afternoon.