Stuart Haszeldine: We’re in the carbon wars. Paying to capture and store CO2 is like paying for waste collection.

**Honza Žižka:** *In 2018, the Intergovernmental Panel on Climate Change (IPCC) published its special report on global warming of 1.5 °C. The report outlined four scenarios for limiting the temperature increase to 1.5 degrees above pre-industrial levels. Three of these scenarios assumed that 350 to 1,200 gigatons of CO₂ would be captured and stored by the end of this century. The IPCC's sixth synthesis report from 2023 noted that storing the necessary CO₂ quantities underground was feasible and that capturing CO₂ directly from the atmosphere would be essential to counter residual emissions from aviation, shipping, and the chemical industry. However,* *carbon capture and storage deployment rates are dramatically slower than those envisaged by the IPCC. Why is this the case? What other energy solutions for climate change do we need to accelerate? And what are the appropriate economic incentives to make these changes happen? I will be asking Stuart Haszeldine, a geologist, a world-renowned expert in carbon capture and storage, and co-director of the Edinburgh Climate Change Institute. It is a pleasure to interview you on behalf of Energy at Edinburgh, Stuart.*

**Stuart Haszeldine:** Glad to be here.

**HŽ:** *According to* *the World Meteorological Organization, there is an 80% likelihood that the annual average temperature will be more than 1.5 degrees higher than the pre-industrial levels in at least one of the next five years. Three years ago, I reported from the COP26 conference in Glasgow. It seems like the optimism with which politicians presented their pledges at that conference has once again been misplaced. Why are we still not moving in the right direction?*

**SH:** Moving in a different direction is really difficult because fossil fuels worldwide still comprise about 80% of energy. And that's energy for transport, heating, making chemicals, making buildings work, and growing food. Fossil fuels are endemic throughout our whole culture. So, it's not surprising that it's difficult to move.

Politicians have taken a quite superficial view of this and have taken the path of minimum resistance in some ways by declaring targets and ambitions and claiming that they are based on science, which often the numbers are. But there's a huge gap between those claims, wishes, and ideas and the actual practical reality of delivering decreases in CO2 emissions.

Since 1990, when carbon accounting began, the UK has performed well in this area. The country has now reduced about half of its carbon dioxide emissions without any major disruptions to the economy. That’s a pathway other countries could follow.

**HŽ:** *Both the UK and the EU are, on paper, doing better than the rest of the world in reducing emissions. According to Carbon Brief, the UK's emissions in 2023 were the lowest since 1879. However, the UK's and the EU's per capita emissions are still high if you compare them to the rest of the world. Can you describe the historical development that led to this?*

**SH:** It’s not due to a single historical development. Industrialised European countries have been able to decrease emissions by switching to different fuels. For example, switching from coal to gas emits less carbon for the same amount of energy. Switching to renewables, such as generating electricity with renewable wind, produces very little carbon.

European countries have also been able to decarbonise by closing down inefficient and old-style processes: old-style steelworks, old-style coal burning, and very inefficient power plants, for example. That’s part of the large gains made in decreasing emissions from Europe.

But it’s also true that if you do the accountancy quite rigorously, some of those emissions—rather than being emitted onshore in Europe—are now emitted onshore in Africa or parts of China, where the manufacturing has been relocated. So, although these are good headline claims, we do need to be careful about validating them.

The key point is that there are many subsidies and much discussion about reducing emissions. Cement works may become more efficient, and a glass factory may emit less carbon dioxide. That’s what the European trading scheme has managed to do—drive down those emissions. But there’s still no payment for storing carbon. Taking carbon out of the atmosphere and the ocean system is needed to allow the Earth to start recovering.

**HŽ:** *Let’s briefly focus on the energy contribution to the UK’s emissions. According to the UK government’s data, it’s 14%. How can we reduce this number even more? Is knowledge transfer from traditional energy production methods to renewables like wind, tidal power, and geothermal heat possible?*

**SH:** I think we’re in the middle of a transition, which you just described as moving away from one technology to boost and accelerate the development of the following technology. There's a famous saying that the oil industry isn't going to run out because we're out of oil, in the same way that the Stone Age didn't run out of stone to move on to the next era. People use their technologies and knowledge to move forward into the next space

In Scotland, we have some particularly good examples around Edinburgh. For instance, west of what is now Edinburgh Airport, the shale oil industry emerged as the world’s first commercial oil industry. It began by heating fine-grained sedimentary rock rich in fossil carbon to extract oil. The chemical industry's refining expertise then acted to locate the present-day oil refineries and petrochemical works there.

Now, they are moving away from refining crude oil and gas out of the North Sea into making more complex petrochemicals and possibly starting to use biomaterials as a biomass feed. Again, these evolutions build on the past each time. It’s very sensible to consider how we can support our skilled workforce in transitioning into these slightly different areas, helping us move forward more effectively.

**HŽ:** *You told the BBC that carbon capture is a technology originally used in oil refineries for gas production. Today, it’s used as a climate change mitigation mechanism. This technology has different types, including post-combustion, pre-combustion CCS, and direct air carbon capture. Some people even include biological photosynthesis-based methods of capture under the term CCS. Could you please describe these different types of carbon capture in more detail?*

**SH:** Yeah. There are many ways to capture carbon from the air or after combustion. It’s important to understand that these different methods exist and have different qualities. In the chemical industries and oil refineries over the past 100 years, methods for separating carbon dioxide from gases have been well established. They are now being adapted to reduce emissions from burning fossil fuels.

For example, if you burn methane gas to generate heat, which then generates electricity, you emit carbon dioxide. Similarly, burning coal as part of steelmaking—both as an energy source and as a reagent—also emits carbon dioxide. The challenge is to capture that carbon dioxide. Here, we might use a chemical solvent, which reduces emissions.

In other situations, we might use techniques to recapture already emitted carbon dioxide and remove it from the atmosphere. The first approach is typically called carbon capture and storage (CCS), while the second is direct air capture (DAC). Between these, there is a spectrum of technologies and techniques.

Planting forests is one example, and you could even call it a "technology". The forest attracts carbon, brings carbon down from the air, and stores that in the biomass of the trees. This reduces atmospheric carbon, locking it up in wood. However, the challenge is how long we want that storage to last. If the carbon is stored in wood, it’s temporary—40, 100, or 200 years—and not permanent in the geological sense.

To achieve permanent storage, we need to find ways to store carbon back underground, where it originally came from. The same applies to capturing emissions from burning oil, gas, or coal. The capturing methods involve different chemistries and, sometimes, distinct forms of electrochemistry. For long-term climate repair, the essential step is putting that carbon back into the ground for permanent storage.

**HŽ:** *The IPCC thinks direct air capture will be necessary to keep our emissions or temperature rise as low as possible. However, it’s expensive and not widely deployed. Are you optimistic about this technology? Do you think it will be used on a larger scale?*

**SH:** So, the way I answer that is that I believe in climate modelling, which shows that even if we start decreasing emissions by doing carbon capture, some emissions will still occur. For instance, if we fit carbon capture to a power station or a petrochemical plant, not all the carbon will be captured from that plant. There’s always going to be some fraction—maybe 5%, maybe 10%—that escapes.

That’s why we need this additional technique and technology to recapture what’s missing. Every molecule of carbon dioxide that enters the atmosphere adds to heating and drives planetary change. So, we have to balance the arithmetic: the total emitted has to be matched by the total recaptured and stored. Capturing emissions at the source and recapturing what’s missed—all needs to go into permanent storage.

And I do think direct air capture is going to be an essential technology. But it’s a totally new concept—something humans haven’t done before. There’s now a global race to develop these technologies, which has particularly escalated over the last 10 years and will continue in the next 10, 15, or 20 years. We need to decrease the cost of these technologies, reduce the energy penalties they come with, and increase the reliability of both capture and long-term storage.

**HŽ:** *Similar to the various types of carbon capture, there are different methods for carbon storage. Scotland is renowned for its Acorn project, which aims to store carbon in the depleted North Sea bed. Additionally, carbon can be stored through biological and geological sequestration. Which of these methods will prove to be the most effective?*

**SH:** So, there are several different ways of storing carbon dioxide. However, the key point is that it needs to be stored for the long term. In terms of geological time scale, that long term might be 10,000 years. That's the time since the last glaciation happened in the northern part of the UK. And you can do that by compressing that pure carbon dioxide, separated from other emissions, to 70 atmospheres like in a fire extinguisher, and injecting that liquid maybe 2 or 3 kilometres deep underground, where that carbon dioxide will seep into the tiny pores between the sand grains of rock. That carbon dioxide can stay there for permanent geological time scales. It’s a permanent storage option.

It will remain as isolated droplets, gradually dissolving in the deep groundwater. As it becomes denser than the groundwater, it will sink deeper. This presents a very safe and secure option. Our geological research here at the University of Edinburgh was the first to demonstrate that the UK has a huge resource both for its own use and potentially for creating new businesses by bringing in carbon dioxide from other countries and storing it.

There are other methods for storing carbon dioxide. Some sorts of rock, particularly volcanic rocks like basalt, are chemically reactive. Carbon dioxide dissolved in water can act as a chemically reactive weak acid. Some sorts of rock, particularly volcanic rocks like basalt, are chemically reactive. Carbon dioxide dissolved in water can act as a chemically reactive weak acid. Test projects focus on injecting carbon dioxide dissolved in water into rock formations to understand how fast that reacts and forms solid minerals. We’re also involved in these projects.

At the other end of the spectrum, some people are crushing up basalt rock and spreading this fine-grade material over agricultural fields, where it reacts faster to draw down carbon dioxide from the air through the natural weathering process. We’ve accelerated this process by crushing the rock into smaller, more reactive pieces.

If you want to plant trees and vegetation and manage the landscape differently, you can do that. But you have to be careful. The move to rewilding and the restoration of original ecosystems is great, but it's much more important for animals, wildlife, and ecosystems—and it stores very little carbon in the long term. It’s good for storing carbon in the immediate term but not for the long term. So, you need to be careful about this spectrum of different methods. What you’re paying for and what you’re getting out of it has to match what you think you’re doing.

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**HŽ:** *You mentioned hydrogen, which is one of the key energy sources of the future. However, to create hydrogen, we sometimes also emit a lot of greenhouse gases. When synthesising hydrogen, the hydrogen itself has to be stored for use. Where can we store all this hydrogen, and how large a part of the UK's annual energy supply could it constitute? And how do we get rid of all that carbon dioxide or methane that's being emitted while synthesising hydrogen?*

**SH** So, hydrogen is quite popular as an anticipated fuel for the future. I suspect it will probably be slightly less popular by the time we actually build and design the projects. But hydrogen looks very promising as a powerful vector and carrier of energy. Just as we can send electricity through wires, you can send hydrogen through gas or oil pipelines. That can be particularly useful for industries that want to decarbonise and move away from methane gas to hydrogen.

But practically, all the hydrogen made at the moment is made by splitting up molecules of crude oil, and that emits many byproducts, one of which is carbon dioxide. If you're making hydrogen but emitting carbon dioxide, you’re not really gaining any environmental benefit because the CO2 is still emitted. So, new process styles are being developed, like blue hydrogen, where organic molecules from crude oil or methane gas are split to make hydrogen, and the carbon dioxide and other byproducts are captured, transported, and stored deep underground in the same way that we might store emissions from a gas fuel power plant. Here, we’re storing the emissions before the hydrogen is combusted, but it still amounts to the same thing. That’s a net benefit for the climate.

In addition, people are moving towards electrolysing water, which means passing an electric current through water—like a simple school experiment. This process produces oxygen at one electrode and hydrogen at the other, with very few emissions. However, it requires a lot more electricity to be generated.

What I think hasn’t been fully realised is that with hydrogen, you can’t just turn it on when you need it. You have to make it first. It’s well understood that we use about 4 to 6 times as much energy in winter as in summer. So, at the moment, we meet that demand by turning on natural gas fields and using them a little faster. But if we move to hydrogen, we’ll need to make hydrogen in the summer and store it until winter. Our calculations at Edinburgh suggest there will be a huge demand for hydrogen storage—something like up to a third of our annual energy consumption will need to be stored. And that’s an unprecedented, enormous industrial ask.

There are ways of storing hydrogen in stainless steel tanks, but it’s expensive, so this may not be a national solution. We can also store it by creating an artificial cavern in rock salt buried deep underground. This works in a few places but hasn’t yet been fully commercialised for hydrogen. It’s worked for methane, so there’s still some work to be done. As we move forward, I think we’ll see an increase in demand for hydrogen storage in salt. We’ll likely exploit offshore and onshore salt locations in the UK. Ultimately, we may use depleted gas fields where we’ve already extracted methane. We can refill those with hydrogen, which will stay there safely and securely.

Some of the fundamental work on this has been done at Edinburgh, where we measure the properties of the rock, how fast or slow hydrogen reacts, and how fast hydrogen moves through the rock. Because, obviously, we don’t want it to escape.

**HŽ:** *As you mentioned, some of the promising applications of CCS are industrial. In the UK, industrial emissions are as large as those in the electricity sector. Teesside and Humber are examples of British industrial clusters demonstrating that our industrial processes' emissions can be captured and stored. Are there any specific Scottish examples worth mentioning?*

**SH:** In Scotland, right now, there are no large operating examples of CO₂ captured on an industrial scale. If the planned Acorn project is funded and developed over the next two or three years, then we will see carbon capture being fitted on some of the larger industrial sources of compressors feeding the North Sea: glass making, paper making, and even perhaps a couple of new power stations fitted with carbon capture and storage.

But what's also happening in Scotland now are projects involving people who are capturing not at the huge industrial scale, but on rural settings, at the farm scale. Clearly, lots of people want to do something. Techniques in the middle ground between forestry and geological storage are starting to emerge.

About 15 years ago, we set up biochar research in Edinburgh. Biochar is made by combusting or heating organic material with very little oxygen. It is well understood that this controlled charcoal can go into the ground and persist for tens and hundreds of years. So, it's a way of locking up carbon in the soil. We're working on how to make that biochar into small pellets to be fed through standard agricultural equipment. You insert a seed into the pellet and put rock dust around it. And that rock dust then gradually, over months, dissolves away and provides a very local fertiliser to that seed. This fertilises agricultural input and increases carbon storage in the ground.

Elsewhere in Scotland, commercial actors use crushed basalt waste from quarries where road stone has been extracted, and the smaller material remains unused. They spread the crushed basalt across fields, enhancing the reaction rate. This process captures carbon dioxide from the atmosphere and transfers it into the groundwater, which subsequently flows into the ocean safely and securely, having drawn down CO₂. These projects are now happening.

People are also trying to plant trees and rewild land. These strategies will all have different degrees of success in drawing down carbon. But part of this immensely active, fertile, hyper-bubbling innovation activity is happening in and around Edinburgh right now.

Agricultural and land-based emissions account for around 20% of all emissions in a country like Scotland. Therefore, we use simple processes to separate carbon dioxide from methane. The methane can be utilised for combustion as a biofuel, effectively recycling the carbon back into the energy system. In contrast, the CO2 must be stored. Projects that enable the capture of carbon dioxide at anaerobic digesters on farms, in distilleries, breweries, and potentially certain areas of refineries can cultivate this ecosystem from the ground up, while large-scale, top-down initiatives—which get the most attention—are also being developed.

**HŽ:** *One concern regarding carbon capture and storage is its cost. CCS technologies are frequently discussed in connection with the idea of “green” growth, which some economists deem unfeasible. You seem to be more optimistic about the potential of both existing and new technologies. What is the most effective way to make carbon capture and storage economically viable? And are we on the right path to achieving this?*

**SH:** Well, I think that's an interesting question because carbon capture and storage is often accused of being too expensive. My question back is, too expensive compared to what? Compared to not doing it? Or compared to just watching the planet gradually heat up and become hotter and hotter? It would be quite ironic if our very advanced analytical civilisation became extinct because we thought we couldn't make a profit out of saving ourselves.

So, "too expensive" is a strange concept. More expensive than now? Yes, that’s correct, and I’m quite happy to agree with that. But that’s in the same way that I’m very happy to pay my local authority to take away my rubbish. I don't tip my rubbish in the street, which would be cheap. More expensive is to pay somebody to take it away and store it permanently. That’s an analogy for putting carbon dioxide up into the common atmosphere. Right now, we’re not paying to store it properly. But we can pay a little bit extra to store it safely and securely underground.

There are a couple of examples to illustrate this. If we take the idea of decarbonising petrol, let's say petrol is sold for £1.50 per litre, about half of which is tax. If we wanted to decarbonise and capture the carbon dioxide and store the carbon dioxide from burning all of that one litre of petrol, the price would increase to £1.70. This makes it more expensive, but that's well within the normal range that petrol prices have shifted

So, when people say it’s too expensive, I think it’s just not really thought through, in my opinion.

**HŽ:** *If we introduce a carbon taxing mechanism or even more extensive emissions trading, does that not lead to inflation and larger-scale economic problems for the entire system?*

**SH:** No. I think the use of carbon capture and storage is to enable us to carry on using fossil fuels over the next 20, 50, maybe 70, or even 100 years as we work to get rid of fossil fuels entirely out of our system. And that will be done by making fossil fuels more expensive. The key point is not to charge for emissions but to pay for storage. It becomes a profit-making activity where people coming out of oil and gas companies can, with the same skills but perhaps a different motivation, create new companies which handle carbon dioxide in the same way that oil and gas are handled: “pipeline” it and inject it through very similar boreholes to those used for oil and gas. That puts the carbon dioxide back underground and removes it from our ecosystem. Paying for that to be a benefit, I think, is the key point.

Some of our research looks at the economics of making this happen. We’re asking how to make paying for storage more attractive and more rewarding than being penalised for emitting. Being penalised for emitting clearly hasn’t worked. It’s been operating in Europe since 1997, and it’s resulted in precisely zero carbon capture and storage operations. What's happened there is that companies that emit carbon dioxide are just choosing to pay slightly higher prices to carry on behaving badly. Whereas we are trying to find a fundamental way of changing the polarity to be rewarded for behaving well.

**HŽ:** *If you had to say in a single sentence why your area and type of research are so important, what would you say?*

**SH:** We're in the carbon wars. So, if we're fighting against too much carbon, we want to be in there doing the technical, scientific stuff to make it smarter.

**HŽ:** *And what value do you personally see in Energy at Edinburgh, which you are part of?*

**SH:** Well, one of the great things about Edinburgh University is its huge diversity of people from different corners of the world, but also diversity in the skills, techniques, and knowledge which people can bring. If you've got a problem and you're in a meeting room in the middle of Edinburgh, within three phone calls, you might find an international expert who can help you.

**HŽ:** *Thank you very much for the interview.*

**SH:** Thank you.