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Welcome to IFLScience, The Big Questions. In this episode, host Eleanor Higgs is joined by the co-founders of Carbon Neutral Fuels, a company that sets its sights on revolutionizing the future of the fuel industry in an effort to help offset climate change.

I: Sophie and Alastair, thank you very much for joining me on IFLScience, The Big Questions. To start off, please could you tell me a little bit about yourselves and about your business and lets kick off talking about that. So, Sophie, if you want to go first.

Sophie: Brilliant, thanks for having us. I have a background in chemistry. I did a bit of a stint in the nuclear industry working on medical radionuclides, but found that my real passion was in trying to understand how we can be part of the solution to solving climate change and was fortunate enough to attend COP26 in Glasgow in 2021 and met Alastair and we had some great conversations about how can we help save the world, and that's really where Carbon Neutral Fuels came about.

Alastair: Great, thanks Sophie. Yeah, so I met Sophie at COP26 and my journey on how I came to be at COP26 was an interesting one. Fifteen years ago – no, more than that, twenty years ago, almost, I studied computer science and absolutely loved doing that, and I started a company that did cloud computing which I ran for 15 years. And in parallel to that I've always had an interest in energy, and around university time I discovered this thing called peak oil which said we're going to run out of oil, and I read all these books about it. Got really really really into energy and so in addition to running my company I started attending conferences and that led me to the world of nuclear, and then through that route to COP26. As Sophie mentioned, we discussed starting a company, and so about eight months ago we started Carbon Neutral Fuels.

I: Wonderful, so a real meeting of minds at COP26 is where it all started. So, what is a carbon neutral fuel?

S: Carbon neutral fuel is…well what we are trying to achieve is helping be a part of the solution to climate change and our ambition is that we are sequestering carbon dioxide from the atmosphere, and then combining that with clean hydrogen and ultimately outputting a carbon neutral fuel in the sense that when you burn the fuel you are then releasing CO_2 and then that is captured back in as a feedstock. Our target market for that is going to be aviation industry because there's obviously a huge amount of fuel that's used in aviation. What we would really like to do is see our fuel being used as a sustainable alternative.

I: Amazing. So, this kind of term, carbon neutral fuels and e-fuels, is this sort of interchangeable or is it different? What's going on there?

A: Absolutely. The terms e-fuels comes about, I think, because the fuels are often made using electricity and with traditional fossil fuels, nature has done the energy collection for you. Plants basically collect sunlight, that process has happened over hundreds of millions of years, those plants have decayed into the ground and become oil and coal etc. We haven't had to do any energy creation, we just come along and dig it up or stick a straw in the ground and it's effectively a free energy supply, and unfortunately, this is having the unintended consequence of filling our atmosphere up with all this excess CO_2 which is obviously causing climate change. So, what you can do artificially or synthetically is suck down that CO_2 and turn it back into fuel, but you need to put energy in to do that and that's where the 'e' part comes from in that part of liquid fuels usually use electricity to make those fuels. It obviously has to be low carbon electricity, you can't burn fossil fuels to make fossil fuels, that doesn't really make sense. So, in our case. We're looking at renewable energy or potentially in the future, advanced nuclear.

I: Incredible. At the moment the aviation industry runs on Kerosene, is that right?

A: Yeah absolutely.

I: So, what you're looking to do is replace this Kerosene with an e-fuel, a carbon neutral fuel.

A: That's correct, yeah. We can talk you through what the process looks like.

I: Yeah amazing, please do.

A: It's quite interesting. The first step is capturing the carbon. When we started the company, we were actually looking at a technology pathway for sucking CO_2 out of the oceans. One of the nice things about CO_2 in the oceans is that it's quite concentrated. It's about 100 times more concentrated and the reason for that is around half or maybe 40 percent of the CO_2 we've emitted has been absorbed into the oceans and it stays at the surface level, which is where that concentration comes from so you can just stick a straw in and suck it out. Liquids take up a lot less volume, maybe around 1,000 times difference between a gas and a liquid phase, and so again, you have those efficiencies. But that technology pathway wasn't established, wasn't mature, wasn't going to be ready in the timescales that we were looking for so, we looked at direct air capture and we're looking at partnering with some direct air capture companies. They use these adsorbents and so they will react with the CO_2 in the air and then you use another technique to release the CO_2 from the adsorbent and that gets you a nice clean stream of CO_2. Sophie touched on this, you also need hydrogen and so a lot a people might remember from chemistry class maybe doing electrolysis, where you stick an anode and a cathode in a beaker, shove in some electricity and you get oxygen, I can't remember if it's the anode or the cathode, and you get hydrogen at the other. So, we just collect that hydrogen, and these days you can buy pretty beefy electrolysers anywhere from 1 megawatt up to hundreds of megawatts. Once you get the CO_2 and the hydrogen you need to smoosh it together somehow. CO_2 is very stable as a molecule, it doesn't really want to do that, so if you can convert that to carbon monoxide and you can combine that with the hydrogen, that's syngas, and syngas is very commonly used in the chemical industry. Once you have your syngas, you can stick that through something called a Fischer Tropsch reactor and that does the smooshing. The way that works is that it's got a typically an iron or cobalt catalyst and it just starts growing these long

chain hydrocarbons. Depending on the configuration of the reactor, the conditions, the pressure, the temperature, the catalysts, you can determine what distribution of hydrocarbons you get. So, the technology we're looking at will predominantly produce things in the Kerosene range.

I: Amazing. So, how long is this process theoretically going to take? If you're capturing carbon from the atmosphere, putting it into this electrolysis, you're adding hydrogen, you're smooshing it all together, and then at the end you're ending up with a…I don't know, a gallon or two gallons of e-fuels. Is it like a physical liquid that you could see and pour into an aeroplane?

A: I believe so, yeah. Kerosene is clear, Sophie? Hydrocarbon is typically clear, I guess.

S: I don't know. I guess so. It's a good question, we'll let you know when we've made some.

A: In terms of the process, it's kind of a steady state operation. So, once you get everything built it will be capturing the CO_2 and feeding that real time into the rest of the system and the hydrocarbons will come out of the bottom of the Fischer Tropsch reactor vessel. You also make methane, which is kind of a waste product. You need to recycle that back in, not all the CO_2 reacts, and the hydrogen, so you need a process for extracting the bits that haven't been used and funnelling them back in. And we're quite early on in our journey to do this. We started the company less than a year ago and so we've also been on a bit of a business adventure, and that business adventure has been speaking with fund raisers to raise money, investors rather, we're the fund raiser and then, what else have we been doing?

S: Well, yeah, there's a little bit of everything we've had to work on really. Because power to liquids is such a new process, there isn't a huge amount of precedent that's been set in the UK in terms of how to go about building a facility. So, it's been engagement with government, The Jet Zero Council for instance are championing the work about how to develop a market and to grow a market as well, important thing, because aviation is obviously an international industry and as the UK, we would like to lead that charge in terms of sustainability. So, they've been doing a huge amount of work. We've been talking to investors which has been really fascinating. I've never raised any money before so learning all the terminology and learning the processes and the rules and regulations and the hurdles that you need to jump through to actually make this a reality has been really fascinating. We're also conscious about research and universities and how that detailed element of the science comes into play.

I: Of course. Because it's so brand new, there's not a framework that you can build upon yet. You are essentially making that framework; maybe other people will build upon what you discover in a few years.

A: What's quite interesting is that a lot of the technology pieces have already been invented. For example, Fischer Tropsch's chemistry was invented close to one hundred years ago and they originally used it to convert coal to liquid fuels. And so, that technology is established, but it wasn't widely used because we've had abundant liquid fuels and it's been some countries that didn't have easy access to liquid fuels. So, South Africa for example and Germany have used it. Then there's also electrolysers, because of the whole green transition, those are now becoming

widely available and then carbon capture as well now. So, all it's taking, hopefully for us is to come along and integrate those technology pieces together to have a complete system for doing this.

I: So, you're basically combining older technology used for a slightly different purpose and you're now re-purposing it to make these long chains of hydrocarbons and to make your e-fuel?

A: That's right. And one key thing that is enabling this is that the governments worldwide, including the EU and the UK are looking at introducing mandates to require people to uplift sustainable fuels, because traditionally, these sustainable fuels cost a lot more than the free fossil fuels we're getting. To process fossil fuels, you just need a distillation column and that's really just about separating out the different weights of the fuels, the light fuels versus the heavy fuels, whereas for us we're actually creating these fuels from scratch and that's very expensive to do. But with the mandates it's going to compel airlines basically to have to uplift some of this fuel and that will enable the development and that will enable us hopefully to bring the price down over time.

I: So, with these fuels, let's say we're a little bit further down the line and you're producing this Kerosene, this e-fuel, could you go to Richard Branson or, you know, United Airlines and say, "I've made all of this fuel. This is much better for the environment, it's carbon neutral, let's put it in your plane," what would he say to that? Would that even be possible?

S: That is possible, yes, absolutely. It exists, to a certain extent, today. You have a thing called a blended fuel which is where the majority of your fuel will be traditional Kerosene but then you're slowly blending in biofuels and other sustainable alternatives and hopefully, over time, the amount that is blended will increase in percentage terms. So, one day it would be great if 100 percent of fuel was SAF, but then you have to think about the implications on the aircraft, for instance. So, traditional Kerosene, or fossil fuel Kerosene, actually contains a lot or a certain amount of impurities, things like sulphur and the nasties, I suppose we would call them, but actually they serve a lot of valuable functions in the actual engine of a plane in that they act as lubricants and you need them to be there in terms of the safety requirements because it's what the plane has always been used to. So, if we then come along and produce our fuel, whilst the blended mix is fine, getting to 100 percent SAF will have implications that we aren't necessarily aware of at the moment. So, there's a lot of testing going on to get us to that point but currently it's not quite there.

I: You just mentioned the term 'SAF'. Is that what you're referring to as your e-fuel?

S: Apologies, yeah, SAF is sustainable aviation fuel. It's sort of an umbrella term.

I: Sustainable aviation fuel, ah, perfect. I'm in with the lingo now, I've got all the acronyms.

A: Sustainable aviation fuel, it's worth mentioning, encompasses many different types of fuel. So, there is biofuels, made from the growing of crops. There's HEFA fuel which is made from waste oil products, like cooking oil and more recently, in a bit of an act of desperation they're looking

at household bin bag waste as a potential carbon feed stock to make sustainable fuels which I think is a little bit sketchy because that is carbon that was going to landfill to stay there and we're talking about turning that into fuel, effectively throwing it into the air as carbon dioxide. But certainly, the majority of sustainable aviation fuel that's going into planes today is biofuels. We are starting to see sustainable fuels entering the market. Another thing that's worth mentioning is that our cars today, if you go to a forecourt in the European Union, including the UK, around 10 percent of the petrol in your car is made from bio-fuel sources. Aviation is looking to move up to 10 percent between now and 2030 and our specific type synthetic fuels, e-fuels, that's a more expensive way of doing it than bio-fuels and so the mandate is going to be point one of a percent by 2030 but it's the cleanest way to do it because you don't need a lot of land, you don't need fertilizer, it doesn't compete with food crops so you're not driving up food prices. So, there's a lot of benefit to power to liquid fuels but it is the newest and the most immature technology.

I: This is what I was going to ask you, because you think of normal Kerosene, fossil fuels are big production plants, they've got oil rigs out in the sea sucking up the fuel like you said but, on a scale, is it going to be the size of a football pitch, is it going to be the size of Manchester. How big a production plant would you need to reliably produce this e-fuel?

S: We would like to keep it as small as possible because we think that much like the nuclear industry, there's a lot of time and a lot of money and a lot of effort that goes into producing these massive installations which, once they're up and running are fantastic but actually the time and the cost to the environment to actually get them to those places is quite extreme. Whereas, if we look at the modular side and actually say lets think about scaling and growth in terms of amount of units versus scale of units. We think there is a real opportunity there. So, size wise you're looking at quite small installations. We're doing the design studies currently, but we can't be too specific, but we're looking at shipping container module sizes plus the land around that you would need to actually do these things. So, it's not going to be massive by any stretch of the imagination and I think that's where the real opportunity for growth and actually having a big impact on climate change can come into play.

I: Absolutely. I was imagining much bigger but then I think I've already scaled it up in my head to fuel the entire global economy of aviation fuel. Because this technology and this process is so new, even a shipping container size could cause a massive difference, couldn't it?

A: Yes. I think the scale will depend on how much fuel you want to produce and the UK uses about 15billion litres of aviation fuel every year and they're targeting 10 percent sustainable by 2030, so that's 1.5 billion litres. We are targeting for a small demonstration plant around just under 1million litres.

I: Amazing. I suppose I should ask you, has anyone beat you to the punch, are people flying planes with your SAF fuel in it, or obviously not your SAF, fuel but SAF fuel made in this way, from power to liquid at the moment?

A: There have been test flights. Certainly, with traditional biofuel based SAF there are planes taking off with that today and certain airports have a very small percentage in their fuel tanks in

the airports. So, any planes that land at that particular airport will uplift a plane with some SAF but with power to liquids it's been mostly test flights and there's companies in the US, there's one other competitor in the UK that was working with the RAF and they flew an RAF test flight on their power to liquid to fuel, so there is precedents.

I: Amazing, that's very exciting. I was going to circle back to the process. Because when you burn it in an aircraft, lets say, you're still burning CO_2. CO_2 is still produced back into the atmosphere so it's not…what am I trying to say? It's carbon neutral because then you're taking that CO_2 back out to recreate it? Is that right? Like an electric car, the way that works would be that it's not producing CO_2 when it runs, right? But your planes are still making CO_2. Please feel free to correct me if I butchered that explanation.

A: No, that's absolutely right. The plane burns the fuel, it emits the CO_2. We effectively un-burn it and turn it back into fuel and it's recycling. We are effectively recycling the CO_2 and it goes round in this circle and there is no net increase in CO_2 emissions and you're displacing fossil fuels where traditionally that CO_2 was stored underground and when you put that in a plane it then releases it and so the overall CO_2 level goes up. There are some challenges still with these fuels in the sense that the engine may still produce nitrous oxides. When you have heat in an engine it can smoosh some nitrogen together and oxygen and NOx is not necessarily what you want at ground level. So certainly, electric cars are great because you're getting rid of the NOx, you're getting rid of the CO_2 and you're getting rid of all the unburned things, but the challenge with aviation is that it doesn't have a lot of options to decarbonise really quickly between now and 2030. There are no electric planes or hydrogen planes in service today with passengers on board. They are developing them but the big problem is energy density, and batteries are orders of magnitude less energy dense than a liquid fuel. I heard an amazing stat, I've not fact checked this but apparently to fly the weight of a battery requires more energy than the battery has. So, electric planes are quite challenging but I think there are some electric plane companies and hydrogen plane companies that are making a lot of progress and it looks like we may get those sooner than you think, but those are going to be for short haul with smaller passenger numbers. I think electric planes are going to be great for these short haul flights but it's going to be quite some time until you see all the planes in the sky going down that route. So, e-fuels are a fantastic bridge technology to rapidly decarbonise aviation. Another great thing about it is what when you replace a plane, a plane might have a 30 year lifespan and you've used all this CO_2 to make the plane and in refining the metals and manufacturing it, so if you have to replace that plane with a new electric one, that also uses all those CO_2 emissions so it makes sense to run these things to the end of their useful life and if you can stick in a carbon neutral fuel then that's great.

I: I was just going to say, I think it's almost better because it's requiring less change, you're blending these fuels with what we have now. It's slowly integrating in and the more the technology involves, the more companies like yours evolve, it's going to be easier to transition away from fossil fuels and into power to liquid fuels.

A: Yes. And you can make any kind of fuel. For example, there is a lot of talk about how do we very quickly move away from methane, natural gas in peoples' homes for heating and cooking and heat pumps are great but they are very expensive and often you need a big overhaul. In

theory you could make methane and you could just feed carbon neutral methane into the gas distribution network. So, there's many other places you could deploy this technology as a bridge technology to buy us time whilst we transition to alternatives.

S: There's also…blue sky thinking…what can you do once you've got those facilities established? This process is carbon neutral but actually what about being carbon negative and how can we actually take this technology one step further and what would that look like in ten, fifteen, twenty years' time? And wouldn't it be cool if these facilities are located near abandoned oil wells and they're then pumping extra CO_2 back down into the ground. So, you're making fuel but you're also sequestering. That would be really awesome. So, there's loads of opportunities and ideas that we haven't even thought of yet as humans that we don't know what we're going to do. So, once we've got this technology established then we can leapfrog to anywhere really.

I: I love the idea of it being carbon negative, eventually be sucking so much CO_2 out of the climate that you would be making a really big difference and even sequester that as well. Incredible. What are the biggest challenges, do you think, at the moment facing this sort of new technology, this e-fuel industry in terms of aviation?

S: For us, the one that we are definitely encountering is having a provable market that means investors are wanting to invest. You can obviously understand concerns around, well this is a thus far unproven technology, despite the fact that the individual components are proven. Actually, putting it all together and having the funds to set up a facility is expensive and it takes a very brave, a very conscious investor to actually say yes, we think this is a good idea. So, funding is tricky but I think with things like Alastair mentioned, the mandates, earlier, things like that really help because it gives validity and it gives confidence to people that we don't otherwise have currently. So funding is a big one, but there are solutions out there.

A: We've also just applied to the Department for Transports advanced fuels fund. The Department for Transport is doing a lot of work looking at how do we decarbonise aviation and they set aside quite a large pot of money, 165 million, to fund sustainable aviation fuel projects. That includes biofuels and bin bag waste to jet fuel project. They didn't manage to spend all of the money in window one and so we've applied in window two, and window two is for 55 million, of which half of that is going towards power to liquid projects specifically. So, we've got our fingers crossed for that because that really will help us. That funding being available has also demonstrated to private investors that government takes this seriously, they believe in the technology. So, it's all working together to help this new emerging field take off.

S: Other challenges are around electricity supply. Electricity in the UK is really really expensive and there are clever things that you can do to secure contracts, not necessarily going via a commercial route, you go through slightly different avenues, so there are things you can do but fundamentally electricity is really expensive and electricity is a massive component of this technology process. But again, because I love a solution, there are alternative options out there, so things like small nuclear reactors are really exciting because once they are up and established, there is going to be a whole host of low carbon electricity out there that people like us can capitalise on. There's also a lot of opportunities in Scotland and places like that where you have an excess supply of electricity that if we can tap into, and this will all come out

in our funding and our design studies, but if we can tap into places like that, then that will really really help. At the moment that is a challenge.

I: Because you need the initial electricity to create your fuel to be green otherwise there's almost no point, is there, because you're then burning the fuels?

S: Exactly, yeah.

A: So effectively, what we're going to be doing is converting electrical potential energy into stored chemical potential energy because as we know, the first law of thermodynamics says energy cannot be created or destroyed, it can only be converted from one form to another.

I: I remember that from way back when.

A: Yeah, it's the only law I can remember.

I: Well, the only one you need for your business.

A: Yeah.

I: I was just going to ask you about safety. Obviously, this is very new, the facilities aren't built, there's so many myths and worry even around nuclear which has been around for much much longer. Are you finding opposition in safety concerns? Are people worried because they don't understand? What's going on there?

S: That's a really good question actually. I think there are a few elements to the whole safety thing in that, as we've mentioned before, the discreet components of the process are proven and they obviously already have existing rules and regulations that surround them and there are very clever people that understand all of that. I'm very confident that within each of those components that they are safe processes. But you're right, when you put it all together, what does that look like and how do you regulate for those things? In the UK we are a really heavily regulated industry and as I mentioned, my background is in nuclear, so very acutely aware of all kinds of regulations that you have to follow but I think the good thing that is coming out of all these things is that climate change is such a pressing problem and such an urgent issue that we need to address that actually, we are being a lot more logical and a lot more sensible about how we address safety concerns and we are looking at it with a bigger picture and going, 'this is a massive safety problem in terms of the security of the world. Let's talk about how we enable those processes that are going to help it. So, we haven't got to that stage yet, but I'm pretty confident that the right process will be in place.

A: It's worth mentioning that the chemical engineering discipline that we're going to be employing has standard processes and practices for designing chemical plants, and part of that includes… so we're going through what's called a front end loading process, where you try and do as much of the front end design of the plant prior to engaging with an engineering company that will actually build it and part of that front end loading process includes things like HAZOP's, which involves looking at your hazards. For example, solid oxide electrolysers which we are hoping to use, they operate at very high temperatures. You might not necessarily want

to put those next to your hydrogen storage tanks, for example, and so this whole process will look at the layout of the plant and making sure that it's designed to be as safe as possible.

I: Yeah, I was thinking about the hydrogen. Obviously, it's gets combined and smooshed together with everything else but as soon as someone says hydrogen, I just imagine those great big airships from the wars and that sort of thing which obviously did not go well but I'm sure…yes, once you've had all these regulations and all these conversations with lots of other people about the best and the safest way to make this. I was wondering, how far away do you think this technology is from becoming mainstream? How long do I have to wait before I get on a flight to my nice holiday in the sunshine and the plane is powered by mostly e-fuels, or mostly SAF fuels?

A: I think by 2030 you will start to see very small amounts in planes. The UK government has said it has to be .1 of a percent of the fuel tank has to be e-fuels. KPMG put out a report that said to meet our net zero ambitions by 2050, that PTL (so power to liquid) fuels will need to be at least 40 percent of a planes tank or 40 percent of the total global supply will need to be power to liquid fuels. It's going to depend a lot on the country, on how this roll out goes, how electric and hydrogen planes go but I am pretty confident within five to ten years you'll start to see noticeable amounts of power to liquid SAF coming out. Whether we will get to 100 percent or when we will get to 100 percent, I am not sure and how much of it will be biofuels versus power to liquid fuels remains to be seen. The airline industry is very price sensitive. They want ticket prices to be as low as possible and fuel makes up a very large percentage of the ticket price, especially for long distance flights. So, power to liquids, as I mentioned, it's one of the more expensive ways of doing it so you might see if fossil fuels are squeezed out, there may be 75 percent biofuels, 25 percent power to liquid mix ratio. But the KPMG report that we saw, they thought that biofuels can't be scaled to the size required for this industry and therefore power to liquid, which don't suffer the same constraints might take over in the future. So, it might be 75 percent, 25 percent, in favour of power to liquids.

S: Having said that though, there is actually a planned flight which is being run by Virgin Atlantic in November this year, and obviously it's a one off and it's been a huge undertaking I'm sure by all the teams involved, but they are planning on flying from Heathrow to somewhere in America, I believe, purely on SAF, so that is 100 percent blend. So, it won't be mainstream for a very long time but there are things happening and that is happening in 2023, so that's pretty exciting.

I: That's amazing, I've learned so much that I didn't even know I didn't know. Thank you both so much. Is there anything else that you want to add before we wrap up?

A: No, I think we've covered most of it pretty comprehensively. One interesting thing about aviation, and I think this is quite fascinating. Contrails actually contribute quite a lot to the warming effect of taking plane flights and that's water vapor. The reason contrails form is quite often the ice crystals form around soot and dust particles. So, impurities in the fuel can contribute to making contrails. But sustainable fuels have a lot less impurities, and so power to liquid fuels should hopefully reduce contrails. We don't have the studies of the evidence yet, but in theory it should reduce the contrails and that's quite interesting. We also saw a talk that

said contrails can be minimised or almost entirely reduced by modifying flight plans and changing routes. So potentially, through technology deployments alone and smarter routing of planes they might be able to reduce that particular warming effect as well which is quite interesting.

I: That is so interesting, I would never even have thought of contrails as a problem, as anything really other than lines in the sky. So that's fascinating that contrails could be a thing of the past in the next ten to fifteen years because of this new technology.

A: Fingers crossed.

I: Brilliant. That's so exciting that we might, you know, have commercially available featuring e-fuels and these carbon neutral fuels within the next ten years, if not sooner, so thank you Sophie and Alastair for joining me. I've learned an enormous amount so it's been brilliant to have you both on.

A: Thank you very much.

S: Thanks very much.

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