Biological Carbon Capture Part 2

Brian: Hello everyone, and welcome to episode 70 of the HydrogenNowcast for February 10, 2023.

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Today we have back with us for a second time, Richard Sayer, PhD, who's a biotechnology scientist formerly with Los Alamos National Labs, who's a recognized expert in the field of biological carbon capture. Richard, welcome back to the show.

Richard: Well, thank you Brian, it's great to be back again.

Brian: Well, we really appreciate your time to do this a second time because I know how busy you are. Maybe Richard, if you could bear with me a minute, I'd like to give listeners a recap of our first podcast, which was episode 51 on April 29 of 2022.

In that podcast, we talked about how algae can efficiently capture carbon dioxide, either from high concentration point source emitters or by direct air capture from the atmosphere. And we also talked about the specialized algae strains that you and your colleagues have hybridized. And we went on to talk about using Quantum Dots to frequency shift light wavelengths, and of course by wavelengths we mean colors in order to make photosynthesis more efficient. And we also talked about the income producing products that can be made from algae, such as biocrude oil, animal feed, and chemical coproducts that can be used in countless numbers of industrial products.

We talked about how algae strains, the support infrastructure, and harvesting and processing techniques have all been well developed and are ready for commercialization. And I really encourage the listeners to go back to episode 51 from April 29, 2022 and listen to that podcast again.

But what we didn't do in that podcast was that we only briefly touched on the infrastructure needed to start commercially deploying the algae things such as saltwater ponds – the quantum dot films, and the harvesting and processing equipment. So that's why I've invited you back to the podcast a second time, so we could give listeners, which, by the way, I hope includes some entrepreneurs and some investors, a better idea of the infrastructure needed to start commercially deploying this essential and critical technology to capture carbon dioxide from the atmosphere.

It's really pretty well recognized now that in order to avoid a climate catastrophe which could possibly put an end to civilization as we know it, it's not enough to simply stop emitting carbon dioxide and other greenhouse gases. We've got to remove massive amounts of carbon dioxide already in the air. Now, people have proposed machines to do that, but the scale of the problem is simply too vast for machines. But there's another way to remove the atmospheric carbon dioxide, and that's by using biology, and specifically algae. So, Richard, why algae?

Richard: Well, thank you, Brian. That's a great question. So we have two options for biological carbon capture and sequestration. One, of course, is terrestrial land plants, and that includes agriculture and forest. And the second option are the aquatic photosynthetic organisms. In other words, the algae. It so happens on an aerial basis. In other words, per unit acre, algae have the potential to capture carbon dioxide at a fivefold greater rate per unit land area than do trees or agricultural crops. And it's for that reason that we're all excited about developing commercial systems for growing algae at scale that will allow us to capture carbon, not only to sequester the carbon, but also to produce valuable coke products.

Brian: Okay. Well, thanks, Richard. I know last time we talked, you also mentioned that algae, really, the entire plant, was dedicated to capturing carbon. And with land plants, of course, you have things like roots and stems and fruit and things like that that don't really contribute to the photosynthesis. So that's another reason, I think, that algae makes a pretty good way of capturing carbon.

Richard: Yes, indeed. But also, it so happens that the efficiency of converting light energy into reduced carbon, which is what we're using to capture the carbon dioxide, is more efficient in algae. So algae are able to actually actively pump carbon dioxide from the atmosphere into the interior of the cell. And by doing so, they actually suppress a process that reduces the efficiency of photosynthesis. And this process is generally called photorespiration. But what photorespiration is, is the competition of atmospheric oxygen for direct reduction by the photosynthetic system in competition with carbon dioxide. So oxygen actually suppresses photosynthesis, and it can suppress it by 40% to 50%. Algae figured a way to get around that problem of oxygen suppression of photosynthesis, and they do that, again, by actively pumping carbon dioxide from the exterior environment into the chloroplast where photosynthesis takes place. And by doing so, they competitively inhibit oxygen reduction and the process of photorespiration. So this gives algae a big advantage, in addition to what you mentioned earlier. And that is, of course, that they have all the biomass, essentially, of the algae is actively photosynthesizing, in contrast to plants, in which a large fraction of the plant material, of course, including stems and roots, as you mentioned, are actually not carrying out photosynthesis.

Brian: Great. Yes, thank you. And there's one other point I'll bring up that we did talk about last time, and that is that it's pretty easy to turn algae into cash crops. I mean, any plant obviously has some use as a cash crop, but with algae, it's pretty easy to turn that into biocrude or animal feed or some other things. And the nice thing about the biocrude is we could sequester that by pumping it into the ground or we could even use it for carbon neutral. I'll call it hydrocarbon fuel of some kind and we'll talk about that a little bit.

Richard: Yes, indeed.

Brian: All right, Richard. Well, why don't we start out by walking through the steps of the actual propagation and harvesting of the algae. I'd like to try to give listeners an idea of really the mechanics maybe of what that looks like and what it will take to actually process that algae and then what's the infrastructure that's needed to support that, the ponds and those kind of things. So I know we talked about using quantum dots to intensify the light, so why don't we touch on that as well?

Richard: Okay, very good. Well, over the last 15 years, there's been a lot of research effort focused on the best way to cultivate algae. The most economical, the most sustainable, and the most stable way to actually produce algae at scale. And over the last several years, there have been really two competing technologies for growing algae and those are what are called photo bioreactors. And then the open pond system. The Photo-bioreactors are more or less glass tubes or glass containers that contain the algae. And they contain the algae in a very controlled environmental condition. Temperature is regulated, nutrients, gas exchange, and so on. And under these conditions, you can actually nearly double the biomass productivity compared to an open pond cultivation system.

However, what we've learned over the last five years is that these systems really cannot compete with open pond systems on a commercial basis. The operation and capital costs for Photo- bioreactors are estimated to be two and a half times more expensive than the open pond systems.

So the open pond systems then fall into two categories, and that is growing algae with freshwater or growing algae with marine (salt) water. And it's now clear that from various lifecycle and technoeconomic analyses, again, the most cost-effective way of growing algae is in an open pond, but using marine algae. And those ponds then in turn are also located near a source of marine water. And that addresses one of the major cost parameters for growing algae, and that is the cost of water.

So ponds obviously are losing water through evaporation. That has a positive benefit because it allows for evaporative cooling of the pond, and that keeps the temperatures more near air temperature. But there's a cost for that water, of course. And if you're near a marine source of water, then it's a virtually unlimited source of water for replacement. So it's now clear that these open ponds need to be located near the ocean effectively. And furthermore, they probably need to be located at latitudes of 15 degrees north and south of the equator and not much farther north or south of 15 degrees latitude. And the reason for that, again, is the availability of sunlight throughout the year. So, of course, closer to the equator, the duration and intensity of light is greater than it is at higher latitudes than 15 degrees. And of course, the temperature is more ideal for growing algae near the equator.

So we're looking at siting algae growing ponds near marine environments, near the equator, as far as 15 degrees north and south of the equator. And one of the issues is, of course, what do these ponds look like? Well, they more or less look like horse track or horse racing tracks, let me put it that way. They form a loop, and the water is moved continuously using a paddle wheel that's located at one end of this racetrack where the algae circulate around and around. And it's important to keep the algae moving so that they don't settle in the pond, because that would reduce the availability of light for algae at the bottom of that pond. And it's also important for aeration, and for two purposes. One is to get carbon dioxide into the water, and the second reason is actually to get oxygen out of the water. So as algae capture carbon dioxide, for each molecule of carbon dioxide they capture, they actually produce one molecule of oxygen. And that oxygen then can accumulate in the pond. And as I mentioned earlier, oxygen reduces the efficiency of photosynthesis, first by competing with carbon dioxide for reduction by the photosynthetic apparatus. But in addition, oxygen can be toxic to cells at high concentrations for a variety of other reasons that will reduce the productivity of the algae. So getting rid of the oxygen is important.

Now, one of the other important parameters for growing algae and open ponds is light availability and light penetration. And as you mentioned, Brian, photosynthesis only uses certain wavelengths of light, and those are predominantly in the blue light region of the spectrum and also in the red light region of the spectrum. But there's a lot of light that's not captured by photosynthesis, including green light. In fact, that's why plants and algae look green, is they don't capture that light, but also ultraviolet radiation as well. And so if we could shift the frequency of light that's not used by photosynthesis, such as ultraviolet light or green light, to wavelengths that is used by photosynthesis, then we could potentially increase the number of photons coming into the system from the sun. And so that's where the quantum dots come into play.

One of the technologies that we and others have considered for increasing biomass productivity is to impregnate plastic films with what are called giant quantum dots. And these giant quantum dots are actually quite small. They're nanometers in size, so very, very small. But what they are is a metal particle that will absorb light at one frequency and then reemit that light with nearly 100% quantum efficiency to a wavelength of lower energy. And that results in the frequency shift from one color of light to another. So, for example, if we had a quantum dot that absorbed green light and we shifted it to orange light, that orange light has lower energy than the green light, but we would still be generating as many photons as was incident upon the giant quantum dots. And so that would increase the amount of light available for photosynthesis.

Now, these quantum dots have already been impregnated into films and there's a company here in Los Alamos, New Mexico, called Ubiqd that now is commercially producing these films impregnated with giant quantum dots for use in greenhouses. And what they do is they again increase the amount available photosynthetically active radiation by frequency shifting it, but they also diffuse the light. Those two processes, frequency shifting and diffusion, allow the light to penetrate deeper into the plant canopies for plants that are grown in greenhouses. And so that makes light available at a deeper part of the plant architecture than normally would occur. Well, the same thing could happen in a pond. So we could increase the amount of light, we would diffuse it so that it would penetrate deeper into the water.

One other potential useful application of these films, though, has to do with reduction in pond evaporation and maintenance of pond temperatures at night. So photosynthesis obviously is not going on at night. There's no light available, and water evaporation is occurring at night as well. So the thought is that these films could be dropped over the surface of the pond, effectively sealing them at night. And that would accomplish two things reduce water evaporation potentially by half and also maintain the temperature in the pond more efficiently, so that in the morning, when the sun comes up, the temperature of the pond is ideal for photosynthesis to occur.

There's one caveat, though, with all of this, and that is actually an important caveat. That is all photosynthetic organisms actually light saturate their photosynthesis at one quarter full sunlight intensity. That includes terrestrial plants, algae, seaweeds, you name it. They all have this problem that they only can use 25% of the light coming in. They absorb all that light with their pigments, such as chlorophylls and so on. But they can't use that light because of downstream bottlenecks in rates of electron transfer in photosynthesis. So the rate of light capture is actually about ten times faster than the photosynthetic apparatus can actually use it. So while I've been talking about increasing light in a system to improve photosynthesis, it has two issues. One is by increasing the light we may have it penetrate deeper into the pond. And so algae at the bottom of the pond will have more available light. But we've also got the issue that well, at the top of the pond the algae are going to be light saturating and they're going to waste that energy that they capture. So our group has developed a genetically engineered algae that solves that problem. Of too much light coming into the system, and it does it in a very elegant way. What we do is we engineer the apparatus that actually absorbs the light, which is a protein that contains the chlorophylls, and we change the size of that, what's called antenna, that actually captures the light so that it is optimized to capture light at a rate that is comparable to the rate of photosynthetic electron transfer. In other words, every photon that comes in and is captured by the chlorophyll pigments is used efficiently without being reradiated out of the system as heat or as fluorescence. In other words, a wasteful loss of that energy that's already captured. And we do that by continuously adjusting the size of this antenna that actually captures the light for the photosynthetic system. And by continuously adjusting the system, it allows the algae to grow at higher efficiencies. We've shown in simulations in what are called photo-bioreactors that mimic upon production system that we can actually double and nearly triple the biomass yield by making light harvesting more efficient so that every photon is used to drive an electron transfer process that leads to the conversion of carbon dioxide into biomass. So this system is really ideally set up for the giant quantum dots that I mentioned earlier. And that is, as we increase the light intensity, our system with these engineered algae can actually respond to that in an appropriate way and use those extra available photons to produce biomass. One last comment on this subject, and that is that very recently it was discovered that there are some natural strains of algae, there are at least two that have now been published that can effectively do what I described that we engineered into transgenic algae. And that is these natural algae have now been shown to be able to self-adjust the size of their light harvesting antennas to optimize photosynthetic efficiency. And these algae that do this, and there are just a few examples known in the literature are actually the most productive algae that have ever been identified. So while we went ahead and engineered an organism that's incapable of adjusting its antenna size and this was done about three years ago, now it's more recently been discovered that there are actually some algae that do this naturally as well.

Brian: All right, thanks Richard. Well, it sounds like the algae exists and is basically ready for commercialization. And as you pointed out, there's a company now in Los Alamos, New Mexico, making the quantum dot films. I'm trying to picture these ponds. You already said they're kind of long and narrow. They look like a racetrack, and I'm picturing like a greenhouse roof or something above the pond. You mentioned maybe lowering that at night to keep from losing heat and as well as stop evaporation, would you say? That's a pretty fair characterization of what these look like, and this really is ready for commercialization?

Richard: What we imagine is actually a plastic film that would be held in place by a frame, and this frame that could be lowered and raised to accomplish the reduction in evaporative water loss that you want to have happen at night. And so at night, you would lower this frame over the pond, but during the day you would want to raise it above the pond to allow for efficient gas exchange. And so what I see happening is more or less a continuous film held in place by a very simple metal frame that can move up and down. And so not nearly as complicated as a greenhouse architecture that we're familiar with.

Brian: Okay. All right, thanks. Well, in the last podcast, we talked about a pond, if you could think of it this way, one pond the size of the state of Texas as being big enough to pull all the CO_2 we need to pull out of the atmosphere. Obviously, that would be a lot of this film. Is this film fairly inexpensive? We don't need to talk about absolute numbers, but we're going to need a lot of it. Is it reasonably priced, would you say?

Richard: Well, that's a great question. And of course, as the demand increases, presumably the price would be reduced. But currently, it is being used commercially in greenhouse operations. Now, these greenhouse operations are largely in Europe, and in Europe, particularly in the Netherlands, there are very extensive greenhouse operations that produce high value products such as vegetables, tomatoes and so on for the local markets. And in that type of environment, these films have been shown to boost productivity by about 10%. And so they are cost effective at that level. But to go to scale, to cover Texas, as you mentioned, with a plastic film, is expensive. And at the present time, we don't really have the economics worked out for what the cost benefit would be for doing this.

Brian: Okay, fair enough. But I think we can imagine if it is cost effective for a food greenhouse, it's probably within the realm of being cost effective for algae. So maybe we'll leave it at that.

Let's switch over to the next stage here. So we've got algae growing in a pond, fairly low tech pond, really. Some high-tech film above it, but it seems like a fairly reasonable cost infrastructure. So let's talk now about harvesting. And I know you've already mentioned that the algae are not necessarily floating on the top. They're incorporated in the water column. And in the last podcast, we talked about two methods, either filtration or a centrifuge. And I think you had said it was determined that filtration was probably the most cost effective. Could you talk about that process and maybe that infrastructure? I'm picturing some filters that are fairly low tech, but maybe there's more to it. What's involved with the scale of that equipment?

Richard: Well, that's a great question. I'll mention in some of the earlier integrated Department of Energy projects that I was involved in that we identified harvesting of algae as really one of the most expensive parameters for producing algal biomass. And the objectives of those early DoE programs were actually to produce biofuels. And so we set a benchmark for the cost of harvesting algae at a 10% parasitic energy loss. In other words, we could use no more than 10% of the energy in the algae to actually harvest that algae. And so that benchmark then eliminated a lot of competing technologies. And as you mentioned, centrifuges were really the go-to system in the early days of alcohol biomass production. Well, they couldn't actually meet this threshold of 10% parasitic energy cost. And we looked at four or five other technologies, and eventually we came to a technology that's based on Ultra Filtration, as you mentioned. And so what the Ultra Filtration systems are, are membranes that have a pore size of several microns in diameter. The way these systems work is the algae are pumped against the surface of this membrane, and they accumulate on the surface to a point where the pressure gets too high for it to actually continue to pump the algae onto the surface of the membrane. Once it reaches a threshold point, (and this is sort-of proprietary information that's been developed by these companies), then what they do is they stop pumping the algae against this membrane. And the cake that is formed on the surface of the membrane is then literally blown off by reversing the flow and pumping air through the Ultra Filtration membrane to push this cake of concentrated algae off the surface. That's then collected as it falls by gravity to a container. And then the system is restarted. And then again, when it reaches a certain pressure where it's not efficient to concentrate the algae anymore, then they do the same thing again. They pump the algae cake off the membrane using air pressure.

So there are now commercial systems that do this, and they do it at very large scale. So, for example, there's a company in Oklahoma called Porelogix that we worked with on some of our DoE projects, and they actually won an award from the US. Department of Energy for being able to harvest algae at less than a 10% energy cost. And they now have commercial Ultra Filtration systems, the largest, which operates at 800 gallons per minute. And those systems are about 6,000 pounds. And they contain 30 or more of these Ultra Filtration units that are operating continuously in a sequential manner. So as one cakes up and reaches its maximum harvest capacity, the others then in the system take the water that's being diverted from that particular filter. The algae is released from the filter, and then the process starts all over again. So this is all automated in these systems, and they're now in commercial production, as I mentioned, and being used in a variety of locations throughout the country.

Brian: Okay, that sounds pretty straightforward about what you'd expect and not too high tech, in that there doesn't seem to be any exotic materials required or very, very close tolerance techniques or anything.

So now that we've harvested the algae, what are the steps to convert that algae biomass into usable products? And the products, again, just to refresh everyone, is animal feed, some kind of a biofuel or a biocrude, and then, of course, the co-products, the industrial chemicals and things like that. Now, in the last podcast, you mentioned that the preferred technique is called Hydro-Thermal Liquefaction, or HTL. What does that extraction machinery look like? I mean, is it the scale of cargo containers or is it as big as an oil refinery? Is it terribly exotic or take a lot of energy? Describe that for us a little bit.

Richard: Yeah. Great. So the HTL systems that are currently being commercially produced are being produced by two companies that I'm aware of, Licella in Australia and Genifuel, which is based in Salt Lake City. Genifuel is a system that I'm most familiar with. Of course, we actually worked with Genifuel over the years, and Genifuel is, at the present time, actually building an HTL facility for the city of Vancouver, British Columbia. And that facility is going to process the sewage sludge from their wastewater treatment facility in Vancouver into biofuels. That facility, based on looking at the pictures of the site where it's being built, currently is on the order of a few acres in size. So it's scalable. The units that we're familiar with that are usually associated with harvesting and converting biomass from algae into biocrude are about the size of a flatbed truck, a tractor trailer in size. And so they're relatively portable and they're entirely self-contained. And so that includes the pumps, the systems that recycle waste heat, and the outputs, which includes three streams. One is the biocrude, which can be used to produce biofuels, or, as we propose, it may be an effective strategy for actually sequestering carbon permanently in oil fields that are no longer operational. For example, the second stream that comes out of that is water. And that water contains most of the nutrients that were used to grow the algae. So that includes the nitrogen and phosphorus. And in a typical pond operation, that water would be recycled so that those nutrients are also recycled. So this is actually a very important aspect of the fully integrated system, is recycling the water and the nutrients, particularly the nutrients, because that's a big cost factor for the production.

But it's also an advantage of growth of using algae to produce biomass, because in terrestrial agriculture systems, more than 90% of the nutrients input into the system actually are lost. They leach out through the soil. They get into rivers and streams, eventually getting into the Gulf of Mexico in the case of the Mississippi River, and causing dead zones in the Gulf of Mexico. But in these closed systems with the ponds, the nitrogen and phosphorus essentially recycle. So that's a big advantage in terms of environmental sustainability of using HTL because we can recover the nitrogen and phosphorus and recycle it.

And then the third stream that comes out of the HTL is actually what you might call syngas. This is a fraction of the carbon in the algae biomass that is reduced to basically methane. And that methane, which accounts for about 10% of the carbon in the system. In most models that we're looking at, we use that methane, which is a renewable fuel source, essentially to generate energy for the operations of the algal biomass production systems. And so that reduces energy demand on the grid. It's locally produced renewable energy. And again, that's another advantage of the HTL systems. So hopefully that gives you a flavor of what we can do using HTL. It's a very efficient process.

There's one other thing I'd like to mention though, about HTL, and that is it's particularly relevant to some of our environmental concerns dealing with micro-plastics. And as you're aware, micro-plastics are now recognized as a major problem in the environment. They're continuously released from wastewater treatment plants, they're getting into the oceans, they're causing all sorts of environmental degradation in the ocean. Well, one of the upsides of HTL is you can actually take this sewage, that's sewage sludge from sewage treatment plants, run it through the HTL and all of the micro-plastics are converted into biocrude. So we can eliminate microplastics from sewage treatment facilities. And in fact, another option is to include plastic that's chipped up into small pieces in the HTL process as we're producing biocrude from algae to eliminate potential pollution from micro plastics in the environment. So some of the recent research in HTL now shows that this is very feasible, that we can take plastics and eliminate this problem of micro plastics by processing it in the HTL operation.

Brian: Well, that's fantastic. And that's basically another benefit to this whole idea, this whole system of creating these products, whether they're biofuels or animal feed or whatever. Very interesting.

I would like to focus in a little bit on the biocrude. I know that you and your team were originally envisioning that this algae system would be set up and the profits from selling animal feed and the industrial coproducts and so forth would basically pay for the system. And then the biocrude would simply be sequestered. And we talked about maybe pumping it down old oil wells or whatever.

But I think there's another idea here. We've got certain energy sectors that are really, really difficult to decarbonize and one of those is aviation. And the other one, which I think is the most difficult sector of all, is building heating. Now aviation is difficult because it's hard to replace petroleum with something that's as energy dense, yet light and wade and small in volume as jet fuel. I mean, that's basically. A technical problem.

But building heating is difficult to decarbonize for another reason, which is economics. Now, although technical solutions exist like electric heat pumps, the cost to retrofit existing buildings is astronomical because of the installed base of a massive number of furnaces that would all need to be replaced. And really this cost is pretty staggering at probably tens of thousands of dollars per home for the material and labor and how would we pay for that. But not only that, but a furnace retrofit on a house would also require getting people to agree to have their home furnace changed out to something else. And you always get naysayers that would be reluctant to do it. So getting everyone to make that change is problematic. And then lastly, we'd have to change our energy grids to take the energy burden from one system, which is natural gas or oil, in this case over to a different grid like electricity. And this causes a domino effect of infrastructure change and the cost to do it.

So to me it seems obvious that the only practical solution is to keep the furnaces but change the fuel.

And while gas or even oil furnaces could probably be run on hydrogen, getting the hydrogen to the homes is impractical in most cases because the natural gas system can't carry 100% hydrogen. So this is where I think a carbon neutral hydrocarbon that could be created by algae, by direct air capture of carbon dioxide might be a really practical solution. Now, although the biofuels would only be carbon neutral, not zero carbon, we could possibly mandate that some of the biocrude from the algae be sequestered and that is pumped into the ground and therefore this system could be partially carbon negative.

And I think we all have to be pragmatic, although we'd all like to be purists and find absolute zero carbon solutions to everything in the energy sector, there may be no practical way to convert every home furnace in the world from gas or oil to a heat pump. And there may not be a way to convert every aircraft to hydrogen. But if we could have carbon neutral hydrocarbons created, by cost-effectively removing carbon from the air, at least these would be carbon neutral and can be somewhat carbon-negative if we sequester some of the biocrude. I don't know if you'd care to comment on that.

Richard: Well, that's a great suggestion. There's another energy sector, by the way, that's also recognized as demanding, if not absolutely requiring hydrocarbons as a source of energy and that is ocean transport. Those ships use tremendous amounts of high energy density fuels and petroleum based or hydrocarbon-based fuels are really the best option there as well for many of the reasons you're mentioning for home heating. I used to live in the Boston area years ago and we used oil to heat our house. And many of the homes in New England still do use oil. So the technology is there to do that. And as you mentioned, if we proportion this algal biomass appropriately and what I mean by proportion is fractionated into products that generate income. As you mentioned, the high value co-products, products that can be used for animal nutrition. Or human nutrition, so that as we grow the algae, we don't displace agricultural farmland from producing food and then take some fraction of that. The third fraction, which we're processing through the HTL process into biocrude, which then can be further fractionated into two groups, one for renewable fuels, as you're suggesting, and then the second fraction, which is carbon sequestration. We can actually make this process, in the end, negative carbon in the overall context of the total biomass that goes into the system. So it's a very feasible approach. And we've argued in the past that we are largely focused on sequestering carbon to ameliorate and mitigate greenhouse gases in the atmosphere. But energy use is still an important issue. And if we can address the immediate needs by using renewable fuels or renewable carbon systems, then, yeah, I think that's a good direction to go.

Brian: Well, thanks, Richard. And maybe to kind of tie a bow around all this and recap, I'd like the listeners to consider two things, and that is that direct air carbon capture is a thing. It's practical, it's efficient. It's here now, it's ready for commercialization, I'll say. And so we really should be considering that.

And then the second one is that maybe we can't make every one of our energy systems like marine or aviation or building heating, perfectly zero carbon. And we should be open to the idea that if we can at least make it somewhat carbon negative or carbon neutral, that's not necessarily a bad thing. So let's stay open to that rather than to stand in one place wringing our hands and doing nothing because we can't find a solution.

Well, Richard, why don't we conclude the podcast with an update from you regarding what's going on around the world to advance biological carbon capture. I know in the last podcast we mentioned that you were associated with a number of colleagues in the group Kontra Carbon. And again, folks, don't try to Google that because there is no website for that. But in addition to Kontra Carbon, I know you're speaking next week in Italy at the Aquafarm Conference, which maybe you could tell us a little bit more about. And also I want to mention that you're affiliated with the New Mexico Consortium, which does research in biofuels and algo biomass production. And by the way, listeners, the New Mexico Consortium website is all one word, NewMexicoConsortium.org. So Richard, just a few words, maybe give us an update on what's going on with biological carbon capture around the world. And maybe a few words about the conference in Italy if you like.

Richard: Well, great, thank you. First, with respect to biological carbon capture, the US. Department of energy just announced a few weeks ago that they'd awarded nearly $150,000,000 to private companies in the carbon capture sector specifically focused on biofuels. Nearly half of those awards went to companies that are using algae, and the other half went to more traditional terrestrial agricultural systems. But the focus with DoE, of course, is largely on producing biofuels, renewable hydrocarbons that we just discussed. But again, that model fits very nicely into the carbon sequestration strategy that we mentioned earlier focused on sequestering biocrude in oil fields. So that's a great investment on the part of the US. Department of Energy and that'll move the system towards commercial viability, I think, in the next few years. We also know from a lot of the work that's gone on just in the last two years that the major bottlenecks in actually making these biological carbon capture and sequestration systems feasible have been effectively addressed. For example, in the case of growing algae, one of the big constraints and actually producing algae at scale, is the stability of the algae in the pond. As you can imagine, you have this giant vat of algae. They're all the same. And for some organism that would like to eat those algae, it's like a smorgasbord. And so they move in. And the net result of that is that certain herbivores that would eat the algae or pathogens that will kill the algae can cause pond crashes. And so one of the big challenges always has been for scaling the system up is how do you mitigate disease and how do you mitigate herbivory by other organisms?

Well, now, in the last two years, there have been new strains of algae that have been identified and or developed that have gone outdoors and have grown continuously without pond crashes for over half a year. And that moves the needle in a big way. And so some of the problems that we knew about five years ago now have been addressed by using these advanced strains of algae or using genetic engineering approaches to improve their stability in the long term. That's been a very big accomplishment just in the last couple of years. Are there other opportunities for making this system go? And again, if I come back to the US. Department of Energy, they've also made big investments in producing high-value co-products from algae. And this is called the Biorefinery Program, which is based at Lawrence Berkeley National Labs. And that program is focused on how you can valorize algae to make the economics favorable for carbon capture, but also for renewable fuels. And so there are new high value products being developed, industrial enzymes, including enzymes that can degrade PET plastics into their monomers, and high value hydrocolloids that are used in medicine and industry. And so those programs are moving forward very rapidly as well.

You mentioned the Algae Farm Conference in Italy. Europe, I think it's fair to say, has been a few years behind us in developing the technology to grow algae at scale, either for biomass production or biocrude production. But they're catching up. And there's also been a tremendous investment in Europe in algae as a source of new bio products, and that includes pharmaceuticals and foods as well as biofuels. And so this conference brings together a number of European algae organizations in one location, and they'll have a series of talks on sort of cutting edge technologies that will help them achieve their objectives of producing foods and biofuels and high volume coproducts from algae at the lowest cost possible.

So I've been invited to make a presentation to the group on the technologies that we've developed to increase photosynthetic efficiency in algae and improve biomass production. And so I'm looking forward to meeting with new colleagues, hopefully in Europe and in that environment, and hoping to see algae move forward in the future to address many of the concerns that we've talked about today.

Brian: Well, fantastic. Thank you, Richard, and good luck with the conference and safe travels going over there. I wish you the best of luck with that.

Well, I think maybe we'll wrap it up now. And thank you again so much for your time to be with us twice on the podcast. If the listeners want to reach out to you, what's the best way for them to contact you?

Richard: Well, the best way to contact me is by email, and my email address is richardtsayre@gmail.com. And we're looking forward to talking to interested parties to see if we can push this system forward in the future. So please reach out to me. I'd be happy to discuss opportunities with interested parties.

So thank you, Brian, for the opportunity to share this update on the system that we're working on and discuss some of the future potentials for algae to capture carbon as well as feed the world and produce high-value co-products.

Brian: Yeah, what's not to like, as they say!

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And if you'd like to contact me, I'd love to hear from you, and you can reach me through the website@coloradohydrogen.org or on LinkedIn.

So until next time, this is Brian DeBruine wishing you health and prosperity. Goodbye.