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WEBINAR

CARBON REMOVAL INNOVATIONS AND THEIR CHALLENGES: A CONVERSATION WITH SUSTEON PRESIDENT SHANTANU AGARWAL

Washington, D.C.

Wednesday, October 13, 2021

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Welcome:

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Keynote Address:

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P R O C E E D I N G S

MR. PATNAIK: Hello and welcome to this fireside chat of the Center on Regulations and Markets at the Brookings Institution. My name is Sanjay Patnaik, and I'm the director of the center. In our series of fireside chats, we've explored important topics related to modern-day markets and regulations through one-on-one conversations with regulators, business executives, and academics. Today it is my pleasure to welcome Shantanu Agarwal, who is the co-founder and president of Susteon, a decarbonization technology developer based in North Carolina. Susteon is commercializing CO2 capture and utilization technologies. Shantanu is a decarbonization entrepreneur who has dedicated his life to climate change technology development. Over his last two decades in the energy industry, Shantanu has worked in Asia, Western Europe, and the Americas. He has a track record of identifying, investing, and commercializing early-stage energy technologies, and he has an MB from Harvard University, as well as a BS in Chemical Engineering from IIT - Roorkee in India. He has worked at (inaudible) and McKinsey and Energy Ventures in the past. Welcome, Shantanu, it's a real pleasure to have you here today.

MR. AGARWAL: Thank you, Sanjay, and thank you, Brookings, for hosting this event. Quite exciting for having you guys talking about something which is very dear to my heart, which is carbon removal.

MR. PATNAIK: Great, thank you. So I want to start off to talk today with something that has been in the media quite a lot. Bill Gates wrote a book about it, right, and so we are talking much more about kind of like what is the nexus of climate change and technology and innovation? So, what role do you see for technology and innovation in solving the climate crisis?

MR. AGARWAL: So, technology and innovation are -- have to be the foundation of what we are able to do with climate crisis, right, because they are -- they are -- if you think about the actors of what can solve climate crisis, there are really three actors. One is technologies, which can actually solve this climate crisis that we have created for ourselves. Second is the political will, which needs to educate and inform and make sure that the crowds and the people and the -- the swell of the public, actually, understands the problem and is allowing us to make changes to our way of life to really address that problem. And the third and most importantly is a market incentive system which allows for these technologies to be commercialized. So these three actors have to work in conjunction and, obviously,

technology is being one of these most important actors. It has to be sort of successful.

Now let's talk about, in terms of climate change technologies, why -- what is sort of the process of these technologies which -- which need to act to come out, to be commercialized. What is the -- what are the challenges to those technologies coming out? So the biggest -- biggest problem I see is that innovation and technology go problem-solving in the climate space is related to more hardware kind of solutions. It's energy technology, so it's really not software, so the cycle time and the iterative improvements is much longer, and -- and that's the reason, even though we need these solutions now, they're taking much longer. So we need to really (inaudible) the technology and innovation is the fundamental foundation of what we have to do with the climate crisis. That's -- that's how we're gonna solve it.

MR. PATNAIK: Great, thank you. So related to that, like most of the times when we look at the public discussion of climate, it revolves around reducing the emissions of greenhouse gasses, and rightly so. But there is another side to the coin, which is there's work being done to develop removal technologies for carbon. And so, can you explain how these technologies work, and what kind of technologies you see that are being developed to remove carbon?

MR. AGARWAL: Sure. So, firstly, I do not want to take away the importance of emission-reducing technologies. Emission-reducing technologies are now scaled up, are cost effective or economic. They need to scale further; they need to penetrate every nook and corner for our way of life so that our overall emissions are going down significantly and fast. So that needs to happen. We are still, however, emitting today greater than 40 gigatons of carbon every year. So, it's not happening fast enough, obviously. And, you know, that one and a half degree promises which was earlier made by the countries together in IPCC Conference, is really, for all practical purposes, I think, almost impossible in my view.

MR. PATNAIK: I would agree.

MR. AGARWAL: But doing something great is what they're walking towards, and if we achieve that I'll be really happy. I mean, that's -- that's something again. It's -- it's got a hard target to achieve the two degrees Centigrade ahead of us. That's what science tells us. The budget we have, the amount of emissions we can make. So -- so emission-reducing technologies a must-have to be done. At

the same time, a lot of people kind of defer the idea of carbon removal technologies to be done later, after the emission technologies -- emission-reduction technologies have been deployed or scaled and our emissions have gone down. And that's what I think I need to really emphasize, and people need to understand that that's not really an option. The carbon removal technologies need to scale in parallel because they don't exist today. They have -- they don't take their own time to really get to a place where they are making a dent in the scale of emissions which we make. So, even in the most conservative estimates, if you look at what IPCC says, at the two-degree Centigrade estimate, they talk about five gigatons per annum of carbon removal already in place by 2050. Okay? So, 2050 -- 30 years from now, or 29 years from now -- they're talking about five (inaudible) that number. That is five billion tons of carbon dioxide removal per annum, and today we are at 10,000 tons of carbon dioxide removal. This is a 500,000 times scale. It's a half a million scale. Half a million scale up off industry in a 30-year period is unprecedented. It's -- it's something which we really need to pay attention now, otherwise 10 years from now when we start paying attention it's going to become even more unachievable. So, I think it's -- it's achievable if we start really paying attention at it. I'll give you an example of what has been achieved in the past. So, electric cars went about 250X, or 230X or something, between 2010 and 2020. So the scale up, and it's going to kind of need to increase , so -- so in ten years we are as mankind been able to achieve further technology to go from almost nothing to 230X to everybody talking about it today and everybody wanting to buy something. Similarly, carbon capture, which needs to achieve a 500,000 today, and hopefully by 2024 it will be 5,000 because we have had the first million ton per annum facility online. That will start looking better. But even a 5,000X from 2024 to 2050, which is 25 years, is -- is a large target, 5,000X. But in ten years we were able to do 230, so we should be able to do 5,000X in 25 years if we put our hearts and minds and policy and market incentives to it. So that's what I want to emphasize. We talk about it as it -- it can happen in the future, we don't need to pay attention to it today. But it's going to become unachievable if we don't pay attention to it today.

MR. PATNAIK: So if we have kind of an approach of all the above. We need to reduce emissions at the same time while investing in technology that maybe reduces the carbon that we are producing, and we will continue to produce at least for the next decade because in all the developing countries they're relying on it, and -- and it is not possible to switch away so -- so quickly, right? Okay.

That's interesting.

MR. AGARWAL: Absolutely. There -- there are spaces where abatement will not be possible. Even in 2050, there will be domains in our economy, where everybody is signing up to say okay, I'm gonna be net zero, I'm going to be net zero. So many companies, so many countries. There will be a -- a significant portion of our economy, of the global economy, which will be still emitting greenhouse gasses. And forecasts are between five to 10 gigatons per annum will still be emitted. Per annum. Even with the most aggressive emission reduction. So, those things have to be canceled out. And that's why negative emission technologies are a must. You can't really avoid it.

MR. PATNAIK: I think that's a great point because we -- we have multiple sectors where the chemical process is required to have access to CO2. You cannot avoid it, right? I mean, there are some innovations in INST {phonetic), for instance, that tried to do it without, but it's going to be very difficult. And there are a lot of times people forget that we have another big sector where people haven't really looked at how or -- or not much invested in how to reduce these emissions, which is agriculture. And agriculture produces a lot of greenhouse gasses, so -- so that's a great point.

MR. AGARWAL: Unabated industries, unabated countries, because there are only some countries who'll just say, I don't care. I'm not doing it. I need to go -- go forward. You can't convince them enough. And then unabated geology or unabated nature. Because climate change is also going to impact a lot of (inaudible) that are going to come out of the earth. And there's going to be GHG emissions coming out of there, but you can't control them. Today for all practical purpose, we don't really have a very, very strong quality or good quality estimate. So, we'll have to have some buffer to deal with the earth when climate change starts hitting us and creating more GHG emissions.

MR. PATNAIK: We can already see that in -- in the permafrost in -- in Siberia, right? Where some of the thawing is releasing huge amounts of greenhouse gasses that will continue onwards. So, let me turn to the U.S. a little bit and -- and especially about the specific technologies. So can you talk a little bit about what is the state of development for low-carbon technologies, and especially carbon removal technologies in the U.S., and can you talk a little bit about what are those technologies? Does that include the traditional carbon capture and storage, with other technologies to take out CO2 from the atmosphere? Because I have seen ideas for quite ingenious inventions where you would start filtering

out CO2 from the atmosphere, kind of like trying to reduce the concentration through that, or absorbing so that -- I'd be curious what -- to see what kind of technologies we are talking about here.

MR. AGARWAL: Yes. So that's probably one of the most exciting spaces for me and gives me a lot of hope that carbon capture and its application can actually achieve the -- the enormous task which we have set to it. If you think about carbon capture or carbon removal in general, there are -- there are two major sort of divisions or pathways to it. One is biosphere-based, and the second is the geosphere-based. So let me explain what that means. The biosphere base would mean that you take CO2 from air or -- or nature. In a sense we capture it into by growing more forests, managing forests, or by soil sequestration by managing the -- the various ways that it can actually go and sit in the -- in the soil, on the surface, or just below surface.

So that is commercial, scaled up, very accessible today. We can obviously plant a lot of forests and we can capture all this CO2, and it can actually be done at quite substantial scale today. So, that's very encouraging and needs to be done for sure. The only downside with biosphere-based is that we are not very good at managing it, and we don't really have the reliability or the longevity of this biosphere-based sequestration, because there are various forces which we don't have control over, which include climate change itself, which causes various types of inclement weather and forest fires and things like that. And then a growing population, which we are still going to continue to increase our population, so deploying a lot of land to sequester and sort of manage forests is both difficult and not a reliable source of sequestration that what we do today can be lasting 20 years or 50 years from now, which we need it to last. And because otherwise if we have a large-scale burnout in 50 years, then certainly all that work has gone to -- gone to dust. So -- so that's why I personally prefer geosphere-based sequestration, which is where we can also -- there are two major pieces of it. One is the bioenergy CCSBE -- CCS, it's called -- and the other is air-capture based CCS.

MR. PATNAIK: So how to they work?

MR. AGARWAL: Yes, so the bioenergy CCS basically is taking any kind of biomaterial, which could be plants, it could be forests, it could be forest residues, whatever else, you know? And then you dig that and convert that into some sort of form whether it's CO2 or it's some sort of alternative of CO2 which has carbon, and take that material, and some people have actually produced liquids out of --

out of biomaterials, and taking that and sort of injecting that into the earth. In (inaudible) where they are sitting in the formations and they've got sequestered much like where -- where we got all this carbon from, like the oil and the coal we got from the earth, they're essentially going and putting that down deep in the earth in various formations where the -- the geology study we made sure that they are stuck there for eons of time.

MR. PATNAIK: So you take biomass -- so you don't filter it out of factory stack or something, you take this -- the carbon that is captured in biomass and you -- you deposit it underground, is that correct? Am I understanding that?

MR. AGARWAL: That is the BECCS, that's the --

MR. PATNAIK: Oh, the trapping thing, okay.

MR. AGARWAL: The other -- other pieces, air-capture based CCS. And in there, you are essentially taking -- so, air-capture, or points of capture, which are talking about stacks, where industry is trying to capture. But I'm -- I'm right now talking about carbon removal, which is already there, so when you talk about industry stacks, that's -- that's new carbon which is being produced.

MR. PATNAIK: Okay.

MR. AGARWAL: Capturing that is a different sector. We can talk about that as well. But in terms of carbon removal from what's already been emitted, BECCS and the air-capture are the new (inaudible). Air-capture is where you take essentially all this air which is accessible anywhere and essentially capture CO2 from air and make a pure stream of CO2 or a relatively pure stream of CO2 and then inject it down in a deep aquifer, typically an aquifer, in the earth, 5,000, 10,000 feet down below, and in there -- and a lot of scenarios in these aquifers, the CO2 essentially converts to rock or some sort of carbonate. So, what you're doing is, you're taking all the CO2 and injecting it in the aquifer, and then it, over two, three years, five years, converts into a rock and just stays there forever. And that is a very, very reliable and long-term way of capturing. Now, the problem between these two geosphere pathways, right now air-capture is more expensive that BECCS, or relatively expensive, but we believe with our technology we -- we are spinning out a technology, actually, air capture and some of the others which are out there in this marketplace as well. Air-capture or the -- sort of once these things scale up and commercialize, will be at par or even lower than BECCS. And it doesn't have the disadvantages of

BECCS, which is you're competing with the agriculture, you're competing with the growing biomass or taking biomass from a food supply or biodiversity because you're growing and capturing and then sort of burning it or converting it into CCS (inaudible).

Air-capture just takes air, so it can be anywhere, everywhere, as long as it's cheap enough to do it. I think that's the path of sustainable long-term reliable capture, but it's expensive right now. So that's what people are working on and engineering. We ourselves tracked about -- about 30 technologies which are working and various types of air-capture or various ways of doing air-capture, and we believe there is so much intensity of innovation going on that within five -- five years or so, we will start seeing technologies which actually are very, very economically viable and scalable to make air-captures the bat (phonetic) for long-term carbon capture.

MR. PATNAIK: So what about the two -- two aspects of that. One is, what's the current average cost per (inaudible) of CO2 capture for these technologies, and then what's the energy balance, right? Because you don't want to spend more energy and create more greenhouse gasses by capturing that. So how would you sort the problem, because as I understand it, these technologies require quite a bit of energy. Would you have to combine it with renewable energy to make it environmentally friendly (inaudible) as positive? What's kind of like the approach here?

MR. AGARWAL: Very good questions. So, let's focus on the geosphere-based capture here for answering this question, right? So, the bioenergy CCS has the advantage of the capture is being done by nature. So it's basically, the CO2 is captured by some sort of plant, and then you're converting it into some sort of material that's generally (inaudible). So, it is more energy efficient because the capture cost is not required, but at the same time, the conversion process is quite energy-intensive in a lot of cases. So it kind of balances out. It doesn't really come out on top. In air capture, you're absolutely right. Depending on the process and the path that you are taking, you might be actually burning fossils fuels in some cases. So in some of the carbon capture technologies, burn fossil fuel, and produce carbon and then capture that as well in the process, but they're still producing new carbon dioxide as part of their process, and others are sort of more efficient, others are less efficient, some are using renewables. So there's quite a wide sort of world of how much carbon you're emitting as you're capturing CO2. In our

case, the technology which I am working on, we are using only a renewable electricity, so there is no carbon emission at all, and essentially we just capture CO2 from air and put it down in the earth. And that's the advantage of our technology which we are promoting. And there are others as well who are trying to do the same. And the average amount of energy required per ton, you would be surprised to know, Sanjay, is -- is also quite high today. It can be anywhere from, I mean, one and a half thousand kilowatt hours to even 5,000 kilowatt hours right now.

MR. PATNAIK: That's a lot.

MR. AGARWAL: Okay, so depending on what your source of energy is, you're talking about a huge amount of energy required as well as we scale this carbon capture industry, and that will create a lot of jobs in the (inaudible) industry opportunities for all sorts of people, right? From power sector to even EPC type of people who are supporting the fossil fuel industry currently. They will get jobs in this industry as it -- as it kind of comes on its own.

MR. PATNAIK: And what are the average costs per pound of CO2 currently with their technology, if you were -- if you were to put a range on it? Just to get a sense of where we're at in terms of technologies development.

MR. AGARWAL: Sure, so I'll give you the whole range. So, air capture today is at anywhere from 300 to $600 a ton.

MR. PATNAIK: That's -- that's expensive.

MR. AGARWAL: Okay. And bioenergy-based CCS is also in the same range for the ones which we have seen commercially trying to do it. There are some who claim to be slightly lower, but kind of the same range.

MR. PATNAIK: Okay.

MR. AGARWAL: On the other hand, forest and soils sequestration credits sell for seven, eight dollars a ton.

MR. PATNAIK: Yeah.

MR. AGARWAL: So -- so that's the huge challenge where when a -- a company or industry has to choose and pick, okay, I'm going to -- I'm gonna market and use it as a marketing ploy to greenwash my operations, and I'm going to essentially buy carbon credits and say that I'm carbon neutral.

They are incentivized to buy forest credits at $7 a ton rather than buying carbon capture credits, which are 300 or $600 a ton. And although this -- there's a price curve on this. This $300 a ton will come down, and in our case, we believe we can get it to below $100 a ton in our process quite soon on our next scale-up. So we are working towards that. And I think the long-term price of air capture will also be between 50 to $100 a ton.

MR. PATNAIK: (Inaudible) it's high, but if -- if the carbon price is high enough so that you could get there to some degree. I think one problem with them -- I mean, I think the biosphere one obviously is a route that is often easier implementable in developing countries, right? I think the trends we've seen in the past is just a rarefication. And endurance, right? Like, to really verify those reductions to make sure that the forest stays in place. And then one solution that I see as a low-hanging fruit is maybe stop cutting down original forest, right? Like we still do in the rainforest. That at least could be a first step. And maybe issuing credits for that so that these countries have some other source of income that they don't have to cut down the -- the forest. The (inaudible) thing is that listening to my next question, because when we talk about things like -- like this, like carbon removal technology that takes it out of the air, this is significant technological innovation, and often time it's developed in the private sector, but most or many times with substantial government support, either through grants or research, et cetera. So, what do you see as corrected government role in fostering your carbon technologies? And -- and especially kind of like, what policies do you think could strengthen the U.S. ability to develop some of these new climate-friendly technologies? Given that there's a lot of talk now about investing in low-carbon economy, in the transition to a low-carbon economy, kind of like what kind of incentives would it take from the government side?

MR. AGARWAL: So -- so this is a public good which we are trying to unwrap right? And today there are not enough incentives in the marketplace which allow for a normal entrepreneur and a normal venture capitalist to essentially invest and say I'm going to make money out of carbon capture. Especially air-capture technologies, because carbon price, as you know, better than most out there, there are about 69 or so places where there are some sort of carbon pricing mechanism, and --

MR. PATNAIK: Because I'm a man of the world.

MR. AGARWAL: -- most of them are below 50 bucks. And --

MR. PATNAIK: Right.

MR. AGARWAL: -- if you do a frequency chart, you'll see that most of them are actually around 10 bucks. Or 12 bucks, so -- so at that sort of price level, supporting a business where -- where the cost of capture is $300 or $600 a ton, or long-term can get to even $75 or $100 a ton, is really not viable for normal enterprise. And even companies and corporates will have shareholders who have to answer to those shareholders. So -- so government's role in understanding and sort of incentivizing and promoting this public good is extremely, extremely important because of that. Because otherwise, by the time the carbon price is going up and there is economical prerogative to sort of invest and make money in air capture, we might be too late. We might come to the party too late, and everything is -- I mean, the large-scale impact of climate change is already hitting us, and its runoff effect that you can't stop anymore. So -- so the government's role is -- has to be big, has to be now, has to quite urgently placed, and I think it has to be a cause which in U.S. specifically, not just -- just the Democrats are worried about, but even Republicans are worried about, and that's what I've -- I've seen lately. All -- I mean, a lot of Republicans who are -- who are -- understand the situation are fully onboard with the climate change problem, recognize the problem. I mean, I was talking to the ex-Congressman in Florida recently, and they are facing climate change in day-to-day life already on the Miami beach where they have to put the levees up and things like that. So things are already happening in the front of people's lives that people are thinking more as they're making an impact.

MR. PATNAIK: So, what can government do is the question.

MR. AGARWAL: So, the government has to essentially help this innovation happen faster. So, let me -- give you the reason why. So, in software, when we talk about software industry, the innovation cycles are quite fast, because there is a -- a ability for an idea to become a product and the product to scale within a year to year and a half. You have a new idea or new company forming and one and a half billion users on that technology.

MR. PATNAIK: Yeah.

MR. AGARWAL: And that sort of a cycle time and iterative improvement and sort of being able to brew up ideas has allowed them to really, you know, become a very, very robust prosperous industry which has innovating that is fast. On the other hand, in energy, in carbon capture, a typical cycle

time from an idea to a prototype to a bench-scale unit to a pilot unit -- at the pilot unit scale you know the economics of the technology. Before that you don't even know the economics properly. All this cycle, all this time, takes about two to five years.

MR. PATNAIK: Wow, that's a lot there.

MR. AGARWAL: And -- and at the end of that, you don't even know if you're -- if it's real technology or not, so there is a lot of funding (inaudible) at-risk funding where you come to a place where you figure out okay, now this could work, or no, this doesn't work, let's kill it. Right? So -- so because this is a public good, this is -- this is something which we all need. It has to be government-based mechanisms which allow for these technologies to be accelerated and don't get me wrong, there's a lot of government-based teams in E.U. and U.S. specifically right now, which are allowing these incentives to happen, allowing these technologies to be developed via beneficiaries of quite a few of those incentives and grants and things the government is doing. But my position is that it's -- it's -- it needs to be increased by an order of magnitude, because the problem which we are facing, it needs a fast resolution. So -- so the government --

MR. PATNAIK: It's kind of like a -- an investment. It -- it can be through grants or financial support similar to maybe what we have seen with the COVID vaccines, right? Where the government stepped in and provided a lot of funding, basically no-risk funding that provided some safeguard for the (inaudible). And I think that's an interesting point, because we often forget that both fossil fuel companies and nuclear technology all got off the ground with significant government support decades ago. And so especially when there is this large capital investment that sometimes not possible to get it for the private market with these long cycle times.

MR. AGARWAL: That's interesting too.

MR. PATNAIK: Yeah. Go ahead.

MR. AGARWAL: And -- and I'd just add there -- so when you mentioned incentive system and those little fossil fuel industry growth and all that, in my view, you know, this -- this carbon capture industry is the next -- next multi-trillion-dollar industry. Because, you know, we are actually developing some processes ourselves, Susteon and lots of others doing this as well. You can make products out of CO2 as well. You can make synthetic clothes, you can make -- I mean, you can make

anything which -- which crude oil can help you source, you can make it out of CO2. CO2 is a carbon source. Instead of fossil fuels being your carbon source you can make CO2 your carbon source and essentially produce these products that you need by just recycling CO2 from air. So that's --

MR. PATNAIK: It is renewable, right? They have found some pilot rubber cement where they just use it for that. One of our audience members brought that up.

MR. AGARWAL: Absolutely. Absolutely. So that's -- this is the -- this is the pathway where a lot of the jobs, a lot of the manpower has to be deployed and incentivized to be deployed so that the private industry can actually take that -- take that out to -- to create this multi-trillion-dollar industry. Which can actually provide a lateral job opportunity for a lot of people who are currently employed in the fossil industry.

It is still the same sort of EPC, engineering, process, construction type of work which needs to be done. I'll give you an example. I did a rough estimation and I think it's definitely shy. Most likely there is upside here for when we get enough capacity built for carbon capture, you need at least 800,000 man-years --

MR. PATNAIK: Okay. Wow.

MR. AGARWAL: -- of -- of work. Okay?

MR. PATNAIK: Yeah.

MR. AGARWAL: So -- so there's a huge amount of opportunity in terms of work for people to -- to get employment, to -- to work and this is -- this is work which people are doing right now for petrochemical plants, for power plants, for fossil plants, and these people who are doing this chemical engineering, mechanical engineering, electrical engineering, can actually transfer really easily to the air-capture industry or CO2 capture industry. So that's -- that's where I think the policymakers need to understand that this is a great place to incentivize the current energy industry to refocus and reinvent themselves so that we are not only creating jobs, sustaining jobs that we have, sustaining the economy, creating growth in the economy, at the same time we are helping the environment, so it's -- it's a double whammy, double benefit.

MR. PATNAIK: That's an interesting point, and I think one -- one interesting aspect that people forget is when you look at the cost, right? I mean, as you said 300 to $600 per pound is a high

cost, but then if you weigh that against the increasing benefits for climate change, which are going into the billions already, I think one has to look at the -- at the calculations and see at some point, what is cheaper? Is it to invest in taking out the CO2 and maybe mitigating some of the climate change, or trying to rebuild cities and entire parts of the coast after they burn down or like, being hit by hurricanes every year, right? So I think that's an interesting calculation that -- that one would have to look at. I haven't seen any studies on that, but it would be interesting to explore.

MR. AGARWAL: I completely agree. We need the insurance companies to just get together and figure out okay, we maybe have to pay out a lot of money here, why don't we just invest in carbon capture technology and stop climate change? We just -- otherwise -- otherwise we are just paying out a lot of money here.

MR. PATNAIK: So we have actually two questions from the audience that relate to that. So one is, what technologies specifically are scalable and economic that you think are kind of like really the promising? And the second one, what role in your view can carbon pricing play in helping kind of like a transition and -- and helping boost that carbon removal industry?

MR. AGARWAL: Sure. So let me take the first one. So, firstly we have to, right now, do everything and we have to do it in parallel. Okay? We cannot just say, okay, this is the type and the definition and the characteristics which Shantanu said, and that -- that means that we have to eliminate the others which are -- don't fit the mold, you know. So because we don't have a lot of time and we have to figure out -- we have everything on the wall to what sticks, okay? But still, the question is what -- what type of technology should succeed and sort of be scalable in air capture, in sort of carbon removal? So in my view, we really need a -- a (inaudible) 2.0 innovation, and we are absolutely working in that domain. Because of the speed at which we need the carbon removal to scale up, we need technologies which are absolutely modular and can actually work in a factory like a construction mechanism were built on-scale in a modular facility and then deployed at a very rapid pace to really go out and grow. Because otherwise if you're building one plant at a time, engineering one plant at a time, that's not really a scalable or fast, rapid deployment method. So my view is that the technologies which we should look at should be more modular, more factory-like, more like a gigafactory which tests well.

MR. PATNAIK: It would have to be like standardized so you can scale up easy and you

don't have to rest in specific engineering modifications.

MR. AGARWAL: Absolutely. Then -- then the second point, which I think in my mind is evaluation of technology, when I think about it, they need to be able to leverage existing supply chains. If you're building something new and you say, well, I have this very, very amazing absorbent material, but really it's -- I have to manufacture it in the lab, and nobody else has any manufacturing capability of it and it's so specialized that I am doing it in this lab and this process, and taking that material to scale up that material manufacturing itself is gonna take me a lot of time and then I've got the rest of industry to figure out how to really scale your process. So, something which is leveraging and able to use existing supply chains and can rapidly scale up is a very important piece of what the challenge we are trying to address. So -- so that's something which we have been very conscientious about. Trying to figure out technologies and components, which can leverage existing supply chains so that we can grow fast.

MR. PATNAIK: That makes sense.

MR. AGARWAL: And then last but not the least, which is mostly an obvious answer, I think, is that our scale needs to be economically very, very viable. It has to be -- at the end of the day it has to be economically viable. It has to make money. Otherwise, nobody is going to invest in it, it's not going to be a good company, it's not gonna scale because somebody's making a profit at it. Somebody needs to make a profit. It cannot run on grants. So the cost needs to be at scale, it needs to be less than a dollar hundred per ton as a prerequisite, and the lower the better so that you can create economics, create financial means that the current industry can actually pay a common price, which -- which allows for capture to happen.

MR. PATNAIK: Yeah.

MR. AGARWAL: So -- so I think that's -- those are the kind of technologies which are available to do scale in my view.

MR. PATNAIK: Okay.

MR. AGARWAL: And that's the lens you should look at it. Now, you had a second question.

MR. PATNAIK: Carbon pricing. What role it can play in kind of like fostering that industry.

MR. AGARWAL: Yes. So, carbon pricing. So, I think carbon pricing is a difficult challenge, it's a lot. Everybody is kind of trying to wrangle it right now, and there are multiple sides to the (inaudible) here. My personal opinion is that I think we need some sort of like economic prerogative for the capitalist and the entrepreneurial ecosystem to really come into commercialize and scale technologies. So, without a carbon price, just one in three carbon pricing is not going to work, and U.S. doesn't have a federal carbon price today.

MR. PATNAIK: Yeah.

MR. AGARWAL: There is something of 45Q too, which has a good role to play and maybe can scale and provide the early indicators for that.

MR. PATNAIK: What is that? Can you explain that a little for our audience that doesn't know what it is?

MR. AGARWAL: So, 45Q is a tax credit which a company which is providing sequestration of carbon, or removal of carbon, can actually get per ton, and it's a scaling value of that tax credit, which I think caps out around $45 or something like that in -- in five years from now or some time period. But it's basically scaling from -- from around 20 bucks to around 45 bucks over a period of time. And -- and then, basically, it's a tax credit, so it has to be taken against a tax burden that somebody has. So it's not really a cash payment or a cash price that somebody can do. You can sell and trade these tax credits, but you'll never get a full price. So --

MR. PATNAIK: So it's more kind of like an incentive, a positive incentive. It's not a price on someone emitting carbon. Okay. I see.

MR. AGARWAL: And it's a -- it's a scaling, growing price, but it's not a large price. So I think, what -- what my suggestion for carbon price, at least in U.S. for the current policy and current restrictions and -- I think 45Q is a admittedly program, but it needs to be devised and engineered for incentivizing the early-stage technologies which we need for public good in the long run. Those kind of technologies can be incentivized by -- by tweaking the 45Q to have a different price for the categories of capture which we want to incentivize technologically.

MR. PATNAIK: So that would be more kind of like a positive reinforcement.

MR. AGARWAL: Absolutely.

MR. PATNAIK: And not -- not a tax. It's not a carbon tax or something. So what do you think about carbon tax? By that I mean we have -- we have written about it recently at Brookings because a lot of economists -- most economists -- argue that we need a carbon price otherwise you won't have any transition, and there is a good opportunity now, right, in -- in reconciliation to try to put in a carbon price and I think there's some proposals on the table, so I'm curious what your perspective in on that for the technology development.

MR. AGARWAL: So, as I said, I am fully supportive of a clear, defined, economic prerogative for carbon pricing. It could be EDS, it could be carbon price, it could be something else, but without that economic activity cannot take place because everything is uncertain. So that needs to be put in place. However, I -- I -- what I read about the current situation is that the right side of the Congress is not really supportive of that, and there are lots of people in the middle also not supportive of that. So, I think the best thing we have right now is the 45Q, and we can actually clear the 45Q program which allows for technology which needs these incentives now to benefit from a higher 45Q price, for example, in the -- in some of the bill versions the carbon removal 45Q price was around $180. So I think something like that can be good incentive to allow these technologies to -- to start with. I think it needs to be even higher for carbon capture technologies like air capture, because unless you have the cost at 300 or $600, 180 doesn't cut it. So, maybe it starts at $1,000 and scales down over the period of five, six years. Something like that has to be figured out so that their early technologies have a way to make a living, make a business mean, make a business model, which -- which satisfies the investors to invest in it and then we can actually (inaudible) their technology and the incentive of the 45Q price drives -- comes down the cost curve as the cost curve actually happens as well from -- from these carbon technologies. At the same time, I think what we also need is, in 45Q, some of these credits need to be treasury-redeemable. They cannot just be tax credits, because tax credits are -- there is already too many tax credits trading around, and the capacity to trade tax credits is limited in the economy, so I think there has to be some redemption basis in the -- in the treasury at least for the incentivized technologies which we want.

MR. PATNAIK: Okay. That's actually really interesting, and I -- I'd love to also hear kind of like your perspective on developing countries, right? Because those are obviously -- they're increasing

their emissions. We have tried in India and a -- a lot of developing countries are also kind of like vulnerable to planet change more so than some of the Western countries, and so how do you see the transition of this type of technology helping meet the climate goals there, especially given how expensive it is and most of those countries have less funds than many developed nations, and -- and what country, if you look around, do you think currently is best suited to kind of like kick-start that industry, that -- that carbon removal industry among the developed or developing countries?

MR. AGARWAL: So -- so the science engineering technology that (inaudible) innovation is gonna happen and it'll look worse. And I think it's gonna happen in most likely E.U. and U.S. because these are the places where incentive systems and innovation incentives and technologies development is happening right now. So, something which actually works and is scalable most likely comes out of these two places. And both are -- I mean, E.U. has got a lot of incentives. The U.S. has to actually catch up to E.U. to really show up to the game in terms of how much incentives they're reporting and how much innovation is going on.

So that's on the innovation side. In terms of impact and ability for a developing country, I think most of the developing world the one thing is the amount of energy they are using per capita today is -- is an order of magnitude, in a lot of cases, less than U.S. Okay? So if you're -- if you're at 40, they're at 4, okay? So -- so the beauty is that as they get developed, and they will get developed over the next 50 years, their four will also become 25 if not 40, because energy consumption is directly correlated to quality of life. So, we cannot expect or ask for a human being to give up his quality of life in service of the environment. What -- that will be a very difficult trade. What we have to figure out is a pathway to show them that we can give you an equivalent of better quality of life, which is also sustainable. Those are the path -- those are the pathways which we need to find out, and so developed countries we need to work really hard to incentivize the pathways in which these developing countries' citizens go from the 4 to 25 and increase their energy consumption. There is still 21 incoming. What I'm trying to say is on a relative basis, they are going to increase their energy consumption by multiple fours in the next 30 years.

MR. PATNAIK: Yeah.

MR. AGARWAL: And these fours is what we need to focus on rather than what they are consuming today. So what we have to incentivize that the economy, the incentive system, the carbon

pricing system, the technology access, they are related to -- be able to economically and commercially build a business around renewable electricity should be such that in a developing a country, an entrepreneur would rather build a solar or a wind plant as compared to a natural gas plant or -- or a coal plant.

MR. PATNAIK: And we do these at a federal level in India, right? Like where solar is actually cheaper than a lot of the -- a lot of the coal plants, and --

MR. AGARWAL: Absolutely.

MR. PATNAIK: -- so -- so we need to decouple the -- the -- the energy increase and economic growth from emissions.

MR. AGARWAL: Absolutely. Absolutely. So I think in terms of selecting a country, I think one country which is massive and has a huge -- can play a huge role because their energy consumption is going to increase is India, which you just mentioned. But at the same time I think we cannot ignore Africa. I think Africa as a whole is massive and will increase their energy consumption significantly. The problem with Africa is -- is it's so multifaceted that you can't really paint it with one color. So I can't even address Africa in one, but their energy consumption is going to go up in multiple fours in the next 30 years.

MR. PATNAIK: And I think you bring up a really good point that is often ignored in the debate, right? It's most of the greenhouse gas emissions in the atmosphere were produced by U.S. and by Europe, and we cannot prevent other people from having the same lifestyle or aspire to the same lifestyle, right? And I think it's really critical to think about it in the way that you framed it, that we need to provide that economic growth and that energy growth for people to improve their lifestyle while reducing emissions, and there are ways to do so. And we have seen if you scale the technology large enough, that you can do it actually. There's a reason why coal-fired powerplants are uneconomical in many parts of the world. It's not because of government necessarily, it's because of market forces. And I think that's a really critical point that -- that people have to realize.

MR. AGARWAL: I'll give you an example. So, my -- my better half works in a nonprofit in India, and they work in rural coal belt in India. And so, to go there in the coal belt, and talk to a religion or a tribal -- there are lots of tribals there -- and tell them that okay, you should not use coal, it's bad for the

environment and give it up, is like telling them that okay, there's no more job and no more income from tomorrow. So it's a -- you have to create and alternative industry before they'll give up coal. Because that's their means of making a living. So, just expecting them to give up coal is -- is unrealistic. Even if the leader of the government can come and say, oh, I'll make this promise, it's unrealistic until there is an industry or groundswell of entrepreneurs who actually create alternative source of employment for these people to actually work in. Otherwise, it's all -- it's all going to be greenwashed.

MR. PATNAIK: And it's the same a little bit with these suggestions that I see that people are saying you -- you have to stop using airplanes and flying. I mean, that's not feasible, right? It's part of our lifestyle, but we have to find a way to reduce the emissions or take them out to make it neutral if we use it, right? I think that's the better way forward.

MR. AGARWAL: We are working on exactly that, so if you've got a -- actually, one of a very exciting technologies we are working on is sustainable aviation fuel and making --

MR. PATNAIK: Oh, interesting.

MR. AGARWAL: -- making aviation fuel out of CO2.

MR. PATNAIK: Oh, cool.

MR. AGARWAL: And we are very, very excited about that, and I think that is a little bit still in the lab, but once it comes out I think that can give a full circle that you emit CO2 while you are flying in the plane, and then it takes CO2 from the air, and capture it and then use renewable electricity and water and convert it to (inaudible).

MR. PATNAIK: Oh, that's super interesting. And I think that's a way where you can think about it in a way that gets more -- more support from the public, right? Because they -- they see this is a way where we can go forward and -- and we -- we have a way to decarbonize our economy but maintain our lifestyle. I have a really great, interesting question from the audience, which I probably know the answer to what -- what you are going to say, but until carbon capture removal is considered a public good like defense, we will be unlikely to be able to scale up fast enough. It's an emergency. We didn't wait until aircraft got cheap enough to develop them for World War II, right? The same should be true for carbon removal. Do you agree? What is your thought on that?

MR. AGARWAL: I -- I couldn't agree with you more, and I think -- so, it is a public good, it

needs to be incentivized, but at the same time, the incentives in my view should be a market prerogative. I think grants and incentives for technology are great ways, and I think they should absolutely happen, but a market prerogative creates and sort of unleashes, in my view, the entrepreneurial ecosystem on trying to find a way to make money, and that's the best way how U.S. knows how to create innovation. If you give them a way to make money on something, they will find hundred different ways to sort of figure out a path to make that money. So that is what we need to create on carbon capture and carbon removal so that we unleash all the entrepreneurs who are sitting around and -- and I mean, who are doing (inaudible) stuff, but they see this is the best way to make money now, so let's run after this.

MR. PATNAIK: I think for the market aspect is we have to -- we have to make sure -- through market forces and -- and government policy that fossil fuels get too expensive and too risky to -- for new investments and you -- you shift some of the money over to either carbon removal, right, or renewable energies to actually make it competitive. And then once you start scaling it, it will become competitive on its own, like we have seen with renewable energy quite significantly over the last 20 years, I would say.

MR. AGARWAL: Absolutely, and I think U.S. government is doing a lot of good things on that. I mean, loan guarantees is exactly a step in the right direction to allow that risk to be taken by the government rather than public enterprise and private enterprise. Similarly, a lot of these innovation programs which the government has got, even in this infrastructure bill, the $1 billion bill, there are some very, very good programs which people are talking about or have been built into the program for -- for carbon removal, so -- so those things are there, but I think more is needed faster. It's part of the challenge.

MR. PATNAIK: And I think it's really a question of the timeframe, right? I agree with you. I think that 1.5-degree target that we have locked in carries at least part of it is -- is quite unattainable at this -- at this point. I think we -- we can be lucky if we can reach two -- two degrees. But for that we need significant investment, and we need the major players, including the U.S., playing a major part. I think the Europeans are doing a lot. Their carbon price is significant right now. It's almost like €65 for a ton, so that is relatively high, and so they have been doing a lot on this front, but I do think it's time for the U.S. on the field to be part of the competitive industries in the future, right? The U.S. wants to invest in that now,

so that these industries will be created here and not in Europe or somewhere else, so that the U.S. can become a leader in -- in that new -- a new, decarbonized economy.

MR. AGARWAL: This -- this is the new multi-trillion-dollar industry. Either we can be the leaders in it, or we can be licensing those technologies from E.U. and other places.

MR. PATNAIK: Yes.

MR. AGARWAL: So it's better to be investing now and be the licensor rather than the licensee.

MR. PATNAIK: I agree. And I think that's the perfect place to stop today. So thank you so much for your time. This was really interesting, and good luck with all your ventures. I think you work on very interesting projects. Let's hope that -- that we see the transition happen as fast as we need it to happen. Thank you.

MR. AGARWAL: Absolutely. Thank you, Sanjay. Thank you, Brookings.

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I, Carleton J. Anderson, III do hereby certify that the forgoing electronic file when originally transmitted was reduced to text at my direction; that said transcript is a true record of the proceedings therein referenced; that I am neither counsel for, related to, nor employed by any of the parties to the action in which these proceedings were taken; and, furthermore, that I am neither a relative or employee of any attorney or counsel employed by the parties hereto, nor financially or otherwise interested in the outcome of this action.

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Expires: November 30, 2024