
TSEC

Could a new superplant solve the climate crisis?

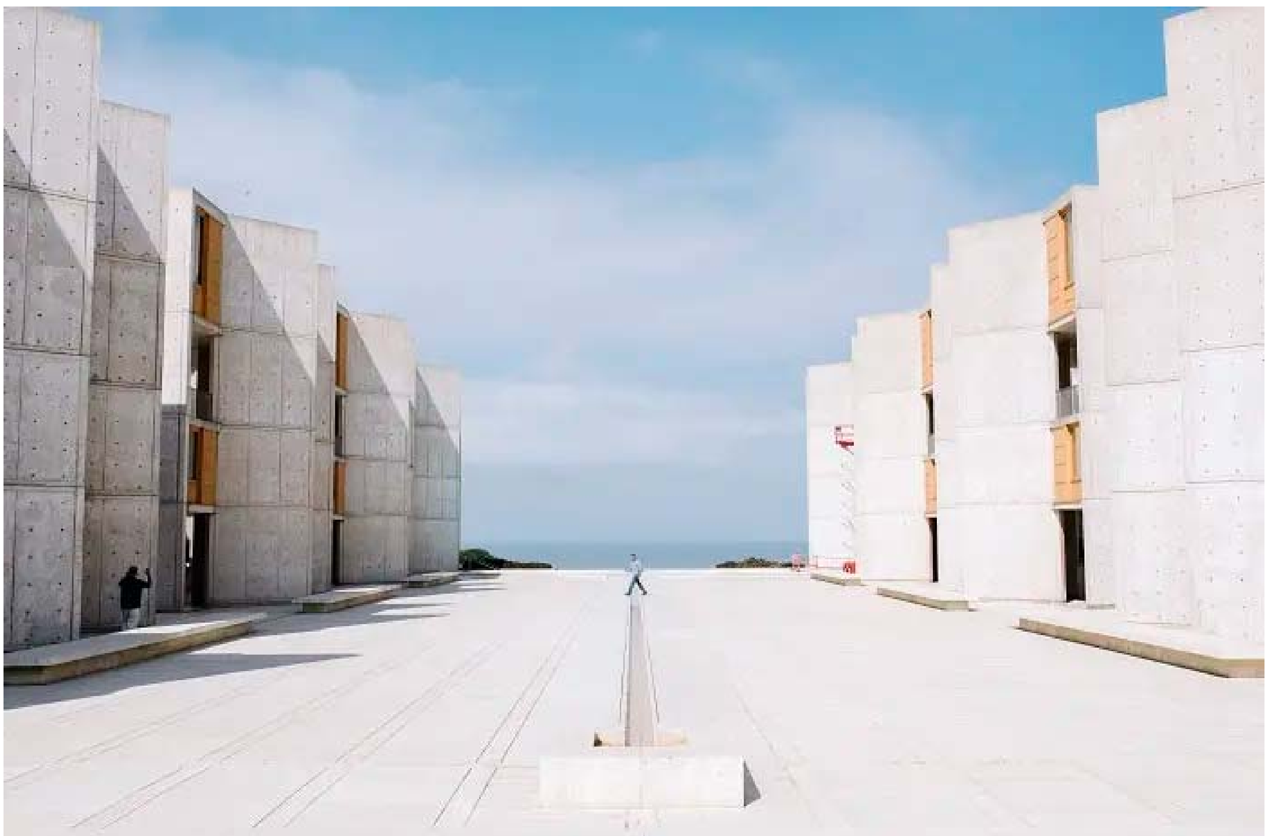
Leslie Hook in San Diego January 30, 2019

On a cliff overlooking the Pacific Ocean, the Salk Institute stands like a concrete temple: an open courtyard facing the sea, flanked by two rows of buildings.

The California campus, designed by Louis Kahn in the early 1960s, is one of the most celebrated examples of modernist architecture in the world. Its stark grandeur is as ambitious as the groundbreaking research taking place inside.

The institute was founded by Jonas Salk, the developer of the first safe polio vaccine, who wanted to create a world-class centre for biological research. Funded by a mix of government grants and philanthropic donations, scientists here have long sought cures for deadly diseases, from cancer to Alzheimer's.

Now a group of them are tackling another life-threatening problem: climate change. They are setting out to do something that has never been done before, to create the "Ideal Plant" — one that will help curb global warming.



The courtyard and lab buildings at Salk © John Francis Peters

"It's an interesting site, isn't it," says Professor Joanne Chory, with a degree of understatement, as we sit down to talk in her office. Chory, one of the world's pre-eminent plant biologists and a leading figure behind the Ideal Plant initiative, has had a prolific career: after a PhD in microbiology, she worked at Harvard Medical School before joining the Salk Institute for Biological Studies in 1988.

In the years since, she has made important discoveries about how plants react to light and produce growth hormones, winning numerous prizes for her work.

There is one more problem she wants to solve: how to design plants that will be able to store more carbon dioxide in their roots. Planted on a large scale, she explains, these might suck enough carbon dioxide out of the atmosphere to help slow down climate change.

Scientist Joanne Chory at Salk: 'I want to do something where I can really make a difference. Climate change is where we have this total need to do it now' © John Francis Peters

Salk is talking to seed companies and preparing to do tests on major agricultural crops — including wheat, soyabeans, corn and cotton — so that the Ideal Plant might one day be introduced on farms around the world.

"We are all pretty passionate about it, because I think we really believe we can do it," says Chory, her leaf-shaped earrings glinting. She is one of five professors at Salk working on the initiative. "I've turned 60, and I want to do something where I can really make a difference. Climate change is where we have this total need to do it now. We have to do it now — maybe it is already too late. I don't know."

That sense of urgency reflects a dire reality: global emissions of carbon dioxide keep rising despite years of policy efforts to control them. The world has already warmed by 1C; to prevent a temperature rise of 2C or more — after which millions of people are likely to face dangerous heatwaves and droughts — many scientists argue that we must add a new strategy to the mix.

If the world cannot cut carbon emissions quickly enough to avoid extreme climate change, can the problem be addressed from the other end — by removing large amounts of CO_2 from the air and storing it long term?

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One of the people excited about this idea is Howard Newman, a private-equity veteran and Salk board member who provided a major donation to help kick off the Ideal Plant project. A 20-year veteran of Warburg Pincus and founder of his own firm, Pine Brook Partners, which invests extensively in oil and gas companies, Newman is one of the project's biggest cheerleaders.

"I'm in the energy business and I was looking at the climate problem. And I noticed that everyone was looking at it in the same way, and if you look at it in a different way, a solution suggested itself," he tells me over the phone from New York. "Bio-sequestration is for real, and people have ignored it . . . This is a technology the world needs. It is a part of the climate problem that no one else has really addressed."

The Ideal Plant concept is just one of a number of carbon dioxide removal projects being pursued around the world — from huge machines to pull CO2 out of the air, to power plants that inject carbon underground. But some environmentalists believe these technologies will never work as hoped, and that focusing on them creates a dangerous illusion that polluters can keep polluting.

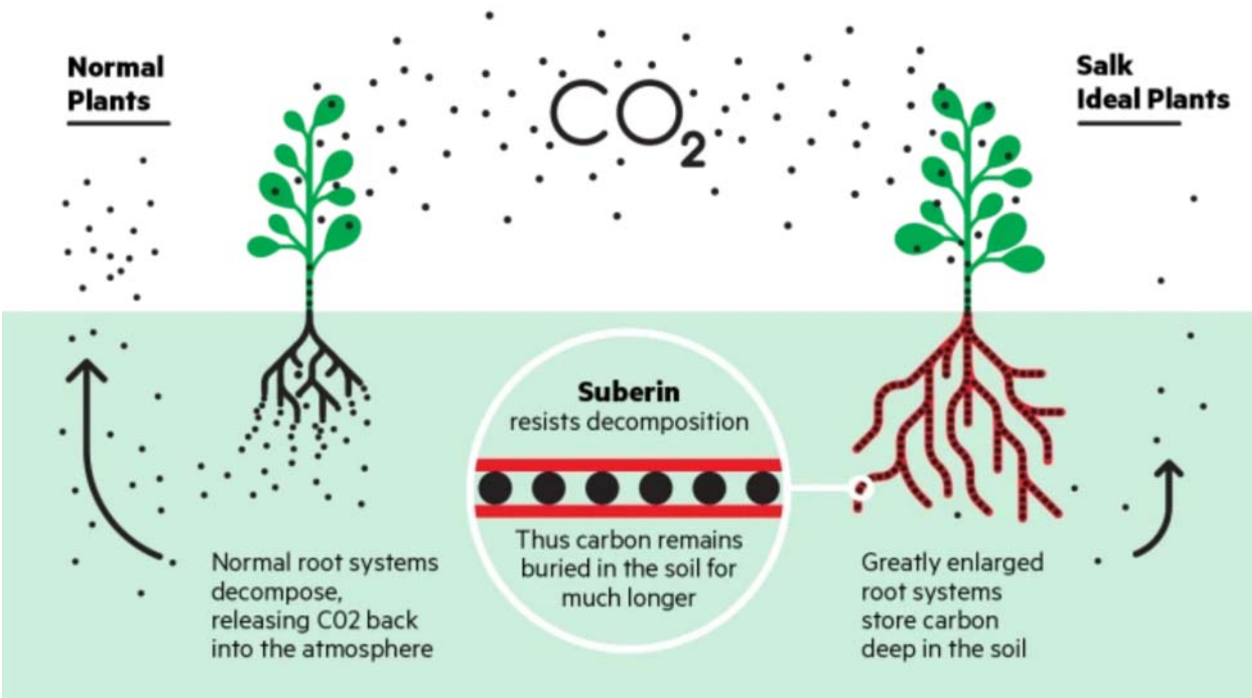
Plants in the greenhouse where experiments are carried out on 'Arabidopsis' © John Francis Peters

“Reliance on negative-emission concepts locks in humankind’s carbon addiction,” argued Kevin Anderson and Glen Peters in a 2016 article in the journal Science. “There is a real risk they will be unable to deliver on the scale of their promise.”

It is also difficult to predict what effect these radical projects seeking to alter the atmosphere might have on earth’s delicate ecosystems. Yet with global CO_2 emissions hitting a record high last year, the scale of the challenge has prompted a growing number of scientists to believe that carbon dioxide removal will be necessary to keep the planet habitable.

In October, a landmark study from the Intergovernmental Panel on Climate Change found that carbon dioxide removal would be essential to keep warming below 1.5C, even if countries were to start drastically cutting emissions immediately.

How the ideal plant works



© Harry Haysom; Source: The Salk Institute

"I feel like I have an obligation to at least try and do something," Chory tells me. She fingers a mug on her desk that shows a mustard-like plant, *Arabidopsis*, which has been the basis of much of her research. The plant, which reproduces quickly and is a mainstay of genetic research laboratories because it produces identical seeds, has already yielded some early results for the Ideal Plant initiative.

Out behind the main Salk campus, in a greenhouse that sits on the bluff, row after row of *Arabidopsis* are absorbing the California sun. Associate Professor Julie Law, who studies gene regulation, shows me around.

"These plants are genetic clones of each other, so it allows us to have reproducibility in our experiments," she says, putting some mustard seeds in my hand. *Arabidopsis* was the first plant to have its entire genome sequenced, with part of that research taking place at Salk.

Scientist Julie Law in one of Salk’s greenhouses: 'Plants have basically been adapted to take carbon dioxide as their food source. The beauty is that plants are already doing this on such a large global scale, that if we can just tap into that a little bit, we can make a big impact' © John Francis Peters

While the idea of genetically engineering a plant to hold carbon dioxide in the ground may sound strange, Law explains it is just a tweak to what plants already do. “The whole job of plants is to take carbon dioxide out of the atmosphere and turn those carbon molecules into sugars, into biomass. They have basically been adapted to take carbon dioxide as their food source,” she explains. “The beauty is that plants are already doing this on such a large global scale, that if we can just tap into that a little bit, we can make a big impact.”

To harness plants so that they sequester more carbon, the first step is to figure out how to keep the carbon fixed in the soil. Normally, plants return most of their carbon back to the atmosphere when they decompose, leaving only a tiny fraction behind in the ground.

This forms part of an annual carbon cycle, as plants take in carbon dioxide during spring growth, and release it back to the atmosphere when they decay in the autumn — sort of like the earth breathing.

“We started looking for those molecules that are the most resistant to decomposition,” explains Professor Joseph Noel, a chemist working on the Ideal Plant project. He says a eureka moment came when he thought back to the compost heap that he maintained as a kid, recalling corks that didn’t decay.

“There was an interesting molecule that was staring us in the face: suberin. It is actually cork. Suberin is a kind of complex natural plastic, it has things that look like diesel fuel in it, but it also has other components . . . It is the way that the plant regulates what gets into the root, like oxygen or other minerals."

Most importantly, suberin doesn't decay easily in soil. Certain plants, such as cork trees, naturally produce a lot of suberin. But all plants produce some suberin — meaning it should be possible to find a gene that would prompt them to increase production. "We started asking, 'How can we select varieties of plants that actually exist, that produce more of this cork and, in particular, more cork in the roots?'"

Noel holds up a vial containing ground cork and another containing brown liquid, a sort of suberin extract. One of his first tasks was to analyse the chemical properties of the suberin polymer.

Last autumn, the team, led by Law, made a key discovery, finding a gene that could increase suberin content in roots dramatically. "Now, not only can we select varieties of plants that bury carbon in the soil . . . it also allows the plant to survive with less water or with more water," Noel says, explaining that suberin helps plants be more drought- and flood-resistant.

Tubes containing bark samples from cork oak trees © John Francis Peters

Although he makes it sound like a wonder molecule, suberin isn't the only approach the team has been testing. Developing plants that have deeper and more massive roots — which wouldn't degrade as much — has also been a core mission. In recent months, the team has successfully identified genes that can do all three things in *Arabidopsis*: trigger a deep root system, increase root mass and develop more cork in the roots.

The task now is to see whether those genes work the same way in other plants. Field-testing will begin later this year to examine how long suberin stays in the soil. A prototype Ideal Plant could be produced within five years, the group says, and large-scale rollout could happen within a decade.

There are broadly three ways to pull carbon dioxide from the air. One is to boost earth's natural carbon sinks, such as planting more forests or restoring seagrass beds. Nature-based methods for CO2 removal also include sequestering carbon in soils, as with the Ideal Plant or by using different agricultural practices such as no-till farming, which can help soils store more carbon.

"We are very interested in soil carbons because over the course of recent human history, we have lost the equivalent of 450 billion tonnes of carbon dioxide from agricultural soils," says Roger Aines, head of negative emissions research at Lawrence Livermore National Laboratory in California.

Restoring this lost carbon can make agricultural soils more productive, he points out. The top two metres of the earth's soil already store more than three times as much carbon as the atmosphere, according to a recent paper in the journal Nature Sustainability, and have the potential to store even more.

A second approach is to use machines to suck carbon dioxide from the air, which is known as direct air capture. This is difficult because CO2 is not very concentrated in the atmosphere — it is just 0.04 per cent of the air we breathe — and a lot of energy and chemicals are required to draw it out.

Several start-ups are working on ways to do this more cheaply, including a Bill Gates-backed group, Carbon Engineering, and a Zurich-based start-up called Climeworks. But no one has found a solution yet.

The third method is to capture carbon dioxide emissions at their source, for example in the smokestack of a power plant, then inject it underground. The advantage is that CO2 is more concentrated there, but the process still requires a lot of energy and a lot of space.

'Arabidopsis' seedlings in a grow room at the Salk Institute © John Francis Peters

About 18 commercial carbon capture and storage facilities operate around the world today but the technology is still too expensive to roll out on a large scale. Oil and power companies have lobbied for more research into this approach, usually called carbon capture and storage, and the US recently passed a tax credit to encourage companies to inject CO2 underground.

All these approaches have significant drawbacks, however. “These CO2 reduction technologies don’t yet exist at the scale that we need,” admits Janos Pasztor, former climate change chief at the UN, now head of the Carnegie Climate Geoengineering Governance Initiative.

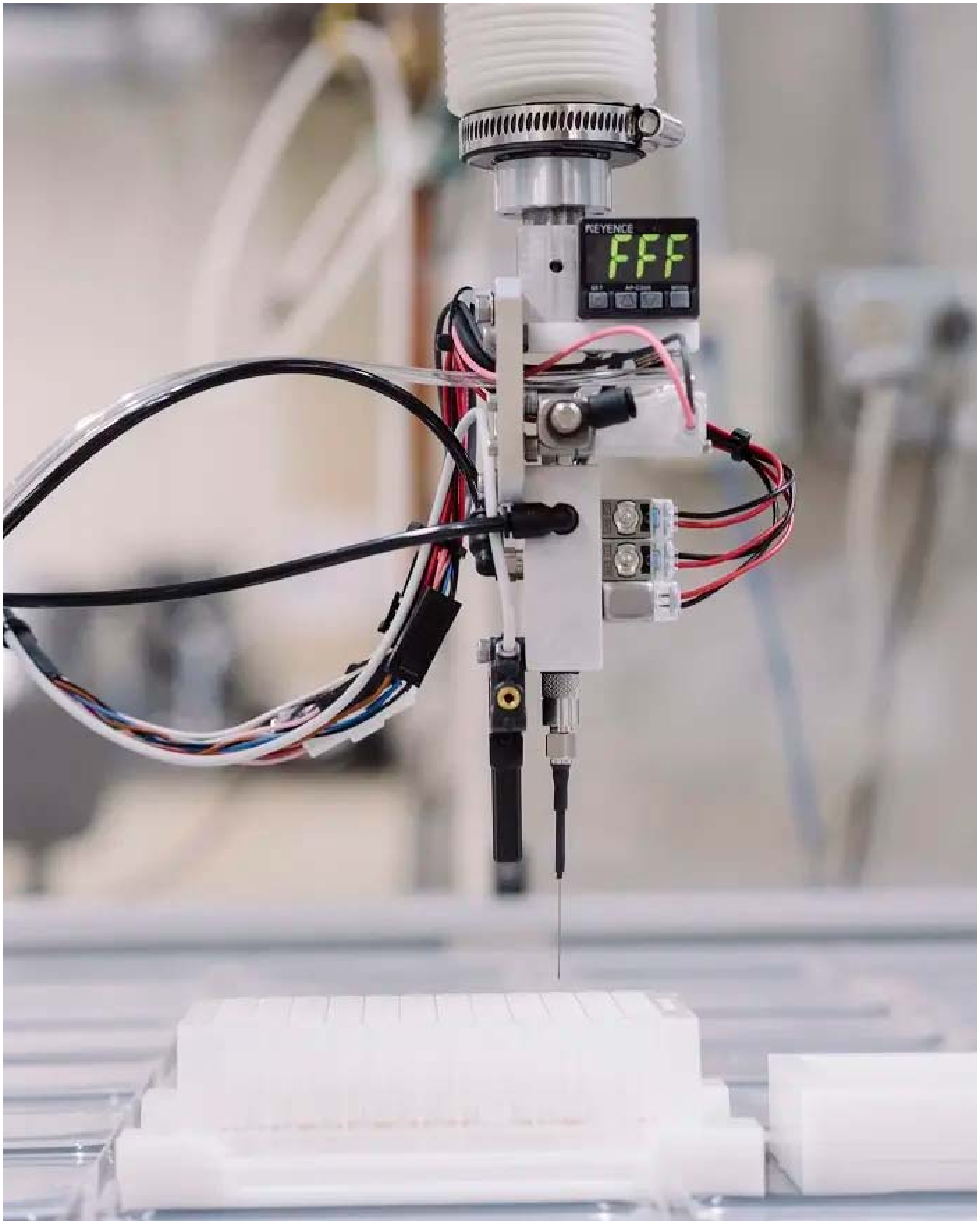
“If we had done what we knew we should have done 20 to 30 years ago — massively reduce our emissions — we wouldn’t be here today, and we wouldn’t have to worry about CO2 removal. Now the time has come that policymakers have to realise that they have to do something else.”

Nature-based approaches to carbon dioxide removal are simpler and better understood than many of the technology-based methods, prompting many researchers to argue that they should be implemented first. Planting more forests, restoring peatland and restoring seagrass beds in the ocean are all considered some of the easiest ways to help increase the earth’s natural carbon sinks.

Several billionaires have adopted carbon dioxide removal as a sort of pet project but it hasn’t yet received significant government funding. Richard Branson launched a $25m global contest for carbon dioxide removal technology in 2007. But even after more than a decade, no solution has been found.

Other backers of carbon dioxide removal include Jeremy Grantham and a range of American foundations, including the Hewlett Foundation and the Packard Foundation.

These philanthropists are attracted to carbon dioxide removal for different reasons. "Photosynthesis is the most effective way to sequester carbon," says Ilkka Herlin, a Finnish billionaire who runs Cargotec, a container logistics company. He recently funded a sequestration programme that studies how farming methods affect carbon content in soils, with much of the research taking place on his own farm.



The Salk Institute's seed-planting robot © John Francis Peters

Other philanthropists take a dim view of humanity's ability to cut carbon emissions. "Most people say the solution to the problem is to get humans to reduce their emissions by 50 per cent, at a time when the world's population is going to expand . . . and incomes are going to rise," says Newman, the backer of the Ideal Plant.

"As a practical matter I just think that is really unlikely to happen. It doesn't mean that we should not move to a low-carbon environment. We just can't move to a low-carbon environment fast enough."

For fossil-fuel companies, finding a breakthrough in carbon removal initiatives would make it much easier for them to continue their current business models while reducing emissions at the same time. Chevron recently invested in Carbon Engineering, one of the start-ups that work on direct air capture. Newman says that when he mentions soil carbon sequestration to energy companies, the response is usually, "How can we help?"

The support from the fossil-fuel industry has fuelled the scepticism of some environmentalists. Negative emissions technologies are a "high-stakes gamble", Anderson and Peters wrote in their Science article. "If we rely on these and they are not deployed or are unsuccessful at removing CO2 . . . society will be locked into a high-temperature pathway." They describe negative emissions as a "moral hazard par excellence".

However, when I call Peters for an interview, more than two years after that article was published, he acknowledges that he now sees a role for carbon removal. He explains that if the world is ever to bring global emissions to "net zero" — the level that would halt global warming — some form of negative emissions will have to occur, to compensate for all the industrial processes (such as cement and steel) that will never be carbon free. "Negative emissions is something that we are going to need, but we don't want to depend on it, or over-depend on it," he adds.

Back at the Salk Institute, where the California sunshine cuts across the central courtyard and an occasional paraglider floats by on the ocean breeze, the Salk group is focused on getting field tests started, and finding a way to get Ideal Plant traits into as many plants as possible.

Chemist Joseph Noel in one of Salk's labs © John Francis Peters

“We all agree in the group that time is of the essence, so we will basically start massively and in parallel working on nine different crop plants,” says Associate Professor Wolfgang Busch, one of the project leaders, who studies deep root systems. “We realised from calculations that we ran that the way to achieve the biggest impact for the Ideal Plant is to focus on crop plants, to tap into this global massive agricultural endeavour.”

These include soyabeans, corn, wheat, cotton, rice, rapeseed and several non-food cover crops that help soil health. “We have to focus on the ones with the highest acreage,” Busch explains.

While introducing the specially designed crop on a large scale could certainly have unintended consequences or be controversial — witness the bitter debates over genetically modified (GM) corn — the Salk team believe it is worth trying. They point out that they don’t use GM techniques (which introduce foreign genetic material); instead, they identify natural genetic variations within plants. Busch’s lab found a gene that can make the *Arabidopsis* grow deeper roots.

“That has already been tested by evolution in the wild — that also makes us hopeful that, in many different species, there are such variants that can do this,” he says.

The Ideal Plant traits being studied can then be switched on using traditional breeding techniques, or by using Crispr, a gene-editing technology. “If [we do it] by traditional breeding, that can be rolled out much faster than if genetic engineering is involved, because the regulatory aspect might take longer,” says Busch.

A few months ago, a European court ruled that Crispr should be regulated in the same way as GM products, but no similar ruling has been made in the US.

However it is produced, the Ideal Plant would have to be planted on a very, very large scale — across millions of acres — to have its intended effect. If half the total acreage of all six major crops had Ideal Plant traits, this might sequester about one-fifth of annual man-made carbon dioxide emissions, Busch estimates.

"The impact of this solution only comes with the amount of plants that are planted in agriculture systems, and while technically we are all very convinced that this is a great solution to make a big impact, of course it is not only up to us."

An immediate challenge for the project is to test how suberin degrades in soil over time, and how high-suberin roots impact soil health. Questions remain over whether suberin turns into an active carbon that enriches the soil or remains inert.

The first job of any of these technologies — whether the Ideal Plant or another form of carbon dioxide removal — will be to prove that the pros outweigh the cons. When it comes to interfering with any natural processes on a very large scale, the risk of unintended consequences is high.

Yet as the planet warms, ideas that once seemed outlandish are starting to be taken seriously. Compared with proposals like colonising Mars or sprinkling aerosols in the sky, using plants to draw down carbon dioxide is hardly the strangest approach to address global warming.

A growing number of climate advocates believe we will need a combination of nature-based and technology-based solutions to limit global warming to 2C. Roger Aines points out that this would mean removing around 10 billion tonnes of carbon dioxide annually by the middle of the century, using median estimates. That's equivalent to the entire annual emissions of China.

"We can't assume that a single solution is good enough," he says. "We have to prepare all of the tools to be ready, and the scale of the thing is unimaginable."

Leslie Hook is the FT's environment and clean energy correspondent

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