Carbon Super-Eaters

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1. Introduction

It is widely recognized that old-growth trees in normal forests are an excellent way to sequester carbon for hundreds of years. One variant of this technique is to harvest mature trees and use them to build long-lived structures. Another variant is to harvest woody biomass (which could include undergrowth pruned from trees, harvested trees or even wood structures at the end of their lives) burn it, and geologically sequester the CO_2 and other greenhouse gasses (GHGs) emitted by the combustion. At their most efficient state of development, these processes would provide negative GHG emissions.

Most or all of the above techniques would benefit from tree-like plants that have accelerated growth-rates. This post is about two variants of these carbon super-eaters: bamboo and genetically-modified variants of normal trees.

2. Bamboo

Bamboo is the fastest growing plant on earth. Some species of bamboo can grow more than 1 meter (3.3 feet) per day, which is about 4 cm (1.6 inches) per hour. No other plant grows faster. Two examples of such fast growing bamboos are Madake (Phyllostachys reticulata) and Moso (Phyllostachys edulis).[1]

A new bamboo shoot will reach its full height in less than a year by going through several rapid spikes of growth. The largest bamboo species in the world is Dendrocalamus sinicus, which can grow up to 46 m (150 feet) in height and up to 37 cm (15 inches) in diameter.

While bamboo may grow taller than some trees, bamboo is not a tree but a group of plants that belong to the grass family. Bamboo plants come out of the ground with a fixed diameter and stems will not get thicker over the years (as is the case with trees). In addition, bamboo also doesn't grow taller as it gets older. A fully grown 1 year old bamboo stem, however, is not considered mature yet. Depending on the species and diameter, it usually takes another 1 to 4 years for a bamboo stem to mature into a hard, wood-like material. The bigger the stem, the longer it will take to mature.

Another amazing feature of bamboo is that it is the only type of grass that can develop itself into a forest. Bamboo will constantly reproduce itself, even after harvesting, new shoots will continue to sprout from its extensive root system without having to replant. Because of all these unique characteristics, bamboo is rightfully labeled as a highly renewable and sustainable resource.

2.1. Carbon Sequestration Potential

Bamboo plants absorbs enormous amounts of greenhouse gases, and because of its rapid growth, bamboo is very useful as a tool for carbon sequestration.

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[1] Guadua Bamboo, "10 Reasons Why Bamboo is the World's Most Amazing Plant," 2023, https://www.guaduabamboo.com/why-bamboo

When a single bamboo seedling is planted it will convert into a clump. In case of giant tropical bamboo, one newly planted bamboo plant can sequester 2 tons of carbon dioxide in just 7 years. In comparison, a typical hardwood tree will sequester 1 ton of carbon dioxide in 40 years. When compared to pine, bamboo can absorb up to 5 times more CO_2.

If 10 million hectares (25 million acres) of bamboo were planted on degraded land throughout the world, it is estimated that bamboo plants and their products could save more than 7 gigatons of carbon dioxide in 30 years. That is more than what 300 million electric cars could save in the same period of time.

2.1.1. Combustion

Bamboo is a sustainable energy source that produces 1 kWh of electricity from 1,2 kg (2.65 lb.) of bamboo. This is similar to the biomass requirements for wood products, but outperforms other types of biomass sources such as hemp, bagasse or rice husk. Bamboo can produce an enormous amount of biomass in a relatively short period of time, which makes it an important reforestation resource in many countries.

Bamboo biomass can be used as a substitute for firewood as it is processed into various energy products such as charcoal, pellets and briquettes through thermal or biochemical transformations. See below for the various bamboo fuels.


Bamboo Chips


Bamboo Charcoal


Bamboo Pellets


Bamboo Briquettes

2.1.2. Bamboo Structures

Bamboo can be utilized as a building material for scaffolding, bridges, houses and buildings. Bamboo, like wood, is a natural composite material with a high strength-to-weight ratio useful for structures. Bamboo's strength-to-weight ratio is similar to timber, and its strength is generally similar to a strong softwood or hardwood timber...[2]

Bamboo can be cut and laminated into sheets and planks. This process involves cutting stalks into thin strips, planning them flat, and drying the strips; they are then glued, pressed and finished. Long used in China and Japan, entrepreneurs started developing and selling laminated bamboo flooring in the West during the mid-1990s; products made from bamboo laminate, including flooring, cabinetry, furniture and even decorations, are currently surging in popularity, transitioning from the boutique market to mainstream providers such as Home Depot. The quality of bamboo laminate varies among manufacturers and varies according to the maturity of the plant from which it was harvested (six years being considered the optimum).

[2] Wikipedia Article on "Bamboo construction," https://en.wikipedia.org/wiki/Bamboo_construction

Author's comment: In the U.S. bamboo laminate is most commonly used for flooring, but it is available in forms resembling normal lumber. Thus in the future it could be used for a large percentage of structures for homes and somewhat larger buildings. See the site below for more information.

https://www.moso-bamboo.com/us/bamboo/how-bamboo-products-are-made/laminated-bamboo-production/

3. Living Carbon

Fifty-three million years ago, the Earth was much warmer than it is today. Even the Arctic Ocean was a balmy 50 °F—an almost-tropical environment that looked something like Florida, complete with swaying palm trees and roving crocodiles.[3]

Then the world seemed to pivot. The amount of carbon in the atmosphere plummeted, and things began to cool toward today's "icehouse" conditions, meaning that glaciers can persist well beyond the poles.

What caused the change was, for decades, unclear. Eventually, scientists drilling into Arctic mud discovered a potential clue: a layer of fossilized freshwater ferns up to 20 meters thick. The site suggested that the Arctic Ocean may have been covered for a time in vast mats of small-leaved aquatic Azolla ferns. Azollas are among the fastest-growing plants on the planet, and the scientists theorized that if such ferns coated the ocean, they could have consumed huge quantities of carbon, helping scrub the atmosphere of greenhouse gasses and thereby cooling the planet.

Patrick Mellor, paleobiologist and chief technology officer of the biotech startup Living Carbon,[4] *sees a lesson in the story about these diminutive ferns: photosynthesis can save the world. Certain fluke conditions seem to have helped the Azollas along, though. The arrangement of continental plates at the time meant the Arctic Ocean was mostly enclosed, like a massive lake, which allowed a thin layer of fresh river water to collect atop it, creating the kind of conditions the ferns needed. And crucially, when each generation of ferns died, they settled into saltier water that helped inhibit decay, keeping microbes from releasing the ferns' stored carbon back into the atmosphere.*

Mellor says we can't wait millions of years for the right conditions to return. If we want plants to save the climate again, we have to prod them along. "How do we engineer an anthropogenic Azolla event?" he says. "That's what I wanted to do."

At Living Carbon, Mellor is trying to design trees that grow faster and grab more carbon than their natural peers, as well as trees that resist rot, keeping that carbon out of the atmosphere. In February, less than four years after he co-founded it, the company made headlines by planting its first "photosynthesis-enhanced" poplar trees in a strip of bottomland forests in Georgia.

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[3] Boyce Upholt, MIT Technology Review, "Inside the quest to engineer climate-saving 'super trees'," June 8, 2023, https://www.technologyreview.com/2023/06/08/1074287/inside-the-quest-to-engineer-climate-saving-super-trees/

[4] Living Carbon, Hayward, CA, https://www.livingcarbon.com/

This is a breakthrough, clearly: it's the first forest in the United States that contains genetically engineered trees. But there's still much we don't know. How will these trees affect the rest of the forest? How far will their genes spread? And how good are they, really, at pulling more carbon from the atmosphere?

Living Carbon has already sold carbon credits for its new forest to individual consumers interested in paying to offset some of their own greenhouse gas emissions. They're working with larger companies, to which they plan to deliver credits in the coming years. But academics who study forest health and tree photosynthesis question whether the trees will be able to absorb as much carbon as advertised…

In photosynthesis, plants pull carbon dioxide out of the atmosphere and use the energy from sunlight to turn it into sugars. They burn some sugars for energy and use some to build more plant matter—a store of carbon.

A research group based at the University of Illinois Urbana-Champaign supercharged this process, publishing their results in early 2019. They solved a problem presented by RuBisCO, an enzyme many plants use to grab atmospheric carbon. Sometimes the enzyme accidentally bonds with oxygen, a mistake that yields something akin to a toxin. As the plant processes this material, it must burn some of its sugars, thereby releasing carbon back to the sky. A quarter or more of the carbon absorbed by plants can be wasted through this process, known as photorespiration.

The researchers inserted genes into tobacco plants that helped them turn the toxin-like material into more sugar. These genetically tweaked plants grew 25% larger than controls.

The breakthrough offered good news for the world's natural landscapes: if this genetic pathway yields more productive crops, we'll need less farmland, sparing forests and grasslands that otherwise would have to be cleared. As for the plants' ability to remove atmospheric carbon over the long term, the new trick doesn't help much. Each year, much of the carbon in a crop plant's biomass gets returned to the atmosphere after it's consumed, whether by microbes or fungi or human beings.

Still, the result caught the attention of Maddie Hall, a veteran of several Silicon Valley startups who was interested in launching her own carbon-capture venture. Hall reached out to Donald Ort, the biologist who'd led the project, and learned that the same tweaks might work in trees—which stay in the ground long enough to serve as a potential climate solution.

Late in 2019, Hall settled on the name for her startup: Living Carbon. Not long afterward, she met Mellor at a climate conference. Mellor was then serving as a fellow with the Foresight Institute, a think tank focused on ambitious future technologies, and had become interested in plants like Pycnandra acuminata. This tree, native to the South Pacific islands of New Caledonia, pulls huge quantities of nickel out of the soil. That's likely a defense against insects, but as nickel has natural antifungal properties, the resulting wood is less prone to decay. Mellor figured if he could transfer the correct gene into more species, he could engineer his Azolla event.

When Mellor and Hall met, they realized their projects were complementary: put the genes together and you'd get a truly super tree, faster-growing and capable of more permanent carbon storage. Hall tapped various contacts in Silicon Valley to collect $15 million in seed money, and a company was born.

In some ways, Living Carbon's goal was simple, at least when it came to photosynthesis: take known genetic pathways and place them in new species, a process that's been conducted with plants for nearly 40 years. "There's a lot of mystification of this stuff, but really it's just a set of laboratory techniques," Mellor says.

Since neither Mellor nor Hall had substantial experience with genetic transformation, they enlisted outside scientists to do some of the early work. The company focused on replicating Ort's enhanced-photosynthesis pathway in trees, targeting two species: poplars, which are popular with researchers because of their well-studied genome, and loblolly pines, a common timber species. By 2020, the tweaked trees had been planted in a grow room, a converted recording studio in San Francisco. The enhanced poplars quickly showed results even more promising than Ort's tobacco plants. In early 2022, Living Carbon's team posted a paper on the preprint server bioRxiv claiming that the best-performing tree showed 53% more above-ground biomass than controls after five months. (A peer-reviewed version of the paper appeared in the journal Forests in April.)

Plant genetics research can be a long scientific slog. What works in a greenhouse, where conditions can be carefully controlled, may not work as well in outdoor settings, where the amounts of light and nutrients a plant receives vary. The standard next step after a successful greenhouse result is a field trial, which allows scientists to observe how genetically engineered (GE) plants might fare outside without actually setting them fully loose.

US Department of Agriculture (USDA) regulations for GE field trials aim to minimize "gene drift," in which the novel genes might spread into the wild. Permits require that biotech trees be planted far from species with which they could potentially reproduce, and in some cases the rules dictate that any flowers be removed. Researchers must check the field site after the study to ensure no trace of the GE plants remain.

Before planting trees in Georgia, Living Carbon launched its own field trials. The company hired Oregon State's Strauss, who had given Living Carbon the poplar clone it had used in its gene transfer experiments. In the summer of 2021, Strauss planted the redesigned trees in a section of the university's property in Oregon.

Strauss has been conducting such field trials for decades, often for commercial companies trying to create better timber technologies. It's a process that requires patience, he says: most companies want to wait until a "half rotation," or midway to harvest age, before determining whether a field trial's results are promising enough to move forward with a commercial planting. Living Carbon's trees may never be harvested, which makes setting a cutoff date difficult…

Author's comment: Early genetic modification was performed with a microbe, and the USDA was concerned that this microbe would escape and create detrimental-plants like super-weeds. This gave it justification to regulate this work. The USDA considered the microbe a "plant pest".

In 1987, just one year after the USDA established its policy, a team of Cornell researchers announced the successful use of what's become known as a "gene gun"—or, less colorfully, "biolistics"—in which bits of DNA are literally blasted into a plant cell, carried by high-velocity particles. No plant pest was involved. This created a loophole in the system, a way to produce GE plants that the current laws did not cover.

Since then, more than 100 GE plants, mostly modified crop plants, have thus escaped the USDA's regulatory scrutiny…

Once Living Carbon saw that its trees had promise, it dove through the loophole, creating new versions of its enhanced trees via biolistics. In formal letters to the USDA the company explained what it was doing; the agency replied that, because the resulting trees had not been exposed to and did not contain genes from a plant pest, they were not subject to regulations…

A year after Living Carbon announced its greenhouse results—before the data from the field trial had any meaning, according to Strauss—the company sent a team to Georgia to plant the first batch of seedlings outside strictly controlled fields. Mellor indicated that this would double as one more study site, where the trees would be measured to estimate the rate of biomass accumulation. The company could make an effort to start soaking up carbon even as it was verifying the efficacy of its trees.

"I think it'd be difficult to on purpose make a tree that was a weed—that was able to invade and take over a forest," said Sean McMahon, a forest ecologist with the Smithsonian Tropical Research Institute. "I think it'd be impossible by accident to do it. I'm really not worried about a tree that takes over the world. I just think you're going to break [the tree]."

He pointed out that the timber industry has been working with scientists for decades, hoping to engineer fast-growing trees. "This is a billion-dollar industry, and if they could make trees grow to harvest in five years, they would," he said...

The other reason for the quiet reception of these trees may be climate change: in a ravaged world, people may be more willing to tolerate risk. Keolu Fox, a geneticist at the University of California San Diego, is a co-director of science at Lab to Land, a nonprofit that is studying the potential for biotechnology to accelerate conservation goals on threatened lands, particularly in California. "We're now talking about editing natural lands—that's desperation," Fox says. He thinks this desperation is appropriate, given the state of the climate crisis…

Living Carbon's poplars seem to grow faster and survive droughts better than their natural counterparts, Mellor says. The rest of their genes match. "So, if, say, that competitively replaces the non-photosynthesis-enhanced version, is that a problem?" he asks. "And what kind of a problem is that? That's the question now."

In 2019, before Living Carbon was formed, the USDA announced its intention to update its regulatory approach to transgenic plants. The new rules went into effect in August 2020, just after Living Carbon submitted letters seeking exemption for its trees; the letters were reviewed and the trees were grandfathered in under the old rules.

Any further biotechnology the company develops will be analyzed using the new approach, which focuses on what traits are inserted into plants rather than how they get there. There are still ways to avoid scrutiny: products whose genetic modification could be accomplished through conventional breeding, for example, are not subject to regulation—a loophole watchdog groups find problematic. But according to USDA spokespeople, Living Carbon's core technology—fast-growing trees, produced through genetic insertion—does not appear to qualify for such exemptions. If Living Carbon wants to make even a slight genetic tweak to its trees, the new product will require further examination.

The USDA's first step is to determine whether there is "a plausible pathway to increased plant pest risk." If the answer is yes, the company will need permits to move or plant such trees until the USDA can complete a full regulatory review.

Final author's comment: Although it appears that Living Carbon's first product (the enhanced poplar) is reasonably successful. Even if some minor issue is discovered in field testing, and this issue requires further genetic modification to fix, I expect they could argue that this specific example does not materially impact the risk imposed by the original design. Furthermore, from their web-site (reference 4 above), it appears that they are working on other genetically modified plants, so they need to work with the USDA to define a set of rules for these. Their current projects appear to be focused on carbon removal. Thus the argument made above in the paragraph beginning with "The other reason for the quiet reception of these trees may be climate change…" That is, the desperate need for climate change mitigation justifies some risk.