Enhanced Photosynthesis

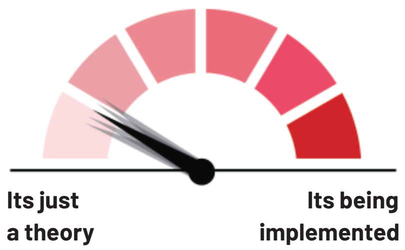
Description and purpose of the technology

Photosynthesis enhancement is a theoretical geoengineering technology based on the idea that plants and algae can be genetically modified to exhibit "more efficient" photosynthetic traits, leading those organisms to absorb and metabolize more CO_2. According to critics of the approach, enhancing photosynthesis by converting plants is a high-tech, high-risk project, with high risks to food security in particular.[1] There are serious concerns that accompany all genetic engineering of plant life, involving unexpected side effects, risks of contamination in natural systems, poorly-understood long-term impacts on humans and ecosystems, and corporate control.

Proponents primarily justify research into altering the photosynthesis of plants through food security arguments: that world population is growing, crop yields have reached a plateau and, given growing demands for food and fuel in the face of climate change, we must find a way to increase crop yields. For geoengineering photosynthesis engineers, "the key remaining route to increase the genetic yield potential of our major crops"[2] is enhancing photosynthesis. However, since this modification is designed to remove more CO_2 by photosynthesis from the atmosphere, carbon dioxide removal (CDR) aims are also used to justify this research. The anticipated CDR effects of enhanced photosynthesis are based on the assumption that the additional CO_2 that would be absorbed by the genetically modified plants would permanently remain in soils or at the bottom of the sea.

Point of Intervention:

Reality Check:



The use of monocultures of crops genetically modified to reflect more light could exacerbate land grabs and forced displacement.

Actors involved

The C_4 Rice Project is a collaboration between scientists from Europe, North America and Asia. Kick-started in 2008, it has been supported by the Bill and Melinda Gates Foundation to the tune of US$ 25 million of funding so far. The project aims to transform rice – a plant with C_3-photosynthesis – into a plant with C_4-photosynthesis, aiming to theoretically increase yields, enhance nitrogen use and water use efficiency, improve adaptation to hotter and drier climates and eventually remove more CO_2 from the atmosphere. The present funding phase aims to develop a prototype of rice with C_4-photosynthesis.[3]

Critics question the wisdom of using rice as the target crop for such extreme genetic engineering, in a time of water stress, and when it is one of the worlds staple crops, and the pillar of the livelihood of billions of people.[4]

Notwithstanding, some researchers consider rice "an ideal crop" to practice C_4 engineering using synthetic biology because it was the first crop species to have its genome sequenced and has large amounts of physiological, genetic and genomic data available.

Rice could pave the way to engineered C_4 wheat, C_4 cotton and C_4 trees.[5] In time, proponents say, switching major crops to enhanced photosynthesis on a large scale would theoretically draw down large amounts of CO_2.

The European Union funded its own "3To4" project from 2012 to 2016, with an overall budget of €8.9 million. A consortium of private and public-sector researchers tried to enhance photosynthesis by engineering the characteristics of C_4 photosynthesis into C_3 crops. Supporting the C_4 Rice Project has been another project focus. While the researchers were focusing initially on rice as a model crop, they "envisage rapid transfer of technological advances into mainstream EU crops, such as wheat and rape."[6] Private sector consortium members included Bayer Crop Science and Chemtex Italia (now Biochemtex). The pan-European project BEEP (bio-inspired and bionic materials for enhanced photosynthesis) looks at photosynthetic processes in a marine environment, aiming to understand the mechanisms affecting photosynthetic efficiency, for example for marine bacteria and algae, and to apply the insights for "boosting photosynthesis in living organisms".[7]

Other research is currently underway to show how plants' absorption of CO_2 could be increased synthetically. Synthetic biologists have built entirely novel biochemical processes into engineered organisms to speed up the carbon fixation process and make plants better at turning carbon dioxide into energy.

> **"The genetic engineering of plant life is accompanied by serious concerns and enhancing photosynthesis by converting C_3 plants into C_4 plants is a high-tech, high-risk project."**

In 2016, a team of synthetic biologists at the German Max Planck Institute for Terrestrial Microbiology in Marburg stitched together 17 different enzymes from nine different organisms (e.g. gut bacteria, further microbes and plants) to achieve a proof-of-principle CO_2-fixation pathway in an engineered organism that exceeds what can be found in nature.

The so-called CETCH cycle includes three engineered enzymes, among them a new synthetic CO_2-fixing enzyme that is nearly 20 times faster than the most prevalent enzyme in nature responsible for capturing CO_2. After demonstrating the process in vitro, the research team is now aiming to transplant the process into living cells. Future applications are envisaged for higher biofuel and food production.[8]

The vast variety and diversity of maize is being lost because of intensive agriculture. This only reduces climate resilience
Photo by The International Maize and Wheat Improvement Center via Flickr

In another study, researchers enhanced crop productivity by reducing the time it takes plants to "recover" from detecting too much light.[9] By adding proteins to certain tobacco plants, the engineered plants grew up to 20% bigger, and the focus is now achieving the same with crops like rice, sorghum, and cassava. The research is also funded by the Bill and Melinda Gates Foundation.

Billions of people depend on rice harvests – what if genetically engineered rice had unintended consequences on traditional varieties?
Photo by SarahTz via Flickr

A research project conducted by the Chinese Qingdao Institute of Bioenergy and Bioprocess Technology aims to combine CO_2-uptake, enhanced microalgal photosynthesis and biofuel-production by genetically modifying the microalgae Nannochloropsis oceanica. The objective is to improve the microalgal tolerance to high levels of CO_2 to establish a microalgae production with flue gas for oil production.[10]

The California-based Salk Institute announced the commercialization of the "Ideal Plant" around 2025. The Ideal Plant Project applies gene editing methods to enhance plants' capacity to store carbon and to resist decomposition, by increasing the amount of suberin, a plant substance comparable to cork, in plant roots.

The US company ZeaKal is presently further developing and testing its "PhotoSeed" plants, in cooperation with chemical company Dow DuPont. According to ZeaKal, enzymatic reactions in PhotoSeed plants have been genetically modified for enhanced photosynthesis, growth rates and CO_2 uptake.[11]

Impacts of the technology

The ability to manipulate photosynthesis implies control over just about everything that determines how and if a plant survives and thrives: how efficiently it uses water and nutrients to grow and produce the biomass that we use for food, fibre and fuel, as well as how efficiently it fixes CO_2 and releases oxygen.

The genetic engineering of plant life is accompanied by serious concerns and enhancing photosynthesis by converting C_3 plants into C_4 plants is a high-tech, high-risk project. Jill E. Gready, Research Professor at the Australian National University, argues: "pursuit and public promotion of some very high-tech solutions for photosynthesis improvement with high risk of failure... present a high-level risk to food security as they provide false confidence that the problem is being addressed, and, by diverting funds, lead to lost opportunity for R&D with greater likelihood of success and impact."[12]

Cornell University's Norman Uphoff, another critic, has spearheaded an agroecologically-based method of cultivating rice known as the System of Rice Intensification. He recently published data demonstrating that a change in farm management practices – such as wider spacing of plants and increased soil aeration – can dramatically increase rice yields beyond what has been thought possible, and without increased dependence on chemical inputs or genetic engineering.[13]

Reality check

Research into photosynthesis enhancement is well underway and projects are moving from engineering in vitro to engineering crop plants. However, the effectiveness of enhanced photosynthesis as a method for carbon storage is mostly theoretical, particularly because there are many uncertainties related to the permanence of the absorbed carbon in soils or sea.

Further reading

ETC Group and Heinrich Böll Foundation, "***Outsmarting Nature? Synthetic Biology and Climate Smart Agriculture***": http://www.etcgroup.org/content/outsmarting-nature/report

This video summarizes what the researchers are trying to achieve through photosynthesis enhancement but doesn't discuss the potential impacts: www.youtube.com/watch?v=Av0dTk9KzIY

Endnotes

1 Gready (2014) Best-fit options of crop staples for food security: productivity, nutrition and sustainability, in: Jha, et al. (2014) Handbook on Food, chapter 15, page 406

2 Long, et al. (2015) Meeting the Global Food Demand of the Future by Engineering Crop Photosynthesis and Yield Potential, in: Cell, Vol. 161:56-66, https://doi.org/10.1016/j.cell.2015.03.019

3 ETC Group and Heinrich Böll Foundation (2020) Geoengineering Map, https://map.geoengineeringmonitor.org

4 ETC Group and Heinrich Böll Foundation (2015) Outsmarting Nature? Synthetic Biology and Climate Smart Agriculture, Communiqué 114, https://www.boell.de/en/2015/11/30/outsmarting-nature-synthetic-biology-and-climate-smart-agriculture

5 Zhu, et al. (2010) C4 Rice – an ideal arena for systems biology research, in: J Integr Plant Biol., Vol. 52(8):762 - 770, https://doi.org/10.1111/j.1744-7909.2010.00983.x

6 CORDIS (2016) 3to4: Converting C3 to C4 photosynthesis for sustainable agriculture, CORDIS project database of the European Union, accessed: February 2020, https://cordis.europa.eu/project/id/289582; ETC Group and Heinrich Böll Foundation (2020)

7 ETC Group and Heinrich Böll Foundation (2020)

8 Schwander, et al. (2016), A synthetic pathway for the fixation of carbon dioxide in vitro, in: Science, Vol. 354(6314):900 - 904, http://doi.org/ 10.1126/science.aah5237 ; ETC Group and Heinrich Böll Foundation (2020)

9 Kromdijk, et al. (2016) Improving photosynthesis and crop productivity by accelerating recovery from photoprotection, in: Science, Vol. 354(6314): 857 - 861, http://doi.org/10.1126/science.aai8878

10 ETC Group and Heinrich Böll Foundation (2020)

11 ETC Group and Heinrich Böll Foundation (2020)

12 Gready (2014)

13 Uphoff (2013) Rethinking the concept of 'yield ceiling' for rice: implications of the System of Rice Intensification (SRI) for agricultural science and practice, in: Journal of Crop and Weed, Vol. 9(1):1 – 19, http://www.cropandweed.com/vol9issue1/1.1.html