Outsmarting Nature?

Synthetic Biology and Climate Smart Agriculture

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Summary

Issue

Many of the world's largest agro-industrial corporations have already sworn fealty to "Climate-Smart agriculture" (CSA) as part of the new Global Alliance for Climate-Smart Agriculture (GACSA) – and they're preparing to march into Paris for the UN's December Climate Conference (UNFCCC COP 21)[1] waving the Climate-Smart flag. Although it's currently below the radar, both public- and private-sector advocates of CSA are embracing tools of synthetic biology ("Syn Bio") as the latest, greatest game-changing technology to combat climate change. If they get their way in Paris, industry will insist that synthetic biology's made-from-scratch living organisms and designer crops are essential adaptation and mitigation strategies as the climate crisis deepens.

The world's largest agrochemical and seed companies, public-sector researchers and biotech start-ups are actively incorporating synthetic biology in current R&D. This report briefly examines agriculture-related R&D involving Syn Bio's microorganisms and crops being developed in the name of climate-change mitigation and adaptation, including high-tech approaches to enhance photosynthesis (e.g., engineered pathways regulating nitrogen fixation and environmental stress tolerance). We examine one research team that seeks to activate drought tolerance in crops with proprietary chemicals; we also look at how synthetic biologists envision the use of controversial "gene drives" to engineer weeds in the wild to become more susceptible to pesticides.

Actors

The UN's Food and Agriculture Organization (FAO) began talking about "Climate-Smart" agriculture in 2009 as a way to bring agriculture – and its role in mitigation, adaptation and food security – into the climate negotiations.[2] Two FAO conferences dedicated to Climate-Smart agriculture, organized with the World Bank and a small group of governments, followed in 2010 and 2012. Formally launched as The Global Alliance for Climate-Smart Agriculture (GACSA) in 2014, its membership now includes 22 national governments, agribusiness lobby groups (the majority representing the fertilizer industry)[3], the world's largest network of public agricultural scientists – the Consultative Group on International Agricultural Research (CGIAR) – universities and NGOs. Climate-smart agriculture is also promoted by the World Business Council for Sustainable Development (WBCSD) through its Low Carbon Technology Partnerships Initiative (LCTPi), which aims to influence climate negotiations in Paris and beyond.

Policy

More than 350 civil society organizations from around the world (including social movements, peasant/farmers' organizations and faith-based communities) are urging negotiators in Paris to reject the "Climate-Smart" brand of the Global Alliance. The coalition warns that CSA "does not involve any criteria to define what can or cannot be called 'Climate Smart.' Agribusiness corporations that promote synthetic fertilisers, industrial meat production and large-scale industrial agriculture – all of which are widely recognised as contributing to climate change and undermining the resilience of farming systems – can and do call themselves 'Climate Smart.'"[4] The immediate danger is that industry-led lobby efforts could result in climate negotiators explicitly endorsing Climate-Smart agriculture at COP 21 and steering the Convention's Green Climate Fund resources toward specious Climate-Smart projects that distract from real solutions to build resilience. (The Green Climate Fund is a financing mechanism of the Convention to support developing country mitigation and adaptation projects – including agriculture.)[5]

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Governments meeting in Paris must reject "Climate-Smart" agriculture and instead promote Climate-Resilient strategies based on Agroecology. Farmer-led strategies for climate change survival and adaptation must be recognized, strengthened and supported, with the direct involvement of farming communities.

What is Synthetic Biology?

Synthetic biology

…dubbed "genetic engineering on steroids," broadly refers to the use of computer-assisted, biological engineering to design and construct new synthetic life forms, living parts, devices and systems that do not exist in nature. The term also refers to the intentional redesign of existing biological organisms using these same techniques. Synthetic biology attempts to bring a predictive engineering approach to biology, using genetic "parts" that are thought to be well characterized and which will exhibit the predicted behavior in the engineered organism.

While the field aims to make bioengineering predictable, it is still a long way from that ideal. In fact, many geneticists and microbiologists (and even some synthetic biologists, privately) contend that this will likely never be possible. Living organisms are highly dependent on context and environmental influences for their function, health and behavior; they are fundamentally not like machines.[7]

The field of Synthetic Biology is somewhat nebulous, and scientists don't always agree at what point "classical" genetic engineering crosses the line into Synthetic Biology. In its simplest form, genetic engineering involves cutting genetic material out of one organism and pasting it into another. Synthetic biology, modeled on the fields of mechanical and electronic engineering, typically involves the assembly of standard and reusable biological components, providing flexibility to move beyond what already exists in nature. The rapidly falling price of DNA synthesis and genome editing, modular assembly tools and increased computing capacity is propelling the field of Synthetic Biology.

Synthetic biology can differ from conventional genetic engineering in the complexity of organisms or systems that researchers create and/or manipulate. Rather than focus on expression of single genes or gene components, the work of synthetic biologists may involve whole interacting genetic networks, genomes and entire organisms.[6]

The genetic engineering of any organism may give rise to unpredictable and unforeseen effects, often not immediate; and the increased complexity of Synthetic Biology will heighten these risks. Releasing Syn Bio organisms (intentionally or not) that reproduce on their own and spread throughout the biosphere increases the dangers to plants, animals, microbes – and entire ecosystems.

Regulators are struggling to catch up to this new set of genetic techniques and to understand how to assess and control the products derived from them. The European Union and the UN Convention On Biological Diversity are now involved in processes to formally define the term "Synthetic Biology."[8]

1 United Nations Framework Convention on Climate Change, 21st Conference of the Parties, 30 Nov-11 Dec 2015.

2 See FAO news release, "Promoting Climate-Smart Agriculture" (09 November 2009), on the launch of its report, *Food Security and Agricultural Mitigation in Developing Countries: Options for Capturing Synergies*, at the Barcelona climate talks: www.fao.org/news/story/en/item/36894/icode/.

3 According to GRAIN and CIDSE: 60% of the private sector members of the Alliance represent the fertilizer industry. See: GRAIN, "The Exxons of Agriculture," September 2015: www.grain.org/article/entries/5270-the-exxons-of-agriculture. See also: CIDSE, "Climate-smart revolution … or green washing 2.0?," May 2015: www.cidse.org/publications/just-food/food-andclimate/climate-smart-revolution-or-a-new-era-of-green-washing-2.html.

4 To read the full CSO statement, see: http://www.cidse.org/newsroom/civil-society-proposals-to-europeanleaders-at-the-eu-celac-summit-1.html.

5 The 24-member Board makes funding decisions with guidance from the COP: http://unfccc.int/cooperation_and_support/financial_mechanism/green_climate_fund/items/5869.php.

6 European Commission, *Ethics of Synthetic Biology*, European Group on Ethics in Science and the New Technologies to the European Commission, Opinion No. 25, Brussels, 17 November 2009.

7 Craig Holdredge, "When engineers take hold of life," *In Context*, The Nature Institute: www.natureinstitute.org/pub/ic/ic32/.

8 Information on the CBD process related to defining Synthetic Biology is available here: https://bch.cbd.int/synbio.

Synthetic Biology and Agriculture

Depending on context, Syn Bio is promoted as an enabler of agriculture or as an alternative to it. Engineered microorganisms housed in industrial vats, which directly produce fuels, fragrances or flavors, for example, are seen as a "green" alternative that can make ever scarcer arable land available for food production. On the other hand, proponents suggest, Synthetic Biology could usher in an era of more efficient and productive agriculture – a way to do more with less.[9] To date, the vast majority of Syn Bio circuitry has been produced in microorganisms such as bacteria.[10] Now, despite the staggering complexity of plant genomes and protein networks, synthetic biologists are working to design "predictive and quantitative functions in plants...with traits that are new to evolution and beneficial to humanity" – including crops that can better withstand climate change.[11] In July 2015, a consortium of scientists published a common standard for DNA parts in plants.[12] The idea is that the standard will facilitate the sharing of parts between researchers and will set "a basis for the development of software and hardware that will support accelerated design and automated assembly" – the first step in developing "an extensive catalogue of standardised, characterised DNA parts to accelerate plant bioengineering."[13]

9 Josie Garthwaite, "Beyond GMOs: The Rice of Synthetic Biology," *The Atlantic*, 25 September 2014: www.theatlantic.com/technology/archive/2014/09/beyond-gmos-the-rise-of-syntheticbiology/380770/.

10 June Medford and Ashok Prasad, "Plant Synthetic Biology takes root," *Science* 346, p. 162, 2014.

11 *Ibid.*

12 Patron, N. J., Orzaez, D., Marillonnet, S., Warzecha, H., Matthewman, C., Youles, M., Raitskin, O., Leveau, A., Farré, G., Rogers, C., Smith, A., Hibberd, J., Webb, A. A. R., Locke, J., Schornack, S., Ajioka, J., Baulcombe, D. C., Zipfel, C., Kamoun, S., Jones, J. D. G., Kuhn, H., Robatzek, S., Van Esse, H. P., Sanders, D., Oldroyd, G., Martin, C., Field, R., O'Connor, S., Fox, S., Wulff, B., Miller, B., Breakspear, A., Radhakrishnan, G., Delaux, P.-M., Loqué, D., Granell, A., Tissier, A., Shih, P., Brutnell, T. P., Quick, W. P., Rischer, H., Fraser, P. D., Aharoni, A., Raines, C., South, P. F., Ané, J.-M., Hamberger, B. R., Langdale, J., Stougaard, J., Bouwmeester, H., Udvardi, M., Murray, J. A. H., Ntoukakis, V., Schäfer, P., Denby, K., Edwards, K. J., Osbourn, A. and Haseloff, J., "Standards for plant synthetic biology: a common syntax for exchange of DNA parts," New Phytologist, 208, 2015, pp. 13–19: doi:10.1111/nph.13532.

Who's Pushing the CSA Agenda?

FAO initially developed the concept of Climate-Smart agriculture as a way to explicitly integrate the agendas of agriculture, food security and climate change. To build momentum, a consortium led by FAO, the World Bank, CGIAR and government partners (the Netherlands, Norway, Vietnam, Ethiopia, Mexico, New Zealand) hosted two international conferences in 2010 (The Hague) and 2012 (Hanoi).[14]

A formal network, the **Global Alliance for Climate-Smart Agriculture (GACSA)** was officially launched by the US government's Secretary of State and Secretary of Agriculture at the UN Secretary-General's 2014 Climate Change Summit in New York. GACSA's 100+ members include 22 national governments, agribusiness lobby groups (the majority representing the fertilizer industry[15]), international agriculture-related institutions (including the CGIAR Consortium and FAO, which houses GACSA's facilitation unit), universities and NGOs.

State Members of GACSA

Of the 22 national governments that are members of GACSA (as of 19 Oct. 2015), eight are G77 members and one (Tanzania) is an LDC. They are: **Canada, Costa Rica, France, Grenada, Ireland, Italy, Japan, Netherlands, Malawi, Mexico, Nigeria, Niger, Norway, Philippines, Republic of Cyprus, South Africa, Spain, Switzerland, Tanzania, United Kingdom, United States of America and Vietnam.**

13 See http://openplant.org/blog/2015/07/first-common-standard-for-assembly-of-dna-parts-in-plant-synbiopublished/.

14 Global Conference on Agriculture, Food Security and Climate Change in The Hague, 2010: www.fao.org/climate-smart-agriculture/74789/en/; 2nd Global Conference on Agriculture, Food Security and Climate Change, 2012: https://ccafs.cgiar.org/2nd-global-conference-agriculture-food-security-and-climatechange#.Vj0Ko-tFviS.

15 According to GRAIN and CIDSE: 60% of the private sector members of the Alliance represent the fertilizer industry. See: GRAIN, "The Exxons of Agriculture," September 2015: www.grain.org/article/entries/5270-the-exxons-of-agriculture. See also, CIDSE, "Climate-smart revolution ... or green washing 2.0?," May 2015: www.cidse.org/publications/just-food/food-andclimate/climate-smart-revolution-or-a-new-era-of-green-washing-2.html.

World Business Council for Sustainable Development

WBCSD has signed on to GACSA, but is plenty influential on its own and is deeply entrenched in multilateral negotiations, having been established to "ensure the business voice was heard"[16] at the 1992 Rio Earth Summit.[17] For the Paris Climate Convention "and beyond,"[18] WBCSD has articulated two straightforward but ambitious objectives that it hopes to achieve through its Low Carbon Technology Partnerships Initiative (LCTPi):

1) **Accelerate the diffusion of existing technologies** by removing technological, market and social barriers and introducing required policy and financial instruments
2) **Develop Public Private Partnerships** (PPPs) on the Research, Development, Demonstration and Deployment (RDD&D) of potentially game changing new technologies.

The program is co-chaired by Monsanto[20] and also includes: Olam, DuPont, Kellogg's, Dow, Walmart, Tyson Foods, PepsiCo, Diageo, Starbucks, Yara, Jain Irrigation, ITC, Uniphos, Coca-Cola and Unilever.

Technologies – existing and aspirational – are central to the World Business Council's Paris proposals, as is the need to remove market barriers and social opposition in order to facilitate technology diffusion and development.

WBCSD's LCTPi was launched at COP 20 in Lima (December 2014), together with the International Energy Agency (IEA) and the Sustainable Development Solutions Network (SDSN). According to WBCSD, 82 companies are taking an "active role" in preparing the Paris (and beyond) business agenda.[19] "Climate-Smart Agriculture" is one of the LCTPi's eight focus areas, involving major food- and ag-related companies. The program is co-chaired by Monsanto[20] and also includes: Olam, DuPont, Kellogg's, Dow, Walmart, Tyson Foods, PepsiCo, Diageo, Starbucks, Yara, Jain Irrigation, ITC, Uniphos, Coca-Cola and Unilever.

In the lead-up to UNFCCC COP21 there is growing pressure on governments to let industry call the shots on how to define climate strategies and control greenhouse gas (GHG) emissions. A November 2015 report by PricewaterhouseCoopers asserts that the strategies outlined by the World Business Council's LCTPi, if realized, could achieve 65% of the cuts in GHG emissions that are needed to prevent global temperatures from rising more than 2 degrees.[21] These strategies include "overcoming barriers to deployment of 'game changer' technologies."

CGIAR

The Consultative Group on International Agricultural Research is the world's largest public-sector network of agricultural researchers (housed at 15 international research centers) and a founding member of the Global Alliance. The CGIAR's Research Program on Climate Change, Agriculture and Food Security (CCAFS) is the umbrella under which CGIAR's researchers undertake research related to climate change and food security, and it is instrumental in promoting CSA among national agricultural researchers in the global South.

The conceptual boundaries defining – and separating – Climate-Smart agriculture as (re)framed by GACSA, Green Revolution 2.0, and Green Economy are fuzzy. While the terms aren't necessarily interchangeable, they are – sometimes implicitly and sometimes explicitly – related. All three terms aspire to participate in sustainable development. FAO's 500+-page *Climate-Smart Agriculture Sourcebook* explains: "CSA shares with sustainable development and green economy objectives and guiding principles...it has close links with the concept of sustainable intensification, which has been fully developed by FAO for crop production."[22] CGIAR documents commonly link Green Revolution 2.0 to CSA.[23]

16 At the 2015 World Economic Forum, WBCSD launched its first Policy Advisory Council; Council members include Mexico's former president Felipe Calderón, UNFCCC Executive Secretary Christiana Figueres and UNEP Executive Director Achim Steiner.

17 www.wbcsd.org/Pages/EDocument/EDocumentDetails.aspx?ID=16495&NoSearchContextKey=true.

18 WBCSD, "The Road to Paris and beyond," no date: www.wbcsd.org/roadtoparis.aspx.

19 *Ibid.*

20 See http://monsantoblog.com/2015/09/21/from-nyc-to-paris-the-road-to-a-cooler-planet/.

21 PWC, Low Carbon Technology Partnerships initiative: Impact Assessment, November 2015: http://lctpi.wbcsdservers.org.

22 FAO, *Climate-Smart Agriculture Sourcebook*, 2013, pp. 27-29.

23 For example, Leslie Reyes, "Unleashing the Rice Market," Rice Today, January – March 2015, pp. 36-39.

CSA's Wide Tent

None of the promoters of CSA delineate the specific techniques involved. FAO states that CSA "is not a new agricultural system, nor is it a set of practices."[24] Unfortunately, the lack of proscription is precisely the problem – allowing the concept to be co-opted by some of the world's biggest industrial contributors to climate change: If every agricultural practice and every agribusiness is "smart" enough for GACSA, then even the most carbon-intensive, resource-wasting ones make the grade. The wholesale rejection of CSA by the vast majority of CSOs active in the climate arena[25] is the result of CSA's "inclusivity."

Synthetic Biologists: Photosynthesis Hackers

Proponents of Synthetic Biology espouse a familiar narrative to justify their research: World population is growing and crop yields have reached a plateau.[26] Given growing demands for food and fuel in the face of climate change, we must find a way to increase crop yields. For synthetic biologists, "the key remaining route to increase the genetic yield potential of our major crops"[27] is enhancing photosynthesis – the complex, biomolecular process that plants use to convert sunlight into chemical energy while releasing oxygen as a waste product. In the view of synthetic biologists, photosynthesis, "has been improved little in crops and falls far short of its biological limit…"[28] In other words, because photosynthesis is so inefficient a natural process, Synthetic Biology offers the tools to improve it for the benefit of humankind.[29]

Syn Bio's techno-imperative sets aside the reality that suboptimal crop yields are not the reason there are – and will be – hungry people in the world.[30] Rather than confront the realities of inequality and overconsumption (e.g., of meat, fuel), "hacking photosynthesis" to create "turbocharged" plants and microorganisms[31] has become a major focus of Synthetic Biology research and investment – from "grand challenge"-type international agricultural research projects and consortia of university labs, to Big Ag corporate labs and boutique biotech start-ups.

What is Photosynthesis?

Photosynthesis is the process that plants, algae and cyanobacteria (aquatic organisms often called "blue-green algae") use to convert sunlight into chemical energy while releasing oxygen as a waste product. The chemical energy is stored as carbohydrate molecules (sugars) that are food to animals, including humans and livestock; without photosynthesis, both food and oxygen would disappear from the Earth. While it may seem "difficult to find fault with a process that can create food from sunlight, water and air,"[32] some technologists argue nonetheless: "for many plants, there is room for improvement."[33]

The ability to manipulate photosynthesis implies the control of 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, fiber and fuel, as well as how efficiently it fixes carbon dioxide (CO_2) and releases oxygen.

24 FAO, *Climate-Smart Agriculture Sourcebook*, 2013, pp. 27.

25 To read the full CSO statement, see: www.cidse.org/newsroom/civil-society-proposals-to-europeanleaders-at-the-eu-celac-summit-1.html.

26 Christine A. Raines, "Increasing Photosynthetic Carbon Assimilation in C3 Plants to Improve Crop Yield: Current and Future Strategies," *Plant Physiology*, Vol. 155, Issue 1, January 2011, pp. 36–42.

27 Stephen P. Long *et al*. (abstract), "Meeting the Global Food Demand of the Future by Engineering Crop Photosynthesis and Yield Potential," *Cell*, Vol. 161, Issue 1, 26 March 2015, pp. 56-66.

28 *Ibid*.

29 Christine A. Raines, "Increasing Photosynthetic Carbon Assimilation in C3 Plants to Improve Crop Yield: Current and Future Strategies," *Plant Physiology*, Vol. 155, Issue 1, January 2011, pp. 36–42.

30 See Mark Bittman, "How to Feed the World," *New York Times*, 14 October 2013; see also, ETC Group, *Who Will Feed Us?*, September 2013: www.etcgroup.org/content/poster-who-will-feed-us-industrial-food-chain-orpeasant-food-webs.

31 Heidi Ledford, "Hacked photosynthesis could boost crop yields," *Nature News*, 17 September 2014: www.nature.com/news/hacked-photosynthesis-could-boost-crop-yields-1.15949.

32 *Ibid*.

33 *Ibid*.

The Green Revolution of the 1960s, which has been seen in retrospect as a rudimentary and indirect attempt to increase photosynthesis – by increasing chemical inputs (i.e., fertilizers, pesticides) – is giving way to a Green Revolution 2.0.[34] Applying multi-gene and metabolic engineering techniques (Synthetic Biology), the aim is to "redesign" plants, algae and bacteria with the goal of producing abundant food, fuel and other bioproducts.

> ***"The next green revolution will supercharge the tools of the old one."***
>
> – Robert Fraley, chief technology officer, Monsanto[35]

Take the C3 to C4... or a Different Road Altogether?

One high-profile example of "blue-sky"[36] research is taking place in the flagship labs of the first Green Revolution, the International Rice Research Institute (IRRI) in Los Baños, Philippines, which is one of the 15 international agricultural research centers known as CGIAR. Kickstarted with an initial US$ 11.1 million grant in 2008 from the Bill & Melinda Gates Foundation, the C4 Rice Project involves a consortium of scientists from Europe, North America and Asia. C4 rice, named one of 2015's breakthrough technologies by MIT's Technology Review,[37] refers to genetically engineered rice plants that exhibit the "more efficient" photosynthetic pathway properties of plants like maize and sugar cane. Rice is categorized a "C3" plant based on the way it converts CO_2 to carbohydrates; but if rice can be transformed into a "C4" plant, it is expected to be faster in carbon dioxide fixation, resulting in more efficient water- and nitrogen-use and improved adaptation to hotter and drier climates. Concomitant yield increases are expected to be between 30% and 50%. A functional C4 rice crop isn't expected for another decade, but IRRI's outgoing director general considers it integral to a "Green Revolution 3.0."[38]

Rice, as the first crop species to have its genome sequenced, is providing mountains of "omics" data to be mined – that is, biological data sets related to its genome (DNA), proteome (proteins), metabolome (small molecule byproducts of metabolism) and transcriptome (messenger RNA molecules expressed from its genes). Some researchers consider rice "an ideal crop" to practice C4 engineering using systems biology and Synthetic Biology, paving the way to engineered C4 wheat, C4 cotton and C4 trees.[39] (Four of the authors contributing to the recently published Synthetic Biology standard for the exchange of DNA parts for plant bioengineering are C4 Rice Project Principal Investigators.)[40]

The European Union is funding (EUR 6.8 million) its own consortium of private and public sector researchers to engineer C4 photosynthesis into C3 crops; many of them are also partners in the C4 Rice Project. The collaborative project, known as 3to4, is funded at least through the end of 2016. While the researchers are focusing initially on rice and Arabidopsis as model crops, they "envisage rapid transfer of technological advances into mainstream EU crops, such as wheat and rape."[41] Private sector consortium members include Bayer Crop Science and Chemtex Italia (now Biochemtex).[42]

34 Walter Leal Filho, Franziska Mannke, Romeela Mohee, Veronika Schulte, Dinesh Surroop (eds.), *Climate-Smart Technologies: Integrating Renewable Energy and Energy Efficiency in Mitigation and Adaptation Responses*, Berlin and Heidelberg: Springer-Verlag, 2013, p. 252.

35 Fraley quoted in Tim Folger, "The Next Green Revolution," *National Geographic Magazine*, October 2014: www.nationalgeographic.com/foodfeatures/green-revolution/.

36 Leigh Dayton, "Agribiotechnology: Blue-sky rice," *Nature* 514, 30 October 2014, pp. S52-S54.

37 Kevin Bullis, "Supercharged Photosynthesis," *Technology Review*, February 2015: www.technologyreview.com/featuredstory/535011/supercharged-photosynthesis/.

38 Robert S. Zeigler, "High science and smart policies will alleviate hunger and poverty," 5 June 2015: http://irri.org/blogs/bob-s-blog/high-science-and-smart-policies-will-alleviate-hunger-and-poverty.

39 Xin-Guang Zhu, Lanlan Shan, Yu Wang and William Paul Quick, "C4 Rice – an Ideal Arena for Systems Biology Research," *Journal of Integrative Plant Biology*, Vol. 52, Issue 8, 2010, pp. 762–770.

40 Patron, N. J. *et al.*, "Standards for plant synthetic biology: a common syntax for exchange of DNA parts," *New Phytologist*, 208, 2015, pp. 13–19: doi:10.1111/nph.13532.

41 See: http://cordis.europa.eu/project/rcn/101753_en.html.

42 According to the CORDIS web site, Bayer Crop Science is receiving EUR 19 200 and Biochemtex is receiving EUR 14 400.

Enhancing photosynthesis by converting C3 plants into C4 plants is a high-tech, high-risk project. Critics of the approach, such as Cornell University's Norman Uphoff, argue against the very premise that rice has hit a "yield ceiling." Uphoff spearheaded an agro-ecologically-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.[43] Others have questioned the fundamental appropriateness of promoting rice as a staple crop[44] in an era of climate change.

Rather than confront the realities of inequality and overconsumption (e.g., of meat, fossil fuels), Synthetic Biology research is focusing on "hacking photosynthesis" to create "turbocharged" plants and microorganisms.

Another critic of the C4 Rice 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 coupled with a long timeline for assessment of likelihood of success (e.g., 25 years) as well as high research cost compared with general low investment levels in crop development...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"[45] (emphasis in original).

"Instead of asking why the existing metabolic pathways evolved the way they did, our goal is to take advantage of the repertoire of known enzymes to design better pathways for human needs."

– Arren Bar-Even and colleagues, Weizmann Institute, Israel[49]

Photosynthetic Microbes: The New Photoshop?

Rather than rely on the naturally occurring C4 pathway for maximizing photosynthesis, some synthetic biologists are aiming to design entirely novel, faster-acting carbon fixation pathways; while these could theoretically be engineered into plants and algae, the current focus is engineering them into microorganisms that are not naturally photosynthetic.

Arren Bar-Even and colleagues at Israel's Weizmann Institute modeled all of the 5,000 metabolic enzymes known to occur naturally in order to identify those that are most efficient at carbon fixation.[46] Based on their computational analysis, they proposed a "family" of synthetic pathways that appear to be two to three times more active than naturally-occurring pathways, but acknowledge the difficulty of assimilating them into a host cell – describing transformation as a "'metabolic heart transplant,' which the host cell may well reject;"[47] nonetheless, the Yeda Research and Development Co. – the commercial technology-transfer arm of the Weizmann Institute – has applied for patents on the faster "carbon fixation system" and an E. coli bacterium engineered to express photosynthetic enzymes.[48]

43 Norman Uphoff, "Rethinking the concept of 'yield ceiling' for rice: implications of the System of Rice Intensification (SRI) for agricultural science and practice," *Journal of Crop and Weed*, Vol. 9, Issue 1, 2013, pp. 1-19.

44 Jill E. Gready, "Best-fit options of crop staples for food security: productivity, nutrition and sustainability," in Raghbendra Jha, Raghav Gaiha and Anil B. Deolalikar, (eds.), *Handbook on Food: Demand, Supply, Sustainability and Security*, Cheltenham, UK and Northampton, MA, USA: Edward Elgar Publishing, 2015, p. 406.

45 *Ibid.*, p. 417.

46 Arren Bar-Even, Elad Noor, Nathan E. Lewis and Ron Milo, "Design and analysis of synthetic carbon fixation pathways," Proceedings of the National Academy of Sciences of the United States of America, Vol. 107, No. 19, pp. 8889-8894.

47 *Ibid.*

48 WIPO publication WO2011099006A3 (corresponds to US application 20120301947 A1), published 29 November 2012, "Enzymatic systems for carbon fixation and methods of generating same," assigned to Yeda Research and Development Co. Ltd.

49 Arren Bar-Even, Elad Noor, Nathan E. Lewis and Ron Milo, "Design and analysis of synthetic carbon fixation pathways," *Proceedings of the National Academy of Sciences of the United States of America*, Vol. 107, No. 19, pp. 8889-8894.

Joule Unlimited is a private, US-based start-up that claims to be "replicating photosynthesis at industrial scale."[50] The aim is not to produce food; rather, Joule aims to produce fuels and industrial chemicals. With dozens of granted patents and nearly one hundred applications pending, Joule is laying claim to an intellectual property "estate" involving the processes, hardware and products of microbe-driven photosynthesis. The company is developing "product-specific bacteria" that can be injected, along with (non-potable) water, and "micronutrients"[51] into transparent, tube-like modular fermenters assembled on top of flat, "barren" land. Waste CO_2 (industrial effluent from a cement factory or brewery, for example) will be captured, piped in and pumped into the modules. Sunlight will then drive photosynthesis to directly produce fuels or chemicals. According to Joule, a full-scale commercial facility, which they call a SolarConverter array, will encompass 10,000 acres (4,047 ha). While it may turn out to be challenging to find "waste" land equivalent to the size of a dozen of New York's Central Park, which is, at the same time, close to a water source and an industrial facility emitting CO_2, Joule claims to have identified more than 1,000 suitable sites around the globe.[52] The privately held company has raised more than US$200 million in funding and aims for a 2017 commercial-scale launch.

Engineered Microbials

In addition to investigating high-tech pathway engineering, the world's largest industrial agriculture enterprises are now investing in the development and commercialization of "microbials" that can be added to seeds and soils with the aim of increasing crop yields and pest-resistance. Microbials aren't new: for example, Bacillus thuringiensis, or Bt, is a bacterium that has been used as a pesticide for more than a half-century.

But now, companies are taking advantage of advances in genome sequencing and bioinformatics to identify other apparently beneficial microbes – as well as communities of microbes working together as "functional consortia."[53] Synthetic biology-enabled fermentation technologies are allowing companies to quickly add microbials to their product offerings as an environmentally-friendly and sustainable "complement"[54] to agrochemicals. Monsanto took the plunge in early 2013 when it announced it had struck a 5-year R&D deal with Synthetic Genomics, Inc. – the Craig Venter-owned start-up – and bought some "technology assets" from Venter's Agradis, Inc., including its collection of plant-associated microbes and screening processes.[55] In late 2013, Monsanto announced a collaboration with the world's largest enzyme producer, Denmark-based Novozymes, to commercialize microbials for agriculture. The newly-minted BioAg Alliance boasts field trials on an unprecedented scale: hundreds of microbial strains were tested in 170,000 field plots across 70 US locations in 2014 – the BioAg Alliance expects to double the number of field plots by the end of 2015.[56] Not to be left behind, DuPont acquired Taxon Biosciences, a California-based industrial microbial producer, in April 2015;[57] and in October 2015, Dow AgroSciences announced a collaboration with Synthace, Ltd., self-described as the UK's "first dedicated Synthetic Biology company with a world leading platform of technologies for the rapid engineering and optimisation of novel biological production systems."[58] Its collaboration with Dow aims to "support development of superior microbial production strains" to boost yield and protect against pests.[59]

The newly-minted BioAg Alliance boasts field trials on an unprecedented scale: hundreds of microbial strains were tested in 170,000 field plots across 70 US locations in 2014 – the BioAg Alliance expects to double the number of field plots by the end of 2015.[56]

50 Joule Executive Vice president of Corporate Development Tom Jensen quoted by Laura Hepler, "Joule raises $40 million to rev up alt-fuel industry," *GreenBiz*, 11 May 2015: www.greenbiz.com/article/jouleunlimited-40-million-funding-alternative-fuel-industry.

51 Information from Joule's web site: www.jouleunlimited.com/how-it-works.

52 Information from Joule's web site: www.jouleunlimited.com/joule-plants-heading-scale

53 See: www.taxon.com/technology-platform.php#syntheticconsortia.

54 See: www.monsanto.com/products/pages/agricultural-biologicals.aspx.

55 See: www.syntheticgenomics.com/300113.html.

56 See: www.novozymes.com/en/about-us/brochures/Documents/BioAg-Alliance-factsheet.pdf.

57 See: www.dupont.com/corporate-functions/media-center/press-releases/dupont-acquires-taxonbiosciences.html.

58 See http://newsroom.dowagro.com/press-release/dow-agrosciences-synthace-research-collaborationaccelerate-product-development-using-

59 *Ibid.*

Engineering Nitrogen Fixation for Self-Fertilizing Crops

Background

Engineering "self-fertilizing" plants has been an elusive goal of plant agricultural biotechnology for decades. Today, several teams of synthetic biologists in the US and the UK are attempting to engineer crops that can fix their own nitrogen and reduce the need for costly, polluting and GHG-generating chemical fertilizers.

Globally, an estimated two-thirds of the nitrogen fertilizers applied to wheat, rice and maize is wasted – either as nitrous oxides (ozone-destroying GHG that have 300 times as much heat-trapping power as carbon dioxide), or in the form of polluting nitrates that leach into freshwater and marine environments.[61] Agriculture accounts for ~80% of human-caused nitrous oxide emissions worldwide – primarily due to overuse of chemical fertilizers. In addition, the fertilizer industry consumes vast amounts of fossil fuel in the production of chemical fertilizers.

Although nitrogen is plentiful in the atmosphere, atmospheric nitrogen must be "fixed," or converted into compounds that make the nitrogen available to plants. But some crop species, especially legumes (beans, peas, forage crops, etc.), have a built-in capacity to fix nitrogen because tiny nodules on the plant's roots have a symbiotic relationship with soil-dwelling rhizobial bacteria. The bacteria "fix" atmospheric nitrogen in the soil and feed it to the legumes; in exchange the plant "feeds" the bacteria. Legume cover crops are able to naturally fertilize the soil (i.e., "green manures") – without chemicals – when they are turned under for the next crop.

"Agriculture would be revolutionized if plants can be engineered to fix their own nitrogen; this would free agriculture from synthetic nitrogenous fertilizers and significantly decouple it from the fossil fuel industry."

– OECD, "Emerging Policy Issues in Synthetic Biology," 2014[60]

Synthetic Biology to the Rescue?

The goal of engineering nitrogen fixation in plants is exceedingly complex, involving a suite of multi-gene constructs and metabolic pathways. However, with the cost of gene synthesis falling and advances in DNA modular assembly, researchers claim that "the DNA assembly tasks required to test large numbers of synthetic gene constructs are now trivial..."[62] Research teams are pursing a variety of strategies for engineering nitrogen fixation in plants. These include, for example:

Transplanting Nitrogen Fixation

With funding from the US National Science Foundation, a team of scientists at Washington University in St. Louis is using tools of Synthetic Biology to transplant the nitrogen fixation system in one species of blue-green bacteria (cyanobacterium) to another bacterium that doesn't fix nitrogen. The ultimate goal is to transfer the molecular machinery for nitrogen fixation – involving roughly 30 genes – into plant cells so that they will gain the capacity to fix nitrogen.[63] The feat is stunningly complex because photosynthesis and nitrogen fixation are normally incompatible processes within plant cells (because the oxygen produced during photosynthesis is toxic to nitrogenase – the enzyme needed to fix nitrogen).

The goal of engineering nitrogen fixation in plants is exceedingly complex, involving a suite of multi-gene constructs and metabolic pathways.

60 OECD, "Synthetic biology: A new and promising technology," in OECD, *Emerging Policy Issues in Synthetic Biology,* OECD Publishing, Paris, 2014. DOI: http://dx.doi.org/10.1787/9789264208421-4-en.

61 Christian Rogers and Giles Oldroyd, "Synthetic biology approaches to engineering the nitrogen symbiosis in cereals," *Journal of Experimental Botany*, 2014: http://jxb.oxfordjournals.org/content/early/2014/03/28/jxb.eru098.full..

62 *Ibid*., 2014.

63 Diana Lutz, "Creating plants that make their own fertilizer," Washington University in St. Louis news release, 22 August 2013: http://news.wustl.edu/news/Pages/25585.aspx.

Build-It-From Scratch

Another team of synthetic biologists has already constructed a synthetic biological module from the bottom up that performs (at least partially) the nitrogen fixation function in a host bacterium.[64] The scientists from the University of California Berkeley and MIT began by stripping out and replacing the "native" 20-gene nitrogen fixation gene cluster in Klebsiella oxytoca bacterium.[65] Using the stripped-down bacterium as a chassis, they then replaced the nitrogen fixation machinery with synthetic genetic components made entirely from scratch.[66] The ultimate goal is to transfer the host cell and someday give plants entirely new nitrogen-fixing function.

Engineering the Nitrogen Symbiosis for Africa

With funding from the Bill & Melinda Gates Foundation, Synthetic Biology researchers at the John Innes Centre (UK) are taking steps to reconstruct the nitrogen-fixing capability of legumes in cereals to "significantly raise yields in the low input agricultural systems of sub-Saharan Africa."[67] As a first step, the researchers are focusing on the engineering of nitrogen symbiosis in cereal roots by activating signals and "machinery" in the SYM pathway (the signaling symbiosis pathway in plants that allows recognition of nitrogen-fixing bacteria).

In a publication describing their work, the researchers explain that the goal of moving the legume symbiosis into cereals is less suitable for high-input industrial agriculture in the developed world because the increased demands of nitrogen fixation would put extra demands on the plant's photosynthetic machinery and ultimately lower yields. However, the researchers argue that even low levels of engineered nitrogen fixation "could be transformative for crop yields in the developing world" where plant nutrients are in short supply.[68]

High-tech, high-risk interventions are not needed to curtail production and use of chemical fertilizers, which are major contributors to climate-destroying GHG emissions. Per capita GHG emissions related to agriculture are substantially higher in developed countries than in developing countries. Critics of "Climate-Smart agriculture" point out that the Climate-Smart agenda threatens to shift the focus of mitigation from the industrial North to the global South – those most vulnerable to climate change and the least responsible for GHG emissions.[69] High-tech efforts to transfer nitrogen-fixation genes to African cereals is a high-risk, unproven strategy that ignores the Climate-Resilient practices of ecologically based, low-input agricultural systems – as well as the need for balanced plant nutrients – beyond a narrow focus on nitrogen. The high-tech approach also ignores the vast and readily-available, nitrogen-fixing potential of legumes that are widely used and adapted to African farming systems. In fact, research indicates that the use of leguminous cover crops in both temperate and tropical farming systems has the potential to fix enough nitrogen to replace the amount of synthetic fertilizer currently in use.[70]

High-tech efforts to transfer nitrogen-fixation genes to African cereals is a high-risk, unproven strategy that ignores the Climate-Resilient practices of ecologically based, low-input agricultural systems

64 Karsten Temme, Dehua Zhao and Christopher Voight, "Restoring the nitrogen fixation gene cluster from Klebsiella oxytoca," *PNAS*, May 2, 2012, Vol. 109, No. 18.

65 Andrew Jermy, "We Can Rebuild You," *Nature Review Microbiology*, Vol. 10, June 2012.

66 Karsten Temme, Dehua Zhao and Christopher Voight, "Restoring the nitrogen fixation gene cluster from Klebsiella oxytoca," *PNAS*, May 2, 2012, Vol. 109, No. 18.

67 Christian Rogers and Giles Oldroyd, "Synthetic biology approaches to engineering the nitrogen symbiosis in cereals," *Journal of Experimental Botany*, 2014: http://jxb.oxfordjournals.org/content/early/2014/03/28/jxb.eru098.full.

68 *Ibid.*

69 Doreen Stabinsky, "Climate-Smart Agriculture: myths and problems," Heinrich-Böll-Stiftung, September 2014:. www.boell.de.

70 Catherine Badgley, Jeremy Moghtader, Eileen Quintero, Emily Zakem, M. Jahi Chappell, Katia Avilés-Vázquez, Andrea Samulon and Ivette Perfecto, "Organic agriculture and the global food supply," *Renewable Agriculture and Food Systems*, 22, 2007, pp. 86-108. doi:10.1017/S1742170507001640.

Synthetic Biology Tools Aim to Expand Agrochemical Use and Reinforce Farmers' Dependence on Dangerous Pesticides

For more than a decade all of the world's largest agrochemical and seed corporations have been focusing on the identification and patenting of "climate ready" genes and traits associated with resistance to abiotic stresses (i.e., environmental stresses such as drought, saline soils, low nitrogen, heat, cold, chilling, freezing, flooding, nutrient levels, high light intensity, ozone and anaerobic stresses.) These traits will theoretically enable plants to withstand environmental stresses associated with climate change.[71] A 2010 report by ETC Group identified 262 patent families filed in patent offices worldwide. The study found that just three companies – DuPont, BASF and Monsanto – accounted for two-thirds of the patent families identified, while the public sector accounted for only 9%. In some cases, the patent claims extended to gene sequences that are responsible for endowing similar abiotic traits across multiple plant genomes (known as homologous DNA). Because of the similarity in DNA sequences between individuals of the same species or among different species – "homologous sequences" – a single patent may claim rights that extend not just to stress tolerance in a single engineered plant species, but also to a substantially similar genetic sequence in numerous species of transformed plants.

The agrochemical / seed industry continues to develop high-tech seeds designed to increase chemical use and boost profits – this time under the guise of "Climate-Smart" agriculture.

A separate review of patenting activity related to plant biotechnology at the U.S. Patent & Trademark Office found that patent applications on traits associated with abiotic stress in plants were the subject of more patent applications than any other plant biotech area.[72]

Drought tolerance, especially for corn, is an on-going focus of R&D programs in the private and public sectors.[73] The technical hurdle is to develop crops that can withstand dry periods or use water more efficiently – without sacrificing yields. Monsanto's genetically engineered DroughtGard corn (MON87460) has been sold commercially on a limited basis since 2012 – with mixed reviews of its ability to withstand drought.[74] DuPont Pioneer is field-testing a drought tolerant corn, and Dow is partnering with Arcadia Biosciences and Bioceres to release stress tolerant soybeans (stacked with traits for herbicide tolerance and insect resistance). Transgenic, drought tolerant sugarcane developed by Indonesian researchers, in cooperation with Japan's Ajinomoto Company, is growing on an 83,000-ha estate in Indonesia.[75] Everyone agrees that that we need crops that can thrive with less water, but some researchers doubt that genetic engineers can achieve significant drought tolerance without yield penalty. In the words of one corn breeder interviewed by *Nature Biotechnology*: "Drought tolerance is not a trait, it's a fantasy word."[76]

Now, synthetic biologists are conducting R&D that goes beyond the first generation of monopoly patent claims on climate genes and traits.

71 ETC Group, "Capturing Climate Genes: Gene Giants Stockpile 'Climate Ready' Crops," October 2010: www.etcgroup.org/content/gene-giants-stockpile-patents-"climate-ready"-crops-bid-becomebiomassters-0; See also: ETC Group, "Patenting the 'Climate Genes'... and Capturing the Climate Agenda," June2008: www.etcgroup.org/content/patenting-climate-genes-and-capturing-climate-agenda.

72 Anonymous, "Plant biotechnology patent watch review," *Agrow World Crop Protection News*, 608, 2011, pp. xxv-xxvi. For example, there were 132 patent applications related to abiotic stress tolerance compared to just 15 for herbicide tolerance; 80 for pest or pathogen resistance; 35 for altered lignin; 51 for altered phenotype.

73 Emily Waltz, "Beating the Heat," *Nature Biotechnology*, Vol. 32, No. 7, July 2014.

74 Tom Philpott, "USDA Greenlights Monsanto's Utterly Useless New GMO Corn," *Mother Jones*, 23 Jan. 2012: www.motherjones.com/tom-philpott/2012/01/monsanto-gmo-drought-tolerant-corn.

75 Emily Waltz, "Beating the Heat", *Nature Biotechnology,* Vol. 32, No. 7, July 2014.

76 Seth Murray quoted in *Ibid*.

Background

Rather than breed plants to resist pests/disease and climatic conditions, the agrochemical industry's first generation of GM crops focused overwhelmingly on the genetic engineering of proprietary seeds that are designed to boost sales of agrochemicals (i.e., herbicide tolerance). Worldwide, an estimated 85% of the total area devoted to GM crops in 2014 contained at least one trait for herbicide tolerance.[77]

With the widespread introduction of herbicide tolerant crops, chemical weedkillers like Roundup (glyphosate) became the pesticide industry's best-selling products. In the US alone, the use of glyphosate on corn and soybeans shot up 20-fold from 1995-2013 (from 10 million to 205 million lbs/year); global use increased by a factor of more than 10.[78] But after two decades of relentless chemical warfare, more and more weeds are evolving resistance to herbicides. Today, resistant "superweeds" are proliferating and herbicide tolerant crops are failing in the field. In the U.S., farmers now face nearly 100 million acres (40.4 million ha) of herbicide resistant weeds in 36 states.[79] Worldwide, at least 24 species of weeds are now glyphosate-resistant.[80] Synthetic biologists are engineering crops to better withstand drought after they are sprayed with a proprietary pesticide.[81]

Synthetic Biologists Activate Drought Tolerance in Plants with Pesticides

With funding from Syngenta (the world's largest agrochemical corporation) and the US National Science Foundation, Sean Cutler at the University of California-Riverside boasted of his team's research achievements in early 2015: "We successfully repurposed an agrochemical for a new application by genetically engineering a plant receptor – something that has not been done before," said Cutler, a professor of plant sciences.[82] "We anticipate that this strategy of reprogramming plant responses using Synthetic Biology will allow other agrochemicals to control other useful traits – such as disease resistance or growth rates, for example."[83]

"We successfully repurposed an agrochemical for a new application by genetically engineering a plant receptor – something that has not been done before," said Cutler, a professor of plant sciences.[82]

How does it work? When plants suffer from drought, they naturally produce elevated amounts of a stress hormone called abscisic acid (ABA) that tells the plant to go into "survival mode" by inhibiting growth and reducing water consumption. Specifically, ABA activates a receptor in plants that closes stomata (tiny pore openings) on leaves to reduce water loss.

Using Synthetic Biology, the researchers re-configured the plant's ABA receptor to be activated by Syngenta's fungicide, instead of ABA. Syngenta's proprietary fungicide, mandipropamid (tradename: Revus®) is widely used to control late blight (Phytophthora infestans) in fruit, potatoes and vegetable crops.

77 Canadian Biotechnology Action Network (CBAN), Where in the World are GM crops and foods? March, 2015. According to CBAN's analysis of ISAAA statistics: In 2014, 57% of the world's GM crops were engineered to be herbicide-tolerant, 15% were engineered to be toxic to pests, and 28% were "stacked" with both herbicide tolerance and insect resistance. Other traits – virus resistance and drought tolerance – collectively account for less than 1% of global GM crop hectares: www.gmoinquiry.ca/where.

78 Philip Landrigan and Charles Benbrook, "GMOs, Herbicides and Public Health," *New England Journal of Medicine*, 373: 693-695, 20 August 2015.

79 *Ibid*.

80 Union of Concerned Scientists – USA, "The Rise of Superweeds—and What to Do About It," December 2013: www.ucsusa.org/sites/default/files/legacy/assets/documents/food_and_agriculture/rise-ofsuperweeds.pdf.

81 Sang-Youl Park, Francis C. Peterson, Assaf Mosquna, Jin Yao, Brian F. Volkman & Sean R. Cutler, "Agrochemical control of plant water use using engineered abscisic acid receptors," *Nature* 520, 23 April 2015, pp. 545–548: www.nature.com/nature/journal/v520/n7548/full/nature14123.html.

82 Iqbal Pittalwala, "Scientists Reprogram Plants for Drought Tolerance," University of California Riverside news release: http://ucrtoday.ucr.edu/26996.

83 *Ibid*.

The researchers conducted laboratory experiments using the model plant species Arabidopsis, as well as tomato plants. The plants effectively survived drought conditions because the chemical fungicide activated the plant's abscisic acid pathway, which closed the tiny pores (i.e., stomata) on their leaves to prevent water loss. Syngenta and UC Riverside have filed an international patent application, published on 31 December 2014, entitled, "Compounds that induce ABA responses."

The patent application filed by Syngenta and the University of California reveals that researchers envision a far wider use of chemical inputs to induce stress tolerant responses in plants – including fertilizers: "In some embodiments, the agricultural formulation further comprises at least one of a fungicide, an herbicide, a pesticide, a nematicide, an insecticide, a plant activator, a synergist, a herbicide safener, a plant growth regulator, an insect repellant, an acaricide, a molluscicide, or a fertilizer."[84]

Agrochemical-induced stress tolerance in plants would be a bonanza for the pesticide / seed industry and a disaster for the planet.

To be clear, the article published by Cutler's academic team demonstrates proof-of-concept, but research on agrochemical-induced stress tolerance in crops is still experimental – it has not been field-tested or commercialized.

The use of Synthetic Biology to activate stress-tolerant traits in crops with proprietary chemical inputs – pesticides and fertilizers – reveals one danger of Climate-Smart rhetoric: The agrochemical/seed industry continues to develop high-tech seeds designed to increase chemical use and boost profits – this time under the guise of "Climate-Smart" agriculture. The perverse, chemical-intensive approach will amplify the use of industrial farming inputs that are driving both climate and food crisis. Agrochemical-induced stress tolerance in plants would be a bonanza for the pesticide/seed industry and a disaster for the planet.

Synthetic Gene Drives for "Sustainable" Agrochemical Profits

A team of synthetic biologists at Harvard is developing synthetic gene drives that are designed to spread engineered traits through wild populations of organisms.[85] The researchers who are developing synthetic gene drives believe these tools have the potential to merge the fields of genomics and "ecological engineering."[86] In a July 2014 article, the synthetic biologists describe how RNA-guided gene drives could be used to edit genomes of sexual species in the wild and "would offer substantial benefits to humanity and the environment" such as preventing insect-borne disease transmission, the rise of pesticide resistance in agriculture and eradicating invasive species. However, given the potential for gene drives to alter wild populations and entire ecosystems, the Harvard researchers warn that the technology must be developed with "robust safeguards and methods of control."[87]

What are gene drives?

Gene drives refer to genetic elements – found naturally in most organisms – that increase the odds of the genes they carry being inherited by all their offspring. Researchers are now developing synthetic gene drives that are constructed using an RNA-guided gene editing system known as CRISPR, based on the Cas9 nuclease (an enzyme that can be directed to cut targeted DNA sequences).[88] Synthetic biologists claim that the discovery of the Cas9 enzyme (directed by the guide RNA molecule) has "democratized" the ability to efficiently target, cut and edit multiple genes.[89] Scientists describe the CRISPR Cas9 system as a "simple, inexpensive and remarkably effective" method for making specific genome modifications.[90]

84 WIPO patent application WO2014210555, published 31 Dec. 2014.

85 Kevin Esvelt, Andrea Smidler, Flaminia Catteruccia, George Church, "Concerning RNA-guided gene drives for the alteration of wild populations," *eLife*, 3 eo3401, 2014: http://elifesciences.org/content/3/e03401.

86 *Ibid*.

87 *Ibid*.

88 *Ibid*, p. 2: "Cas9 is a non-repetitive enzyme that can be directed to cut almost any DNA sequence by simply expressing a 'guide RNA' containing that same sequence."

89 *Ibid*., p. 4.

90 David Baltimore *et al*., "A Prudent Path Forward for Genomic Engineering and Germline Gene Modification," *Science*, Vol. 348 Issue 6230, 2015, pp. 36-38.

However, even proponents of genome editing technologies warn of serious risks related to unintentional release of synthetic gene drive systems. (See below.)

Although RNA-guided gene drives are still largely theoretical and has so far been limited to laboratory experiments with mosquitoes and fruit flies, the technology "is advancing at a historically unprecedented pace."[91] A potential application focuses on curtailing the spread of mosquito-borne diseases (such as malaria, dengue, etc.) by altering mosquito genes that are responsible for transmission of the disease. In theory, once mosquitoes bearing the synthetic gene drive are constructed in the laboratory, they would be released into the wild to breed with wild-type mosquitoes – thus beginning the process of spreading the engineered gene edits throughout the wild population.

....researchers theorize that synthetic gene drives could be used to reverse pesticide and herbicide resistance in insects and weeds by making them genetically susceptible to the agrochemicals that used to poison them.

Reversing Pesticide Resistance

Synthetic biologists also envision the use of gene drives to address the problem of weeds that have evolved resistance to pesticides in agriculture. (A problem that proliferated with the introduction of biotech's first generation of genetically engineered crops – i.e., herbicide tolerant crops). In other words, researchers theorize that synthetic gene drives could be used to reverse pesticide and herbicide resistance in insects and weeds by making them genetically susceptible to the agrochemicals that used to poison them.

> ***The evolution of resistance to pesticides and herbicides is a major problem for agriculture... We propose that RNA-guided sensitizing drives might replace resistant alleles with their ancestral equivalents to restore vulnerability. For example, sensitizing drives could potentially reverse the mutations allowing the western corn rootworm to resist Bt toxins or horseweed and pigweed to resist the herbicide glyphosate, which is currently essential to more sustainable no-till agriculture.***[92]

Is No-Till Climate Smart? Synthetic biologists believe that reversing herbicide resistance in weeds is a desirable goal because the widespread adoption of herbicide tolerant crops promotes no-till farming. No-till farming avoids plowing, which conserves soil and water, and cuts labor costs. Proponents of GM crops frequently claim that no-till is climate-friendly because it reduces carbon dioxide emissions by sequestering more carbon in the soil. Even the USDA showcases no-till farming as one of 10 building blocks for Climate-Smart agriculture.[93] In reality, recent studies show that the role of no-till agriculture in mitigating climate change is "widely overstated."[94]

Synthetic biologists explain that initial releases of RNA-guided gene drives could be released to restore vulnerability in insects and weeds in areas that have not yet developed resistance to pesticides. Over subsequent generations the weed population with the edited genome would spread into adjacent fields. The Big Six agrochemical companies will be intrigued by the suggestion that:

> ***"Periodically releasing new drives could potentially allow any given pesticide or herbicide to be utilized indefinitely."***[95]

The July 2014 article on advances in synthetic gene drive technology (RNA-guided CRISPR-Cas9-mediated gene drive) has sparked discussion among scientists about the potential dangers of engineering the genomes of species in the wild. In August 2015 a self-appointed group of 26 scientists – including genetic engineers and fruit fly geneticists – released a paper in the journal *Science* that preemptively outlines recommendations for safeguarding gene drive experiments in the laboratory.

91 Esvelt *et al.*, "Concerning RNA-guided gene drives for the alteration of wild populations," *eLife*, 3 eo3401, 2014: http://elifesciences.org/content/3/e03401, p. 2.

92 *Ibid.*, p. 14.

93 USDA's Building Blocks for Climate-Smart Agriculture & Forestry – Fact Sheet. See www.usda.gov/documents/climate-smart-fact-sheet.pdf.

94 David S. Powlson *et al.*, "Limited potential of no-till agriculture for climate change mitigation," *Nature Climate Change* 4, 2014, pp. 678–683: doi:10.1038/nclimate2292.

95 Esvelt *et al.*, "Concerning RNA-guided gene drives for the alteration of wild populations," *eLife*, 3 eo3401, 2014: http://elifesciences.org/content/3/e03401, p. 15.

The scientists describe their recommendations as "unanimous international consensus"[96] despite the fact that only two of its members are from outside the United States (Austria and Australia) and no governments or non-scientists were included in the discussion. The scientists recommend that "multiple stringent confinement strategies should be used whenever possible." They also recommend thorough assessment by relevant biosafety authorities, the development of protocols for distributing materials, and broadly inclusive and ongoing discussions concerning safeguards, transparency, proper use and public involvement to inform expert bodies.[97] A committee established by the US National Academy of Sciences is also formulating recommendations for "responsible gene drive research."

Bottom Line

It is a classic techno-fix that seeks to address a problem created by biotech's failed technology (herbicide tolerant crops). If realized, it will entrench corporate farming and reinforce farmers' dependence on toxic agrochemicals.

The engineering of wild populations of weeds and insects to reverse resistance or make them more susceptible to chemical pesticides is a dangerous, distorted and unacceptable objective that has nothing to do with sustainable solutions to address climate change. It is a classic techno-fix that seeks to address a problem created by biotech's failed technology (herbicide tolerant crops). If realized, it will entrench corporate farming and reinforce farmers' dependence on toxic agrochemicals.

96 Omar S. Akbari, H. J. Bellen, E. Bier, S. L. Bullock, A. Burt, G. M. Church, K. R. Cook, P. Duchek, O. R. Edwards, K. M. Esvelt, V. M. Gantz, K. G. Golic, S. J. Gratz, M. M. Harrison, K. R. Hayes, A. A. James, T. C. Kaufman, J. Knoblich, H. S. Malik, K. A. Matthews, K. M. O'Connor-Giles, A. L. Parks, N. Perrimon, F. Port, S. Russell, R. Ueda, J. Wildonger, "Safeguarding gene drive experiments in the laboratory," *Science*, Vol. 349, Issue 6251, 28 August 2015.

97 *Ibid*.

The Big Six's Relationship With Syn Bio and "Climate Smart" Agriculture

The Big Six (BASF, Bayer, Dow, DuPont, Monsanto, Syngenta) are the engines of industrial agriculture. With collective revenues of over $65 billion in agrochemicals, seeds and biotech traits, these companies already control three-quarters of the global agrochemical market and 63% of the commercial seed market (based on 2013 figures).

Accounting for over three-quarters of private sector research in seeds/pesticides, the Big Six determine the current priorities and future direction of agriculture research worldwide. The chart below offers examples of Synthetic Biology R&D related to agriculture and the mitigation of climate change impacts – but it is not an exhaustive survey of the Synthetic Biology R&D supported by these companies.

The 'Big Six's relationship with Syn Bio and "Climate Smart" agriculture

Big Six	Description / Partners	"Climate-Smart" Connection?
Monsanto	5-year R&D deal with **Synthetic Genomics**; BioAg Alliance with **Novozymes** to commercialize ag microbials	Co-chair of "Climate-Smart Ag" program for World Business Council's Low Carbon Low Carbon Technology Partnerships Initiative (WBCSD).
DuPont	Acquired **Taxon Biosciences** for industrial microbial production	Member, "Climate-Smart" program - Low Carbon Technology Partnership Initiative. Participates in "CSA" Program (WBCSD).
Syngenta	Agrochemical-induced drought tolerance with **University of California - Riverside**	Member WBCSD. Syngenta Foundation initiative in Kenya and Rwanda: "Climate-Smart Crop-Index Insurance;" Insured farmers can buy certified seeds and invest in fertilizer.
Dow AgroSciences	**Synthace, Ltd**. for development of microbials; **Arcadia Biosciences** and **Bioceres** stress tolerant soybean	Member, "Climate-Smart" program - Low Carbon Technology Partnership Initiative. Participates in "CSA" Program (WBCSD).
Bayer Crop Science	R&D agreement with **KeyGene** (Wageningen, Netherlands) for trait development in wheat using molecular mutagenesis	Partner in "Asian-German Better Rice Initiative," explicitly Climate-Smart initiative; Via CropLife, part of North American Alliance for Climate-Smart Agriculture.
BASF	R&D partnerships with Syn Bio companies **Evolva**, **Genomatica** and **Amyris**; R&D partnership with **Monsanto** to engineer genetic pathways of corn and other crops for stress tolerance	Member WBCSD. Partner in "Asian-German Better Rice Initiative," explicitly Climate-Smart initiative.

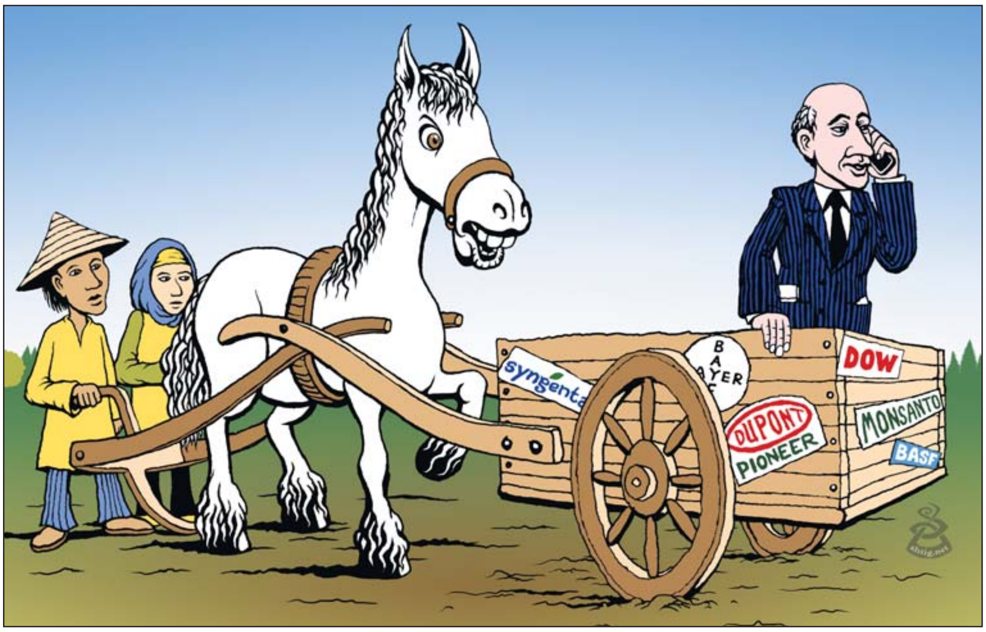
Conclusion

Synthetic biology R&D now focuses on numerous applications that are described as sustainable strategies for adapting plants and microorganisms to increase crop yields and survive climate change. The examples highlighted in this report illustrate how Synthetic Biology seeks to reinforce business-as-usual: the corporate food and farming system that generates an enormous share of global GHG emissions.[98] Syn Bio's techno-fixes aim to entrench the chemical-intensive industrial farming model and reinforce farmers' dependence on industrial inputs.

The world cannot rely on high-tech fixes to solve problems of poverty, hunger and climate crisis. Governments meeting in Paris for UNFCCC COP21 must reject corporatized "Climate-Smart Agriculture" and, instead, promote Climate-Resilient strategies based on Agroecology.[99]

The world cannot rely on high-tech fixes to solve problems of poverty, hunger and climate crisis. Governments meeting in Paris for UNFCCC COP21 must reject corporatized "Climate-Smart agriculture" and, instead, promote Climate-Resilient strategies based on Agroecology.[99]

Agroecology refers to a range of farming techniques (e.g., intercropping, the recycling of manure and food scraps into fertilizers) that reduce the need for external inputs and maximize resource efficiency in a sustainable way. Agroecological techniques improve the resilience and sustainability of food systems; their aim is not limited to increasing yield, though their use may result in greater productivity. Agroecology is gaining increasingly wide acceptance by the scientific community, for example, in the recommendations of the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD), the United Nations Environment Programme and, more recently, FAO.[100] Climate resilience ultimately depends on local food and farming systems and agro-ecological processes in the hands of farming communities. Instead of being on the receiving end of corporate-inspired, high-risk technologies, farming communities must be directly involved in setting priorities and strategies for climate change adaptation and mitigation.

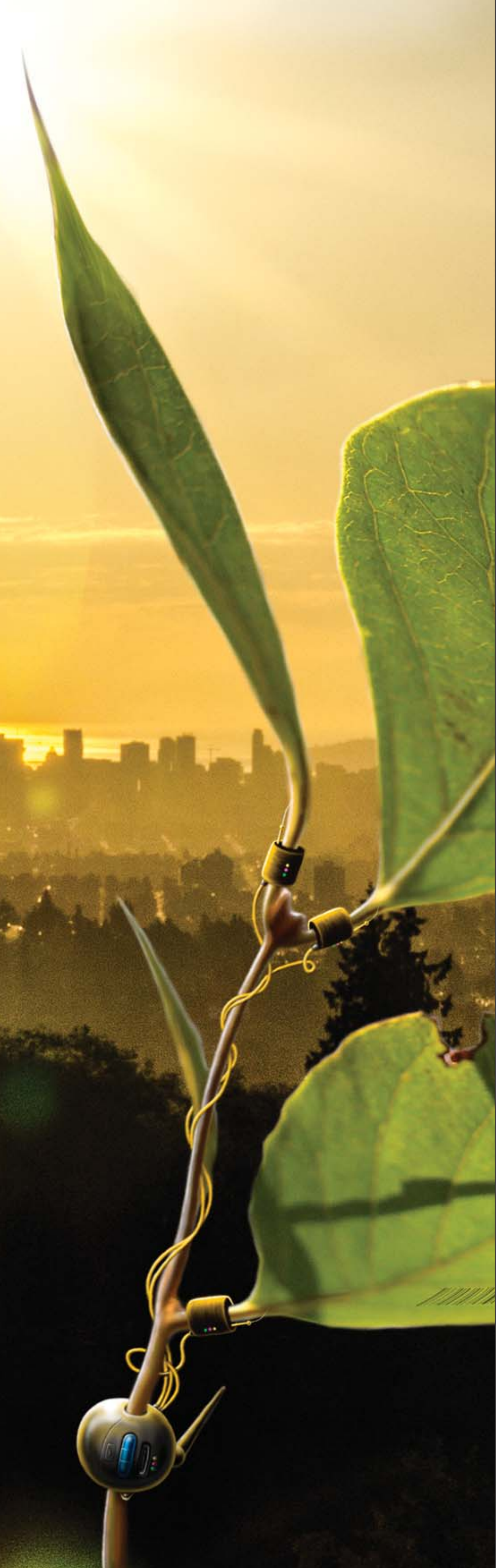


Putting the cartel before the horse *- ETC cartoon from 2013 - an apt summary of a recurring problem: the Big Six put profits and high-tech gimmicks ahead of traditional and effective agricultural practices*

98 GRAIN, "Food and Climate Change: The Forgotten Link," 2011: https://www.grain.org/article/entries/4357-food-and-climate-change-the-forgotten-link.

99 Miguel A. Altieri, Clara I. Nicholls, Alejandro Henao and Marcos A. Lana, "Agroecology and the design of climate change-resilient farming systems," *Agronomy For Sustainable Development*, May 2015.

100 See International Assessment of Agricultural Knowledge, Science and Technology for Development, "Summary for decision-makers of the global report," 2009April 2008, Key Ffinding 7, p. 6; United Nations Environment Programme, *The Environmental Food Crisis*, Nairobi, 2009; www.fao.org/about/meetings/afns/en/.



Many of the world's largest agro-industrial corporations are pushing forward the poorly-defined idea of "Climate-Smart Agriculture" (CSA) to re-market industrial agriculture as 'climate-ready'.

This report uncovers how some advocates of CSA are embracing the extreme genetic engineering tools of synthetic biology ("Syn Bio") to develop a set of false solutions to the climate crisis.

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