Green transition: How agriculture can drive climate change solutions

It is widely recognized that we must transition our energy economies to a greener, more sustainable state. This will only happen through the development of innovative technologies, and as a recent report from the Information Technology and Innovation Foundation (ITIF) makes clear, trying to force the green transition with government regulations, subsidies, and exhortation will not work. The economic reality is that clean energy technologies must reach price/performance parity with dirty energy (P3).

Yet most climate policy recommendations ignore what may well be the most promising source for innovations that will reach price/performance parity: biology. We have said it before, but it bears repeating: novel applications of synthetic biology have considerable potential to deliver lower carbon solutions to climate challenges. This is taken for granted in biomedicine, but for various reasons not so much in other fields.

It’s useful to recall that the foundation of all human economies is agriculture. Only agriculture reliably delivers enough surplus food production to allow for specialization, and thus civilization. And agriculture depends ultimately on the ability of plants to turn sunlight into food—photosynthesis. This process is neither simple nor particularly efficient, and the different types—C3, C4, Cam—work better under different conditions. But it is generally agreed that the maximum theoretical efficiency of photosynthesis as we know it is around 11 percent.

We can improve on that. Photosynthesis involves many individual steps, as illustrated in the diagram below from a research article by Yu Wang and colleagues for the University of Illinois at Urbana-Champaign. Each arrow in this figure indicates a chemical reaction, and each reaction is executed by an enzyme, a protein encoded by the plants’ DNA. With modern methods of gene editing and engineering, each enzyme/step/arrow presents opportunities for manipulation and improvement.

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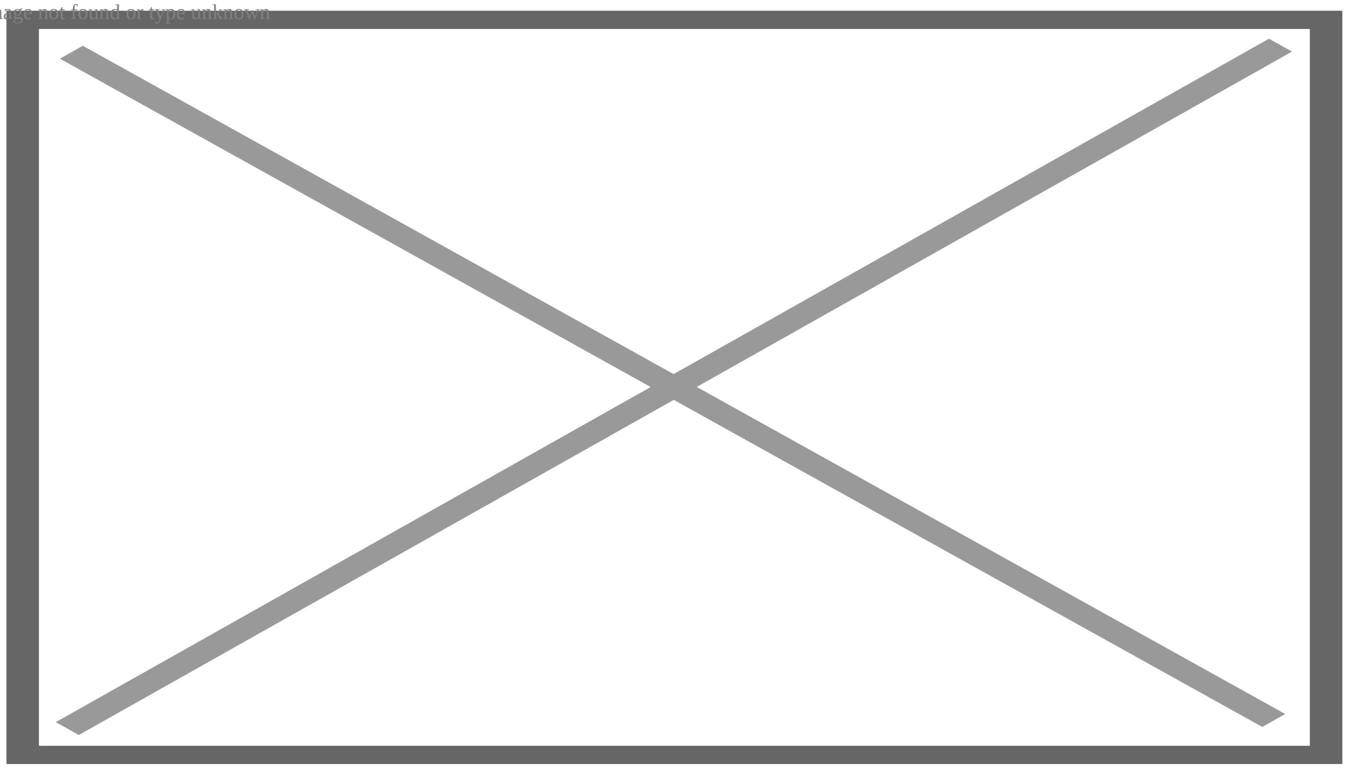

Figure 1: Metabolic model schematic of C4 photosynthesis

Advances by research teams in recent years have brought our understanding of the chemistry of photosynthesis to a level of such fine detail that manipulating the individual reactions to improve them is within our reach. Researchers can now devise many different ways to tweak the DNA sequences encoding these enzymes so they work better—improving the photosynthetic efficiency, hence productivity, of the plant.

Harvard Medical School’s Silver Lab is examining myriad forms of the most important enzyme in photosynthesis (RuBisCO) to identify those that are most efficient. These could then be installed in a plant to make it more productive. Principal Investigator Pam Silver is also working with Dan Nocera at Harvard to incorporate enhanced RuBisCO enzymes into his synthetic platform to produce an artificial leaf, a system that can run photosynthesis on a silicon chip with efficiencies (under laboratory conditions) as high as 80 percent. Other research teams are taking different approaches with similarly promising results.

But in a field marked by brilliant innovations like these, perhaps the most ambitious is an approach taken by Tobias Erb of the Max Planck Institute. His team has been studying populations of microbes and extremophiles from around the world to discover as many strange and unusual variations in photosynthetic metabolism as possible. Erb and his team are building on the understanding of how these chemistries work in detail to construct an approach combining their most efficient aspects to produce a superior, novel photosynthetic pathway. The potential of this approach is enormous.

Biofuels, a.k.a. biomass energy, would seem also to have great and direct potential to help wean us from fossil fuels. While life cycle audits have illuminated a complicated and ambivalent reality, and cast doubt on some of the claims of reaching or approximating P3, there remains clear potential. Whatever the present state, there is no doubt the economics and practicality of biofuels could be improved by advances in photosynthesis.

Researchers are tweaking biology to improve plants, microbes, and animals in other ways as well. Food waste is also a big issue and ripe opportunity. All the different ways food can be lost between farm and fork combine to dispose of almost half of what is produced. Better methods of production, packaging, distribution, and preparation can all reduce these losses, providing investment capital with numerous rich opportunities.

Julie Gray at the University of Sheffield is manipulating plant metabolism to reduce water consumption by altering the number of stomata—the pores in plant leaves through which they exchange oxygen, carbon dioxide, and water vapor with the environment. Pam Ronald at the University of California, Davis is working to extend the survival time of plants submerged in floodwaters. Modifications like these could reduce GHG emissions while improving the productivity of rice (or other plants) by reducing the need for irrigation as well as by improving plants abilities to cope with too much of a good thing. The bottom line is an increase in productivity and efficiency, both dearly needed.

Mary Lidstrom at the University of Washington is capturing methane from the air—a greenhouse gas (GHG) as much as 80 times more potent than CO2—using a type of bacteria known as aerobic methanotrophs**.** Dairy farmers are tweaking livestock diets to reduce methane emissions, while cattle breeders are selecting for dairy herds with digestive tracts that host microbial fauna producing far less methane. Either of these approaches could substantially reduce or eliminate greenhouse gases from livestock.

The explosion in the use of synthetic nitrogen fertilizers over the last century, made possible only through synthetic chemistry, has flooded soil microbes with an unprecedented superfluosity of Nitrogen. They react to such imbalanced superabundance with biological responses (nitrification) that produce powerful greenhouse gases (nitrous oxide). Lisa Stein (University of Alberta) is developing inhibitors to reduce these emissions.

Forest Biotech company FuturaGene (parent company Suzano SA, Brazil) is focused on using modern genetic approaches to deliver sustainable enhancement of renewable plantation forest trees. Their objective is to increase the availability of wood for all its various uses and increase the potential of trees as agents for carbon capture and sequestration. A major side effect would benefit biodiversity by reducing pressures on native forests.

Project Vesta, the brainchild of USC Professor Emeritus Ken Nealson, uses microbes (selected and engineered) to accelerate the natural geological process of silicate-carbonate mineral weathering as a method of atmospheric CO_2 drawdown. Natural rates of such weathering reactions are very slow, but Project Vesta is developing living microbial catalysts that greatly enhance the rate of this weathering. Preliminary work has shown major rate enhancement(s), and the project is now ready to begin screening and genetically engineering microbes to maximize the rate(s) at which they accelerate silicate weathering. After scaling up, Vesta anticipates about 5 million tons of carbon removal per year with current supply partners, and there are sufficient mineral reserves and mine tailings to scale beyond the gigaton level in less than a decade. Their approach will encompass coastal, terrestrial (soil) and freshwater mineral enhancement, and include both reactor-based and in-situ systems. This, alone, could be a game changer.

Not only do few governments have policies providing the degree of support that possibilities like these justify, many have policies and regulations that specifically discriminate against biological innovations. This is not helpful. Originally aimed at ensuring safety, experience has shown initial concerns were unwarranted, and it is now clear that gene edited and modified crops and livestock are, if anything, safer than their conventionally bred counterparts. Further, the public opinion such regulations were designed to mollify has clearly shifted. The European Union and its member states (current and erstwhile) have proposed changes to existing regulations to address this, but they are widely seen to be insufficient. But despite the unwarranted albatross such regulations have placed around the neck of seed improvement technologies, they have already delivered enormous global benefits. There is a widespread and growing eagerness to unshackle these technologies and harness the benefits for which they hold such high promise.

Investments in basic agricultural research have a stellar record, historically producing returns on investment of at least 10:1, and in most accounts closer to 20:1. Despite this, government support has been steadily diminishing for decades. This is a trend self-interest suggests should be emphatically and immediately reversed.

What should governments do to fix this? The Biden administration has taken commendable steps in the right direction with new, concrete programs to strengthen biomanufacturing. But regulatory reforms will yield high benefits at very low costs and should be a high priority. The historical record cited above also argues strongly for substantial increases in support for basic biological research across the board.

The wide availability and low cost of sunlight gives biotechnologies an enormous advantage on the path to price/performance parity. This is the way.

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