Genetically Engineered Algae: "Living cell factories" or looming disaster?

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Introduction

Microalgae, both diverse and adaptable, are vital to regulating ecosystems and the earth's climate. But they are also the focus of hopes, ambitions and massive investments in their potential use for producing biofuels. Proponents argue that algae biofuels will effectively bypass the now well-documented negative impacts from first-generation biofuels, such as corn ethanol, that include the use of large amounts of land, water and chemicals, along with increases in food prices.[1,2] But viable commercial production of algae biofuels, even after decades of research and massive investment, has not yet been achieved.[3,4]

Meanwhile, researchers are increasingly turning to the use of genetic engineering (GE), including *synthetic biology*, to convert algae into "living factories" that can be made to secrete fuels and industrial chemicals,[5] industrial lubricants, and a wide array of chemicals for consumer products, including cosmetics, nutraceuticals (such as omega oils),[6] algae based food products (such as Terra Via's Thrive cooking oil)[7] and animal feeds.[8]

Why are algae important?

Algae are among the most essential organisms on the planet. They form the base of marine and fresh water food chains and provide roughly *half* of Earth's oxygen[9]. The term *microalgae* refers to a very diverse array of mostly single-celled, photosynthetic, *eukaryotic* (with a cell nucleus) organisms. Cyanobacteria, also called "blue-green algae," are also considered microalgae even though they are *prokaryotes* (no cell nucleus). *Macroalgae* refers to kelps and seaweeds.[10] This issue brief will focus on microalgae, a group containing perhaps hundreds of thousands of species, only about 50,000 of which have been identified and described by scientists[11].

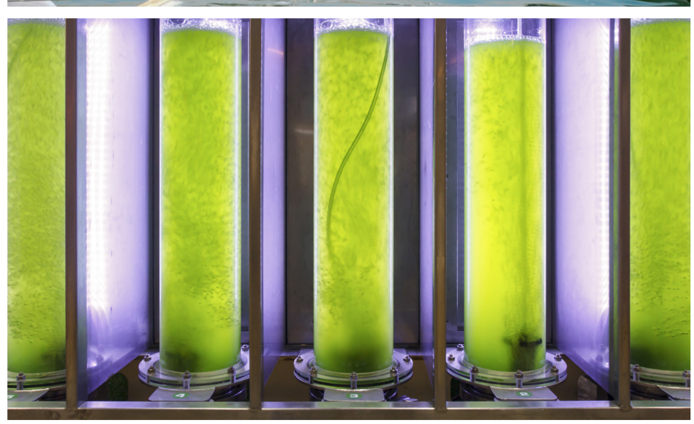
Are commercial algae biofuels viable?

In spite of claims that algae can produce massive quantities of biofuels with "nothing but water, CO2 and sunlight,"[12] industrial cultivation of algae and conversion to biofuels requires massive amounts of energy,[13] water, [14] nutrients,[15] concentrated CO2,[16] access to light and land, [17] and sheer know-how. Despite the amount of research and development that has been underway since at least the mid-twentieth century,[18] no viable algae biofuels have reached the market.

Researchers are attempting to cultivate algae with strains from species that are *autotrophic* (derive energy from the sun) or *heterotrophic* (derive energy from sugars). Heterotrophic algae cultivation requires a continuous supply of biomass (commonly sugarcane or corn), and thus has similar land use, food supply and ecological implications to those of first-generation biofuels.[19]

How are microalgae cultivated and can they be contained?

Industrial-scale cultivation of microalgae is typically done in either *open ponds* or *photobioreactors* (PBRs).[20] PBRs hold the algae in tubes, flat plates or columns, and may only consist of thin plastic.[21] There are problems with each method. Open ponds are more vulnerable to weather and evaporation, as well as invading pathogens, which can ruin the algae.[22] PBRs provide more control, but are more costly.[23] Open ponds require more stringent permitting processes because they are not "contained structures."[24, 25] PBRs, although they are made from thin plastic and must be periodically cleaned out, are considered to be a "contained use."[26] In reality, due to their very small (microscopic) size and their capacity to become airborne, microalgae will inevitably escape from any industrial cultivation facility.[27]



Top Photo: An open tank of algae at a spirulina harvesting farm. This is one way of cultivating algae. Source: Shutterstock **Bottom**: A photobioreactor (PBR for short) holds algae in tubes. This method of cultivation is costly. Source: Shutterstock.

What risks do genetically engineered microalgae pose to the environment?

- **Escape is inevitable**. In addition, once the algae escape, it will be virtually impossible to recall them.[28]
- **Escaped microalgae may outcompete native species and proliferate.[29]** Researchers and industry representatives claim that engineered microalgae are unlikely to survive in the wild, but there is little basis for this claim.[30,31] In fact, the traits that are being engineered are often precisely those that could provide a competitive advantage in natural ecosystems.[32] For example, microalgae are being genetically engineered to withstand the stressful conditions of mass cultivation,[33] which may include resistance to pathogens or chemical controls such as herbicides and insecticides.[34] They may also be engineered with the capacity to grow rapidly by using light and nutrients more efficiently.[35]
- **Potential for harmful algae blooms (HABs)**. Microalgae are also being engineered to directly secrete chemicals such as ethanol, alkanes and isoprene, as well as specific kinds of lipids (fats).[36,37] Such microalgae could be unappetizing to predators that normally keep wild algae populations in check, and as a result they may proliferate.[38] HABs occur when algae proliferate and secrete toxins, some of which can be lethal to wildlife and even to humans,[39] rendering fisheries and waterways unusable.[40] HABs have already become increasingly common due to increased runoff of pollution that supports algae growth and warming waters symptomatic of climate change.[41] Introduction of engineered microalgae, or even microalgae that are not engineered but are non-native species, could result in potentially disastrous algae blooms.
- **How the engineered traits will evolve is unpredictable.** Microalgae can transfer genetic material not only to their direct progeny, but also to other organisms in the environment through *horizontal gene transfer* (HGT).[42] It is possible that engineered traits will move into other species or even enter the human food chain.[43] Furthermore, given high mutation rates, traits may not remain stable over time, leading to unpredictable consequences.[44]
- **Researchers do not know enough about algae to predict and control the risks** associated with release of GE microalgae into natural ecosystems[45].

Who is investing and where is the money really going?

Commercial scale algae biofuels remain elusive, given the costs of cultivation[46] and the necessity to compete with cheap oil prices.[47] Companies are turning to low volume, high-priced products to remain economically viable, with some such products already on the market,[48] including oils for food and household cleaning products, all of which are derived from GE algae.[49] These products are largely unregulated and are entering the market unassessed for their health and environmental impacts. For example, TerraVia's "Algenist" is a line of anti-wrinkle face creams,[50] and the same company is marketing "Thrive" culinary cooking oil.[51] Even with the supplemental niche products, GE algae products may not be economically viable.

Meanwhile, government agencies, including Department of Energy (DOE),[52,53] and U.S. Department of Agriculture (USDA),[54] along with various state and private sources,[55] continue to dump funding into algae biofuels. Funding also comes from the world's largest oil companies, including Exxon, BP, Shell, and Chevron.[56]

Recently, Exxon renewed $600 million dollars in funding for collaboration with Synthetic Genomics (SGI) to develop microalgae biofuels.[57] Yet in 2009, while CEO of Exxon, Rex Tillerson stated that algae biofuels were "*at least 25 years away… what we've come to understand is that the hurdle is pretty high, and the hurdle seems to come at the basic science level which means it's even more difficult to solve.*"[58] Exxon/SGI have now turned to the use of new genetic engineering techniques to create microalgae cell factories.In June 2017 they announced a new "breakthrough" towards commercial production

Photo: A blue-green algae bloom at Clear Lake, Lake County, California, resulted in oxygen depletion in the water and the subsequent mortality of multiple aquatic species. Photo by Kirsten Macintyre via California Department of Fish and Wildlife Flickr.

based on the use of CRISPR-Cas9 genome editing, which they claimed resulted in improvements to algae lipid production.[59] However, we have heard for decades now that algae biofuels are "just around the corner."[60] In reality, algae biofuels may not be commercially viable, and the claims may only be a marketing strategy for companies like Exxon.

Conclusion

The hype and investment around algae biofuels has not resulted in commercially viable biofuels. Worse yet, they distract attention and resources from more promising, less risky and proven solutions to climate and energy concerns, such as efficiency, solar and wind energy, relocalization, expanded public transportation, dietary shifts and regenerative agriculture. Meanwhile, the risks associated with creation and release of GE microalgae loom, and new genetically engineered microalgae research is focusing on producing chemicals for consumer products like cosmetics and food ingredients. Is it worth significant risks to our ecosystems to make commercially viable GE algae biofuels? Is it worth taking those same risks for production of industrial chemicals, consumer products like algae derived surfboards,[61] or TerraVia's anti-wrinkle skin cream?[62] Thus far, engineered algae biofuels do not provide a viable alternative to avoid the many problems associated with first generation biofuels and may create significant, irreversible environmental problems. A precautionary approach is urgently needed, along with a realistic and holistic weighing of costs and benefits to society and ecosystems as a whole, rather than allowing the potential profit of a few corporations outweigh the potential for ecological disaster.

Recommendations

- A precautionary approach to developing genetically engineered algae, which weighs the costs and benefits of GE algae to society and ecosystems as a whole.
- Robust federal regulation, oversight, and assessment which addresses the process of production, contamination risks, and which places the burden of responsibility for ecological contamination on the producer.
- A transparent, democratic process with which to evaluate and appropriately regulate new, emerging and proposed applications of genetic engineering.
- Investment and resources into more sustainable, less risky and proven solutions to climate and energy concerns, such as efficiency, solar and wind energy, relocalization, expanded public transportation, and regenerative agriculture.
- Increased investment in more socially just and less risky solutions to environmental, health and social problems.

For more information, see Biofuelwatch's report: **Microalgae Biofuels: Myths and Risks**.

Photo: Harmful algae bloom near Pelee Island, Ohio. Photo by T. Archer via NOAA Great Lakes Environmental Research Laboratory Flickr.

Endnotes

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