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EDITORIAL

Fuels from microalgae

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"Algal biofuels have a clear potential for contributing to environmental, social and economic sustainability."

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Microalgae are microscopic plants that make seas, lakes and rivers green. Algae and some other organisms use sunlight to produce biochemical energy via photosynthesis, the ultimate source of all biofuels. Algal biofuels are potentially renewable and their production is sustainable so long as the sun shines. Production of fuels and chemicals from renewable algal biomass has the potential to be carbon neutral.

Coal, petroleum and natural gas are cheap and may not run out soon. Nevertheless, we have to decide whether the adverse economic impact of the greenhouse gases associated with the use of fossil fuels outweighs their continued use. Many in the scientific community are convinced that at current levels, continued emissions of manmade greenhouse gases is incompatible with our survival. Considering the global environmental impact of carbon dioxide emissions, there appears to be no net economic benefit of using fossil fuels. Sustainable alternatives to fossil fuels are necessary not just for energy but also for the many other products that are sourced from coal, petroleum and natural gas [1]. Algal fuels are one potentially sustainable alternative to fossil fuels.

Algal biofuels have a tremendous variety. Photosynthetically produced algal biomass may be used directly as a solid biofuel to generate heat, steam and electricity. Alternatively, the biomass may be converted to gaseous biofuels, such as biogas and biohydrogen, by various types of microbial processes [2–9]. Biohydrogen can also be produced directly from sunlight using photobiological microbial processes [10]. Algal biomass can be tailormade to be rich in starch that can be easily fermented to liquid biofuels such as bioethanol and biobutanol [11]. In addition, sunlight can be used directly to produce algal bioethanol from carbon dioxide without the involvement of a separate fermentation step [12]. Some algae are rich in oils [13–15] and others can be grown under conditions that favor accumulation of large quantities of oil [14,16]. Algal oils may be similar to other vegetable oils, or they may be mainly hydrocarbons [13], depending on the algal species used to produce them. Algal oils can be converted to diesel, gasoline and jet fuel using existing technology [16].

In view of their tremendous potential, algae are receiving much attention as possible sources of energy-dense liquid transport fuels [13–20]. Production of algae-based liquid fuels is being intensively investigated by nearly every major oil company [20–26] and many emerging companies [20,27] as a potential replacement for petroleum. Direct production of bioethanol via algal photosynthesis is being actively developed [12]. Algal crude oil and biomass are potentially important renewable feedstocks for the future chemical industry [1].

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Nearly all the biofuels that can be sourced from algae can also be produced by crop plants. Why then the interest in algae? This is simply because algae are more productive than plants. Under suitable culture conditions, the biomass and oil productivity of microalgae greatly exceeds that of vascular plants [14,17]. For example, the median value of the maximum specific growth rate of microalgal species is approximately 1 day^{-1} whereas for higher plants it is 0.1 day^{-1} or less [28]. Each algal cell is photosynthetically active whereas only a fraction of the plant biomass photosynthesizes. Each algal cell can absorb nutrients directly from its surroundings and, therefore, algae do not have to rely on energy-consuming, long-distance transport of nutrients via roots and stem.

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In addition to light, photosynthesis requires carbon dioxide. In plants, photosynthetic tissue can access carbon dioxide only through pores known as stomata. These pores are not always open and carbon dioxide must move through them against a flow of water vapor. The carbon dioxide diffusion pathway from the surface of the photosynthetic tissue to a photosynthesizing cell is much longer in plants than in microalgae and increases with increasing thickness of the photosynthetic structure [28,29]. Algae, therefore, can access carbon dioxide more easily than vascular plants and this contributes to the relatively rapid growth of algae.

Owing to its high solubility in water, the equilibrium concentration of carbon dioxide in an algal suspension is greater than in the atmosphere above the suspension. Effectively, water enriches carbon dioxide that is essential for photosynthesis. This too improves algal productivity relative to plants. Furthermore, because of a short lifecycle, algal biomass can be harvested daily or hourly, whereas plant biomass typically remains in the field for much longer.

Unfortunately, owing to the low productivity of plants, existing plant-derived biofuels cannot displace petroleum-based transport fuels to any significant extent [14,17]. This severe limitation can only be overcome with a new generation of biofuels such as algae-based fuels. Unlike the existing crop-derived biofuels, algal fuels can be produced without encroaching on cropland and without further deforestation [14,17]. Production of algal biofuels need not reduce the supply of food, feed, other agricultural products and freshwater [14,17].

Production of some existing biofuels demands unsustainable inputs of nitrogenous fertilizers, which are generated from fossil fuels and require huge inputs of energy to produce [30]. Some plant-symbiotic bacteria, algae and other photosynthetic microorganisms can naturally convert the atmospheric nitrogen to a form that can be used by life forms, but most crop plants and microalgae being considered for producing biofuels do not do this. Engineering plants and algae for nitrogen fixation capability is therefore important for sustainable production of biofuels.

Production of all kinds of biofuels, including biomass itself, can be improved substantially by genetic and metabolic engineering [1,14,31–40], bioprocess engineering [3,14,41,42], the use of extremophilic species [43], and in other ways [2]. The future of biofuels is intertwined with genetic and metabolic engineering.

No form of renewable energy can fuel infinite growth and, therefore, society will have to learn to live within limits, including limits on population. Increasing the efficiency of energy use will be essential and will need to be achieved without changes to the lifestyle that we are accustomed to in the developed world. Within the constraints of sustainability, all humanity must attain an equitable quality of life. Algal biofuels have a clear potential for contributing to environmental, social and economic sustainability.

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