

Review (Narrative)

Challenge and Potential of Biofuels from Algae

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SUMMARY

Algae biofuels could give a viable alternative to fossil fuels; however, this technology has to overcome several of hurdles before it can contend in fuel market and be deployed. The main challenges faced are production management, harvesting, coproduct development, fuel extraction, strain isolation, nutrient sourcing and utilization, refining and residual biomass utilization. The solution to these hurdles is simple but needs time and effort. The affordable growth densities, high growth rates and high oil contents are solid reasons to invest notable capital to convert alga into biofuels. Furthermore, bioprospecting (in which natural diversity is used to increase productivity), breeding and classical genetics (for trait identification and improvement), bioengineering (in which synthetic biology is used to improve traits) and fuel molecules are some of the techniques under research that can make algal biofuel competitive with fossil fuel. No technology is without its challenges; same is the case with this new technology, as we learn more to it we discover more challenges and obstacles. Even given these uncertainties, it is believed that fuel production from algae will be widely deployable and priced competitive within the next 7 to 10 years, however we still need expand our understanding of this wonderful organism so we can expand our ability to engineer them for the specific task of developing a brand new energy industry. ■

KEYWORDS Algae; Fuel; Biotransformation; Energy; Sustainable development

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Algae biofuels could give a viable alternative to fossil fuels; however, this technology has to overcome several hurdles before it can contend in fuel market and be deployed. These challenges are strain identification and improvement, in terms of oil productivity and crop protection, nutrient and resource allocation and use, and also the production of co-products to enhance the productivity of the whole system. Though there is abundant excitement concerning the potential of algae biofuels, much work continues to be needed in the field. This article discusses major challenges to economic algae biofuels at scale, and improves the main focus of the scientific community to deal with these challenges and move algae biofuels from promise to reality.

IMPORTANCE AND CHALLENGES OF ALGAL BIOFUELS

The global economy needs fossil hydrocarbons to operate, from manufacturing plastics and fertilizers to providing the energy required for transportation, lighting and heating. With our increasing population and growing economy, there will be enhanced fuel use. As countries improve their gross domestic product per capita, data suggest that their fuel use will increase, and competition for these restricted resources will increase. Additionally, there comes increasing atmospheric carbon dioxide concentration, and therefore the potential for vital greenhouse gas-mediated global climate change (1), that currently appears to have an effect on all components of the planet. Finally, petroleum, which is partly derived from ancient alga deposits, is a limited resource that may eventually run out or become too costly to recover (2). These factors are driving the exploration of renewable energy sources which will replace fossil fuels, and permit larger access to fuel resources for all nations, while greatly reducing carbon emissions into the atmosphere. A variety of technologies are examined as renewable energy sources and, though no single strategy is probably going to supply a complete answer, it looks possible that a mixture of ways may be utilized that may considerably make us independence on fossil fuels (3). The challenge that still remains is to develop renewable energy industries that operate sustainably and might be price competitive with existing energy choices.

PRESENT ECONOMIC REALITY OF LIQUID FUELS

There are significant challenges to creating biofuels capable of competing with fossil fuel. Certainly, a premium worth is bonded for clean fuels (fuels that have a 50 percent lower carbon dioxide cradle-to-grave footprint than petroleum); but, calculable prices of a barrel of algae-based fuel using

current technology is US\$300–\$2,600, compared with \$40–\$80 (2009) for fossil fuel (4), though all of the estimates for cost of a barrel of alga oil in specific regions reach as low as \$84 (5). The upper estimates are more common and almost like our own estimates, and exclude algal oil from the present liquid fuel market. The challenges and techniques to tackle this economic discrepancy are mentioned in this article.

BENEFITS OF MICROALGAL BIOFUELS

Microalgae are a diverse cluster of unicellular organisms that have the potential to supply a range of solutions for our liquid transportation fuel needs through variety of avenues. Algae species grow in a wide selection of aquatic environments, from fresh through saturated saline water. Algae use carbon dioxide, and are liable for over 40 percent of the worldwide carbon fixation, with the bulk of this productivity coming from marine microalgae (6). Algae can reproduce biomass very quickly, with some species doubling in as few as six hours, and a lot of them exhibiting 2 doublings per day (7). All algae have the capability to supply energy-rich oils, and variety of microalga species are found to naturally store high oil levels in their total dry biomass (8). For instance, some *Botryococcus* spp. are known to that have up to half of their dry mass stored as long-chain hydrocarbons (9). With probably innumerable species, algal diversity provides researchers several choices for distinguishing production strains and conjointly provides sources for genetic data that may be used to improve these production strains. The micro algal species being investigated as potential biofuel producers originate from the groups whose ancestral relationships are considerably broader than most of land plants, providing a wealth of genetic diversity (10). The groups most frequently thought of when discussing microalgae are prymnesiophytes, diatoms, green algae, golden brown, eustigmatophytes and blue-green algae (11), and members from all of these groups are examined as potential fuel production strains. However, it ought to be noted that blue-green algae are not considered as algae but a category of photosynthetic bacteria.

CHALLENGES FOR ALGAL BIOFUELS

The affordable growth densities, high growth rates and high oil contents are solid reasons to invest notable capital to convert alga into biofuels. However, for alga to mature as an economically viable platform to offset fossil oil and, consequently, mitigate carbon dioxide release, there are a few of hurdles to beat like where and how to grow these algae for maximized oil extraction and increased fuel processing. The biofuels production chain tells that the main challenges faced are production management, harvesting, coproduct development, fuel extraction, strain isolation,

nutrient sourcing and utilization, refining and residual biomass utilization.

Improving Oil Extraction

Oil extraction is another challenge that can most simply be addressed from the engineering aspect. There are 3 major methods for extracting oil from algae: supercritical carbon dioxide fluid extraction, oil press/expeller and hexane extraction (12). These technologies have all been used successfully; however they are comparatively costly, either in terms of equipment required or energy needed to extract the oil. Luckily, all are amenable to engineering enhancements. Once extracted, because crude algal oil is chemically identical to crude oil, the challenges related to alga oil conversion to usable liquid fuels are same as those already well managed by crude oil firms, though improved catalysts are needed to boost gasoline production from bio-oil (13). Owing to these similarities, it appears reasonable to assume that partnership between major oil firms and algal producing firms are possible, since these firms have expertise increasing downstream processing efficiencies.

Water Use

Water is doubtless a significant limiting factor in algal growth. Protoctist growth into non arable land requires water; luckily, several of those places have considerable alkaline or saline water reservoirs underneath them, resulting in a supply of nonpotable water that's appropriate for growth of the many algal species. Surprisingly, algae maturing in open ponds have water needs per unit area like that of cotton or wheat, however lower than that of corn, to refill the water lost in evaporation (for an outline of water needs of terrestrial plants utilized in biofuel production see (14)). It's imperative once considering broad preparation of alga, to think about water use to avoid a future 'water versus fuel' discussion. Though substantial alkaline reserves are available, water remains an issue for algal fuel production and is needed to be thought about rigorously as the business expands.

MAKING ALGAL GROWTH AND HARVESTING MORE EFFICIENT

Improved engineering can create a major impact on alga biofuel production. These enhancements include economical methods for nutrient circulation and exposure, and have been reviewed before (15). In brief, there are important challenges for engineers to either develop photo bioreactors (PBRs) that are cheap enough for large-scale production, or for engineers and biologists to combine forces to develop species that grow normally in affordable open systems (16). PBRs have benefits over open systems as they can more efficiently maintain axenic cultures, and may maintain more controlled growth environments, which can result in increase in productivity; but contained systems are challenged

by efficiencies in gas exchange and a demand for supplemental cooling (17). Despite the advantage of minimizing contamination and raising productivity, it's still not clear whether or not PBRs can ever become cost competitive with open pond systems. Despite the growth strategy used, substantial enhancements over current technologies for extracting oil from and harvesting algae ought to be created, and coordinated efforts are required to couple improved production strains with engineering advancements.

NUTRIENT CHALLENGE

Algae need nutrients, light, water and a carbon supply, most frequently carbon dioxide, for economic growth. The nutrients necessary for growth of algae are phosphorous, nitrogen, iron and sulfur. The nutrient demand necessary for algal growth is neglected most of times, algae is pretty efficient at sequestering those nutrients when present in their atmosphere (18). Changes in nutrient load and algae growth has been studied extensively in terms of coastal regions and eutrophication of lakes, however not as heavily in terms of productivity in large-scale cultivation (19). If terrestrial agriculture is a model for a few of the challenges for algal cultivation, then providing ample nutrients for large-scale algal growth may be a vital challenge. Fertilizer or Micro- and macro-nutrient supplements, or account for vital costs within the current terrestrial agriculture business (20), and biofuels don't seem to be expected to be an exception. The utilization of fertilizers has been increasing globally. Sadly, several fertilizer elements are generated from fossil fuels or mined and, as such, they're not renewable (21). Algae, just like plants, need sources of phosphorus, nitrogen and potassium, these are the most important elements of agricultural fertilizers, and large-scale cultivation can impact these already restricted supplies. Additionally, optimum growth of the many algal species needs chelated iron and sulfur.

CROP PROTECTION

Much like terrestrial monocultures, pests and pathogens invade multicellular algal monocultures, and thus, crop protection could be a major challenge to algal pool sustainability. Distinctive strains immune to pathogens, together with several different methods, will need to be used. These methods might include engineering specific pest resistance into production species that have sturdy growth characteristics and important lipid composition. Alternative approaches might include utilizing multiple species, which may be adequate to the slow spread of specific pests and minimize crop loss in multicellular algal facilities.

Competition with Petroleum

With current estimates of algal-based biofuels starting from \$300–\$2,600 USD per barrel acquired by current technolo-

gy, technical hurdles ought to be overcome to reduce this price. A number of these enhancements will come from improving growth methods and engineering, as mentioned previously, however enhancements may also come from optimizing the utilization of the whole algal organism. The price of a barrel of algal biofuel when production goes to large scale is tough to extrapolate from the current small production facilities, system enhancements will definitely bring prices down.

Growth of Algal Strains

A key characteristic for deciding the viability of new identified algal species as a potential fuel yielding strains is their growth. Growth rates and the growth densities should be characterized in terms of real-world growth conditions instead of laboratory conditions. These conditions are often simulated to some extent in the laboratory by utilization of appropriate media, combining condition and light regimes; but, production estimates so far, that are based on laboratory conditions in confined photo bioreactors, will ought to be recalculated for industrially scalable systems before they can be thought of as significant source for biofuel production, whether they are open ponds or advanced photo bioreactors. While helpful information can be gained from these kinds of investigations, for assessing true economic viability, and for alga to be promoted forward from the bench to the pond, all aspects of protist physiology should be assessed under real-world conditions, instead of the theoretically results under perfect conditions.

Optimization of algal species growth in open ponds is a key element of reaching economic viability, and remains a serious challenge for the industry. Identifying species that grow well in these conditions should be the center of attention of analysis in all laboratories. Algae can grow in a very wide range of temperatures, with growth being restricted primarily by nutrient accessibility and light. Light provides the energy for carbon fixation, and is changed to energy through chemical process, providing the building blocks for biofuel production. Algae growth rates are typically restricted by light penetration into the ponds from light absorption by the water and self-shading, and these constraints are major deciding factors of algal pond depth. The identification of production species that have evolved to capture shorter wavelengths of light, which have larger water depth penetration, will enable the algal pond depth to be enhanced beyond the present 15–30 cm (22). This can decrease the overall land needed for algal biofuel production.

POTENTIAL OF BIOFUELS FROM ALGAE

Bioprospecting: Utilizing Natural Diversity to Increase Productivity

Algae are some very diverse organisms that contain thousands of well-known species. The good diversity of algal species provides a large range of starting strains for fuel

production. This presents an implausible chance, however also a major challenge. To maneuver a species into an applied pipeline when the initial species identification is completed, vital physiological, biochemical and genetic characterization should occur. This characterization includes establishing best growth conditions (i.e. nutrient levels, pH and salinity temperature), growth characterization (i.e., growth rate and density of the final culture), and analysis of substance accumulation. In parallel, genomics will offer insight into metabolic pathways that are present in these species and supply a foundation for future metabolic engineering. The United States government-sponsored Aquatic Species Program provided characterization of hundreds of species, from the Nineteen Seventies through to the mid-1990s (23). This work has been done in a number of laboratories round the world. However, there remains a section of biology that's mostly undiscovered. General descriptions of the few algae classes in which one or more species has been characterised follow.

Breeding and Classical Genetics: Trait Identification and Improvement

Artificial selection of desired traits in agricultural plants has most likely been occurring since the dawn of agriculture. The ancient methods are identification of traits of interest from the present diversity of the crop species, and selective combining these traits through interbreeding. Directed and productive breeding of some species of microalgae is feasible, however very little is known concerning the sexual lifecycle of the vast spread of species. This is partially due to the large diversity within the alga groups, from the diploid diatoms to the haploid chlorophyceae, specific processes occurring in one species of algae don't seem to be applicable to other species. However, much more limiting is general lack of knowledge on the complete lifecycle of a vast species of alga, principally due to their aqueous lifecycle and tiny size. There's potential to improve algae for the production biofuels by developing the tools for selective breeding and utilizing these to transfer traits that have an effect on biofuels, between closely related species, or to enhance specific strains of any one of algal species. These breeding methods have a benefit, in that polygenic traits are often transferred between strains; but, nowadays mutagenesis and molecular genetics are at the forefront of algal strain improvement.

Bioengineering: Using Synthetic Biology to Improve Traits

Identification of a perfect, non-modified biofuel organism that fits into the current mechanism for harvesting, purification and extraction, and is economically viable, is possible; but, a more likely situation is identification of a range of species in which each have one or some of these desirable traits. These traits, once engineered into a strain, are also adequate to lead to an economically viable production strain.

Additional to strain enhancements in fuel production, utilizing genes known from other algal species might allow improved expression of heterologous proteins, which either have immense value as a coproduct, protein or enzymatically manufacture a high-value coproduct. Both these ways are being investigated to enhance the economics of algae biofuels.

Improving Fuel Molecules

Algae are often harnessed to provide variety of molecules, which will be used for fuels. The present trend is to use the fatty acids that are naturally made in algae, since several species manufacture these lipids at a considerable proportion of their total mass. Further discussion of lipid production in algae can be reviewed elsewhere (24). In short, for fatty acid production, acetyl CoA is changed to malonyl CoA. Malonyl moiety from the malonyl CoA to an acyl carrier protein (ACP) is transferred by Fatty acid synthase (FAS), generating malonyl-ACP. As a result, condensation reactions catalyzed by FAS elongate the growing acyl chain, whereas the fatty acids are modified by elongases and desaturase. Most algae species accumulate fatty acids with ranging in length of 16–20 carbons, with no to as several as four of five sites of unsaturation. Though for various algal species fatty acid composition varies, once extracted, its chemical composition isn't thought to be totally different from the chemical composition of mixes presently found in sweet light-weight fossil oil. The enzymes concerned with production of oil are also able to be manipulated; therefore, increasing the production oil producing species and also the ensuing that the oil produced can be used after being transesterified as diesel or can endure carbon cracking to

provide biojet fuels or biogasoline (25). For maximizing fuel production and minimizing prices, knowing the precise lipid content in terms of carbon chain length is very important, this can result in optimized chemical modification. Lipid composition is often determined through lipid extraction, fractionation and followed by mass spectrum analysis.

CONCLUSIONS

This article discusses methods to create algae-based fuels prices competitive with fossil fuel. Bioprospecting is of importance to spot algal species that have desired traits (e.g. growth densities, high lipid content, growth rates, and/or the presence of valuable co-products), when growing on inexpensive media. Despite the potential of this strategy, the foremost possible situation is that bioprospecting won't determine species that are price competitive with fossil fuel, and subsequent genetic engineering and breeding are going to be needed to bring these strains to economic viability. The potential of engineering algal cells is starting to be realized, from improvements in lipid biogenesis and rising crop protection, to manufacturing valuable proteins and co-products. No technology is without its challenges; same is the case with this new technology, as we lean more to it we discover more challenges and obstacles. Even given these uncertainties, it is believed that fuel production from algae will be widely deployable and priced competitive within the next 7–10 years, however we still need expand our understanding of this wonderful organism so we can expand our ability to engineer them for the specific task of developing a brand new energy industry. ■

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