The Global Trend in Biofuel Science; Challenges and Opportunities

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The dawn of the new century witnessed a faster intercontinental mobilization and heavy industrialization to meet the huge global commodity requirements which skyrocketed the global energy demands. As a result, faster consumption of fossil fuels initiated their depletion quickly along with the extensive release of greenhouse gases. Global warming is something which cannot be ignored because it has the potential to cause massive destruction on Earth followed by the mass extinction of life from this the only known biosphere. These serious concerns have reinforced the research efforts to develop alternative clean energy technologies using renewable and ecofriendly feedstocks (Figure 1 indicates the rise in global research efforts after 2007). The potential energy is stored in various renewable sources including water, wind, sunlight, and biomass can be harnessed effectively due to their renewable and clean nature.

![Figure 1](image)

**Figure 1.** Global trend in biofuel science based on number of publications published in last 20 years. The data was obtained from SCOPUS and clearly indicates a remarkable rise in biofuel research after 2010 in biomass-based, microalgaebased, and genetic engineer ed based biofuel research.

Biomass produced either on non-profitable/poor soils or obtained from agricultural practices offer abundant, low-cost and carbon-neutral feedstock to produce energy [1]. In this context, the first important step is to select the most suitable biomass/grasses which can be produced on poor soils with minimum management practices (to keep the cost low) and without any pesticides or fertilizers (to ensure the environmental sustainability). It would be required to cultivate these grasses for several years to study the impact of large-scale cultivation on the environment and biodiversity. Nation-wide projects should be launched by the government institutions involving the multi-disciplinary people from environmental agencies, water and soil conservation departments, plant and animal diversity, biotechnology, agronomy, chemical engineering, energy departments and the policy makers to develop a nation-wide strategy for the effective utilization of indigenous biomass sources of each country (Figure 2 indicates that research in biofuels involves multiple disciplines). Various counties have multiple social needs, diverse soil properties and variable environment, and specialized adapted grasses; hence, customized territorial or regional biomass production and utilization strategies should be established. Once a selected biomass is produced on a sustainable basis, a detailed characterization of the biomass should be done to develop an effective biorefinery for sustainable transformation of the biomass into energy, fuels, chemicals, biomaterials, and medicines using thermochemical, biological and/or a combinatorial approach. For instance, the biomass with low-lignin content can be effectively transformed into liquid fuels using biological fermentation while the resilient biomass can be transformed into energy, biooil, gases, and chemicals through pyrolysis. Moreover, biomass with altered lignin content can also be produced using genetically engineered plants [2]. However, the method of choice will depend on the nature of biomass and will require detailed lab-scale and pilot scale studies. In this regard, collaborative projects can only be effectively executed if public sector research institutions, multi-national commercial companies, and government agencies go together positively.

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Figure 2. Multidisciplinary share of research efforts in biofuel science based on number of publications linking various disciplines, published in last 20 years. The data was obtained from SCOPUS and clearly indicates that biofuel science involves various disciplines, hence involvement of these disciplines will be inevitable to achieve the product-oriented commercial goals.

Microalgae are another promising biological resource which is still to be explored in many regions. Due to their extraordinary photosynthetic rates, the highest capability of atmospheric carbon fixation, the highest biomass productivity, remarkable biodiversity, intensive stress adaptation potential, growth in diverse wastewaters, hyperaccumulation of lipids, and storage of a variety of high-value metabolites, they can have a multi-billion dollar share in the global market in future. Although their potential has no match yet, microalgal-based biorefineries to produce fuel, chemicals, and high-value products are limited due to several challenges associated with the contaminations during cultivation, difficult harvesting and tedious downstream processing [3]. Hence, it is required to established cost-effective and energy efficient microalgal biorefineries in the future using robust wild-type engineered strains. The contamination problem can be addressed by isolating fast-growing microalgal strains with a built-in ability to tolerate stress from any of the abiotic factors namely pH, salts, light, or certain nutrients which can be exploited to out-compete the contaminating organisms. Moreover, stress-manipulation [4] does not only help to minimize the contaminations chances but also can force the microalgae to accumulate some of the specific high-value metabolite(s). The stress-tolerant strains can be either isolated from extreme environments or can be developed through forced adaptation or metabolic pathway engineering. It is fortunate that microalgae have a tremendous potential to adjust themselves in a variety of environmental conditions; hence forced adaptation could be a method of choice to develop robust stress-tolerant strains. Once a potential strain is isolated (or developed) and its sustainable cultivation method is established, its cost-effective harvesting is another challenge. One of the most promising harvesting methods is the use of gravity sedimentation which can only be employed if the strain is either self-flocculating or flocculation can be induced using some flocculating agents. The high cost of the microalgal biomass processing can be addressed by using a biorefinery approach. Where harvested biomass can be used to produce energy or fuels after extracting the high-value components including chlorophylls, pigments, carotenoids, omega-3 fatty acids, and others. Moreover, the biomass can be produced in wastewater instead of freshwater to reduce the cost of cultivation and saving the cost of wastewater pretreatment.

Other than direct utilization of biomass either from plants or from microalgae, establishing genetically-engineered microbial platforms is another option to produce petroleum replica molecules [5, 6]. Although it's not easy yet, it's not too difficult to do, because the production of insulin, interferons, and hormones by using genetically engineered microbial platforms have already been successfully achieved on commercial scales. The genetically tractable microbes can be turned into biofuel-producing
platforms by introducing the biofuel-synthesizing metabolic pathways onto their genomes. However, there are challenges regarding the low-titer, cytotoxic nature of petroleum-replica molecules in the case of hyper-accumulation and difficult recovery of these biofuels from the host cells. This problem can be addressed by developing biofuel-secreting systems [7] instead of biofuel-accumulating systems using membrane transporters, where secretion will not only minimize cytotoxic effects of the biofuel molecules but may also increase productivity due to continuous secretion out of the cells. As far as the recovery is concerned, it is interesting that most of the biofuel molecules are hydrophobic in nature and will be accumulated as a separate phase above the surface of the culture media, making the recovery easier and efficient. However, it would take a lot of input in terms of time and money to establish such microbial platforms on commercial scales. In conclusion, a multidisciplinary approach involving all the stakeholders from policy makers, research institutions, and commercial companies should be employed to develop a customized territorial/regional strategy keeping in view the available resources, emerging requirements, and sustainable development goals.

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