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Sustainable technologies: bioenergy and biofuel from biowaste and biomass

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EDITORIAL

Sustainable technologies: bioenergy and biofuel from biowaste and biomass

The combustion of petroleum-based fossil fuels has become a concern with respect to global climate change due to accelerated carbon emissions. Reliance on the burning of fossil fuels has also created a concern for unstable and uncertain petroleum sources, as well as, rising cost of fuels. These concerns have shifted global efforts to utilize renewable resources for the production of greener energy replacement that can also meet the high-energy demand of both the developed and developing countries. Currently, the USA and Brazil are leaders in the production of starch-based fuel from corn and sugarcane crops, respectively. This is the production of first-generation fuel from food crop sugars using conventional technologies; however, starch raw materials will not be sufficient enough to meet increasing demand and are a controversial resource for bioconversion. In a time when a foreseeable complete transformation from a petroleum-based economy to a bio-based global economy finds itself in its early infancy, biowastes (e.g. agricultural wastes, municipal solid wastes, sludge, wastewater and foodwastes), currently seen as low-valued materials, are beginning to be recognized as resources for the production of a variety of eco-friendly and sustainable products, with second-generation liquid biofuels being the leading ones. Agricultural wastes, for instance, contain high levels of cellulose, hemicellulose, starch, proteins, as well as lipids. As such, they constitute inexpensive candidates for the biotechnological production of liquid biofuels (e.g. bioethanol, biodiesel, dimethyl ether and dimethyl furan) without competing directly with the ever-growing need for world food supply. As biowastes are generated in large scales, in the range of billions of kilograms per year, thus largely available and rather inexpensive, these materials are seriously considered to be potential sources for the production of biofuels. Much more consideration is also given to replacement products that stem from microbial metabolism. Ethanol has already become a dominant fuel in Brazil. Butanol has even superior qualities and represents an important bulk compound for the chemical industry. Biodiesel can substitute for diesel fuel. Methane and hydrogen are valuable resources for energy and electricity, with potential for transportation as well. The variety of topics in this Special Issue is manifold, which is typical for the bioenergy sector and is essential for finding concepts with a holistic background. Nevertheless, the problems to be solved need highly sophisticated approaches. Hence, it is the aim of this issue to compile current technological developments in the area of producing biofuels from biowastes and biomass and to attract the awareness of scientists, engineers and industrial and political decision makers to the extent microbes can and will play in securing the world's energy needs. This Special Issue called for scientific contributions that present recent developments and industrial applications in this field. It features 12 review articles and 38 original research articles on the state-of-the-art production of bioethanol, bio-butanol, biodiesel, biohydrogen, and bioelectricity from biowastes and biomass. These papers are published in two parts: Part 1 highlights the challenges and developments; and Part 2 covers the research and technological advances in the field.

The biofuels industry often starts with starches, such as that found in corn, because it is easy to hydrolyse using bacterial amylases. Plant cellulose is often complexed as lignocellulose and/or hemicellulose. Dien et al. found that ammonia pretreatment is an effective way to prepare switchgrass for biochemical conversion to sugars and ethanol. Notable was the absence of a lag phase for fermentation of unconditioned switchgrass hydrolysate, and increases in glucose and ethanol yields. Pretreatment of biomass frequently produces a product that microorganisms are incapable of fermenting because of the presence of inhibitory chemicals. Pretreated biomass is either washed or extensively conditioned prior to fermentation, adding to the process costs. However, ammonia pretreatment was found to be relatively benign compared with other pretreatments because carbohydrates are largely preserved. The future will see a technical process using lignocellulosic hydrolysates (Plecha et al.). However, as the enzymatic hydrolysis reaction of cellulose is about two orders of magnitude slower than the average ethanol fermentation rate, there is a theoretical gap between simultaneous saccharification of cellulosic biomass and ethanol fermentation.

While ethanol has a long lineage as a bio-based fuel, butanol fermentation also builds on a rich history. Despite the lack of biobutanol economy, research and development in universities in Europe, New Zealand, South Africa and USA has continued. The traditional clostridial fermentation of butanol and acetone suffers from difficulties of switching from acidogenic fermentation state to the solventogenic stage and, thus, a discontinuous production mode from common phage infections, the rising substrate costs and the effort required for downstream processing. Schiel-Bengelsdorf et al. detail how modern biotechnology research, including strain engineering and process design substrates, has addressed these challenges and allowed consideration for novel substrates, including lignocellulose and syngas (Bengelsdorf et al.). Efforts are also being made toward isolating novel microbes capable of synthesizing butanol from syngas fermentation (Nguyen et al.).

There is also considerable effort currently underway to find new bio-based substitutes for diesel fuels. Biodiesel is a monoalkyl ester of fatty acids from vegetable oil and is presently produced by catalytical transesterification with petrochemically derived methanol. Instead of using vegetable oil, microalgae could be grown in photobioreactors for the production of suitable oil (Mandal et al.). Because of their high productivity, the specific demand in land area needed is strongly reduced in this concept in contrast to oil from plants. Three papers reported new green diesel alternatives targeting higher volume, lower cost feedstocks, including landfill leachate (Edmundsod and Wilkie), waste water (Santiago et al.), lignocellulosic (Barari et al.) and in the case of algae, sunlight (Lu and Wu). These bio-based diesels have the potential for both lower emissions and higher performance for diesel vehicles, heavy transport, as well as aviation.

Moving onto gaseous fuels, eight papers in this issue focus on the enhancement of biological methane production. Methanogenesis is a widely distributed process in nature. Managed systems include dual-purpose anaerobic digesters that provide both waste treatment and biogas production. Further development of biogas technology is expected to increase production efficiency. Presently, only up to a maximum of 70% of organic matter in biomass is converted to CH_4 and CO_2. In order for this to increase, the hydrolysis stage must be enhanced. The separation of the hydrolysis and acetogenesis/methanogenesis allows for the application of optimized conditions in the two stages, such as pH and temperature adjustment.

Hydrogen is regarded as an ideal fuel for future transportation because it can be converted to electric energy in fuel cells or burnt and converted to mechanical energy without obvious production of CO_2. However, hydrogen production is usually affected by thermal and chemical means and is energy intensive, so the hydrogen produced in such a way cannot be regarded as a renewable primary energy source. In contrast, biological hydrogen production from biomass would provide an energy-saving, cost-effective and pollution-free alternative. Various microorganisms (bacteria, cyanobacteria and algae), which are capable of producing hydrogen from water, solar energy and a variety of organic substrates, have been explored. Currently, biohydrogen production technologies face two major challenges: low yield and high production cost. Gupta et al. detail how hydrogen yield can be improved by process modifications and physiological manipulations through metabolic and genetic engineering. Recently, cell immobilization with nanoparticles in bioreactors has shown increase in hydrogen production. The gains from these advances are significant, making biological hydrogen production more economical, practical and commercially feasible in the future.

Microbial fuel cells (MFCs) represent a completely new method of renewable energy recovery: the direct conversion of organic matter to electricity by using bacteria. While this sounds more like science fiction than science, it has been known for many years that bacteria could be used to generate electricity. We now know that electricity can be made using any biodegradable material, even wastewater. Mathuriya, Pant et al. and Peixoto et al. developed MFCs that can generate electricity while accomplishing wastewater treatment. Although the MFC technology is growing rapidly, enhanced power generation, reduced manufacturing cost, performance stability at process scale up, enhanced coulombic efficiency, reduced electrolyte ohmic losses and better understanding of the role of microbes are the greatest challenges to making this technology feasible for practical wastewater treatment. On overcoming these issues, MFC technology can prove itself as the sustainable future waste to power technology.

Sustainability must be the foundation for economic growth in the twenty-first century. We need to redirect our efforts towards bioenergy production from renewable, low-cost and locally available feedstocks, such as biowastes and agricultural residues. Such efforts will not only alleviate environmental pollution, but also reduce energy demand for declining energy resources. The work presented in this Special Issue collectively draws on the work of many great scientists including highly regarded academics and industrial experts from different disciplines within the science and engineering disciplines. The articles in this Special Issue present dramatic changes in understanding and optimizing processes for converting biowastes as resources for the production of liquid and gaseous biofuels, chemicals and electricity.

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