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*Editorial*

# Biofuels Production and Processing Technology

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**Abstract:** The negative global warming impact and global environmental pollution due to fossil fuels mean that the main challenge of modern society is finding alternatives to conventional fuels. In this scenario, biofuels derived from renewable biomass represent the most promising renewable energy sources. Depending on the biomass used by the fermentation technologies, it is possible obtain first-generation biofuels produced from food crops, second-generation biofuels produced from non-food feedstock, mainly starting from renewable lignocellulosic biomasses, and third-generation biofuels, represented by algae or food waste biomass. Although biofuels appear to be the closest alternative to fossil fuels, it is necessary for them to be produced in competitive quantities and costs, requiring both improvements to production technologies and diversification of feedstock. This Special Issue is focused on technological innovations, which include but are not limited to the utilization of different feedstock; different biomass pretreatments; fermentation strategies, such as simultaneous saccharification and fermentation (SSF) or separate hydrolysis and fermentation (SHF); different applied microorganisms used as monoculture or co-culture; and different setups for biofuel fermentation processes.

**Keywords:** biofuel production technologies; downstream processing; biorefinery; energy; bioethanol production; agroforest and industrial waste feedstock valorization; microorganisms for biofuel; sustainability

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**Citation:** Tropea, A. Biofuels Production and Processing Technology. *Fermentation* **2022**, *8*, 319. https://doi.org/10.3390/fermentation8070319

Received: 24 June 2022
Accepted: 5 July 2022
Published: 7 July 2022



## 1. Biofuel Production Overview

The world's energy consumption has reached 14 billion tons of oil equivalent (TOE) [1,2], and in 2018 fossil fuels consisted of more than the 80% of the world's energy demand [3]. The main cause of the huge greenhouse gas (GHG) emissions in the atmosphere is ascribable to the continuous utilization of fossil fuels for energy generation [4]. Today, environmental policies are pushing for the reduction GHG emissions, and thanks to the support of innovative advances in crop engineering and fermentation processes, bioethanol, biodiesel, and biogas production represent viable and sustainable surrogates for petroleum-based fuels [5]. In this regard, Lee and Tsai [6] reported a study presenting a trend analysis of the motor gasoline supply/consumption, the bioethanol supply, and the regulatory system relevant to bioethanol production and gasohol use since 2007 in Taiwan.

Additionally, new incoming technologies are focused on the $CO_2$ capture and conversion into carbon-neutral value-added products, for instance, via microbial electrosynthesis (MES) [7], which has been reviewed by Quraishi et al. [8] in a comprehensive analysis, including original research and patents of numerous products obtained by the use of MES, including downstream processing and its potential commercialization and limitations. Moreover, it further discusses the recent trends, emphasizing MES and the role of electroactive microbes for their various applications, including electricity production and wastewater treatment [8].

Generally, the main feedstock use for bioethanol production is represented by sugar-containing edible crops, such as sugar cane, sugar beet, and sweet sorghum, while those used for biodiesel production are oil-bearing edible crops, such as soybean, rapeseed, sunflower, and palm tree, due to their high sugar and lipid contents with economic feasibility for upgrading processes [9,10]. The use of edible crops for the production of biofuels give rise to many concerns for their potential competition with food and feed supplies. In addition, the insecure supply chain of biomass feedstock due to regional and seasonal variations is considered as one of the critical constraints for hindering the commercialization of biofuels in many countries [11–13]. Hence, alternatives, such as the production on fallow fields of crops and grasses to produce bioethanol, have recently attracted attention and much effort has been made to discover new feedstock from various lignocellulosic waste materials [4].

Moreover, in order to mitigate GHG emissions and meet the global fuel demand, biofuel technology advancements need to be focused on the optimization of current biofuel-production processes to obtain higher productivity and efficiency of lignocellulosic feedstock bio-conversion; on the diversification of the biomass in order to guarantee the feasibility of biofuel production within existing ecological and economic constraints; and on the increase of the chemical scenario toward designer molecules able to improve fuel performance and economy, reducing in the meantime the carbon emissions. More efforts need to be addressed not only to overcome technological barriers but also to integrate social, economic, and environmental factors in order to provide long-term and cost-effective production systems for biofuel industries [5].

Rai et al. [14] reported an interesting review on the developments in lignocellulosic biofuels as a renewable source of bioenergy, where the impact of environmental factors on biofuel production and the approaches for enhanced biofuel production are well investigated, as is the production of second-generation lignocellulosic biofuels from non-edible plant biomass (i.e., cellulose, lignin, hemi-celluloses, non-food material) in a more sustainable manner.

Another original research has been carried out by Lin and Ma [15] regarding biofuel-production technology. The study was focused on the water-removal process using molecular sieves vibrated using a rotary shaker, since it can be considered a competitive method during the biofuel production reaction to achieve a superior quality of biofuels, starting from feedstock oil. In particular, the aim of the study was to evaluate the effects of vibration modes and operating time of molecular sieves on the fraction of water removal from palm oil and ethanol and to investigate the structural damage of the water-absorbing material after the process. Molecular sieves accompanied by two different kinds of vibrating motions, including electromagnetic stirring and rotary shaking, were used to absorb water from the reactant mixture of trans-esterification. The study pointed out that the rotary shaking motion represents an adequate agitation method for increasing the contact frequency and the area among the reactant mixtures of feedstock oil, water, and alcohol, resulting in a higher reaction rate and faster water-removal efficiency; moreover, the vibrating motion could facilitate the fluidity and mixing extents of the reactant mixture and thus accelerate the chemical reaction [15].

## 2. Bioethanol Production from Food Waste

Bioethanol production from waste, such as municipal waste and food waste, has consistently been one of the most popular alternative energy production pathways. Bioethanol emits lower greenhouse gases in comparison to fossil fuel. For this reason, it represents a valid alternative as vehicle fuel source. It can be mixed in various proportions with gasoline, obtaining gasohol, to be used immediately in internal combustion engines without requiring further engine modifications [16].

With regard to food waste utilization as bioethanol feedstock, nowadays it represents an interesting solution to the environmental crisis caused by the current amount of food waste, which is steadily increasing as the economy and population grow. Globally, 931 million tons of food waste were produced in 2019, with approximately 30% of food produced being discarded as waste [17]. These wastes show a high potential, due to their micro and macro composition [16,18–23], as a low-cost high-potency second-generation feed-stock that can easily undergo biodegradation by different fermentation approaches, such as direct fermentation (DF), separate hydrolysis and fermentation (SHF), and simultaneous saccharification and fermentation (SSF) [24,25] for bioethanol production. Salafia et al. [26] reported a study focused on the evaluation of pineapple waste cell wall sugars as an alternative source of second-generation bioethanol by *Saccharomyces cerevisiae*, carrying out an SSF process using a supplemented medium, by the addition of a specific nitrogen source, salts, and vitamins, which are required by the yeast in order to improve its ability to use the substrate both for alcohol production and for its own growth [27]. The study pointed out that the amount of cell wall sugars detected in pineapple waste after enzymatic hydrolysis makes this substrate an interesting resource for bioethanol production. The ethanol theoretical yield, calculated according to dry matter lost, reached up to 85% (3.9% EtOH), making pineapple waste an excellent raw material for ethanol production by *S. cerevisiae*. Moreover, the resulting fermentation substrate was enriched in single cell protein (SCP). In fact, the protein content increased from 4.45% up to 20.1% during the process and this allows the final fermented product to be suitable as animal feed, thus replacing expensive conventional sources of protein, like fishmeal and soymeal, and preventing the production of further waste by the end of the fermentation process, with respect to environmental sustainability [26].

Food waste bioconversion has also been reported by Jarunglumlert et al. [16]. The main goal of their research was to evaluate how increase the potential of energy production from food waste by the co-production of bioethanol and biomethane, testing different concentrations of enzymes for food waste hydrolysis. It was pointed out that when increasing the enzyme concentration, the amount of reducing sugar produced were increased as well, reaching a maximum amount of 0.49 g/g food waste. The resulting sugars were used as fermentative substrate by *Saccharomyces cerevisiae*, to be converted to ethanol. After 120 h of fermentation the ethanol yield reached up 0.43–0.50 g ethanol/g reducing sugar, ranging between the 84.3–99.6% of theoretical yield. The solid residue resulting from fermentation process was subsequently subjected to anaerobic digestion, allowing the production of biomethane, which reached a maximum yield of 264.53 $\pm$ 2.3 mL/g. This study shown how food waste represents a raw material with high energy production potential [16].

Vucurovic et al. [28] referred to a process and cost model of bioethanol production starting from spent sugar beet pulp, with the aim of applying it in the evaluation of new technologies and products based on lignocellulosic raw materials. The model developed allows the determination of the capital and production costs for a bioethanol-producing plant, processing about 17,000 tons of spent sugar beet pulp per year. Moreover, it can predict the process and economic indicators of the tested biotechnological process, determine the contribute of major components in bioethanol production cost, and compare different model scenarios for processing co-products [28].

KOH-pretreated seed pods of *Bombax ceiba* for ethanol by *S. cerevisiae* in SSF and SHF were used as second-generation feedstock by Ghazanfar et al. [29]. The study shows that the SSF process allows the maximum saccharification (58.6% after 24 h) and highest ethanol yield (57.34 g/L after 96 h) to be obtained. The SSF process was optimized for physical and nutritional parameters by one factor at a time (OFAT) and central composite design (CCD), allowing to set the optimum fermentation parameters for highest ethanol production (72.0 g/L): 0.25 g/L yeast extract, 0.1 g/L $K_2HPO_4$, 0.25 g/L $(NH_4)_2SO_4$, 0.09 g/L $MgSO_4$, 8% substrate, 40 IU/g commercial cellulase, 1% *Saccharomyces cerevisiae* inoculum, pH 5. This study proposed an inexpensive and novel source as a promising feedstock for pilot-scale second-generation bioethanol production [29].

Usually, research on bioethanol production is lacking in economic information on efficiency and profit at larger scales. This gap has been investigated by Rosentrater and Zhang [30] in their study on the techno-economic analysis of integrating soybean biorefinery products into corn-based ethanol fermentation operations. In order to determine the economic feasibility of this bio-refining, a techno-economic analysis for combining corn and soybean bio-refinery processes was carried out. The aim of the study was to use the techno-economic analysis (TEA) for estimate the costs associated with the construction and the operation of this type of integrated system. Moreover, the research compared an integrated corn and soybean bio-refinery with an original corn-based ethanol process in economic performance, for exploring the effect of new applications on the corn-based ethanol production under 40- and 120-million-gallon ethanol production scales.

Derman et al. [31] reported a study where a microbial consortium of *Saccharomyces cerevisiae* and *Trichoderma harzianum* were used in simultaneous saccharification and fermentation (SSF) process of pretreated empty fruit bunches (EFBs) by employing the central composite design of response surface methodology. According to the authors, this represents an innovative study based on the contemporary utilization of a new combination of enzymes and microbes employed in the fermentation process for bioethanol production from EFBs. In the study, the combination of enzymes and microorganisms for bioethanol production was screened in order to determine the optimum concentration of this combination suitable for SSF. It was pointed out that the enzyme combinations of cellulase and β-glucosidase with the microbial consortium of *S. cerevisiae* and *T. harzianum* allowed the best conversion of the EFBs into bioethanol. Several parameters that could affect the fermentation process, such as the fermentation time, the temperature, the pH, and the inoculums concentration, have been evaluated by the authors in their research. The highest bioethanol yield (9.65 g/L) was obtained after 72 h fermentation, at 30 °C, pH 4.8, and by adding an inoculum concentration of 10% (*v/v*) [31].

## 3. Processing Technology

As stated above, the use of fossil-based energy has been declining since its use causes climate changes and air pollution [32] and new solution need to be addressed to solve out this issue. An example is represented by the utilization of biochar that, due to its chemical and physical characteristics, can be used as a product itself or as an ingredient, within a mixed product for multiple objectives, including soil improvement, waste management, energy (or fuel) production, water pollution, and mitigation of climate change, as reported by Tsai et al. [33].

Additionally, there is an increasing interest in the production of renewable and carbon-neutral fuels, mainly obtained by fermentation [34], and in the development of new promising technologies such as the indirect fermentation. This technique consists of the conversion of several kind of carbonaceous compounds to synthesis gas, named syngas, through gasification, followed by its fermentation for obtaining desired products by specific biocatalysts [35]. Syngas is mainly composed by carbon monoxide, carbon dioxide, and hydrogen. It can be produced from biomass, coal, animal or municipal solid waste, and industrial CO-rich off-gases [36]. Benevenuti et al. [37] carried out a study, using *Clostridium carboxidovorans* for syngas fermentation, evaluating the effect of different concentrations of Tween® 80 in the culture medium and the best process conditions were validated in a stirred tank bioreactor (STBR). The study pointed out that the supplementation with Tween® 80 to the culture medium was characterized by an increasing in biomass and ethanol production during *Clostridium carboxidivorans* syngas fermentation in serum bottles and validated in a stirred tank bioreactor. In particular, biomass and ethanol production increased by 15% and 200% using Tween® 80 in the culture medium, respectively, compared to pure culture medium. In the bioreactor, 106% more biomass was produced compared to serum bottle fermentation, but the same ethanol concentration was achieved [37].

Syngas fermentation has been evaluated also by de Medeiros et al. [38]. Their work presented a strategy for optimizing the ethanol production process via integrated gasification and syngas fermentation by using two types of waste feedstock, wood residues, and sugarcane bagasse. The energy efficiency was found to be 32% in both cases, and the main critical variables of the process were found to be the gasification zone temperature, the split fraction of the unreformed syngas sent to the combustion chamber, the dilution rate, and the gas residence time in the bioreactor.

Another promising technology and advantageous solution for the treatment and valorization of organic waste and wastewater is represented by the pressurized anaerobic digestion (PDA) as it allows the generation of a high-quality biogas with a low $CO_2$ content [39]. In pressurized anaerobic digestion the pressure of the biogas is gradually auto-generated during fermentation. Therefore, PAD processes are carried out at pressures greater than atmospheric, which allows the obtainment of a biogas with a high methane fraction and a low carbon dioxide content [40].

The study reported by Siciliano et al. [39] assessed the effects of pressure increase, at different organic load rate (OLR) values, on the pressurized anaerobic digestion of compost leachate process performance. Biogas composition, specific biogas yield (SBY), specific methane yield (SMY), and the main process parameters, such as pH, volatile fatty acids (VFA)/alkalinity ratio, and nutrient concentrations, were evaluated in response to the pressure change. The study pointed out that even if the biogas quality was enhanced by the pressure increasing, the overall amount of methane was lowered. Indeed, the pressured conditions did not cause substantial modification in the characteristics of digestates [39].

A lot of research has been carried out regarding the development of new technologies and the implementation of new feedstock suitable for biofuels production. This topic still represents an interesting challenge for the scientific and industrial world, and many efforts are still needed in this field in order to reduce the negative global warming impact and global environmental pollution due to fossil fuels in accordance with the environmentally sustainable development.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Conflicts of Interest:** The author declares no conflict of interest.

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