Integration of 1st and 2nd Generation Bioethanol Fuel Production: Opportunities and Limitations

Zhanye Xv, Xingyang Xv, Shengdong Zhu *, Guiying Wu and Fang Jin

Bioethanol currently is the most widely used transport biofuel in the world. At present, it is mainly produced from starch-rich grains and sugar cane (the first generation bioethanol fuel). Starch and sugars from existing food materials limit its feedstock supply, and its sustainable production is facing great challenges. Production of bioethanol fuel from the lignocellulosical materials (the second generation bioethanol fuel) has aroused great interest in recent decades because the lignocellulosical materials, such as agricultural and forestry wastes and organic industrial wastes, are abundant, widely available, and inexpensive. However, its large-scale industrial production is still not economically feasible because of high pretreatment and enzyme costs, as well as low ethanol final concentration and yield, based on current technology. Some recent studies indicate that the integration of the first and second generation of bioethanol fuel production can increase the final ethanol concentration and yield, reduce the enzyme and water usage, and effectively improve its process economy. This editorial will give a brief discussion on the integration of the first and second generation of bioethanol fuel production.

DOI: 10.15376/biores.21.2.2760-2762

Keywords: Ethanol biofuel; First generation; Second generation; Process integration

Contact information: Hubei Key Laboratory of Novel Reactor and Green Chemical Technology, Key Laboratory for Green Chemical Process of Ministry of Education, State Key Laboratory of Green and Efficient Development of Phosphorus Resources, School of Chemical Engineering and Pharmacy, Wuhan Institute of Technology, Wuhan 430205, PR China;
** Corresponding author: whictzhusd@sina.com; zhusd2003@21cn.com*

Challenges of Sustainable Production of Bioethanol Fuel

With ever-increasing energy demands and environmental concerns, bioethanol fuel production has drawn much attention in recent decades (Zhang *et al.* 2023). Bioethanol is now the most widely used transport biofuel in the world. It can partly replace the use of liquid petroleum and thus reduce our dependence on fossil fuels and decrease net greenhouse gas emissions (Sa *et al.* 2021; Zhang *et al.* 2026). Bioethanol fuel is currently mainly produced from such food materials as starch-rich grains and sugar cane (the first generation bioethanol fuel). Use of these food materials as main feedstock for bioethanol fuel production can lead to supply shortage of food and feed, as well as increases in their price. This will become even more serious in the future with the growing population. The limited feedstock supply from food materials and high price make the first generation bioethanol production unsustainable (Tang *et al.* 2011; Xu and Wang 2017). Therefore, it is important to reduce the dependency of bioethanol fuel production on food materials.

Lignocellulosical materials, such as agricultural and forestry wastes and organic industrial wastes, are abundant, widely available and inexpensive. Production of bioethanol fuel from lignocellulosical materials (the second generation bioethanol fuel) can escape from its dependency on food materials (Xu and wang, 2017; Zhang *et al.* 2024). To effectively convert lignocellulosical materials into bioethanol, pretreatment is usually required to disrupt the complicated interconnected structure of cellulose, hemicellulose and lignin. Then, the pretreated lignocellulosical materials are enzymatically hydrolyzed into fermentable sugars, and finally the fermentable sugars was converted into bioethanol *via* ethanol fermentation. Because of high pretreatment and enzyme costs, low ethanol final concentration, and low yield, large-scale industrial production of the second generation bioethanol fuel is still not economically feasible based on current technology (Xu and Wang 2017; Yu *et al.* 2017). Some recent studies indicate that the integration of the first and second generation of bioethanol fuel production can increase the final ethanol concentration and yield, reduce the enzyme and water usage, and effectively improve its process economy (Xu and Wang 2017; Zhu *et al.* 2026).

Integration of the First and Second Generation Bioethanol Fuel Production

The main technical problems for large-scale production of the second generation bioethanol fuel come from the following three aspects (Xu and Wang 2017):

1) Pretreatment of lignocellulosical materials produces some inhibitors to subsequent enzymatic hydrolysis and ethanol fermentation. A large amount water is needed to wash out these inhibitors;
2) Difficulty in mass transfer and mixing leads high enzyme usage and low yield of fermentable sugars for the enzymatic hydrolysis process;
3) The residual inhibitors and difficulty in mass transfer and mixing cause low final ethanol concentration and yield for the ethanol fermentation process.

The integration of the first and second generation bioethanol fuel production provides a new solution to these problems by co-fermentation of the mixed substrate of the starch (sugars) and pretreated lignocellulosical materials. By mixing the starch hydrolysate or sugar juice into the fermentation medium, the inhibitors in the medium are diluted and new nutrients are introduced; these changes increase the fermentation activity of yeast (Tang *et al.* 2011). At the same time, the integrated process increases the concentration of fermentable sugars in the medium, which leads to high final ethanol concentration (Xu and Wang 2017). Moreover, it decreases the concentration of pretreated lignocellulosical materials and reduces the viscosity in the medium, which resolves the mixing and mass transfer problems of enzymatic hydrolysis and ethanol fermentation (Xu and Wang 2017; Zhu *et al.* 2026). As a result, it effectively increases the final ethanol concentration and yield, reduces the enzyme and water usage, decreases the equipment investment, and lowers the downstream distillation cost, thus improving the process economy. For example, Damay *et al.* (2018) developed a hybrid first and second generation bioethanol production process using the dried sorghum biomass. Its ethanol yield increased from below 80% to above 90%. Erdei *et al.* (2010) studied the bioethanol fuel production process from mixtures of wheat straw and wheat meal. Its ethanol yield increased from 68% to 99%, and its final ethanol concentration reached 56.5 g l^{-1}. Zhu *et al.* (2026) investigated the cofermentation of fibre residue and crude starch from *Puerariae lobatae* Radix. Its final ethanol concentration and yield arrived at 69.5 g l^{-1} and 87.7%, respectively. Although the integration of the first and second generation bioethanol fuel production has these advantages, this process still partly depends on the use of starch or sugars as its feedstock and can't completely escape from its dependency on food materials. Moreover, it currently is still at a lab-scale stage of development. More work is needed in the future to examine its economic and technical feasibility on an industrial scale.

Acknowledgments

This work was supported by Graduate Innovative Fund of Wuhan Institute of Technology No: CX2025016.

References Cited

Damay, J., Boboescu, I., Duret, X., Lalonde, O., and Lavoie, J. (2018). "A novel hybrid first and second generation hemicellulosic bioethanol production process through steam treatment of dried sorghum biomass," *Bioresource Technology* 263, 103-111. https://doi.org/10.1016/j.biortech.2018.04.045

Erdei, B., Barta, Z., Sipos, B., Réczey, K., Galbe, M., and Zacchi, G. (2010). "Ethanol production from mixtures of wheat straw and wheat meal," *Biotechnology for Biofuels* 3, article 16. https://doi.org/10.1186/1754-6834-3-16

Sa, M., Zhang, B., and Zhu, S. (2021). "Miscanthus: Beyond its use as an energy crop," *BioResources* 16(1), 5-8. https://doi.org/10.15376/biores.16.1.5-8.

Tang, Y., Zhao, D., Cristhian, C., and Jiang, J. (2011). "Simultaneous saccharification and cofermentation of lignocellulosic residues from commercial furfural production and corn kernels using different nutrient media," *Biotechnology for Biofuels* 4, article 22. https://doi.org/10.1186/1754-6834-4-22.

Xu, Y., and Wang, D. (2017). "Integrating starchy substrates into cellulosic ethanol production to boost ethanol titters and yields," *Applied Energy* 195, 196-203. https://doi.org/10.1016/j.apenergy.2017.03.035.

Yu, N., Li, T., Sun, Z., Tang, Y., and Kida, K. (2017). "Production of bio-ethanol by integrating microwave-assisted dilute sulfuric acid pretreated sugarcane bagasse slurry with molasses," *Applied Biochemistry and Biotechnology* 185, 191-206. https://doi.org/10.1007/s12010-017-2651-9.

Zhang, S., Zhang, Q., Guo, X., and Zhu, S. (2024). "Kudzu: An invasive plant or a sustainable resource," *BioResources* 19(3), 4047-4049. https://doi.org/10.15376/biores.19.3.4047-4049.

Zhang, S., Zhang, Q., Sa, M., and Zhu, S. (2023). "Lignocellulosic biomass for sustainable energy: Some neglected issues and misconceptions," *BioResources* 18(2), 2526-2527. https://doi.org/10.15376/biores.18.2.2526-2527.

Zhang, S., Zhu, S., Xv, Z., Jin, F., and Zhu, S. (2026). "Deep processing *Puerariae lobatae* Radix for sustainable biobased products and biofuels production using biorefinery approach," *Biomass and Bioenergy* 205, article 108555. https://doi.org/10.1016/j.biombioe.2025.108555.

Zhu, S., Zhang, S., Xv, Z., Jin, F., and Zhu, S. (2026). "Integrated process for production of bioethanol fuel and high value chemicals from *Puerariae lobatae* Radix," *Renewable Energy* 256, article 124446. https://doi.org/10.1016/j.renene.2025.124446.