Strategies for Converting Non-Edible Biomass into Value-Added Chemicals: Economical and Reliable Biorefining Processes

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About 35% of global greenhouse gas (GHG) emissions come from the energy sector, which accelerates global warming and sea-level rise. As a renewable resource, biomass not only can replace conventional fossil energy with renewable energy, but it is also a key component of the circular bioeconomy (CBE). To achieve efficient use of bioresources, the concept of biorefinery with CBE strategy is increasingly being considered in several countries. In particular, it aims to reduce crude oil consumption and build an economy that is favorable for the climate and nature by replacing carbon-intensive products such as plastics, synthetic rubber, and synthetic fibers with renewable bio-based resources. The purpose of this article is to investigate biomass conversion technologies for building a CBE and to consider successful biorefinery strategies. In particular, five implications of using biomass are suggested as ways to secure the economic feasibility of biorefinery. We propose a biorefinery that produces value-added chemicals from non-edible biomass through saccharification and fermentation as a strategy to achieve the 2050 goal of net-zero carbon.

Keywords: Application; Biomass; Biorefinery; Conversion; Process

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Biorefinery for a Sustainable Society

The immoderate consumption of fossil fuels has caused global climate change by generating greenhouse gas (GHG), which comprises carbon dioxide (CO_2, 72%), methane (CH_4, 18%), and nitrous oxide (NO_x, 9%) (Sri Shalini *et al*. 2020). To respond to rapid climate change, many countries around the world are trying to reduce GHG emissions with the goal of 2050 Net-Zero (Li and Xiao 2020). The concept of a biorefinery using biomass as a feedstock has emerged as a strategy to replace petroleum-based refineries, which are the main culprits of greenhouse gas emissions. Currently, feedstocks that are used for biorefinery at the commercial level are edible biomass such as corn, wheat, sugar cane, and potato, but their use as feedstocks is limited due to food ethics issues (Yang *et al*. 2015). Non-edible biomass, including lignocellulosic biomass (2nd), algae (3rd), and organic waste (4th), is a promising resource to replace edible biomass (Yoo and Kim 2021). The composition of non-edible biomass varies depending on its source. For example, lignocellulosic biomass is mainly composed of cellulose, hemicellulose, and lignin, whereas algae have a relatively high content of protein, lipid, and pigment compared to other biomass (Chun *et al*. 2021). Since organic waste is classified into agricultural residues, municipal residue, food waste, beverage waste, *etc*., these components contain a variety of resources. These components of biomass can be used to prepare value-added substances, including energy, platform chemicals, and pharmaceuticals, *etc*. Thus, the utilization of biomass as a resource could be a key strategy for building a sustainable society.

Current Status of Biorefinery Technologies

Table 1 summarizes the biorefinery technologies for producing various products such as energy, fertilizer, phytochemical, bio-nutrients, platform chemicals, and pharmaceuticals using non-edible biomass. Combustion and composting are relatively simple technologies with low technical barriers, producing energy and fertilizers from lignocellulosic biomass or organic waste, respectively, through chemical or biological processes. However, these technologies have the disadvantage of consuming O_2 in the atmosphere and emitting GHGs such as CO_2, CH_4, and N_2O. Gasification is a technology that replaces fossil fuels and produces energy by treating lignocellulosic biomass or organic waste with heat, oxygen, and steam. However, gasification has a drawback that 20 to 500 kW of energy is consumed to produce the mixture of gases (Pacioni *et al*. 2016). Separation is a technology mainly used to recover energy or phytochemicals from algae or organic waste. Extraction methods such as maceration, supercritical fluid extraction, ultrasonic-assisted extraction, and microwave-assisted extraction are used and have low GHG emission characteristics. Saccharification and fermentation utilize the carbohydrate portion in biomass. Through chemical or biological treatment, carbohydrates in biomass are converted into fermentable sugars that can be metabolized by microorganisms. Although this technology has the advantage of being able to produce various high value-added substances such as energy, platform chemicals, and pharmaceuticals, there is still a technological barrier that purification processes are required. Various studies are trying to achieve economic feasibility by simplifying the purification process (McDowall *et al*. 2022). The successful design of economical purification processes is expected to make saccharification and fermentation the most promising technologies for the production of high value-added substances from biomass.

Table 1. Summary of Biorefinery Technology for Various Applications Using Non-edible Biomass

Conversion Technology	Biomass Type (Feedstocks)	Technical Barrier	GHG Emissions	Application	Processes	Reference
Combustion	Lignocellulosic biomass, Organic waste	+	+++	Energy	Chemical	(Yaashikaa *et al*. 2022)
Composting	Organic waste	+	++	Fertilizer	Biological	(Yaashikaa *et al*. 2022)
Gasification	Lignocellulosic biomass Organic waste	++	+	Energy	Chemical	(Yaashikaa *et al*. 2022)
Separation	Algae, Organic waste	++	+	Energy, Phytochemical, Bio-nutrients	Physical, Chemical	(Lee *et al*. 2021a)
Saccharification and Fermentation	Lignocellulosic biomass, Algae, Organic waste	+++	+	Energy, Platform chemical, Pharmaceutical	Chemical, Biological.	(Lee *et al*. 2021b)

Strategy for Biorefinery to Achieve Economic Feasibility

Biorefinery technology using biomass can have a positive effect on climate and nature by replacing petroleum refinery production, but there are still limitations in industrial application, such as a lack of economic feasibility and reliability (Lee *et al*. 2022).

In order to design a sustainable biorefinery, a strategy that considers the following factors is required.

1) Feedstock quality and price: Feedstock should be of consistent quality and available at a low cost.
2) Number of processes: Since the number of processes is a major factor in the overall cost, the process design should be as simple as possible.
3) Environmental impact: By-products generated in the process should not be harmful to the environment.
4) Process yield: The conversion should be improved by designing a process to remove unnecessary components from feedstock (pre-treatment).
5) Market: It should aim to produce products with a large market size and high economic value.

Future Direction of Biorefinery Using Non-edible Biomass

Currently, commercialized biorefinery processes on an industrial scale are limited to the biofuels that are used for transportation such as bioethanol and biodiesel. In bioethanol production, bagasse, cornstalk, hazel, straw, and cotton have been used as non-edible biomass, and in biodiesel production, oil extracted from algae, copaiba, jatropha, and jojoba was used as feedstock (McWilliams 2020). Fossil fuels, including petrol, diesel, coal, and natural gas, account for 84% of global energy consumption, while biofuels only account for 1% (BP 2021). However, in response to various countries that are aiming to reach the 2050 Net-Zero target by reducing GHG emissions to respond to climate change, the biofuel market is forecasted to grow from $136 billion in 2019 to $153 billion in 2024 (McWilliams 2020). The growth of this market is expected to contribute to the achievement of the European Union (EU)'s the Renewable Energy Directive (RED) II target of replacing 32% of the total energy used with renewable energy by 2030 (Lin and Lu 2021). In the future, for food security, non-food biomass should be utilized as the main feedstock for biorefinery (saccharification and fermentation), and the carbon-intensive petrochemical industry is expected to be replaced by the production of various value-added chemicals as well as biofuels.

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