Mini Review

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# Biological Solutions: Catalyst for the Sustainability Transition of the Palm Oil Industry

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## ABSTRACT

Palm oil is an edible vegetable oil derived from the fruit of the oil palm tree. While it is an agricultural commodity produced at a large scale, consumed, and traded globally, the palm oil industry is also known as a biomass contributor. Biological solutions, among others, can help to upgrade palm oil biomass, offer sustainable ways to produce platform chemicals and bio-based materials for a growing population, and reduce carbon emissions to battle the climate crisis. Therefore, biological solutions can be a catalyst for the sustainability transition of the palm oil industry, rendering it more sustainable and environmentally sound in a climate action world.

**Abbreviations:** EFB: Empty Fruit Bunch; PKC: Palm Kernel Cake; HHF: Separate Hydrolysis and Fermentation; MEG: Monoethylene Glycol; PET: Polyethylene Terephthalate

## Mini Review

Palm oil is an edible vegetable oil, derived from the fruit of the oil palm tree. It is an agricultural commodity produced at large scale, consumed and traded globally. In order to satisfy the high demand for vegetable oils, global palm oil production has increased significantly from 24 million tonnes in 2000/2001, to 73 million tonnes in 2020/2021 [1]. Such an increase in the demand for palm oil has occurred because it is relatively cheap and versatile, both in its edible and non-edible industrial applications. Although the industry has taken actions to improve its sustainability [2] and set new standards [3], including the recently launched standard [4] that covers the traceability of palm oil biomass material along the chain of custody, it is still frequently associated with unsustainable environmental pressures. Therefore, biological solution, among others, can be a catalyst for the sustainability transition of the palm oil industry, rendering it more sustainable and environmentally sound in a climate action world.

## Biological Solutions as Part of the Answer for Sustainability Transition

A biological solution involves working with industrial enzymes and microorganisms to maximise and optimise existing operational processes. Rudimentary biological solutions date back to at least 6,000 B.C. when Neolithic cultures fermented grapes to make wine [5], and Babylonians used microbial yeasts to make beer [6]. Over time, people's knowledge of using biological solutions increased. While a biological solution is an embryonic approach, it is presently applied in a diverse variety of industry sectors, from household care and professional cleaning to agriculture, food and beverages. Biological solutions have already proven their worth in climate change mitigation. According to the Organisation for Economic Co-operation and Development, biological solutions can save energy and significantly reduce CO2 emissions [7]. Products manufactured with biological solution can contribute to the reduction of greenhouse gas emissions, such as laundry detergents that enable low-temperature washing and reduce energy use, breads that stay fresh longer and reduce food waste, and textiles that are produced with less water, energy and traditional chemical usage, to name a few.

## Second-Generation Ethanol from Cellulosic Biomass

When applied to the palm oil industry, biological solution could become a game-changing technology that boosts the sustainability profile of the industry through low-carbon initiatives. Palm oil biomass, including oil palm frond, empty fruit bunch (EFB), palm kernel cake (PKC), and pressed fibre, are all sources of cellulosic biomass. They are typically composed of lignin and a number of mutually entangled and chemically bonded carbohydrate polymers. Biological solutions, a combination of customised enzymes and yeast, can upgrade cellulosic biomass to ethanol (Figure 1). Pre-treatment is an important aspect of the production of cellulosic ethanol. It will help alter the size, structure, and chemical composition of biomass, which enhances the hydrolysis process, produce fermentable sugars in high yields. There are several types of pre-treatment methods. These include steam explosion, acid treatment, alkaline treatment, organic solvents, or a combination of these methods. Historically, enzymes were significantly affected by feedback inhibition resulting from glucose production, which led to ineffective conversion. Later generation of cellulolytic and xylanolytic thermostable enzymes were developed to eliminate this effect on the enzyme complex. These enzymes can then efficiently hydrolyse cellulose and hemicellulose complex and convert pre-treated lignocellulosic materials to fermentable sugars. These enzymes can be applied during steps of simultaneous saccharification and fermentation (SSF), separate hydrolysis and fermentation, or hybrid hydrolysis and fermentation (HHF). The HHF process can also be described as viscosity reduction and pre-saccharification followed by SSF for ethanol production.

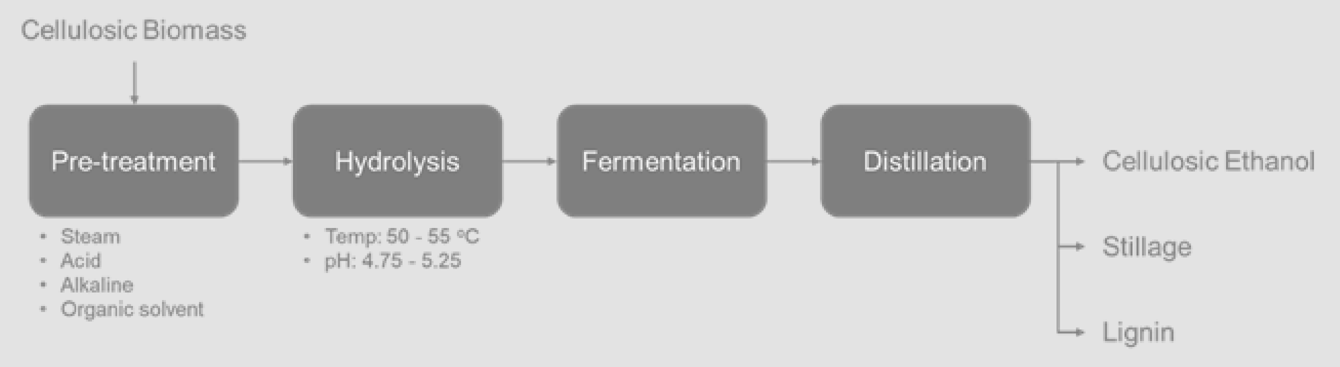

**Figure 1:** Process flow for the production of cellulosic ethanol.

While the optimal conditions can vary with specific pre-treated substrates and process condition, enzyme hydrolysis process is preferred to operate at a temperature range of 50-55 oC and a pH 4.74-5.25. Ethanol yield was low previously, caused by the inability to ferment C5 sugars [8]. Nonetheless, the hurdle of optimising ethanol yield has been overcome, especially with the quantum leap from using yeast strain that has been selectively bred to tolerate high levels of inhibitory compounds commonly found in cellulosic hydrolysate is the major breakthrough. Specially developed yeast enables co-fermentation of both C5 and C6 sugars with fast xylose utilization and high cellulosic ethanol (also known as second-generation ethanol) yield. Just like first-generation ethanol production, cellulosic ethanol is recovered from the fermentation broth by the distillation process, while thin stillage and lignin cake are collected and sold as co-products. Most of the current production of liquid biofuels for transport is made with the first-generation ethanol, large increases in cellulosic ethanol are expected soon because it put much less strain on the use of land for food production. Furthermore, cellulosic ethanol can not only reduce greenhouse gas emissions by 86% [9] compared to gasoline, but it also has a higher octane number [10], providing premium bleeding properties that enhances engine performance. Although it seems like fiction, Raizen proves that it is technically and commercially viable to produce cellulosic ethanol. The global leader in the production of first- and second-generation ethanol has already sold 1 billion litres of cellulosic ethanol [11]. In 2021, the two largest palm oil producing countries, Indonesia and Malaysia, produced approximately 45 million tonnes (dry weight) of cellulosic biomass (Figure 2). If half of this had been used for ethanol production, it would have translated to around 4-fold of the United Kingdom’s ethanol for transport consumption in 2021 [12]. This is how the palm oil industry could contribute to emission climate neutrality through biological solutions. Besides biofuel, bio-based plastic and bio-based synthetic rubber, among others, also have large emission reduction potentials. With the aid of biological solutions, palm oil industry also has a significant role to play in enabling decarbonisation of these sectors. This is because we can now produce platform chemicals from palm oil biomass. Platform chemical is a chemical building block that can serve as a substrate to produce various other higher value-added bio-based products. Ethanol and isoprene, among others, are platform chemicals.

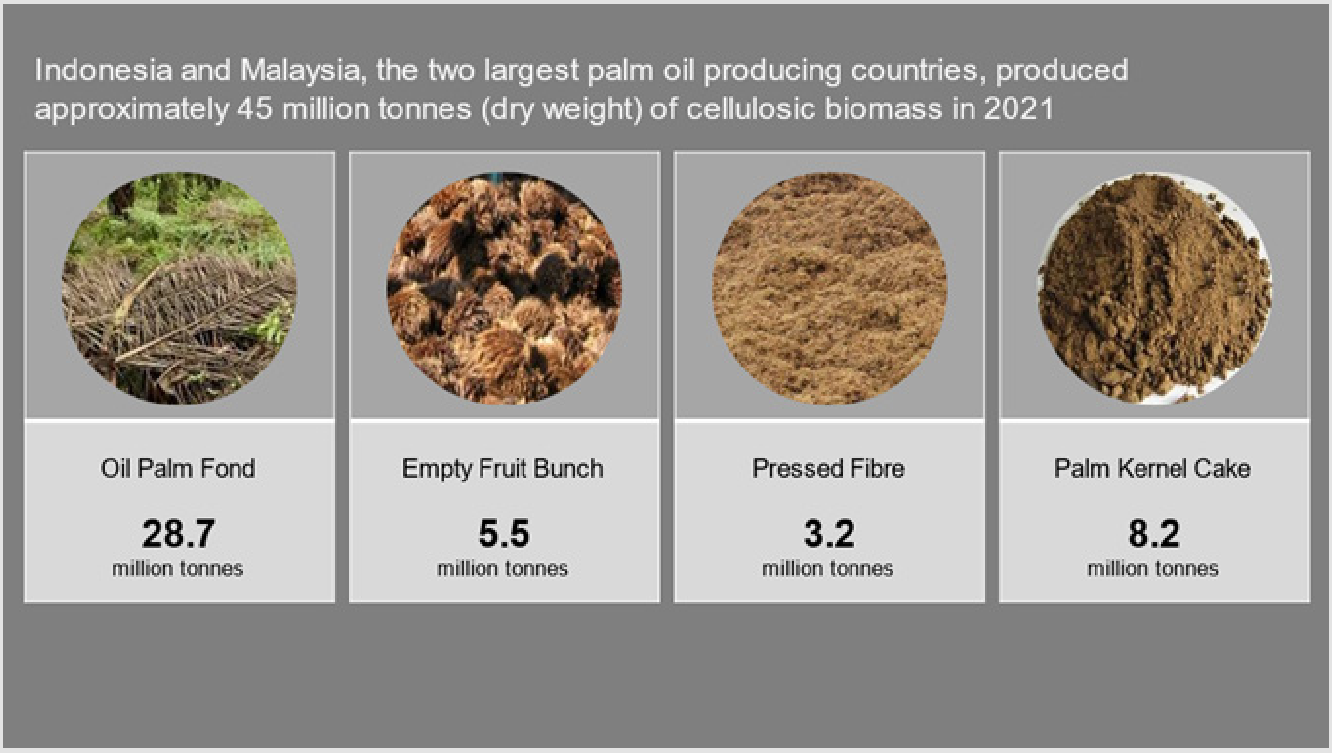

**Figure 2:** Palm biomass production in Indonesia and Malaysia in 2021.

## Bio-Based Monoethylene Glycol From Cellulosic Ethanol

Petroleum-based plastics have grown faster than any other materials for several decades, and the plastic sector will account for 20% of total oil consumption by 2050 [13]. Monoethylene glycol (MEG), a diol mostly used for the production of polyethylene terephthalate (PET), is the most widely-used material for plastic beverage bottles. MEG is produced from ethylene. Conventionally, ethylene production involves steam cracking of fossil fuels, and is one of the highest CO2 emitting process in the chemical industry. This makes bioplastic attractive in terms of emissions, which is evidenced by Coca-Cola using it in their plant bottles [14]. Furthermore, Danone has also claimed that its plant bottles provide a possible 75% greenhouse gas emissions savings compared to petroleum-based plastics [15]. With biological solutions, we can now upgrade palm oil biomass to bio-based MEG (Figure 3). Cellulosic ethanol produced from fermentation of simple sugars can be converted to ethylene via catalytic dehydration over an aluminium catalyst, for instance. While there has been no specific environmental study done with palm oil biomass, researchers suggest that bio-based ethylene production from cellulosic ethanol sources (produced from corn stover) is able to significantly reduce life cycle greenhouse gas emissions by 200% [16]. The subsequent processes are not much different from the conventionally methods. Commercial production of ethylene oxide is the result of direct oxidation of ethylene, under temperature of around 250 oC and a pressure of approximately 2 mPa, with the presence of a silver-based catalyst. MEG is then produced through non-catalytic hydrolysis of ethylene oxide at a temperature of around 200 oC and a pressure of 1.5-2.0 MPa, which itself is obtained via ethylene oxidation. While it is common to produce bio-based MEG from hardwood feedstock [17] taken from sawmill and other wood industry side-streams, Petronas, one of Fortune Global 500's largest corporations in the world, proves that it is also feasible to convert palm oil biomass into green chemistry [18]. If all EFBs produced in this region were used for bio-based MEG production and then PET bottle manufacturing, it would amount to about 17% of the PET bottles littered in the UK yearly [19]. So, upgrading palm oil biomass into a bio-based material would not only promote better utilisation of an agricultural waste, but also help achieve our societal goals on climate.

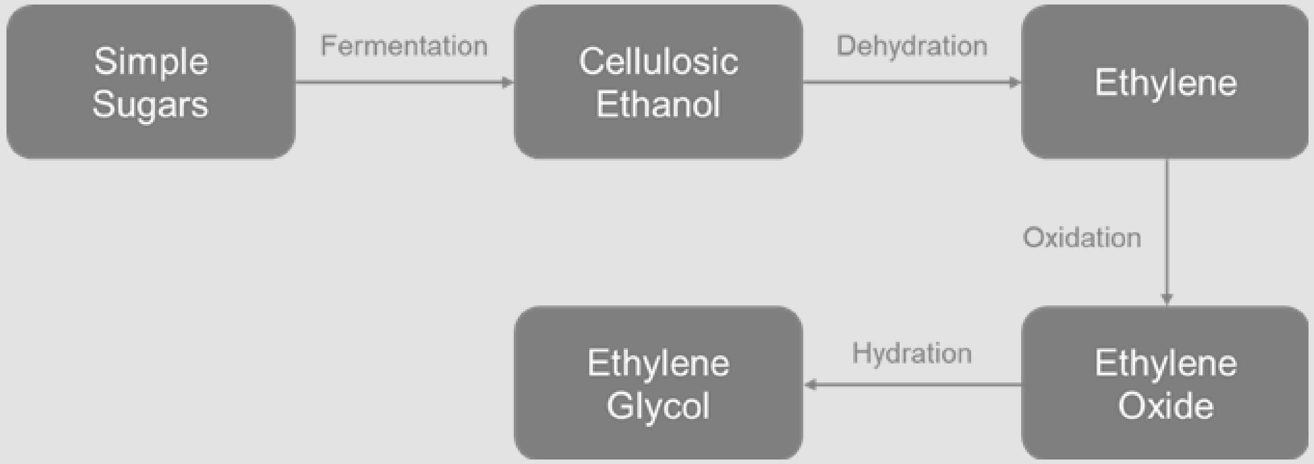

**Figure 3:** Process flow for the production of monoethylene glycol.

## Bio-Based Butadiene from Cellulosic Ethanol

C4 olefins are produced as a by-product of ethylene production from steam cracking of petroleum-based feedstocks in the petrochemical industry. When the C4 stream is fed into extraction units, butadiene is separated from other C4s by distillation. The production capacity of butadiene is expected to increase from 17 million tonnes in 2020 to almost 22 million tonnes worldwide by 2025 [20]. Most butadiene is used to make synthetic rubbers for the manufacture of tyres (styrene butadiene rubber), hand gloves (nitrile butadiene rubber), and hard plastics (acrylonitrile butadiene styrene). When ethylene production is shifted away to a more sustainable way, for instance, converted from cellulosic ethanol, it is a concern that butadiene would become scarce. But the matter of fact that bio-based butadiene manufacturing from ethanol has a long story, starting at the beginning of the 20th Century. There are two processes in use, namely Lebedev and Ostromislensky (Figure 4). Both processes were important sources of bio-based butadiene before being supplanted by petroleum-based routes [21]. However, bio-based butadiene production has now re-emerged as a promising solution to both environmental concerns and the disruption caused by the emergence of shale gas associated with petroleum-based butadiene production. The Lebedev process consists of direct conversion of gaseous ethanol to butadiene over multifunctional catalysts while Ostromislensky process divides the conversion in two steps—a first one for partial dehydrogenation of ethanol to acetaldehyde and a subsequent one for the conversion of the intermediate mixtures to butadiene over silica-supported catalysts.

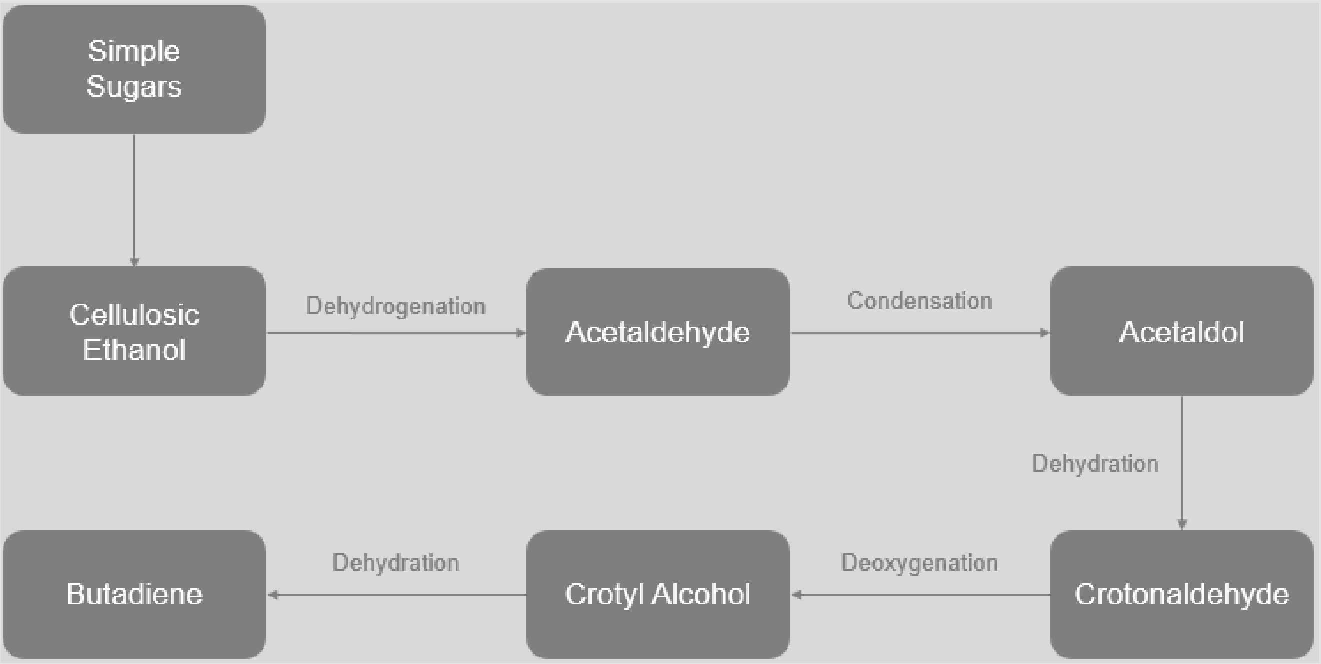

**Figure 4:** Process flow for the production of butadiene.

## Isoprene from Simple Sugar

Isoprene, the building block for a rubbery polymer used in automotive tires, is currently produced from petroleum-based feedstocks. Although its main use is for the production of synthetic tires, other markets for polyisoprene include adhesives, lubricants, and elastomers. The market of isoprene is estimated to be approximately 4 billion USD by 2025, growing at a compound annual growth rate more than 5% [22]. Today, bio-based polyisoprene is experiencing higher demand due to increase in awareness of sustainability and climate issues resulting in major tire companies like Michelin, Bridgestone and Goodyear choosing to partner with biotech companies to seek alternatives for isoprene supply [23]. In this regard, biological solutions could reduce future dependence on petroleum and is expected to contribute reducing carbon dioxide, widely considered to be a cause of global warming. Simple sugars derived from pre-treated and hydrolysed palm oil biomass can be fermented to isoprene to produce rubber (Figure 5). In terms of benefit, researchers suggested that bio-based polyisoprene is able to significantly reduce greenhouse gas emissions by close to 300% as compared to synthetic rubber. In addition, land use intensity of bio-based polyisoprene is 84% lower than that from rubber tree plantations [23].

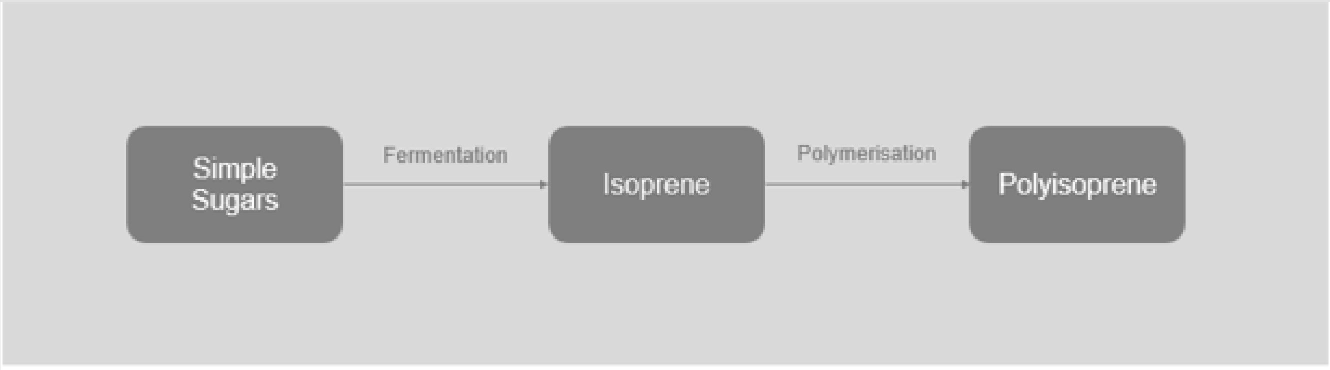

**Figure 5:** Process flow for the production of isoprene.

## The Way Forward

It is clear that biological solutions can help to upgrade palm oil biomass, offer sustainability ways to produce platform chemicals and bio-based materials for a growing population, and reduce carbon emissions to battle climate crisis. The palm oil industry with the aid of biological solutions can catalyse its sustainability transition. However, some processes to produce bio-based materials are currently more expensive than their non-sustainable alternatives because they are not fully scaled yet; they face an underdeveloped market and experience strong competition from fossil fuels solutions that are highly efficient and enjoy economies of scale and decades of knowledge and experience in optimising production and distribution. Therefore, we as chemical engineers have a significant role to play in the development, scale-up and optimisation of processes for the production of bio-based materials.

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