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Green metrics evaluation of isoprene production by microalgae and bacteria

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Isoprene is a key intermediate compound for the production of synthetic rubber and adhesives and is also used as a building block in the chemical industry. Traditionally, isoprene is obtained from crude oil during the refinery process. Nevertheless, plants and animals are also able to synthesize this important compound. This work compares two renewable approaches for isoprene production: by photosynthetic organisms (autotrophic microalgae/cyanobacteria) and by heterotrophic organisms (bacteria). These are two alternative pathways for the conventional isoprene production obtained from the petrochemical-based refinery process, which were assessed in this work using green metrics. Their performance was evaluated in terms of: material efficiency, energy efficiency, economic evaluation and land use. A 10-tonne scale was chosen to perform the green metrics evaluation for both biological processes leading to isoprene. For each process, a comparison was made between a scenario considering the highest isoprene produced reported in the literature and a scenario considering the maximum *theoretical* stoichiometric isoprene productivity.

Introduction

Isoprene (C_5H_8, 2-methyl-1,3-butadiene) is a key intermediate compound for the production of synthetic rubber and adhesives, including car and truck tires. It is also an important polymer building block for the chemical industry, such as for a wide variety of elastomers used in surgical gloves, rubber bands, golf balls, and shoes.[1] Isoprene can also be converted into advanced fuels to be used as gasoline, jet fuel, and diesel supplements.[2,3] The total annual amount of isoprene collectively released into the atmosphere by plants is approximately 500 million tonnes.[4] This amount would be enough to manufacture 60 billion car and truck tires, which is 50 times the current global production.[4] Nevertheless, the collection of the isoprene released by plants and animals for commercial applications is economically unfeasible and therefore the current commercial production routes of isoprene are based on the refinery conversion of petrochemical feedstocks. The global industrial production of synthetic isoprene from petrochemical feedstocks is around 1 million tonnes per year; however, about 20 000 metric tonnes of naphtha cracker are also produced.[4]

Today, the pressure on fossil fuels and chemicals and the environmental concerns related to global warming have increased the need for the production of chemicals such as isoprene from renewable sources. The production of fuels and chemicals from renewable sources with minimal environmental impact offers the promise of closing the "energy gap" between the global supply and demand. It also helps to mitigate the release of greenhouse gases into the atmosphere.

Isoprene can be of natural origin metabolised by several organisms[5] such as animals, plants (including macro- and microalgae), fungi and bacteria.[6] In particular, two pathways have been identified for the biosynthesis of isoprene: the cytosolic mevalonate (MVA) and plastidial 1-deoxy-D-xylulose-5-phosphate (DOXP) pathways.[7] For the algae process the carbon partition to isoprene is able to go only through the DOXP pathway while bacteria are able to produce isoprene both through the DOXP and the MVA pathway through genetic modification.[8,9]

The photosynthetic pathway of isoprene production has been well studied, and it has been shown to be uncommon and not genus specific. Several factors influence the plants' isoprene production, such as light, leaf development, and temperature, and this production can represent up to 2% of the plant's fixed carbon.[10] On the other hand the culture of photosynthetic microalgae might not require either arable land or potable water. The schematic production cycle of isoprene is presented in Fig. 1. Isoprene can be produced from one of the possible pathways of carbon partitioning after the Calvin–Benson cycle.[2]

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