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Review

Methods for enhancing bio-hydrogen production from biological process: A review

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ABSTRACT

Hydrogen (H_2) is considered a clean source of energy and an ideal substitute for fossil fuel owing to its high energy content (122 kJ/g), recyclability and non-polluting nature. The conventional physicochemical methods for hydrogen production are costly owing to high energy input requirements. Hydrogen production by means of biological processes is considered the most environmental friendly and relatively easy to operate, with successful operation under ambient conditions and promising techniques, and having significant advantages compared with conventional chemical processes. The major bottlenecks in biological processes are the low hydrogen yield and production rates at a large scale. The target is improvement of the biological method for hydrogen production and devising path even better in comparison to the conventional methods. The present review article aims to highlight various techniques such as pretreatment, cell immobilization, sequential fermentation, combined fermentation that have been used in biological processes for enhancing hydrogen production. Future developments on these techniques are also outlined.

Contents

Abbreviations: GHG, greenhouse gases; TVFA, total volatile fatty acids; HPB, hydrogen producing bacteria; UASB, up flow anaerobic sludge blanket; HCB, hydrogen-consuming bacteria; OFMSW, organic fraction of municipal solid waste; VFAs, volatile fatty acids; ASBRs, anaerobic sequencing batch reactors; VS, volatile solid; IBR, immobilized bioreactor; POME, palm oil mill effluent; AHB, annular hybrid bioreactor; BESA, bromoethanesulfonate; CSTR, continuous stirred tank reactor; PDMS, polydimethylsiloxane; PVA, polyvinyl alcohol; VSS, volatile suspended solids; GAC, granular activated carbon; HRT, hydraulic retention time; CCD, central composite design; EVA, ethylene vinyl acetate copolymer; TCOD, total chemical oxygen demand; PMMA, polymethyl methaacrylate; COD, chemical oxygen demand; CA, calcium alginate matrix; CH, chitosan; TiO_2, titanium oxide.

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Introduction

Worldwide, the extensive use of fossil fuels for power plants, automobiles, and rapid industrialization is increasing day by day, resulting in not only environmental pollution, but also economic and diplomatic problems owing to their limited reserves and uneven distributions [1]. Furthermore, the burning of fossil fuels (coal, natural gas, oil, petroleum) in different sectors contributes to the emission of greenhouse gases as shown in Fig. 1. These gases, such as CO_2, CH_4, NO_2, SO_2 and other toxic pollutants, are the main causes of ozone layer depletion, global warming, climate change and acid rain. These problems are surely the most hazardous for the future of the earth and should be solved without delay. It is an urgent issue to find alternative energy sources that are environmentally benign, cost-competitive, and renewable [2,3]. Hydrogen is a viable alternative source to replace conventional fossil fuels owing to its clean, renewable and high energy yielding (122 kJ/g) nature. This energy yield is 2.75 times higher than those of hydrocarbon fuels. When hydrogen is used as a fuel, its main combustion product is water, which can be recycled again to produce more hydrogen, but unlike fossil fuels, hydrogen gas is not readily available in nature, and the commonly used production methods are quite expensive [4]. In recent years, a significant use of hydrogen has been demonstrated for hydrogen-fueled transit buses, ships and submarines, including chemical and petrochemical applications. Currently, about 98% of hydrogen comes from fossil fuels [5]. Worldwide, 40% of hydrogen is produced from natural gas or steam reforming of hydrocarbons, 30% from oil (mostly consumed within refineries), 18% from coal, and the remaining 4% via water electrolysis [6]. However, these processes and also those involving electricity productions are energy-exhaustive, expensive and not always environmentally friendly. Biological processes for hydrogen production provide an alternative method of hydrogen production can be operated at ambient temperatures and pressures, are less energy intensive and more eco-friendly compared with conventional chemical methods [7]. This approach is not only eco-friendly but also opens new paths for the exploitation of renewable energy resources that are unlimited [8–10]. In addition, they can also use various waste materials, which facilitate waste recycling. Hydrogen production by biological methods can be divided into two main categories: that involving photo energy dependence fermentation [11,12] and anaerobic fermentation [13–15]. Production of hydrogen via dark fermentation has some advantages over other biological processes, such as the high rate of cell growth, non-requirement of light energy, no oxygen limitation problems and the potential for cost-effective hydrogen production [16–18]. However, low hydrogen yields, low production rates and reactor instability for continuous high volume hydrogen production remain the major problems of the anaerobic method for hydrogen production at commercial levels. Current hydrogen productivities reported in the literature are 10–20% molar ratio [19–21], much lower than the theoretical value (33%).

The main reasons for low hydrogen yield and unstable hydrogen production rate in biological methods are:

(1) Consumption of hydrogen by hydrogen-consuming bacteria (HCB).
(2) Production of more reduced products (e.g., solvents).
(3) For high rate and continuous hydrogen production, there is a need for a correspondingly high feeding rate of medium, which will result in washout of the cells.

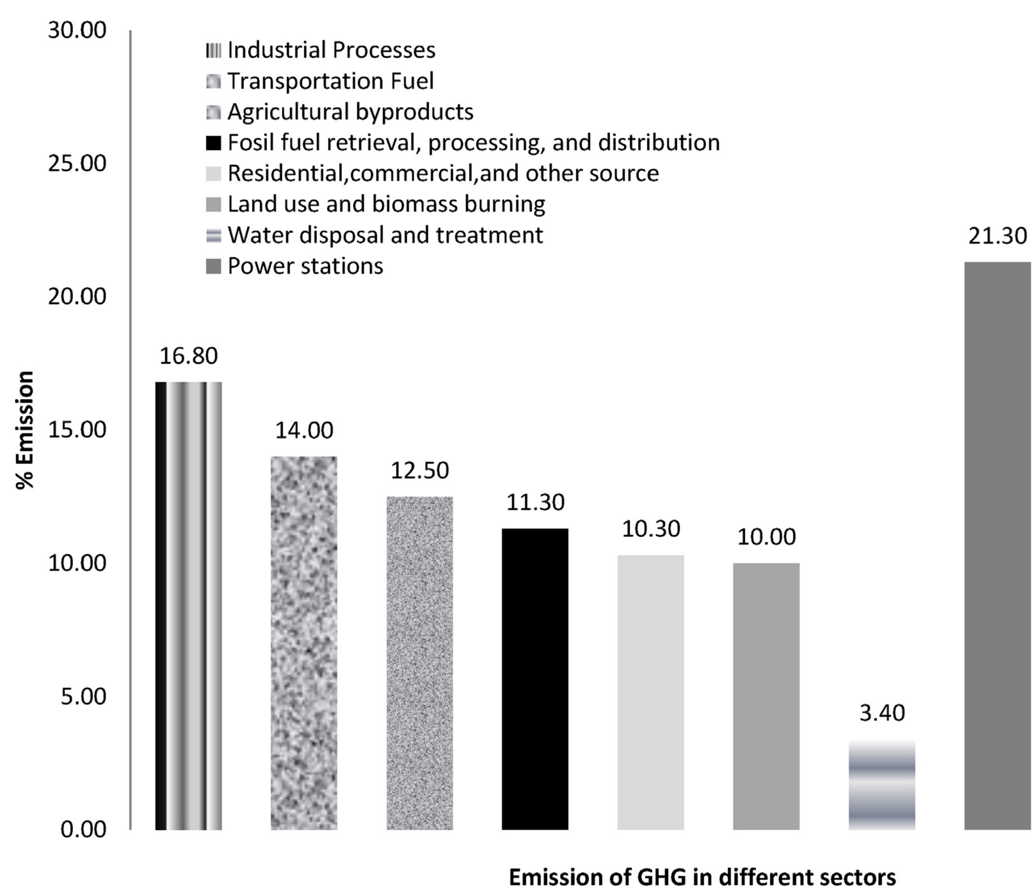

Fig. 1. Annual GHG emissions by different sectors.
[*Source*: Global anthropogenic green house gas emissions in 2004].