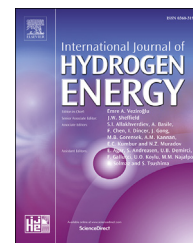


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## Review Article

# Scaling-up bio-hydrogen production from food waste: Feasibilities and challenges

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## ABSTRACT

Hydrogen has potential as a renewable energy source due to its outstanding clean energy content. The production of hydrogen from food waste by dark fermentation gains attention from researchers across the world as it requires lower energy and chemicals compared to other chemical routes, not to mention that the use of food waste as raw material could help lessen the global waste dumping crisis. Currently, the knowledge of hydrogen production from food waste by dark fermentation is still limited in a laboratory scale. This article intends to provide up-to-date status quo on this technology. Factors affecting production potential, appropriate condition of production, feasibility of scaled-up production and economic value analysis of such technology is summarized and analyzed.

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## Introduction

Known for its great green energy potential, hydrogen ( $H_2$ ) has gained considerable research interest.  $H_2$  possesses 142 MJ/kg energy content compared to methane (55.5 MJ/kg) and gasoline (47.3 MJ/kg) [1], and only generates water as a product of combustion.  $H_2$  is also used in several other processes including oil refining, chemical production (ammonia, alcohols, and aldehydes), food production, and metal treatment [2]. However, commercializing  $H_2$  production involves severe conditions and somehow requires non-renewable fossil fuel. In other words, the production of  $H_2$  itself causes a large quantity of  $CO_2$  being released [3].

A dark fermentation (DF) has been proposed as a promising technique to produce the “real” clean  $H_2$  owing to its low chemical energy requirement and thus more environmentally friendly compared to the conventional chemical process. DF can be operated under ambient temperature and pressure with a variety of feedstocks including waste materials [4] such as agriculture waste, wastewater, leachate, municipal organic fraction waste, and food waste (FW) [5,6]. A rapid increase of global waste generation, especially municipal solid waste (MSW) that depends on the growth of urbanization, is one of the most critical environmental issues. This problem pushes global to think about sustainable waste management including how the wastes could be utilized rather than simply throw them away, not to mention how to dispose them of without causing environmental concern. Based on the Pollution Control Department (PCD) in Thailand, Thailand's MSW are classified as FW (or organic fraction waste), plastic, paper, glass, and metal. In Asia, organic waste and FW which can be used as feedstocks of DF process account for as much as 40–65% of produced MSW [7]. In general, due to its high moisture content and its highly biodegradable character, FW is difficult to transport and will rot quickly. An onsite conversion unit of FW is therefore needed, and converting FW to energy, particularly  $H_2$  and  $CH_4$ , is an attractive option. However, the large variation of FW composition becomes an important factor affecting the production efficiency [8,9]. Preferred feedstocks for  $H_2$  production by DF is readily biodegradable substances, such as simple sugars and starch. Therefore,  $H_2$  produced from carbohydrate-rich waste is always obtained in a greater quantity than that from complex substrates such as cellulosic waste, protein- and fat-rich waste. In other words,  $H_2$  production yield depends significantly on its carbohydrate content [10].

Due to low  $H_2$  production yield of DF, many researchers have extensively studied the effect of fermentation conditions, substrate compositions, inoculum, types of reactors, etc. with the aim to produce the highest amount of  $H_2$ . However,  $H_2$

yields from DF reported by most studies were still relatively low at 20–30% of its theoretical yield [9,11,12]. To deal with this problem, converting the effluent from DF to  $CH_4$  via anaerobic digestion (AD) has been effectively proposed. Based on energy recovery standpoint, combination of  $H_2$  and  $CH_4$  production yielded 7–9 times greater energy output than traditional  $H_2$  production alone and 10–12% higher than the individual production of  $CH_4$  [13]. A good example of energy production from FW was a case study of Chu et al. (2008) [14] where the energy generated from each ton of wet FW was 1,862,258 kcal, which was approximately 7.48% from  $H_2$  (during DF) and 92.52% from  $CH_4$  (during AD). Advantageously, regardless of separation, the mixture of  $H_2$  and  $CH_4$ , called Hythane, could be used directly and efficiently for some applications such as engine fuel [15,16]. Therefore, the 2-stage fermentation (DF coupled with AD) has been proposed as a perfect combination that maximizes the energy recovery from FW substrate.

With all the above noteworthiness and the growing process development, there has been an increase in research attention in the use of FW as substrate for bio- $H_2$  production which can be seen by the increasing amount of research articles being published since 2002 (Fig. 1).

It is noted, however, that most research emphasizes on increasing the production yield, production volume and production rate by adjusting DF conditions, and the design of most studied reactors was in laboratory scale without mentioning the feasibility of the scaled-up production. Moreover, recommended techniques for energy recovery improvement at laboratory level, such as pretreatment of substrate, pH adjustment, control temperature, etc. seem costly and difficult to operate on a large scale. Only a few researchers have studied the production in different scales, and experiences with large-scale production are limited. Thus, the information needed for scaling up such as feasible operating conditions, economic viability, reactor and plant design, as well as waste management are still lacking. Therefore, the aim of this review is to provide the information necessary for the scale up of the production of  $H_2$  from FW via the DF method, the estimation of the commercial worthiness, and other factors that affect the production efficiency. Moreover, the couple processes, DF with AD, for the production of bio-hythane with improved energy recovery option from FW will also be discussed.

## Effects of FW composition on $H_2$ production yield

Theoretically, there are 2 typical pathways where  $H_2$  is produced from FW via DF. Described by Eqs. (1) and (2), a mole of glucose reacts with water producing 4 moles of  $H_2$  if the by-

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