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Industrialization roadmap model for fermentative hydrogen production from biomass in Taiwan

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ABSTRACT

The study aimed to construct a technology industrialization roadmap model and apply it to illustrate the fermentative hydrogen production from biomass in Taiwan. The paper distinguishes and defines the emerging industrialization process technology and collects and analyzes secondary data. Subsequently, it identifies the current phase of technology development and investigates the future activities of the industrial phase and the relationship between technology, product, applications, and markets by further formulating the industrialization roadmap. The results are as follows. The industrialization of hydrogen production by fermentation from biomass in Taiwan is currently in the "technology-application transition phase," in which key technologies such as selection and cultivation of dominant hydrogen-producing bacteria, processing of biomass feedstock, and control of operation parameters have been mastered. The industrialization roadmap has designated the years 2016–2020 as the "nurture phase," 2021–2025 as the "application-market transition phase," and 2026–2035 as the "growth phase."

Introduction

Energy conservation and carbon reduction have emerged as a priority issue for the Taiwanese government in its search for sustainable energy resources and methods for mitigating climate change. In 2009, the government identified solar PV, LED lighting, wind energy, hydrogen energy and fuel cell technologies, energy information communication technology, biofuel, and electric vehicles as Taiwan's key industries of the future [1]. Further, in 2016, the government proposed investment in green energy development, including hydrogen energy, as one of the five target industries [2]. The benefits of developing the hydrogen energy and fuel cell industry in Taiwan includes less dependency on fossil fuel, increasing safety in energy supply, decreasing CO_2 emission, and increasing energy usage effectiveness through the use of fuel cell systems [3].

Hydrogen application is an emerging technology industry that includes hydrogen production, hydrogen storage, hydrogen transport, hydrogen refueling, and hydrogen usage. Finding an appropriate hydrogen production method is important for the development of hydrogen energy applications. Currently, the major hydrogen production methods include coal gasification, natural gas reforming, water electrolysis, solar photocatalysis, thermochemical cycles by nuclear energy, and hydrogen from biomass [4]. A study by Chang et al. [5] based on economic, environment, technology,

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and social assessments showed that wind power and biomass fermentation are suitable technologies for the development of hydrogen production in Taiwan.

In Taiwan, dark fermentation is a main research field in hydrogen production technology. Since 1998, the Taiwan National Science Council (now renamed as Ministry of Science and Technology) has supported universities in conducting basic research on biomass fermentative hydrogen production technology. Further, the Bureau of Energy (BOE), Ministry of Economic Affairs (MOEA), provided funds to universities and research institutes such as Feng Chia University and the Industrial Technology Research Institute (ITRI) during the period 2000–2008 for application-related research in the field. Thus, many vital research results have been obtained in Taiwan's academic and research institution circles. For example, this work proposes a study design for a new type of anaerobic bioreactor based on prefabricated building wastewater treatment facility and plug flow bioreactor structures. Specifically, it is obtained a peak hydrogen content of $40 \pm 2.4\%$, a hydrogen production rate of 10.9 ± 1.5 L/L-d, and a hydrogen production yield of 1.7 ± 0.2 mol H_2/mol sucrose [6].

How to industrialize the emerging technology in the future is a key issue in promoting the application of fermentative hydrogen production technology in Taiwan. That is to say, this industry needs large-scale commercial application and sustained increase in its production value. The government, industrial and academic circles, and research institutes of Taiwan should formulate appropriate development strategies to accelerate the industrialization of fermentative hydrogen production technology. These strategies should clearly describe the tasks and policy measures for this industry. As in the US [7,8], Canada [9], the United Kingdom [10], Australia [11], and China [12], a technology roadmap can be used to describe and shape a technology development strategy for the national hydrogen energy and fuel cell industry and establish R&D targets for the domestic industry, academia, and research institutions.

The Industry Technology White Paper issued by the BOE of Taiwan in 2010 [13] does not provide a technology roadmap plan for the hydrogen energy and fuel cell industry as a whole, other than a brief description about some key points and schedules for hydrogen production, hydrogen storage, and fuel cell technology development. The BOE set the following short-, medium-, and long-term goals for the development of fermentative hydrogen production technology in the Industry Technology White Paper: establish 500 Nm^3/d demonstration plants for wastewater-based hydrogen production before 2015; complete the industrial application population of fermentative hydrogen production technology before 2020; finish fermentative hydrogen production of modular/commercial equipment before 2025.

The main purpose of this study is to construct a model for an emerging-energy technology roadmap and discuss an industrialization roadmap for fermentative hydrogen production from biomass as the basis for the development of a commercialization strategy in Taiwan. It also provides a reference source for research institutes in related technologies and investment decision-makers in the industry. The framework of this study is as follows: first, we describe fermentative hydrogen production from biomass, application of the technology, and roadmapping; second, we construct an industrialization roadmapping model and simulate Taiwan's fermentative hydrogen production from biomass using this model; finally, the paper concludes with some suggestions.

Literature reviews

Fermentative hydrogen production from biomass and technology application

Biological hydrogen production technologies can be mainly classified into the following three types: photosynthesis hydrogen production, light fermentative hydrogen production, and dark fermentative hydrogen production. Dark fermentative hydrogen production uses microorganisms (such as *Clostridium*) under anoxic or anaerobic conditions, with no need for a light source, to transform organic materials into hydrogen gas, carbon dioxide (CO_2), and other byproducts (such as ethanol, acetic acid, propionic acid, and butyric acid).

Biohydrogen production combines hydrogen energy with bioenergy applications to afford benefits such as reduction of CO_2 emissions owing to the utilization of biomass, increased income from agricultural produce via waste conversion, replacement of petrochemical fuels with sustainable biofuels, and reduction in municipal solid waste management costs [14]. Therefore, the development of biohydrogen production has remarkable implications for energy conservation, carbon reduction, and economic growth for these emerging industries.

The commercialization of dark fermentative hydrogen production has been investigated from a business model perspective. For example, Chang et al. [15] have proposed an innovative business model for production from wastewater treatment. In the model, soft drink manufacturers could use sugar-rich wastewater as the raw material for dark fermentation to obtain products rich in $H_2/CO_2/CH_4$ that could be marketed and sold. Chang and Hsu [16] also indicated in their research that fermentative hydrogen production from a biomass system would increase the value of a wastewater treatment system and make its commercialization more feasible. Hsu and Lin [17] have suggested that the energy service company ESCo was established as a link between production and marketing model for the production of hydrogen using organic materials. In essence, working together with soft drink manufacturers, ESCo played the role of hydrogen producer and seller. Chang et al. [15] described that low profitability of dark fermentative hydrogen production would be caused by potential risks due to lack of actual operational data for equipment reliability. The other major reason would be costly equipment, such as H_2/CO_2 purifiers, CH_4 fermenters and purifiers, and fuel batteries.

However, the biohydrogen production technology is still at its preliminary stage and faces many barriers and challenges. For example, the feedstock for biohydrogen production is easily influenced by the season of the year, resulting in high processing costs [18]; the equipment is easily corroded and exhibits hydrogen aging.

A major challenge to the development of biohydrogen production is the high cost of feedstock (e.g., carbohydrate-