INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 41 (2016) 21583–21599

Available online at www.sciencedirect.com

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journal homepage: www.elsevier.com/locate/he

Levelized cost of energy and financial evaluation for biobutanol, algal biodiesel and biohydrogen during commercial development

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ARTICLE INFO

Article history:
Received 31 March 2016
Received in revised form
24 July 2016
Accepted 29 July 2016

Keywords:
Levelized cost of energy (LCOE)
Engineering economic analysis
Biobutanol
Algae biodiesel
Biohydrogen

ABSTRACT

This study applies engineering economic analysis with modifications that concern profit rate, opportunity cost, price inflation, financial leverage, risk premium, learning curve effect, the effect of nth-generation chemical plants effect, interest rate and full commercializatioguren to capture realistic conditions to evaluate the economic feasibility of biohydrogen, biobutanol and algal biodiesel plants in a future bioeconomy.

Analytical results reveal that biohydrogen and biobutanol can replace fossil fuels with high economic feasibility. Biohydrogen has the most flexibility under variation in the production cost of biomass feedstock. Algae biodiesel is less financially competitive than biohydrogen and biobutanol. Three bioenergies are cost-competitive with fossil fuels under ideal conditions.

Sensitivity analysis reveals that biomass feedstock cost more strongly affects the financial performance of bioenergy than does operating and Maintenance (O&M) cost. Interest rate has the greatest impact on levelized cost of energy (LCOE), and is followed in that respect by price inflation, economic incentives and the two-tier learning curve effect. The factors that are related of bioenergy should be paid considerable attention to maintain the stability of biomass feedstock supply to make bioenergy competitive with fossil fuels.

Introduction

The IPCC's 21st conference was held in Paris on December 2015, and settled on the “Paris Agreement”, which forces the parties to the convention to set constraints on their emissions of greenhouse gases, based on “the Fifth Assessment Report” [1], with the goal of keeping no more than 2 °C of global average temperature. The OECD and IEA are planning a low-carbon economy as a long-term development goal of EU [2] consistent with the Paris Agreement. The foundations of such a low-carbon society is a bio-based economy (bioeconomy hereafter) and green growth to offset the negative effect of reducing greenhouse gases emissions and the accompanying decline in economic growth. The bioeconomy is a key component of the low-carbon economy or green economy [3,4]. Bioenergy is an important bio-based industry, and which drives the bio-based economy [5]. Since bioenergy

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http://dx.doi.org/10.1016/j.ijhydene.2016.07.242

is environmentally friendly, independent of fossil energy, carbon-neutral [6,7]. Based on state-of-the-art technology, it has potential as an alternative energy source and will be a major driver of the transformation of the petro-economy to a bioeconomy [8–10].

Conventional biofuels are made from sugar, starch, vegetable oil, or animal fats using conventional biotechnologies; they have some disadvantages, including stress on food production as production materials and land use are diverted away therefore, detrimentally affecting human welfare [11], and the use of lignocellulose, which increases the society required to generate second-generation biofuels. Third-generation forms of bioenergy, such as biobutanol, algal biodiesel and biohydrogen, have great potential to replace early-generation biofuels because they can be formed from the same fermentable agricultural biomass, waste and algal biomass as feedstocks [12] and so do not impinge upon the global food supply [13].

Ref. [14] stated that biobutanol can overcome the shortcomings of conventional biofuels, such as bioethanol, owing its superior attributes such as higher energy density than bioethanol, better diesel miscibility and lower vapor pressure, favoring compatibility with conventional fuels. Biobutanol has a similar energy content and energy density, to those of gasoline, but is less hygroscopic and has a lower volatility [15,16]; it also exhibits better performance and corrosion resistance than ethanol [12]. Butanol can be used in an unmodified gasoline engine [17] and in diesel engines [18]. The challenges of biobutanol production are the low butanol titer and availability of compatible feedstocks. The characteristics of biobutanol make it an attractive, promising and economic alternative liquid fuel [16,19].

Algal biofuel is representative of the third generation of biofuels [20,21]. From 1978 to 1996, the US Department of Energy performed a long-term pioneering program of research on algae that was called the Aquatic Species Program [22,23] to investigate the potential of various microalgae species to be developed into algal biofuels. The solid long-term research results concerning technology for producing algae, and its superior characteristics such as algae biomass have supported the carbon-neutral [24] mass-production of lipids, proteins and carbohydrates in a short period [25] to ensure a stable supply of algal biomass and biofuels [7]. Algal biodiesel is a much more competitive and effective alternative to fossil fuels than other bioenergies [26,27]. The major constraint on the commercialization of algal biodiesel is its high cost [28,29], which is associated with the use of land for open raceway cultivation, or with electricity and CO_2 for photobioreactor cultivation [30]. Macroalgae is another potential source of algal biodiesel [31] and can be cultivated using a marine photobioreactor in seawater [32]. Owing to its various advantages and the many sources species for the generation of algal biomass, algal biodiesel may become a major alternative energy source with strong technological and financing support [33].

Hydrogen has high energy content; its combustion produces energy and water as by-products; it is a source for electricity generation in fuel cells, and it can be produced by multiple methods, including biotechnological methods, making it a sustainable energy carrier [34]. Transitioning to a hydrogen economy is a common part of many national blueprints for the future of energy production [35,36]. Biohydrogen is an attractive and promising alternative source of energy because it is environmentally friendly; readily generated by biological process with high production rates, and can be utilized under a wide range of conditions [37] using methods of low energy intensity such as dark-fermentation or photo-fermentation [38,39]. The use of agricultural biomass waste and algal biomass [40] as feedstock make it cost-competitive with hydrogen made using a costly method such as a steam reforming processes and electrolysis [37,41,42]. Not only hydrogen production, but also hydrogen storage, distribution, refueling and application technologies have been developed, leading to its commercialization [43]. The advantages of biohydrogen will likely make it an extremely premier source of energy after 2050 [16,19,44].

In summary, this study focuses on constructing bioenergy plants in commercialization process without their applications to simplify the financial feasibility analysis and to provide a fair comparison between three bioenergies. Numerous financial indices were calculated by discounted process, such as net present value (NPV), internal rate of return (IRR), external rate of return (ERR), benefit-cost ratio (BCR), break-even-point (BEP), payback period and levelized cost of energy (LCOE) can be provided by an engineering economic analysis, and can help decision-makers identify worthy projects [45].

This study conducts many modifications to conventional engineering economic analysis, which considers the reasonable profit rate, opportunity cost, excess profit rate, price inflation, financial leverage, market risk premium and credit risk, the learning curve effect, the nth generation plants effect, and the reasonable minimal attractive rate of return (MARR), to capture realistic conditions under which new bioenergy plants can be developed. This work develops four stages of the full commercialization of biobutanol, algal biodiesel and biohydrogen. An economic feasibility analysis is conducted with an economic-type life-cycle assessment (LCA) to simulate the cradle-to-grave in the development of a new plant. Several sensitivity analyses of various financial factors include biomass feedstock costs, combination of different costs of the three new sources are carried out to compare the three sources of bioenergy in terms of competitiveness.

This work contributes to the literature by being the first, to the best author's knowledge, to determine simultaneously the accurate LCOE or unit cost of new bioenergy from biobutanol, algal biodiesel and biohydrogen by performing an engineering economic analysis with practical economic incentives modifications that involve opportunity cost and a profit index. Second, novel modifications of cash flows are adopted; for example, an economic lifecycle assessment (LCA) is performed on fully commercialized process, and cash flow adjustments, such as those related to two-tier learning curve effects and cost-capacity scaling factors, are made. Third, parameter settings of interest to investors are used in calculating financial indices, and sensitivity analysis are performed. The modifications to theory and data herein elucidate realistic financial conditions for chemical engineering projects with the three sources of bioenergy of interest.