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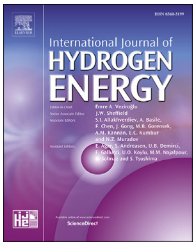

Evaluation the financial feasibility of biogas upgrading to biomethane, heat, CHP and AwR

Duu-Hwa Lee*

Institute of Applied Economics, National Taiwan Ocean University, Taiwan

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ABSTRACT

This investigation contributes to the literature on the evaluating financial feasibility of biogas upgrading to biomethane, heat generation, Combined Heat and Power (CHP), and alkaline with regeneration (AwR) by using the modified engineering economy method to establish biogas plants with a single production capacity and full commercialization. Eight scenarios are considered and sensitivity analyses are conducted. The results thus obtained demonstrate that biomethane is the most profitable biogas application, and profits increase with the scale of its production. Biogas with heat generation is also profitable. Biogas with CHP is financially unfeasible, and the relevant results herein oppose most of the related literature. AwR outperforms CHP but is only barely profitable. Financial performance is sensitive to both interest rate and the costs of major cost components of biogas applications. Biomethane is the most profitable bioenergy, followed by biohydrogen, biobutanol and algal biodiesel in that order. Realistic model settings are required for accurate financial evaluation. The results herein help decision-makers in industries related to biogas.

Introduction

Bioenergy is one of the most important alternatives to fossil fuels and can mitigate climate change. It is therefore provides a powerful means of meeting the Intended Nationally Determined Contributions (INDCs) requirement in the Paris Agreement and the sustainable development goals (SDGs) launched by United Nations that were proposed by the United Nations for 2017 and beyond [1]. The bioeconomy uses bio-products, waste materials and bioenergy, with the processing of biological resources [2]. This “circular economy” complements recycling in the bioeconomy and increases the efficiency of the recycling of carbon in particular [3]. It is also a development guideline of bioeconomy, green economic growth, sustainable development and a low-carbon economy bioenergy such as biogas, bio-methane and bio-hydrogen. The bioeconomy and bioenergy are carbon-neutral, and therefore perfectly illustrate the circular economy [3].

Biomethane is a promising biofuel, and its production from energy crops may reduce emission by an average of 68% below those produced using fossil oil [2]. Biogas is a sustainable and renewable source of energy, providing an alternative to common fuels [4]. Biogas can be upgraded to biomethane to meet the quality standards for natural gas by removing 25%–50% CO_2 and other gases which can inject into natural gas grid and uses as a vehicle fuels [5]. Biomethane is environmentally friendly [6] and provides energy security and many green jobs; it is a renewable source of energy, drives economic growth, can be used in as biorefineries. It is the means by which food

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* No.2, Beining Rd., Jhongjheng District, Keelung City 202, Taiwan.
E-mail addresses: dhlee@email.ntou.edu.tw, dhlee@mail.ntou.edu.tw.

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waste is used to generate energy. Its use reduces methane emissions, and makes communities more resilient against climate change [7]. European Commission launched a National Renewable Energy Action Plan (NREAP) to support biogas and biomethane development to 2020 [8]. The efficiency of biomethane production will be reach 30% of its technical limit by 2030 [9], following if the biogas development path in the NREAP is followed. Ref. [6] provided a biomethane roadmap to the production of 18–20 billion cubic meter of biomethane in Europe at year 2030, which would correspond to approximately about 3% of the natural gas consumption of the European Union. In the USA, a biogas roadmap for biogas/biomethane was development based on their abundant food and biomass waste [7]. The efforts that have been made by participate countries in the IEA's (International Energy Agents) Task 37 and stated that the future of biomethane will include extensive upgrades of biogas plants to biomethane plants, with the injection of the power produced into the grid and that more biomethane will be used in this way than as a vehicle fuel [10]. Biomethane is an important bioenergy in both the bioeconomy and the circular economy globally.

Biogas is generated by the anaerobic digestion [11] of various types of organic waste such as food waste [12], solid waste [13], edible soybean oil refinery wastewater [14], microalgae [15], seaweed [16], banana peduncles [17], lignocellulosic biomass [18], pulp and paper mill sludge production [19]. Biomethane also can be produced by new method such as anaerobic cometabolism which enhances liquid AD, via augmenting the biodiversity of inoculums [20]. Using wind electricity to generate hydrogen can be used in the production of biomethane [21]. Biomethane is cost competitive with natural gas, LNG and biodiesel in Brazil [22]. This review of the literature reveals that biomethane is an attractive biofuel in many aspects.

The production of biomethane from biogas requires the removal of CO_2 to purify biogas by a traditional method, such as physical or chemical absorption, pressure swing absorption, the use of membranes [23], or novel methods, such as the use of microalgae [24] and alkaline with regeneration (AwR) which is a new method for converting biogas to biomethane [25]. Biogas with Combine Heat and Power (CHP) is one of the best pathway for the utilization of biogas [26–28]. Based on the part of suggestions of ref. [29], this study evaluates the financial feasibility for decision makers of four applications of biogas production and upgrading to biomethane, heat generation, CHP and AwR.

Various financial indices are calculated in this investigation which are net present value (NPV), benefit-cost ratio (BCR), internal rate of return (IRR), external rate of return (ERR), break-even-point (BEP), profit index (PI), payback period and levelized cost of energy (LCOE) [30]. The economic concepts that are applied herein to capture the actual circumstances of new biogas plants include price inflation, normal profit, opportunity cost (OC) [27], the 2-tier learning curve effect, the n-th generation plants effect, and capital adjustment. An economic life-cycle assessment [31,32] which reveals entire commercialization process of biomethane in this study and numerous sensitivity analyses are also conducted. Project cash flows must be discounted or compounded using an interest rate or discounted rate, which is usually set to the minimum attractive rate of return (MARR) because the rate of return should cover because the time value of an investment varies with inflation, time preference and risks [33,34]. This work contributes to the relevant literature by collecting production cost (cash flows of construction investment and operation expense) and sale data of biogas applications and performing financial analyses of four biogas applications. Numerous modifications are made to calculation processes based on economic concepts and the actual settings of engineering economy model. Model parameter settings which attract to investors are used to calculate financial indices, and several risk analyses are carried out. It provides several important findings for investors and governments.

Models, data and scenario design

Models

Major financial indices are used herein to evaluate the feasibility of biogas production, and all the formulas and meanings can be fined in Ref. [30]. NPV is the discounted value of incomes minus the discounted value of costs over n periods of a life-time of a project to reveal actual purchasing value of the project. The NPV is a reference for investment-related decisions. An investment project is acceptable if discounted cash inflows exceed discounted cash outflows, such that NPV>0, and unacceptable otherwise. Equation (1) applies.

$$\mathrm{NPV}(r) = \frac{B_0 - C_0}{(1+r)^0} + \frac{B_1 - C_1}{(1+r)^1} + \ldots + \frac{B_t - C_t}{(1+r)^T} = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+r)^t} \quad (1)$$

where B_t and C_t are the cash inflows (incomes) and outflows (costs) of a project at time t, and r is the discount rate.

The BCR ratio provides similar information as NPV, but is calculated by dividing sum of discounted income (B_t) by sum of discounted costs (C_t). A BCR ratio of greater than unity indicates financial feasibility.

IRR makes the estimated rate of return of discounted cash inflows in an investment plan equal to the estimated discounted total value of cash outflows; it therefore specifies whether the project breaks even with an NPV of zero. In cases of high cash-flow volatility in an investment project, the IRR can have multiple values, causing indecision among policymakers. In such a case, the IRR is adjusted by using the WACC (weighted average capital cost) as the rate of return of reinvestment and then setting the cash inflow equal to the outflow yielding the ERR. The ERR is a more useful and reasonable index for evaluating accurately the profitability of a project to investors. A project with a higher IRR or ERR is more favorable.

The PI is the factor by which accumulated cash inflows in an operating period exceed the discounted initial capital investment at time zero (current time). A project is feasible if the PI exceeds unity, meaning that the initial expenditure of investors will be obtained and the project has a low risk. The payback period is the estimated operation time after production begins for which investors must wait before they receive accumulated net cash flow their initial investment back and begin to make a profit during life-time of an engineering plan.

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