Integrated Energy Analysis and Advantage Approach for Evaluation of Microalgae Oil Production System at Minamisoma Pilot Plant in Japan

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Abstract

University of Tsukuba build microalgae oil pilot plant in Minamisoma city, Fukushima prefecture, Japan to cope with the third-generation biofuel. The pilot plant was built after the earthquake in 2011 and part of the rehabilitation effort in Fukushima prefecture. The location was prone to the radioactive residue from the nuclear incident therefore not suitable to be developed as agricultural area. Microalgae oil purpose was fuel, not for human consumption therefore no risk in human health involved.

The pilot plant used open raceway pond (ORP) to cultivate microalgae. After cultivation, microalgae are harvested and underwent dewatering process which includes centrifugation and filtration. The final process was extraction to produce microalgae oil. The extraction process was using hydrothermal liquefaction (HTL). Hydrothermal liquefaction will convert not only lipid but also carbohydrate and protein to microalgae oil.

Initial investigation on the Minamisoma pilot plant found that the energy requirements to produce microalgae oil was high. The major contributor to the total energy requirements was HTL process. The EPR (Energy Profit Ratio) is the ratio of the energy produced to the energy consumed by an energy-production method. The highest energy demand came from the nutrients, followed by the HTL process, with around 68% and 22%, respectively. Carbon dioxide from flue gas could be used as a CO2 source in microalgae cultivation. If we could obtain CO2 from another industry, the nutrient percentage would decrease to around 40% of the total energy demand. Further, if we could completely substitute the nutrients, the highest energy consumption would be the HTL process with around a 68% share.

Without the nutrients, the HTL energy consumption was the highest, with 94.29 MJ or slightly more than 68%, followed by cultivation with 15.40 MJ or slightly more than 11%. The drum filtration and centrifuge contributed 14.17 MJ and 13.39 MJ or around 10% and 9%, respectively. With a microalgae-oil energy content of 193.27 MJ, the energy profit ratio was found to be 1.41. With nutrients, the EPR was very low at only 0.45; the EPR value increased to 0.85 if we excluded the CO2 from the system. The EPR value would rise more if we could substitute all the needed nutrients. Therefore, an integrated system for microalgae cultivation or overall microalgae oil production is preferable.

Cultivating microalgae for energy production could be optimized by using traditional methods such as gravity sedimentation to harvest the microalgae; however, the trade-off is the processing time. Time and area could be a trade-off with the energy requirement. The EPR is the decision-making benchmark for the feasibility of converting pilot-type plants to industrial-scale or integrated microalgae production systems.

The EPR result from the calculated energy requirement using a downstream approach for four stages in the Minamisoma pilot plant was more than 1, which means that the amount of energy produced was higher than the energy required in the four stages of oil extraction. The EPR was found to be more than 1 with a nutrient replacement, which indicated the potential of the Minamisoma pilot plant to move to the industrial scale. On the other hand, in the scenario without nutrient replacement, the EPR was lower than 1. In such a case, integrated microalgae production systems were recommended.

Hydrothermal liquefaction (HTL) extraction process in the Minamisoma Pilot Plant holds advantage over the common extraction process such as solvent extraction in which HTL can extract not only lipid but also protein and carbohydrate. But solvent extraction and other extraction process also have their own advantages. Consideration is needed to select the most suitable method for the extraction system.

Considering the advantages of each extraction process, a method named Choosing by Advantages (CBA) is selected. The CBA method used the advantages as the base to judge the problem, therefore appropriate for this kind of selection. Method will help in making the decision and decision will result actions and actions will produce outcomes. Therefore, to produce desired outcome we need to pay attention to the decision-making process.

The first step in CBA would be determining the alternatives. Minamisoma Pilot Plant use HTL, this alternative will be compared to the more common method which is solvent extraction and with pyrolysis which can also process whole biomass for the feedstock. The result from CBA method then compared to Analytic Hierarchy Process (AHP) which is already been established method.

The ranking for the alternatives in CBA in this case was the same with the result form AHP method. In a case where the difference is quite small and with fewer alternatives or criteria, both CBA and AHP can produce consistent results. In this case the first rank was hydrothermal liquefaction, followed by pyrolysis and solvent extraction. The preferred method in this case is CBA because we can get the same results with simpler process. The advantages of CBA compared to AHP was that in CBA exist reconsideration stage where trade-off can be evaluated. While in AHP the decision mainly based on the final ranking of the alternative.