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Life Cycle Assessment of Rapeseed Biodiesel

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Abstract

Life Cycle Assessment(LCA), objective of which is to elucidate the impact of biodiesel on energy supply and natural environment and its economic value while giving an assessment on commercialization application of biodiesel, is performed in this study. Based on LCA methodology, production cost and CO_2 emission estimation of rapeseed biodiesel industry were conducted. Results of the assessment indicate that the total amount of absorbed CO_2 during the whole life cycle of rapeseed biodiesel is much larger than that has been emitted and rapeseed biodiesel is really an environment-friendly energy source. With the contribution of biodiesel derived from rapeseed oil made during the process of its full life cycle, green house emissions could be enormously reduced. However, in terms of production cost, the phenomenon that considerable portion of the total cost is occupied by the cost of raw material is observed in rapeseed biodiesel. Specifically, the portion of raw material cost is larger than 89% while the portion of crew oil is larger than 87%. The improvement of economical efficiency in the commercialization application of rapeseed biodiesel depends on the reduction of raw material cost. If we want to develop rapeseed biodiesel in China, government's encouraging policies, such as tax exceptions and financial subsidies, are necessary.

Keywords: rapeseed oil, biodiesel, life cycle assessment, CO_2, production cost

1 Introduction

Since the petroleum crises in 1970s, the price and uncertainties over petroleum availability have rapidly increased. And there has been growing concern about environment and the effect of greenhouse gases during the last decades. All of these have revived more and more interests in the use of alternative energy as a substitute of fossil fuel [1]. As one of the alternative energy sources, Biodiesel is renewable and widely available from various sources [2] and therefore has special advantages in energy recycling and GHG diminishing. At present, commercial production and consumption of biodiesel are mostly common in American and EU, and the raw material of the biodiesel production in these two regions is mainly soybean and rapeseed, respectively. EU is the biggest market of global biodiesel production and consumption, in where the production of biodiesel has dominated the bio-fuel industry with more than 80%. Based on the data from European Biodiesel Board (EBB), EU produced 8.1 Mt of biodiesel in 2007, and 9.0 Mt in 2009. The U.S. DEO has focused on the development of biodiesel and a series of policies and regulatory actions had been taken to address it. U.S. produced 0.8 Mt of biodiesel in 2007, 1.0 Mt in 2008, and it plans to produce 2.33 Mt biodiesel in 2012.

In China, the shortage of diesel has been increasing year by year. The diesel-gasoline ratio in production has been less than that in consumption. Presently, the ratio in production is 1.8 while the ratio in consumption is above 2.0 [3]. In some provinces, such as Yunnan, Guangxi, Guizhou, the ratio even rise to 2.5. Therefore, the development of biodiesel will be helpful to environmental protection as well as balancing diesel-gasoline ratio, and this is exactly the significance of this research. China is rich in natural resources, such as cotton seeds and rapeseeds, which can be used to produce biodiesel. The supply and demand rapeseed oil in China is now equilibrium, and the potential productivity is great. The plantation of rapeseed crops won't replace the food field, so it can be the most potential resource for commercial production of biodiesel in China [4].

There have already been many researches on the defining, target and scope of full life cycle at abroad, and the applications of full life cycle assessment are mainly focused on energy balances, green house gas emissions and effect of ecological toxicities [5,6,7]. Proceeding from the reality of China, production of rapeseed biodiesel was studied in this paper. In order to serve for commercial production and consumption, full life cycle assessment on CO_2 emission and cost of biodiesel production from rapeseed oil was accomplished based on analyses of full life cycle production process from cultivation of the rape to combustion of the biodiesel.

2 LCA of Rapeseed Biodiesel

The life cycle of a product means the whole process it goes through all the way from raw materials acquisition, product design, manufacture, package and transport, distribution and sale, application and maintenance to final disposal and recycling [8]. According to the definition from SETAC [9], Life Cycle Assessment is an objective procedure used to evaluate the environmental impacts associated with a product's entire life cycle, based on quantitative determination of all the exchange flows between the product system and the ecosphere during all the involved transformation processes, from the acquisition of materials to the end of this product. Basic process of a Life Cycle Assessment involves goal and scope determination, inventory analysis, impact assessment and results explanation [5,6]. Life Cycle Assessment has become a useful tool for investigations on product development, cost estimate and environment impact especially.

As a typically renewable fuel, life cycle process of biodiesel includes raw material growing, raw material extraction, raw material product processing, biodiesel production, production distribution and use. The life cycle of rapeseed biodiesel production is generally divided into four stages. The first stage is the rape plantation stage, the second one is rapeseed oil milling stage, followed by the rapeseed biodiesel production stage and finally the biodiesel combustion in transportation. It should be noted that production distribution exists in the process of each stage .The system boundaries of this study are shown in Fig.1.

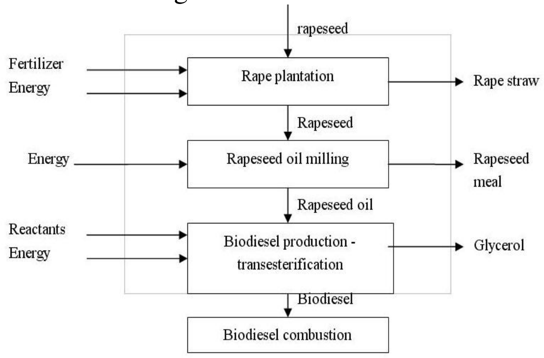

Figure 1:.System boundaries for the production of biodiesel from rapeseed oil

In the rape plantation stage, several processes are involved. The processes include site preparation before planting, seeding in time, field maintenance, integrated pest management and harvesting. In this stage, materials and energy, like seed, fertilizer, pesticide, traction and so on are all needed. The processes of producing and milling these materials need energy, and CO_2 emissions during these processes also should be considered into the assessment. The output of the first stage, rapeseed, should be transported to rapeseed oil mill. Rapeseed oil milling can be divided into two steps, seed pretreatment and getting oil through milling. Seed pretreatment also includes several processes like clearance, shelling, drying, crushing, softening, rolling embryo, and preheating. Electricity, traction and steam are all needed in this stage. Subsequently, rapeseed oil, the major product from the rapeseed oil mill, is transported to a biodiesel plant as feedstock for biodiesel production. Biodiesel is conventionally produced via transesterification reaction with rapeseed oil and alcohols in the presence of alkali catalysts (generally sodium hydroxide), where the outputs are glycerol and esters. The main product is ester, which is just what we called biodiesel, while glycerol is by-product. Finally, in the stage of biodiesel combustion, biodiesel is used in diesel engines which have been widely applied in diesel vehicles, diesel engine marines and diesel generator sets, ect. A mass of CO_2 is produced during the combustion of biodiesel.

2.1 CO_2 Assessment

Throughout the whole life cycle of rapeseed oil, CO_2 assimilation and emission take place simultaneously. Through the process of photosynthesis, rape crops absorb CO_2, water and sunlight energy to produce carbohydrates and oxygen. However, for the process of respiration, the oxygen produced from photosynthesis is used to create CO_2. We know that the amount of CO_2 absorbed in photosynthesis is much more than that is released through respiration. Apart from that, the utilization of fertilizers and traction activities in the plantation sites, which will consume fossil energy, also release CO_2 to the atmosphere. In this paper, it assumes that rape straw is transported to rape oil mill and used for the supply of thermo energy needed in the milling stage so as to save energy. So during the production of rapeseed oil in the milling stage, the incineration of strew releases CO_2 to the atmosphere. On the other hand, the amount of CO_2 emission also comes from the usage of electric, steam and traction fuel. Steam is the main energy of this stage, as it is usually generated by combusting fossil fuel, CO_2 emissions are inevitable. Rapeseed biodiesel production will increase the amount of CO2 in atmosphere. In transesterification site, the amount of CO_2 emissions mainly comes from the electric production and steam boiler. Besides, the utilization of input material–reactant release CO_2 too, which comes from the reactant producing.

The CO_2 emissions coming from every stage of each unit of biodiesel production is given by:

$$\mathrm{M}_{ci} = \sum_{j} \mathrm{M}_{\mathrm{ij}} k_j \tag{1}$$

where Mci is the CO_2 emissions of stage i, Mij is the amount of material j inputted in stage i and Kj is the emission coefficient of material j, while Mc_1, Mc_2 and Mc_3 is respectively corresponding to rape plantation stage, rapeseed oil milling stage and biodiesel production stage. The final stage is biodiesel combustion in vehicles, and the calculation is given by:

$$\mathrm{M}_{cf} = 3.66 \chi_c \tag{2}$$

where χ c is the content of C in liquid fuel, and in diesel, it's 0.87. So CO_2 emissions form biodiesel combustion can be approximately calculated by:

$$\mathrm{M}_{cf} = 3.667 \times 0.87 (\mathrm{kg/kg}) \tag{3}$$

The CO2 emissions of all the stages can be obtained by:

$$M_C = \sum_{i=1}^{3} M_{ci} + M_{cf} \,. \tag{4}$$

Table 1 shows the summary of the CO_2 assessment which includes plantation, production, and combustion of rapeseed biodiesel. From the table, it was found that the amount of CO_2 generated and released to the atmosphere in the rapeseed biodiesel production process is less than the amount of CO_2 used by the plants during assimilation (growth) process. This shows that the utilization of rapeseed biodiesel can sequestrate CO_2 and is indeed an environmentally friendly fuel.

Table 1 The CO_2 assessment for rapeseed biodiesel in full life cycle [10]

	CO_2($kgCO_2$/ton biodiesel)	
Parameter	From atmosphere	To atmosphere
Plantation		
Gross assimilation	441752.10	
Total respiration		264776.88
N-P-K fertilizers		990.84
Traction (diesel)		474.95
Subtotal	441752.10	266242.67
Rapeseed Oil Mill-Rapeseed Oil Generation		
Straw incineration		1240.75
Electricity		223.96
Steam		378.10
Diesel		18.56
Subtotal		1861.37
Biodiesel Production		
Rapeseed oil		1445.98
Methanol		232.91
Sodium hydroxide		5.63
Electricity		60.71
Steam		199.01
Subtotal		1944.25
Biodiesel Combustion		
Combustion		3190.29
Subtotal		3190.29
Total	441752.10	273238.58

2.2 Economic Analysis

Ref [11] indicates that a biodiesel plant is profitable only if its capacity is larger than 50kt/year or 80kt/year. Therefore, life cycle assessment on the cost including raw material cost and operate cost for a 50kt/year class biodiesel plant is done in this paper.

2.2.1 Raw Materials Cost

Cost estimate in this paper is based on classical alkali-catalyzed transesterification using rapeseed oil with excess methyl alcohol. In the transesterification, sodium hydroxide is used for catalyst, HCL and NaOH solutions are used for neutralizer to adjust PH. Accordingly the raw materials cost consists of the cost of rapeseed oil, the cost of methanol, the cost of catalyst and the cost of HCL and NaOH solutions.

The estimation of the cost of the rapeseed oil is based on the overall material balance of the process. Triolein, which is used to represent rapeseed oil, is the real reactant, whose molecular weight is almost equal to that of rapeseed biodiesel (only different in one hydrogen atom). Besides, their molecular weights are all large, so we can suppose that the mass of rapeseed biodiesel produced is equal to that of rapeseed oil inputted. The yield of biodiesel is given by: $\rho = Q/W \times 100\ \%$, where ρ is the rate of production, Q is the yield of biodiesel produced and W is the mass of rapeseed oil. During the production, after separating the biodiesel produced at the first time, the unreacted oil and the remaining reactants are fed to the second reactor. It is assumed that the conversion of the rapeseed oil to biodiesel is 90% for one time, and then combined conversion can reach to 99%. Based on all these presumption, the rapeseed oil required to produce 50 kt/year of biodiesel is 51.0kt/year. The cost of rapeseed oil at the Chinese market varied from ￥7500/t to ￥10000/t in the year 2010 and was steady at ￥10000/t from the beginning of the year of 2011 till now. For the purposes of this study a mean value of ￥10000/t is assumed. As a result the cost of the rapeseed oil is 510. million yuan RMB.

The methanol required is 5.4kt/year and the price of methanol fluctuated widely between ￥1500/t and ￥2150/t. For this study, considering high-priced methanol lasted a long time, ￥1935/t is chosen as an average price. As a result the cost of methanol is 10.449 million yuan RMB. Catalyst is fed at the ratio of 1%, that is to say, for every 100g of biodiesel produced, 1g of sodium hydroxide is inputted. Using similar arguments we can calculate the cost of the catalyst (1.1 million yuan RMB) and the cost of the HCL and NaOH solutions (0.3 million yuan RMB). The overall raw material cost is then 414.75 million yuan RMB. It is interesting to note that the cost of oil accounts for 97% of the raw materials cost.

2.2.2 Operation Cost

The cost of the operation consists of the cost of electricity and the cost of steam. It is estimated through the energy balances of the process that the operation consumption are approximately 30 kWh/t biodiesel produced and 1.4 GJ/t biodiesel produced of electricity and of steam, respectively. In china, the price of industrial power is about ￥0.6/kWh and then the cost of electricity for 50kt/year biodiesel produced is 0.9 million yuan RMB. The steam is supplied by industrial boiler and heat loss during steam transportation and utilization process is inevitable, the total thermal efficiency is only approximate 80%. Accordingly, it needs 82kg steam coal whose heat value is 5000kcal/kg to generate the steam that is consumed by the production of one ton biodiesel. As the price of the coal with the heat value is approximate ￥670/t in present Chinese market, cost of steam coal needed by a 50kt/year class biodiesel plant for steam generation is 2.77 million yuan RMB. And in total, the operation cost for such a biodiesel plant is 3.67 million yuan RMB.

2.2.3 Unit Cost Estimate

Taking the forenamed costs together, the variable cost of a 50kt/year class biodiesel plant turns out to be ￥525.52 million/year. As the variable cost accounting for 90% of the total cost which includes variable and fixed cost, the total cost is finally presented as ￥583.91 million/year while the unit production cost is estimated to be ￥11678.2/t.

Table 2 Cost analyses for a rapeseed biodiesel plant

Items (million yuan RMB/ year)	Cost
Raw Material Cost	
Rapeseed oil	510.0
Methanol	10.45
Catalyst	1.10
HCl and NaOH solutions	0.3
Operation Cost	
Electricity	0.9
steam coal	2.77
Production Cost	
Variable cost	525.52
Fixed cost	58.39
Total production cost	583.91

Purified glycerol is a kind of highly valued chemical product used in the manufacture of foods, pharmaceuticals and personal care products, but until results of research in the raw glycerol utilization are successfully commercialized, no revenues can be attributed to glycerol. In addition, when the conversion of rapeseed oil to biodiesel reaches 99%, very little of glycerol is produced, so this paper assumes that revenues from it is zero.

Table 2 summarizes the calculation of the production costs for a rapeseed biodiesel plant that produces 50kt/year of biodiesel. It shows that Raw material cost accounts for 89.2% of the total production cost while the proportion of rapeseed oil cost in total production cost is up to 86.96%. Besides, the unit production cost is ￥11678.2/t rapeseed biodiesel, much higher than ￥8300/t 0# diesel oil in the present market. But when the price of diesel rises to ￥9.8/L, it will be economically feasible for a biodiesel plant with a capacity of 50kt/year.

3 Conclusion

In this work, CO_2 emissions and economics of biodiesel production plants that use classical alkali-catalyzed transesterification are studied by the method of LCA. As for economics analyses, we assume the plant capacity is 50kt/year. The result of CO_2 assessment shows that, during the whole life cycle of rapeseed biodiesel, the total amount of CO_2 absorption from atmosphere is much larger than that has been emitted and rapeseed biodiesel is really an environment-friendly energy source. However, cost assessment shows the cost of rapeseed biodiesel production is relatively high, and the production is profitable only if the price of diesel reaches to ￥7.8/liter. At present, profit is hardly realized. If we want to develop rapeseed biodiesel in China, government's encouraging policies, such as tax exceptions and financial subsidies, are necessary. The fact that the cost of rapeseed oil is 87% of the total production cost makes regulating the price of rapeseed oil critical for rapeseed biodiesel development. Government should focus on encouraging rape plantation in the light of local condition, breeding new varieties of rice which is rich in oil production and intensive cultivation to improve the yield of rapeseed.

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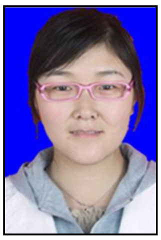

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