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Economic analysis of converting of waste agricultural biomass into liquid fuel: A case study on a biofuel plant in China

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ABSTRACT

Liquid fuel from pyrolysis of waste agricultural biomass has great potential to replace petroleum. In this work, an economic analysis has been carried out to study the production cost of liquid fuel from biomass pyrolysis and economic feasibility of a biofuel plant with a feedstock feeding rate of 4000 kg h^{-1} in China. The results have shown that the production cost of liquid fuel is 1748 yuan per ton, which is less than the expected selling price of pyrolysis liquid fuel (2100 yuan per ton). The liquid fuel production cost is highly sensitive to the liquid fuel yield and unit feedstock cost. The payback period of the biofuel plant with 100% equity financing is about six years. With an internal rate of return of 13%, the biofuel plant would be financially viable if it earns revenues from both liquid fuel and char. If 50% or 30% debt financing is considered, the positive net present value of the biofuel plant would appear at the seventh and eighth year. The results will be helpful for the commercial production and application of liquid fuel from biomass pyrolysis.

1. Introduction

During the period 2000–2015, China's economy grew fast and China's gross domestic product (GDP) grew at a rate of average 9.5% per year (see Table 1) [1]. China's economic growth is largely responsible for its rising energy demand. Thus, China's energy consumption has grown rapidly and will continue to grow along with its economy. Although China is rich in energy resources on an absolute basis, those energy resources can't meet China's rising demand for energy, in particular for oil and gas [2]. The gap between China's supply and demand of oil and natural gas is wider and wider [3].

As the largest agricultural country in the world, China is rich in agricultural biomass resources [4]. According to our previous work [5], about 280 million tons per year of agricultural crop residues are discarded and burned in the field. These agricultural biomass resources can be converted into liquid fuel by means of a certain conversion technology [6], which can alleviate energy shortage in China.

Among various conversion technologies, biomass pyrolysis becomes attractive because it offers a flexible way of converting agricultural biomass resources into liquid fuel [7]. Pyrolysis is the thermochemical decomposition of biomass at elevated temperatures without oxygen [8,9]. Liquid fuel is the main pyrolysis product, char and fuel gas are by-products. Liquid fuel (commonly called as bio-oil [10]) can be used both as an energy source or a feedstock for chemical production [11,12]. Fuel gas can be combusted to produce thermal energy [13]. Char is rich in carbon and can be used as solid fuel [14] or soil amendment [15].

The techno-economic analysis of biomass pyrolysis is very important for the economic feasibility of converting agricultural biomass to liquid fuel by using pyrolysis [16–19]. There existed many researches on the techno-economic analysis of biomass pyrolysis in the literature. Jaroenkhasemmeesuk and Tippayawong [20] performed an economic analysis of the potential of biomass-to-liquid-fuel conversion costs in a demonstrated biofuel plant and viability of biomass pyrolysis commercialization in Thailand and they found that the plant had potential to generate attractive economic return if the upgrading process of liquid products was employed as well as the government subsidy was provided. Wright et al. [21] carried out the techno-economic study of fast pyrolysis of corn stover to liquid fuel. The results showed that the capital costs were \$911 and \$585 million for construction of a pyrolysis and upgrading biorefinery with product values of \$6.55 and \$3.41 per gge (\$1.73 and \$0.90 per liter). Palma et al. [22] analyzed the economic feasibility of a mobile biomass pyrolysis system for the production of liquid fuel, synthesis gas and charcoal substances by using a Monte Carlo simulation model. The results indicated that there was a low probability of a positive Net Present Value (NPV) with current economic conditions. Trippe et al. [23] investigated the economic analysis of a biofuel plant with a capacity of 1000 MW thermal energy inputs which converts biomass into a so-called biosyncrude consisting of liquids and char. They concluded that the production costs for the

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Table 1
China's GDP growth rates during the period 2000–2015.[a]

Year	GDP growth rate/%	Year	GDP growth rate/%
2000	8.43	2008	9.63
2001	8.30	2009	9.21
2002	9.08	2010	10.45
2003	10.03	2011	9.30
2004	10.09	2012	7.65
2005	11.31	2013	7.67
2006	12.68	2014	7.40
2007	14.16	2015	6.90

[a] Data source: Data Center, National Bureau of Statistics, PR China

biosyncrude consist of 50% biomass feedstock costs and 30% investment dependent costs. Rogers and Brammer [24] developed a comprehensive cost and performance model to estimate the production cost of pyrolysis liquid. The model took account sales of char and the electricity consumption of the biofuel plant and biomass pre-processing plants. They found that there was difference in the processing cost for woodchips and baled miscanthus.

The above researches had different scopes, used different feedstocks and reflected different national cost structures. Therefore, the results from those researches can't be directly used to the economic analysis of biomass processing plant in China. A few papers can be found on the economic analysis of biomass pyrolysis in China [25,26]. However, they just gave the value of the liquid fuel production cost, didn't provide the cost components and didn't consider the time value of money. Therefore, the aim of the present work is to evaluate the economic feasibility of a biofuel plant for the production of liquid fuel using pyrolysis in China. The results will be helpful for the industrial application of biomass pyrolysis.

2. Biofuel plant

With partially supported by Chinese government sector, a biofuel plant for the production of liquid fuel through pyrolysis was built in Hefei City, Anhui Province, China. A variety of biomass feedstocks (including agricultural crop residues and forest residues) can be processed in the biofuel plant. As the same as a general conversion process of pyrolysis, the processing steps related in the biofuel plant include feedstock pretreatment, fast pyrolysis, solid removal, liquid fuel recovery, and fuel gas and char combustion [27]. Fig. 1 shows the flow diagram of the liquid fuel production process by fast pyrolysis. First, the feedstock should be pretreated before pyrolysis. Then, the feedstock is converted into a mix of pyrolytic vapor and char under the nitrogen atmosphere at about 500 °C. Then, char is separated from the pyrolytic vapor. Then the pyrolytic vapor is rapidly quenched in the condensation system. The fuel gas and some of char are combusted to heat the reactor and to dry the feedstock. Detailed information about the pyrolysis process can be found in the literature [28].

In China, about 40 million tons per year of rice husk is produced [5]. Therefore, rice husk is chosen as the raw material of this economic analysis. The production yields are 43.2% for liquid fuel, 34.0% for char and 22.8% for fuel gas, respectively. In the biomass conversion system, all fuel gas and 20% of char are combusted to provide the thermal energy to the reactor and the dryer.

3. Total project investment

In order to determine the biofuel plant project's affordability and decide whether to continue, the production cost estimate of liquid fuel should be prepared. Some major assumptions are made as follows: the biofuel plant has the capacity of 4000 kg h^{-1} of feedstocks; the operation time of the biofuel plant is 330 days per year.

The total project investment consists of the cost for equipment and installation, cost for infrastructure and land, contingency cost, working capital and startup cost.

The complete set of equipment for the biofuel plant is assumed to cost 8 million yuan (Chinese currency unit). The total installation cost is assumed to be 2 million yuan. So the total installed cost is estimated to be 10 million yuan.

The contingency cost is assumed to be 20% of the total installed cost: 2 million yuan.

The infrastructure cost includes the costs for the feedstock warehouse, char warehouse, site development, water and electricity supply network and office. The total infrastructure cost is estimated to be 5 million yuan, accounting for 50% of the total installed cost.

The biofuel plant requires a 15 mu (mu is a Chinese area unit, 1 mu=0.0667 ha) of land area. The unit land price is assumed to be 0.2 million yuan per mu. So the total land cost is estimated to be 3 million yuan.

The total capital investment includes the total installed cost, the contingency cost, the infrastructure cost, the land cost and the working capital. The working capital is assumed to be 15% of the total capital investment. The sum of the installed cost, the contingency cost, the infrastructure cost and the land cost accounts for 85% of the total capital investment. Therefore, the working capital and the total capital investment are calculated to be 3.529 and 23.529 million yuan, respectively.

The total project investment includes the total capital investment (accounting for 90% of the total project investment) and the startup cost (accounting for 10% of the total project investment). Therefore, the total startup cost and the total project investment are calculated to be 2.614 and 26.143 million yuan, respectively.

Table 2 lists the details of the project investment.

4. Production cost of liquid fuel

After estimating the total project investment, the annual production cost of liquid fuel can be derived. The production cost includes the depreciation cost and operating costs. The costs for the feedstock, water and electricity, and liquid fuel storage and transportation belong to variable operating costs, while the costs for labor, management, maintenance, and insurance and taxes are fixed operating costs. The biofuel plant is considered 100% equity financed in this section (in the later section, the debt and equity financing will be also considered). So the production cost of liquid fuel does not include the investment loan.

The unit feedstock cost is assumed to be 400 yuan per dry ton of feedstock, which includes the pretreatment fee of the feedstock. The biofuel plant can process 31,680 t of per year (4000×24×330÷1000=31680 t). Then the annual feedstock cost is estimated to be 12.672 million yuan.

The water and electricity cost required for processing one dry ton of feedstock is assumed to be 50 yuan. The annual water and electricity

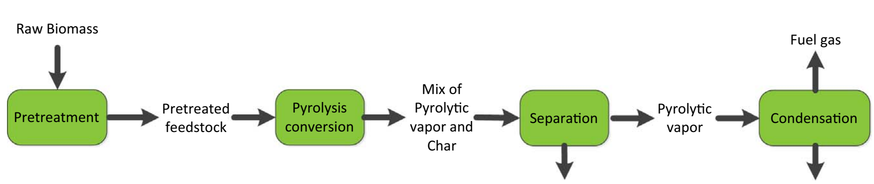

Fig. 1. Biomass pyrolysis process.