Greenhouse gas emission of corn butanol in life-cycle

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Abstract. Since advances in the ABE (acetone-butanol-ethanol) fermentation process in recent years have led to significant increases in its productivity and yields, the production of butanol and its use in motor vehicles have become an option worth evaluating. It employs a well-to-wheels (WTW) analysis tool, and ascertains Bio-butanol-related WTW activities including corn farming, corn transportation, butanol production, butanol transportation, and vehicle operation. According to the 3 kinds of by-product of different methods of distribution, calculation and comparison of the greenhouse gas emissions in the life cycle of corn alcohol. The results show that 1) life cycle GHG emission of the corn butanol reduced 26%—49.5% according to the energy value method and product substitution method;2) bio-acetone that was coproduced with bio-butanol as an alternative to petroleum-based acetone could significantly reduce the life cycle GHG emission of butanol; 3) In the life cycle of the corn butanol, the main source of GHG emission was the use of natural gas, diesel and nitrogen, , accounting for the total GHG emission by 53%, 21.4% and 13.38% respectively.

1. Introduction
2010, crude oil consumed in transportation accounted for about 68% of the total crude oil consumption, of which vehicle oil consumption accounted for about 57%. There is a shortage of domestic oil resources, and more than half of the oil is dependent on imports. The NDRC forecasts that by 2015, China may import 370 million tons of crude oil, equivalent to 7.4 million barrels a day, and the dependence on oil imports will reach 65 percent. The rapid increase of energy consumption has not only brought serious threats to energy security, especially oil security, but also led to high environmental emissions. The development of traffic alternative fuels has become an important measure for our country to get rid of the energy, especially oil predicament [1]. As an alternative fuel for vehicles, butanol has more advantages than ethanol and has become one of the most concerned fuels in recent years.

From the whole life cycle of traffic fuel, the greenhouse gas (greenhouse gas, GHG) emitted by the engine during the driving process of the motor vehicle accounts for only a part of the total carbon emissions, and the rest is derived from the fuel production link, which needs to consume a variety of energy and resources, and greenhouse gas emissions . At present, the domestic research on fuel butanol is focused on the use of vehicles, and there is little research on the life cycle of butanol. In this paper, the life cycle of fuel butanol is evaluated by using corn as raw material.

2. Life cycle inventory analysis of butanol
Taking the national average corn planting area (8500 kg / ha corn yield) as the research object, taking the 150000 t / ha butanol production system as an example, taking the GHG emission index from the
raw material production to the vehicle use in the life cycle of ordinary gasoline as the evaluation basis, the GHG emission in the life cycle of corn butanol is evaluated.

2.1. Formatting the title
The title is set 17 point Times Bold, flush left, unjustified. The first letter of the title should be capitalized with the rest in lower case. It should not be indented. Leave 28 mm of space above the title and 10 mm after the title.

2.2. Life cycle systems
The Butyl alcohol life cycle system includes five stages: raw material production, raw material transportation, butanol production, butanol transport and the use of butanol on vehicles. The raw material production stage refers to the "sowing, growing, harvesting and processing" process of corn. The main material inputs include seed, machinery, nitrogen fertilizer, phosphate fertilizer, potassium fertilizer, electricity, diesel oil, pesticide and so on. The input of substances per hectare of corn production and processing is shown in Table 1. The production stage of butanol is the process of converting the solar energy absorbed by corn production into chemical energy. The main processes include crushing, liquefaction, saccharification, ABE fermentation, gas stripping, distillation, drying, etc. In addition to butanol, there are acetone, ethanol and dry distillerundefineds grains soluble (DDGS) [2].

| Table 1. Material input of every hectare corn production and processing |
|---|---|---|---|---|
| seeds/kg | machinery /kg | powe /kwh | diesel /L | pesticide /kg |
| 32 | 10.8 | 270 | 97 | 1.25 |

In the Butyl alcohol production phase, natural gas is mainly used to provide steam, and the required electricity comes from the national power grid. The demand for natural gas and electricity during the butanol production phase is shown in Table 2.

| Table2. Natural gas and electricity requirement for the corn butanol production process |
| Production | Natural gas (MJ/kg) | Electric energy (kWh/kg) |
| smash | 5.1 | 0.04 |
| dry | 5.5 | |
| ABE fermentation and gas stripping, distillation | 24.05 | 0.04 |
| amount to | 34.65 | 0.08 |

2.3. Evaluation indicators
Greenhouse gases (GHG) are natural and man-made gases in the atmosphere that absorb and re-emerge infrared radiation, such as carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) and chlorofluorocarbons (CFCs), and are related to vehicle fuels in the first three terms. The greenhouse gases calculated in this paper include CO₂, CH₄ and N₂O.

Global warming potential (global warming potential, GWP) refers to the measured values of radiation effects of different greenhouse gases relative to CO₂ in a certain period of time [4]. In this paper, the global warming potential of various GHG issued by the United Nations Intergovernmental Panel on Climate change in 2006 is used, as shown in Table 3. The GHG emission factor EF of various terminal energy or agricultural materials is calculated by three greenhouse gas emissions E, and the unit is carbon dioxide equivalent, as shown in formula (1).

\[
EF = E_{\text{CO}_2} \times 25 + E_{\text{CH}_4} \times 298 + E_{\text{N}_2\text{O}} \times 2298
\]

| Table3. GWP of three GHGS |
|---|---|
| Carbon dioxide equivalent |
| CO₂ | 1 |
| CH₄ | 25 |
| N₂O | 298 |
In the life cycle of corn butanol, there are three sources of greenhouse gas emissions from the system. Firstly, greenhouse gas emissions from a variety of energy and materials in each stage, including chemical fertilizers, natural gas, electricity, diesel oil, etc.; Secondly, CO_2 produced by fermentation during butanol conversion; Thirdly, CO_2 released by combustion of butanol during vehicle use. In this study, only the majority of CO_2 emissions are considered, and greenhouse gas emissions from pesticides and artificial labor are not included in the systematic calculation. The carbon dioxide produced by the chemical reaction of butanol fermentation and combustion comes from the carbon dioxide absorbed from the atmosphere through photosynthesis during corn growth, forming a closed circuit cycle between the atmosphere and corn, as shown in figure 1. Therefore, CO_2 absorbed by corn can be offset by CO_2 emissions in the second and third items at the planting stage. Only the first item is considered when calculating greenhouse gas emissions for the life cycle of corn butanol.

![CO2 cycle in corn butanol life cycle](image)

2.4. Data allocation methods for products

In the analysis of GHG emissions, the data distribution methods of products mainly include weight method, energy value method, product substitution method, market value method and so on. Each allocation method will have an important impact on the evaluation of GHG emission results in the life cycle [3]. Because the yield of acetone and DDGS by-products is higher in the process of producing butanol, different distribution methods will lead to different analysis results, so three distribution methods are selected for analysis in this paper. Method 1: do not consider the treatment and utilization of by-products. Method two: energy distribution method. Acetone, ethanol and DDGS are all regarded as energy products. According to the calorific value and output of the products and by-products, the energy output ratio of various products is calculated to allocate GHG emissions. Method 3: acetone produced by corn fermentation is regarded as renewable energy, which is used to replace acetone produced by traditional oil, and DDGS is used to replace feed.

2.5. Calculation model

The concept of functional unit needs to be introduced in the life cycle analysis of vehicle fuel, which is based on "1 kg corn butanol fuel". Define the total greenhouse gas emissions over the life cycle of corn butanol as \( \text{GHG}_{\text{LC}} \). In the production phase \( j \), the greenhouse gas emissions caused by consumer material \( i \) is calculated by the GHG emission factor \( \text{EF}_i \) and the consumption \( S_{i,j} \) unit corresponding to \( i \), as shown in formula (2).

\[
\text{GHG}_{\text{LC}} = \sum_{j=1}^{4} \text{GHG}_{\text{LC},j} = \sum_{j=1}^{4} \left( \sum_{i=1}^{6} \text{EF}_i \times S_{i,j} \right)
\]

In the formula, \( i = 1 \) to 6 denote the nitrogen fertilizer, the phosphate fertilizer, the potassium fertilizer, the natural gas, the electric power and the diesel oil, and \( j = 1 \) to 4 are the raw material production stage, the raw material transportation stage, the butanol production stage and the butanol transportation stage, respectively.
2.6. Data
This study mainly obtained the data related to corn butanol production through literature research, expert interviews and field research. The relevant data of the use of various agricultural materials in the raw material planting stage mainly came from the domestic statistical yearbook [4], the literature value; in the butanol production stage, the industrial production related data mainly came from the foreign literature and the enterprise research; the GHG emission factor of each material referred to the domestic literature value.

According to the literature, the annual production of butanol is 150000 tons, the consumption of corn is 834000 tons, the yield of butanol is 18%, and the by-product acetone is 84000 tons, ethanol is 4050 tons, DDGS is about 259500 tons. Diesel freight cars are used to transport raw materials and butanol by road, and the consumption of 100 tons of diesel oil is about 5 liters, and the transportation distance is 300 kilometers and 500 kilometers, respectively.

3. Research results

3.1 Greenhouse gas emissions under the three options
According to method 1, the material consumption of 1kg corn butanol is calculated according to the data above, and the greenhouse gas emission of corn butanol is calculated as 3473g CO2 equivalent / kg butanol according to the formula, as shown in the table4.

|          | nitrogenous fertilizer /kg | phosphate fertilizer /kg | potassic fertilizer /kg | natural gas /m³ | powe /kWh | diesel oil /L |
|----------|---------------------------|--------------------------|-------------------------|-----------------|-----------|---------------|
| EF*      | 5148                      | 587                      | 811                     | 1980            | 1071.7    | 4372.5        |
| consumption | 0.105                  | 0.056                    | 0.058                   | 0.93            | 0.25      | 0.17          |
| GHG /g   | 540.5                     | 32.9                     | 47.0                    | 1841.4          | 267.9     | 743.3         |
| GHG /%   | 15.6                      | 0.9                      | 1.4                     | 53              | 7.7       | 21.4          |

* the unit of EF: gCO2 *kg butanol -1

According to method 2, the output and calorific value of products and by-products in the process of butanol production are shown in Table 5 by using energy distribution method. According to formula (3), the life cycle GHG emission of corn butanol can be calculated to be 1962gCO2 equivalent / kg butanol.

$$GHG_{BU} = GHG_{LC} \times \frac{E_{BU}}{E_{LC}}$$

| Product | Output (kg) | Low heating value (MJ/kg) | Energy output ratio |
|---------|-------------|---------------------------|---------------------|
| butanol | 1           | 35.1                      | 56.5%               |
| acetone | 0.56        | 29.73                     | 26.8%               |
| alcohol | 0.027       | 26.77                     | 1.1%                |
| DDGS   | 1.73        | 5.6*                      | 15.6%               |

*energy substitution facto of DDGS

In the formula, the life cycle GHG emission of the main product butanol according to the method is the life cycle GHG emission of the method one butanol, and the energy output of the main product butanol is the energy output of all the products. According to method 3, the petroleum-based acetone was replaced by acetone co-produced by biobutanol, and DDGS is used to replace feed by product substitution method. The traditional raw material for the production of acetone is cumene. It is set that 2.21 tons of cumene is needed to produce 1 ton of acetone. The distance between the diesel truck and the user is 500 kilometers, and the consumption of 100 tons of diesel oil is about 5 liters. Using the GREET model [5] and combined with the relevant literature, it is calculated that the GHG emission of the main product in the life cycle is about 38.5% of that of scheme 1, which is 1337gCO2 equivalent /
kg butanol. The results of the GHG emissions from three programmes are summarized and compared with the equivalent calorific value of the gasoline GHG emissions[6].

3.2 Analysis of results

Compared with the GHG emissions of gasoline with the same calorific value in its life cycle, the GHG emissions of corn butanol in scheme 1 increased by 31%, and the GHG emissions in options II and III decreased by 26% and 49.5%, respectively. If both acetone and DDGS are used as fuel, GHG emissions can be effectively reduced, and biological acetone can be used instead of traditional petroleum acetone. GHG emissions can be significantly reduced. Therefore, it can be seen that acetone is a very critical factor in GHG emission analysis of the corn butanol life cycle. First, traditional acetone production is fossil energy-intensive production, and isopropyl benzene is produced from propylene and benzene, which are extracted from naphtha and natural gas, which is 100% fossil raw material. Secondly, the acetone production of ABE fermentation process is high, and every ton of butanol is produced, 0.56 tons of acetone is produced. When replacing petroleum acetone with bioacetone, renewable energy has replaced fossil energy, which significantly reduces GHG emissions.

4. Conclusion

(1) Using ABE fermentation method to completely replace gasoline with corn as raw material can effectively reduce GHG emission from the point of view of life cycle. According to different distribution schemes, the GHG emission of corn butanol life cycle can be reduced by 26%—49.5% compared with the same calorific value gasoline.

(2) The yield of acetone in the ABE fermentation process is high, and 0.56 ton of acetone is produced when one ton of butanol is produced. As a result, acetone is a very critical factor in the GHG emissions analysis of the corn butanol life cycle. When replacing petroleum acetone with bioacetone, the renewable energy replaces the fossil energy and can significantly reduce GHG emissions.

(3) In the life cycle of the corn, the main source of GHG emissions is the use of natural gas, diesel and nitrogen, accounting for 53%, 21.4% and 13.38% of the total GHG emissions, respectively. If the transport vehicle is replaced with a gasoline truck and corn-butanol is used as a substitute fuel, while minimizing the amount of nitrogen fertilizer used, the GHG emissions can be further reduced.

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