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Life cycle cost analysis of a biological jet fuel process

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ABSTRACT

The research focuses on the life cycle cost-benefit analysis of bio-aviation fuel, encompassing policy, market, and technological aspects, to assess its industrial application and environmental impact. Employing a Life cycle Cost Analysis (LCCA) framework, the study systematically evaluates the internal and external costs associated with bio-aviation fuel production. It conducts a thorough literature review and policy analysis to contextualize findings within the broader scope of sustainable development.

The study meticulously examines the economic and environmental implications of bio-aviation fuel production, revealing its potential to substantially decrease the aviation industry's carbon footprint. The LCCA model, when applied to the bio-aviation fuel lifecycle, identifies key cost drivers and environmental impact points, enabling targeted optimizations. The research findings indicate that despite the current higher production costs compared to traditional jet fuels, the long-term benefits in terms of reduced CO_2 emissions and improved energy security are substantial. The study also highlights the importance of policy support in reducing market risks and encouraging technological advancements. It concludes that with continued research and development, as well as strategic policy initiatives, bio-aviation fuel can become a mainstream and sustainable alternative in the aviation fuel mix, contributing to the global efforts to combat climate change and achieve carbon neutrality. The comprehensive analysis provides a robust foundation for stakeholders to make informed decisions and for policymakers to craft effective strategies for the aviation sector's sustainable development. The study introduces an innovative LCCA model for a comprehensive assessment of bio-aviation fuel's lifecycle costs. It contributes to the field by providing a robust analytical tool for policymakers and industry stakeholders, emphasizing the strategic importance of bio-aviation fuel in achieving carbon neutrality and environmental sustainability.

Keywords: Life Cycle Cost Analysis (LCCA), Bio-aviation Fuel, Sustainable Development

1. INTRODUCTION

In order to seek the healthy development of local refineries, realize the harmonious development of resources and environment, economy and society, and guarantee the win-win situation for the interests of the government, enterprises and residents, it is especially important to carry out a systematic and targeted environmental impact assessment of carbon dioxide utilization in all kinds of production projects in refineries. The research on CO_2 utilization process is mainly carried out at the level of technological innovation, while the research on environmental cost-effectiveness evaluation methods mainly focuses onrecognition, measurement of environmental costs, disclosure of environmental information and the application of environmental information in business decision-making. In this study, a review of domestic and international research is carried out from the dimensions of CO_2 chemical utilization process as well as pathway and environmental benefit evaluation method based on the whole life cycle cost analysis model.

From the existing literature can provide reference and reference for the environmental benefit analysis based on full life cycle cost of CO_2 utilization in independent refineries, but there are still some places that deserve to continue to improve and deepen the research to find a richer and more suitable research perspective.

First of all, although carbon dioxide utilization technology is the focus of various scholars, few scholars have studied the carbon dioxide utilization of independent refineries. In addition, there are more studies on corporate CO_2 utilization pathways in China, but there are few studies on the life cycle cost evaluation of corporate CO_2 chemical utilization processes in independent refineries. Even though researchers in

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China have been improving and expanding LCCA studies to meet the needs of different fields, the application in independent refinery enterprises is rarely mentioned. Furthermore, in the existing literature studies, there are few systems that comprehensively evaluate the economic-environmental costs as well as the benefits of a project. Therefore, this paper decides to construct the LCA-LCCA model to comprehensively evaluate the pathway for chemical utilization of CO_2 in independent refineries by calculating the internal costs, external costs as well as inventory analysis and impact evaluation.

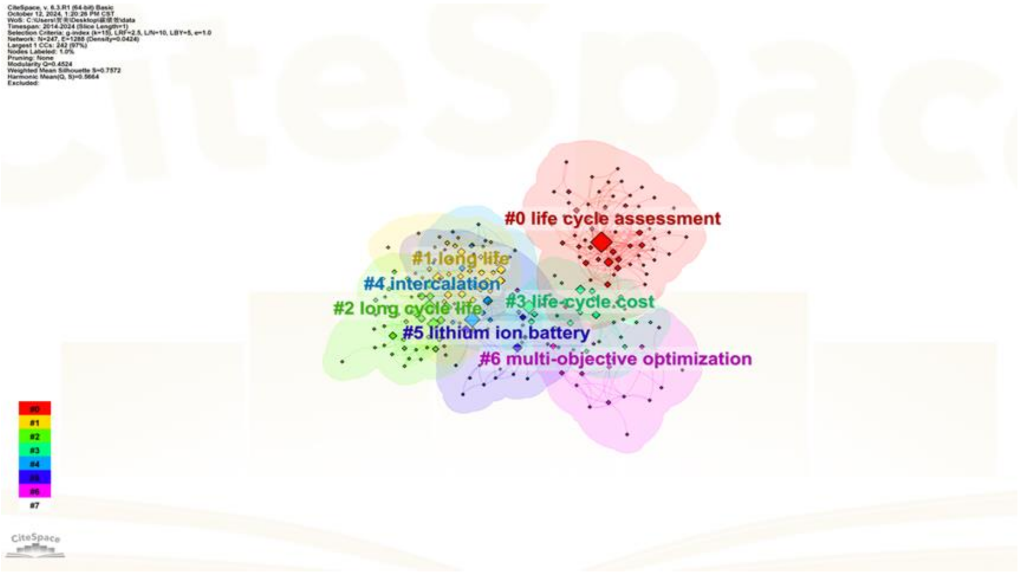

Fig. 1. Keyword Clustering Mapping for Full Life Cycle Costing (LCCA) Research

The data in this section are mainly from two web databases under the Web of Science (WOS) platform, namely, Science Citation Index Expanded (SCI-E) and Social Science Citation Index (SSCI) web-based databases. According to the actual needs of the study, the search term of this section is set as Topic “life cycle cost”, the search period is set as 2010-2024, the search time is October 12, 2024, and the number of highly cited paper is 725 articles.

According to the CiteSpace analysis of the keywords of 725 papers, it can be found that the clustering is 7 categories, including life cycle assessment, long life, long cycle life, life style cost, muti-objective optimization and so on.

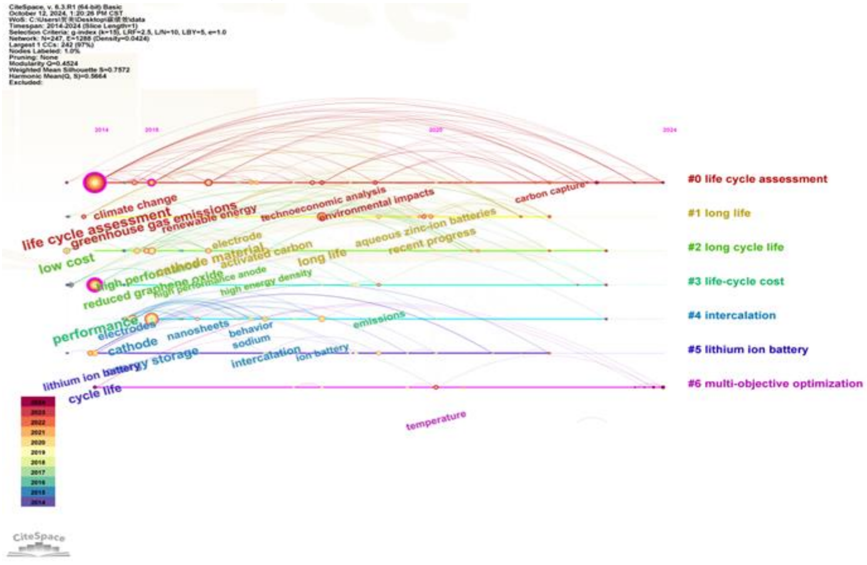

Fig. 2. Full Life Cycle Costing (LCCA) Research Keywords Timeline Chart

After obtaining the keyword clustering analysis of the whole life cycle cost related literature, further, the time line analysis with clustered keywords is shown in Fig.2. The research trend analysis of keywords related to ecological footprint between 2010 and 2024 can be clearly understood. From the figure, the research hotspots are shifting from cost management, cost control, material costs, etc. to information costs, influencing factors, incremental benefits, value creation, etc. year by year.

2. POLICY CONTEXT

2.1 Bio-fuels policy

The United States passed the Energy Policy Act (EPAct) in 2005 and established the Renewable Fuel Standard (RFS), mandating the use of certain renewable fuels to replace fossil fuels. 2007 saw the introduction of the Energy Independence and Security Act (EISA), which amended the Renewable Fuel Standard (RFS2) to expand the targets for renewable fuel use, with a focus on increasing the use of cellulosic biofuels and biomass-based fuels. In 2007, the Energy Independence and Security Act (EISA) amended the Renewable Fuel Standard (RFS2), expanding the targets for renewable fuels, with a focus on increasing the consumption of advanced biofuels, including cellulosic biofuels and biomass-based diesel.

In May 2009, the European Commission developed and implemented the Renewable Energy Directive (RED), which was revised in 2015 and entered into force in 2018 (REDII), and has been implemented since July 2021.REDII establishes a longer-term (2021-2030) plan for the use of renewable energy. In 2023, the European Commission further revised the Renewable Energy Directive REDIII, which continues to push up the 2030 targets for renewable energy use and the share of advanced biofuels, with the exception of crop-based biofuels and animal- and fat-based biofuels. However, the share of crop-based biofuels and animal- and fat-based biofuels will not be increased, and the additional targets will be met mainly by other types of renewable energy.

"RFNBO" refers to Renewable Liquid and Gaseous Fuels from Non-Biological Sources, which is a renewable fuel product group defined in the EU Renewable Energy Directive (Article 2.36). These fuels are produced from renewable energy sources other than biomass. Thus, gaseous renewable hydrogen produced by feeding electricity based on renewable energy sources into an electrolyzer is considered to be RFNBO, while liquid fuels, such as ammonia, methanol and e-fuels, can be considered to be RFNBO when produced from renewable hydrogen.

2.2 Sustainable aviation fuel policies

The EU Renewable Energy Directive (RED I) stipulates that from 2020 onwards, the proportion of bio-jet fuel to be added to aviation fuel will be substantially increased: the proportion of bio-jet fuel to be added to aviation fuel will be no less than 2% in 202, no less than 5% in 2030, no less than 20% in 2035, no less than 32% in 2040, no less than 38% in 2045, and no less than 63% in 2050. In July 2021, the Eminent Council published a climate package called "Fit for 55" ("Carbon Reduction 55"), which puts forward a series of 12 more aggressive initiatives including energy, industry, transportation, buildings, etc., and commits to reducing greenhouse gas emissions by 2030 compared to 1990 levels. The package includes a "Refuel EU Aviation Program" for aviation fuels, which requires fuel suppliers to continuously increase the proportion of sustainable aviation fuels used in onboard aviation fuel at EU airports, with the aim of increasing the proportion to more than 2% of aviation fuel by 2025. The program requires fuel suppliers to continuously increase the proportion of sustainable aviation fuel used in airborne aviation fuel at EU airports, with the aim of increasing the proportion of sustainable aviation fuel to more than 2% by 2025 and more than 63% by 2050. All aircraft flying to the EU are explicitly required to adopt this standard.

The International Civil Aviation Organization (ICAO) has decided to make the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) mandatory for all airlines in its 191 member states after 2026, with excess carbon emissions being recognized through the EU Emissions Trading Market (EU ETS). Excess carbon emissions can be offset by purchasing targets through the EU Emission Trading System.

The Civil Aviation Administration of China (CAAC) proposed in the 14th Five-Year Plan for Green Development of Civil Aviation that it will accelerate the completion of a sustainable aviation fuel certification system, and make every effort to promote the construction of an airworthiness certification system for sustainable aviation fuel. Carry out the demonstration of the normalized application of sustainable aviation fuel, and pilot the blending and supply of sustainable aviation fuel in airports with an annual passenger throughput of more than 5 million in Beijing-Tianjin-Hebei, Yangtze River Delta, Guangdong-Hong Kong-Macao Greater Bay Area, Chengdu-Chongqing, Hainan and other regions, and support the relevant airports in accelerating the construction of supporting infrastructures. Strive to reach a consumption of more than 20,000 tons of bio-jet fuel in 2025, and a cumulative consumption of 50,000 tons during the Fourteenth Five-Year Plan period.

China's research and development and use of aviation biofuels, related laws and regulations and development goals are still relatively rough, most of the policies are mainly reflected in some support for biodiesel, no targeted support policies in the promotion, taxation and financial aspects. As the key support for the future aviation industry, the clean and low-carbon choice of aircraft fuel power is the most important, and relevant subsidies, concessions, taxes and other supporting policies are still expected to be improved and implemented with the promotion of carbon peak and carbon neutral policies.

3. MARKET ANALYSIS

3.1 Overview

Bio jet fuel is aviation kerosene produced from biomass resources, which can effectively reduce carbon dioxide emissions compared with traditional petroleum-based jet fuel, and the use of bio jet fuel for flights operating on European routes can reduce carbon emission fees in the European Greenhouse Gas Emission Trading System (ETS). From the technical and economic point of view of the aviation industry, traditional petroleum-based jet fuel will still occupy the dominant position in aviation fuel, which requires that the nature of alternative fuels must be similar to the existing traditional fuels, which can be completely intermiscible with them, and can be blended and co-transported in any proportion. Biojet fuel is basically similar to the existing traditional fuels in terms of energy density, mobility, etc., and is the main aviation alternative fuel in the international arena at present. Compared with fossil jet fuel, aviation biofuel has excellent thermal stability, combustibility and good material compatibility, and all other performance indicators are basically the same as those required for fossil jet fuel, except for the low density of the product.

3.2 SAF Production and Application Analysis

Before the epidemic, the global consumption of aviation coal was about 367.45 million tons, with the recovery of demand for aviation coal in various countries, it is expected that the consumption of aviation coal can be restored to the level before the epidemic in 2025. At present, there is a large gap between global SAF production and demand, accounting for less than 0.01% of jet coal usage. As the aviation industry seeks to decarbonize, the demand for renewable jet fuel is growing globally, and it is expected that by 2025, when SAF replaces 1-2% of jet fuel, the demand will be at least 5 million tons. It is estimated that if China's existing and planned second-generation biodiesel capacity is converted and expanded for the preparation of sustainable jet fuel, together with the capacity that is currently available, the total potential capacity of SAF in China is expected to be only 2.05 million tons in 2025, accounting for 4.5% of the total domestic consumption of jet fuel in that year.

3.3 CO_2 Preparation of Biojet Fuel Technology

Hydrogenation of carbon dioxide to prepare methanol is a promising research to reduce carbon dioxide emissions, produce bioaviation coal and promote sustainable economic development. In the process of using carbon dioxide to produce methanol, carbon dioxide can be separated and captured from industrial process emissions, hydrogen can be obtained from electrolysis of water or industrial by-products using green and clean energy sources such as solar energy or wind energy, and the production process of carbon dioxide hydrogenation to produce methanol adopts renewable energy sources, which not only significantly reduces carbon dioxide emissions, but also realizes the recyclable and regenerative use of carbon resources, which can effectively alleviate China's It can effectively alleviate the current shortage of energy and chemical raw materials in China. CO_2 hydrogenation to methanol is of great significance to the development of China's bio-coal and resource energy reserves, and plays an important role in the sustainable development of production and environment.

Methanol is an important basic organic raw material in the chemical industry and a necessary prerequisite for the development of bio aviation coal, which can be used to produce formaldehyde, acetic acid, dim-ethyl ether, methyl tertiary butty ether and other organic products, and can also be used as a fuel for fuel cells and engines. Therefore, the hydrogenation of carbon dioxide to methanol is one of the best choices for the chemical utilization of carbon dioxide. The main technologies developed so far are thermostatically conversion, electro-chemical reduction, photo-catalytic reduction, photoelectrically reduction and bio-conversion.

3.4 Thermochemical conversion

The hydrogenation of carbon dioxide to methanol is an exothermic process with the main reactions shown in equations 3.1 to 3.3. The process usually occurs in the presence of a catalyst. Since all reactions of carbon dioxide conversion are exothermic processes, high temperatures reduce the conversion of carbon dioxide. Therefore, in order to obtain high CH_3 OH yields as well as to avoid the generation of unwanted by-products, the process should be carried out with a suitable catalyst, a reaction temperature of less than 150 ° C, and a reaction pressure of 5-10 MPa, i.e., high pressures, low temperatures, and hydrogen excesses are favorable for obtaining high methanol yields.

$$CO_2 + 3H_2 \rightarrow H_2OH + H_2O \quad \Delta H_{298K} = -40.9 kJ/mol \ (3.1)$$

$$CO_2 + H_2 \rightarrow CO + H_2O \quad \Delta H_{298K} = -49.8 kJ/mol \ (3.2)$$

$$CO_2 + 2H_2 \rightarrow CH_3OH$$

$$\Delta H_{298K} = -90.7kJ/mol \quad (3.3)$$

3.5 Electrochemical reduction

Under mild reaction conditions, electrochemical reduction is more favorable than thermochemical methods for the synthesis of methanol from CO_2. The method can store electrical energy as liquid fuel without emitting additional CO_2, and the source of H_2 in this method is generally H_2O, making the process environmentally friendly. However, its development and application in industrial production has been slow. The electrochemical conversion of CO_2 to CH_3OH may yield different reduction products, as shown in 3.4 to 3.8.

$$CO_2+8H^++8e^- \rightarrow CH_4+2H_2O \quad (3.4)$$

$$CO_2+6H^++6e^- \rightarrow CH_3OH+H_2O \quad (3.5)$$

$$CO_2+4H^++4e^- \rightarrow CH_2O+H_2O \quad (3.6)$$

$$CO_2+2H^++2e^- \rightarrow CO+H_2O \quad (3.7)$$

$$CO_2+2H^++2e^- \rightarrow HCOOH \quad (3.8)$$

Therefore, the choice of catalyst and the environmental conditions of the reaction play a crucial role in the regulation of CO_2 conversion products. Among them, the hydrogenolysis reaction (HER) with H_2O as the electrolyte is particularly important in the reduction of CO_2 by electrocatalysts. Due to the need for a relatively high HER over-potential, metals are often used as electrocatalysts.

3.6 Photo-catalytic and photoelectrochemical reduction methods

There are three ways to reduce CO_2 to methanol using solar energy: (i) performing photocatalytic CO_2 reduction; (ii) performing CO_2 photoelectrochemical reduction; and (iii) obtaining electricity from photovoltaic devices, which in turn can be used to electrochemically reduce CO_2 via an electrolyze (i.e., electrochemical reduction method).

The photocatalytic CO_2 reduction reaction process involves three main steps: firstly, the semiconductor photocatalyst is exposed to light radiation, and if the energy of the light radiation is greater than the bandgap energy of the semiconductor, the electrons will be excited from the valence band, which is lower in energy, to the conduction band, which is higher in energy; then the resulting electron-hole pairs are separated through the barrier of the semiconductor junction; and finally the photogenerated electrons will adsorb CO_2 adsorbed onto the surface of the semiconductor electrode and H+ adsorbed on the surface of the semiconductor electrode into reduction products, and the photogenerated holes oxidize with water to produce O_2.

The CO_2 photoelectrochemical reduction method is a combination of photocatalytic reduction and electrochemical reduction, the specific method is to catalyze the CO_2 reduction under the combined effect of solar energy and current input. Therefore, the CO_2 photoelectrochemical reduction method, compared with the photocatalytic reduction method in the choice of catalysts in a wider space, compared with the electrochemical reduction method to reduce the reaction overpotential. However, the poor stability of the photoelectrode has hindered its development, and there are relatively few research results in this area.

4. CONSTRUCTION OF LCCA INDICATOR SYSTEM

4.1 Internal costs

Table 1 The internal costs of CO_2 plus H_2 to make biojet fuel

Internal cost type	Production link
Raw material cost IC_1	$IC_1= \sum_{i=1}^{n} M_i \times MC_i$
Energy cost IC_2	$IC_2= \sum_{i=1}^{n} E_i \times EC_i$
Device cost IC_3	$IC_3= \sum_{i=1}^{n} EQ_i \times EQC_i$
Manpower cost IC_4	$IC_4= \sum_{i=1}^{n} H_i \times HC_i$
Indirect cost IC_5	$IC_5= \sum_{i=1}^{n} IED_i \times IEDC_i$

4.2 Cost of raw materials for production

Production feedstock cost (IC1), which includes the cost of raw materials such as CO_2 and catalysts. For refineries that use biomass as a raw material for refining, the production feedstock cost mainly includes the acquisition cost of biomass, catalyst, and CO_2, which is expressed by the formula:

$$IC_1 = \sum_{i=1}^{n} M_i \times MC_i \quad (4.1)$$

4.3 Energy cost

The cost of energy (IC2), which includes the cost of energy sources such as electricity, gas, steam, etc. The cost of energy consumption in a refinery is an important part of its operating costs, which includes the following: electricity consumption, fuel consumption, process heat consumption, and the cost of consuming auxiliary energy sources such as refrigerants, compressed air, and inert gases, which is expressed by the formula:

$$IC_2 = \sum_{i=1}^{n} E_i \times EC_i \quad (4.2)$$

4.4 Equipment cost

Equipment cost (IC3), which includes the acquisition, maintenance and repair costs of equipment such as separators and coolers. Refinery equipment mainly includes biomass pre-treatment equipment, thermo-chemical treatment equipment, electrochemical treatment equipment, photocatalytic treatment unit, carbon dioxide oxidation equipment, etc., which is expressed by the formula:

$$\mathrm{IC}_3 = \sum_{i=1}^{n} \mathrm{EQ}_i \times \mathrm{EQC}_i \quad (4.3)$$

4.5 Labor cost

Labor cost (IC4), including production personnel, technicians, managers and other labor costs. The labor cost mainly includes the basic salary, bonus, performance, five insurance and one gold, and other welfare benefits for production personnel and technicians. The basic salary of first-line production personnel is about 1440 yuan, plus monthly variable bonuses, usually around 2000 yuan, the total remuneration of about 3000 yuan; technical workers have higher wages, up to 5000 yuan or even more than 6000 yuan, the specific amount depends on the technical content and work tasks, the formula is expressed as:

$$\mathrm{IC}_4 = \sum_{i=1}^{n} \mathrm{H}_i \times \mathrm{HC}_i \quad (4.4)$$

4.6 Indirect costs

Indirect costs (IC5), which include expenses such as production plant rent, utilities, communications, and office expenses. Indirect expenses are not directly associated with a particular product or production batch, but rather provide support and services to the overall refinery operation. For accounting purposes, these expenses are usually summarized and charged to the appropriate expense accounts and apportioned to the cost of each product through appropriate allocation methods (e.g., ratios of production man-hours, production volume, sales, etc.) to allow for accurate accounting of product costs and cost control. These expenses include administrative expenses such as office supplies, depreciation and amortization, and leasing expenses; research and development expenses such as research and development funds, research and experimental consumables, and external cooperation and service fees; selling expenses such as sales agents, commissions, and marketing and advertising expenses; and financial expenses such as interest expenses, financial institution fees, insurance premiums, and taxes.

$$\mathrm{IC}_5 = \sum_{i=1}^{n} \mathrm{IED}_i \times \mathrm{IEDC}_i \quad (4.5)$$

4.7 External cost

External costs are the negative impacts on society and the ecological environment caused by the process of manufacturing bio-jet fuel, which are summarized in the project as four aspects: external transportation of fossil energy EC_1; external costs of production and processing EC_2; external costs of transportation and sales of the product EC_3; and costs of emissions of the waste used in the product EC_4.

4.8 External transportation cost

The cost of external transportation of fossil energy and raw materials is mainly the carbon emissions generated by the consumption of fuel by transportation vehicles, which is calculated by the following formula:

$$EC_1 = Q_1 D_1 \times \sum_{i=1}^{n} (EF_i \times EV_i) \quad (4.6)$$

Where Q1 is the fuel consumption per unit distance; D1 is the transportation distance; EFi is the environmental emission factor of the item-i emission; and EVi is the environmental value of the item-i emission.

4.9 External costs of production and rocessing

The external costs of the manufacturing process are mainly due to carbon emissions from fuel combustion and electricity consumption:

$$EC_2 = Q_2 \times \sum_{i=1}^{n} (EF_i \times EV_i) + Q_3 \times \sum_{j=1}^{n} \left(EF_j \times EV_j\right) \quad (4.7)$$

Where: Q2 is the total processing volume; EFi is the emission of the item-i emission in the chemical reaction per unit processing volume; EVi is the environmental value of the item-i emission; Q3 is the total amount of energy utilized in the processing process; EFj is the environmental emission coefficient of the item-j emission produced by the energy utilization; and EV_j is the environmental value of the item-j emission from the energy utilization.

4.10 External cost of product transport

Transportation of products is similar to transportation of raw materials in that its cost is mainly derived from the burning of fuel for transport vehicles:

$$EC_3 = Q_4 D_2 \times \sum_{i=1}^{n} (EF_i \times EV_i) \quad (4.8)$$

where Q4 is the fuel consumption per unit distance; D2 is the transport distance; EFi is the environmental emission factor of the ith emission; and EVi is the environmental value of the item-i emission.

4.11 Cost of waste emissions from product use

The external cost at this stage is the environmental cost of emissions from the use of products such as bio-aviation coal and diesel fuel, which is calculated using the following formula:

$$EC_4 = Q_5 \times \sum_{i=1}^{n} D_i \times \sum_{i=1}^{n} (EF_i \times EV_i) \quad (4.9)$$

where Q5 is the fuel consumption per unit distance; Di is the transport distance; EFi is the environmental emission factor of the ith emission; and EVi is the environmental value of the item-i emission.

5. ANALYSIS OF MEASUREMENT RESULTS - CO$_2$AF TECHNIQUE

Assuming the production and processing of 10,000 tonnes of bio-aviation coal, using electrocatalysis and a complex iron catalyst for the catalyst, the costs associated with its production are calculated as follows:

Including the cost of carbon dioxide and catalyst, the unit cost of industrial-grade carbon dioxide is RMB 2,000~5,000/tonne, and the cost of catalyst is RMB 40,000~50,000/tonne.

The maximum reduction of carbon dioxide emissions in the whole life cycle of bioaerial coal can be more than 50%, and the production and processing of 10,000 tonnes of bioaerial coal will reduce carbon emissions by about 8,000 tonnes, which can result in a direct carbon benefit of about 568,000 yuan (calculated at a carbon trading price of 71.01 yuan on 9.1.2024)

$$LCC = IC + \sum_{i=1}^{2}\sum_{j=1}^{5} EC_{i,j} \quad (5.1)$$

LCC(CO2AF)=149220.04 (unit: RMB Ten thousand Yuan)

It is obtained from the validation that the life cycle cost of production of 10,000 tonnes of bio-jet fuel per year by CO2AF technology is RMB 988,703,400, and the unit cost is RMB 988,703,400/t.

One of the biggest resistances to the development of sustainable aviation fuels is the cost, including technological cost and environmental cost. Overall, the cost of different technological paths to produce sustainable aviation fuel is two to six times the price of today's jet fuel.

Table 2 The costs of the production and processing of 10,000 tonnes of bio-aviation coal

	Annual consumption	Unit price (100000 yuan)	Amount (100000 yuan)
1. Internal cost			98454.14
1.1 Raw material cost			9343.97
1.1.1 H_2	4800	18000/t	8640
1.1.2 CO_2	35700	132.74/t	473.88
1.1.3 Catalyst	10000	230.09/t	230.09
1.2 Energy cost			1469.39
1.2.1 Electricity	10380000	0.58/kWh	602.04
1.2.2 Production water	888000	4.96/t	440.45
1.2.3 Natural gas	1126400	3.79/t	426.91
1.3 Equipment cost			82368.77
1.3.1 Construction cost			32706.99
1.3.2 Process plant			
1.3.2.1 Green liquid fuel			16954.79
1.3.2.2 Catalyst 1			14684.70
1.3.2.3 Catalyst 2			2270.09
1.3.3 Other supporting systems			15752.2
1.4 Manpower cost			1136
1.4.1 Production personnel wages	2000	3440/person	688
1.4.2 Technical staff wages	800	5600/person	448
1.5 Overhead			1136
1.5.1 Living water	16000	2.2/t	3.52
1.5.2 Operation and maintenance costs			4405.41
1.5.3 Research and development cost			2181.98
2. External cost			3416.20
2.1 Energy transportation cost	400000	2.3/km	92.00
2.2 External processing cost	10000	2840/t	2840.00
2.3 Cost of transportation sold	640000	2.3/km	147.20
2.4 Waste recovery cost	6740	500/t	337.00
Total		98870.34	

6. DEVELOPMENT PROPOSALS

6.1 Increased policy support

Firstly, the development of bio-jet fuel is highly dependent on policies, and the development of China's bio-jet fuel industry requires the pull of strong policies. Carbon reduction in China's aviation industry faces a certain urgency and inevitability, compared with Europe and the United States, China's bio-jet fuel production and application of less, the development of bio-jet fuel industry needs to get the attention of all walks of life. Due to the lack of policy support and stimulation, the domestic use of bio-jet fuel is relatively small, inhibiting the enthusiasm of enterprises to invest in and produce bio-jet fuel, and currently there are manufacturers of products are mainly exported to Europe. Therefore, China's bio-jet fuel development needs the introduction of relevant policies.

Secondly, the consumption side of the policy, can strongly pull the development of the whole industry. CORSIA mechanism and the European Union carbon emission reduction policy is the landing point of the aviation enterprise carbon emission restrictions, but also to encourage and support the aviation enterprise consumption of clean aviation fuels, from the consumption side to promote the supply, production, investment, research and development of various aspects, at present to see a better effect. Therefore, the domestic policy can focus on the consumption side, through the influence of airlines on the effective demand for bio-jet fuel, stimulate, drive the production and supply chain

Third, the policy should be guided, into the bio-aviation oil industry resources integration, cultivate the industry Dragon bucket enterprise, improve China's bio-aviation oil industry development level, at present, China's bio-aviation oil industry outside the dry development of the early stage of the head of the enterprise in the market, raw materials, technology, production areas with absolute advantage, both Sinopec, PetroChina and other state-owned oil giants involved in it, but also the State Power Investment accompanied by the community of enterprises based on their own strengths "Bureau, there are many private oil and chemical, technology, and supply chain of production and supply. There are also a lot of private oil and chemical industry, traditional refining enterprises to participate in the industry, the pattern of upstream, midstream and downstream is still relatively scattered, there is a certain degree of fragmentation of the development of the problem. Suction needs to be guided by the policy, from a strategic height to regulate the development of the industry, to avoid disorderly competition, overcapacity, promote the integration of industry resources, improve industry concentration, cultivate the industry leader, to lead China's bio-aviation oil industry, healthy and orderly development.

Fourth, the policy should be able to stimulate the biological jet fuel science and technology research and development, improve China's biological jet fuel industry in the global influence, the need to avoid the introduction of the policy, the domestic supply is insufficient and need to be imported on a large scale, biological jet fuel as a new industry, its technology is still far from reaching the stage of becoming a stable and stable application, must be encouraged through the policy of the relevant scientific research institutions, enterprises to increase the cattle fuels, in particular, biodiesel, biological jet fuel, not only based on the scientific and technological research and development, but also based on the biological jet fuel. Aviation oil research and development of science and technology, not only based on the national conditions of our country, to improve the level of China's bio-aviation oil technology, but also to absorb, the introduction of foreign advanced production technology, to ensure that China's bio-aviation oil industry chain, supply chain of the core technology has always been safe, so that China's bio-aviation oil industry in the world has considerable influence.

6.2 Gradual restructuring of industry

As the energy transition continues, the function of oil will shift from the production of primarily transport fuels to the production of chemicals. Although carbon emissions from chemical refineries have increased significantly in the production chain, their whole-life carbon intensity has decreased by more than 50 per cent. The refining industry can achieve zero life-cycle carbon emissions if future electricity consumption, fuel combustion and process emissions are addressed by technologies such as green power, electrified heating and CCUS. Chemical refineries have full life-cycle low-carbon characteristics and are the direction of low-carbon development for refiners.

Green hydrogen refining. Grey hydrogen is mainly from fossil fuels, and the carbon emissions from the hydrogen production process using traditional processes are 10-23 tonnes of CO2/tonne of hydrogen. Green hydrogen is prepared by electrolysis of water through green power, and the hydrogen production process has no carbon emission, but the cost is relatively high at present. Green hydrogen refining will be one of the important ways to achieve deep decarbonisation of the refining industry. In the medium to long term, the hydrogen supply structure will gradually transition from grey hydrogen to green hydrogen as the demand for carbon emission reduction increases and green hydrogen technology advances and economics improve.

6.3 Increase the use of technology to further promote energy conservation and carbon reduction

With the transformation and upgrading of the global energy structure, the oil industry is facing unprecedented changes. Traditionally, oil has been used mainly as a raw material for the production of transport fuels, but in the future, its role will gradually tilt towards the production of chemical products. This shift is not only an adaptation to changes in energy demand, but also a positive response to environmental sustainability.

Chemical-based refineries may face carbon emission challenges during production, but by adopting advanced technologies and management practices, they can significantly reduce their full life-cycle carbon intensity. For example, carbon emissions from production can be reduced by optimising production processes and improving energy efficiency. What's more, by adopting technologies such as green power (green electricity), electrified heating, and carbon capture, utilisation and storage (CCUS), electricity consumption emissions, fuel combustion emissions, and process emissions can be further reduced, with the prospect of achieving zero life-cycle carbon emissions from the refining industry.

Green hydrogen refining is another important way to achieve deep decarbonisation of the refining industry. Compared to traditional grey hydrogen, green hydrogen is produced through water electrolysis using renewable energy sources (e.g., wind and solar), a process that produces no carbon emissions and has significant environmental advantages. Although the production cost of green hydrogen is relatively high at present, it is expected to decrease gradually with technological advances and large-scale production. In the medium to long term, with the global demand for carbon emission reduction and the development of green hydrogen technology, the hydrogen energy supply structure will gradually transition from grey hydrogen, which has high carbon emissions, to green hydrogen, which has low or even zero carbon emissions. In the process of transitioning to chemical production, refining companies should also pay attention to technological innovations and improvements in other areas, such as optimising crude oil supply, developing molecular refining technology, and improving the efficient use of hydrogen resources. These measures not only help reduce production costs and improve economic efficiency, but also help reduce carbon emissions and realise environmental benefits.

Policy support also plays a key role in promoting the low-carbon development of refiners. The government can encourage enterprises to adopt low-carbon technologies and optimise production processes by formulating relevant policies, such as providing financial support for research and development (R&D), tax incentives and green financial incentives. At the same time, policies should also encourage enterprises to strengthen international co-operation and introduce and absorb advanced low-carbon technologies and management experience from abroad. Changes in public awareness and market demand are also important factors driving the low-carbon development of refining and chemical enterprises. As society's awareness of environmental protection increases, consumers are increasingly inclined to choose environmentally friendly products. Refiners and chemical companies should respond positively to this trend and meet market demand by producing green and low-carbon chemical products.

With the deepening of energy transformation, refining and chemical enterprises are standing on a new development starting point. Through technological innovation, policy support, market-driven demand, and increased public awareness, refiners are expected to achieve a successful transition from traditional petroleum processing to the production of green chemical products, contributing to the goal of global carbon neutrality. This transformation will not only bring new growth points for the enterprise, but will also have a positive impact on the sustainable development of society and the environment.

6.4 Enhancing resource utilisation efficiency

Optimizing crude oil supply. Crude oil is the most important raw material for refineries, and the cost of crude oil accounts for about 90 per cent of the total production cost of refining, therefore, the rational selection and use of crude oil plays an important role in refineries. Efficient use of crude oil resources can be achieved through the development and application of new technologies on the one hand, and the rational selection of crude oil and adjustment of processing programme on the other. The development of optimization models in line with the actual production of refineries, the optimization of crude oil selection and production operation, and the optimization of the total flow in combination with the refining process model can maximize the benefits of the enterprise, while at the same time efficiently managing the carbon assets of the refinery. It is found that changes in crude oil properties have a significant impact on plant-wide energy consumption and carbon emissions.

Molecular Refining (Component Refining) Molecular refining (component refining) is a feasible route to improve oil refining efficiency and reduce refining energy consumption, the core of which is to use advanced separation technology to separate hydrocarbon components from crude oil or its different fractions, and then refine the separated components. Under a certain crude oil price system, it is found that the product output value and gross profit per ton of oil of the component refining scheme are higher than that of the conventional scheme by comparing the economic benefits of the conventional scheme and the component refining scheme.

Efficient use of hydrogen resources. Nowadays, the cost of hydrogen has become the second largest cost element for refineries after crude oil, however, hydrogen production units are costly, consume huge amounts of energy and emit large amounts of carbon. Therefore, the integrated design and optimization of refinery hydrogen system to improve hydrogen utilization is an important way for refiners to save energy, reduce carbon and increase efficiency. To achieve efficient use of hydrogen resources, refining companies need to transition the concept of hydrogen use from crude hydrogen balance to refined hydrogen management, starting from the optimization of raw materials for hydrogen production devices, hydrogen saving management for hydrogen production devices, hydrogen resource recycling and hydrogen network integration and optimization of the four key aspects of hydrogen network system integration and optimization, to achieve the efficient use of hydrogen resources in the gradient and fine management, to increase the efficiency of hydrogen utilization, to minimize hydrogen consumption and system energy consumption, and to increase the efficiency of hydrogen utilization in the system. It also minimizes hydrogen consumption, system energy consumption and carbon dioxide emissions.

6.5 Significant increase in economic support

It is recommended that the construction of technological innovation projects for the use of carbon dioxide resources should be supported. Give full play to the role of the scientific and technological achievements transformation guidance fund, focus on supporting the innovative development and application transformation of carbon dioxide resource utilization technology, layout a batch of forward-looking, strategic and subversive carbon dioxide resource utilization scientific and technological research projects, build a batch of carbon dioxide resource utilization national technological innovation centre platforms and technological application and transformation bases, and strengthen the construction of green technological innovation consortium that are enterprise-driven, market-led, with the in-depth fusion of industry, academia and research, and with international open cooperation. Strengthen the construction of green technology innovation consortium with enterprise as the main body, market-oriented, deep integration of industry, academia and research, and international open cooperation, and actively make use of the policy of the first set of major technological equipment, focusing on supporting a number of carbon dioxide resource utilization technological achievements transfer and transformation projects.

It is suggested to increase financial and tax support for the carbon dioxide resource utilization industry. Set up special financial funds and budgetary investment to support the construction of carbon dioxide resource utilization projects, study and introduce preferential policies on income tax, value-added tax and other relevant aspects; actively develop and guide the development of green finance to support the development of carbon dioxide resource utilization industry, actively encourage and support the listing of qualified carbon dioxide resource utilization enterprises to raise funds, and support the relevant enterprises to carry out green financing in the international and domestic markets.

Seriously implement the Measures for the Administration of Carbon Emission Rights Trading to support the development of enterprises utilizing carbon dioxide resources. Actively guide and support enterprises that utilize carbon dioxide resources to make full use of the Administrative Measures for Carbon Emission Right Trading and other relevant policies to trade the carbon dioxide indexes consumed in excess of the standard in the market, effectively reduce the cost of carbon dioxide resourcing, actively expand the scale of the industry of carbon dioxide resourcing and utilization, and create a fairer legal environment for enterprises to utilize carbon dioxide resources.

DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

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