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# The investigation on the application of dimethyl-ether-based green synthetic fuel to marine power industry

Fuels - Alternative & New Fuels

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## ABSTRACT

This paper aims to explore the practical application potential of dimethyl-ether (DME) as a green synthetic fuel in the decarbonization development of the marine power industry. It will be discussed from the following chapters, including an introduction to DME, engine design concepts, engine operational testing, fuel economy, and regulatory compliance.

The DME propertities chapter will focus on the physical and chemical properties of DME, and provide global DME production capacity and main production processes. At the same time, it will also predict the carbon emissions of this fuel and its future development trends, providing a forward-looking perspective for the industry.

The DME engine design concepts chapter will focus on the application of DME in low-speed engines for ocean transportation. It will discuss in detail the key technical features of the DME injection system, supply system, and safety design.

The single-cylinder testing chapter will introduce the combustion test results of low-speed engines using DME as fuel. This will verify the effectiveness of DME as a marine power fuel. It helps provide a more comprehensive assessment of its application potential.

The fuel economy chapter will predict the operational costs of typical ships, such as container ships, tankers, and bulk carriers, when using green DME as fuel. This will provide economic reference for the industry.

The regulatory compliance chapter will discuss the current regulatory environment applicable to marine engines using DME and explore possible compliance strategies to ensure that the fuel meets all regulatory requirements in practical applications.

Finally, this paper aims to provide valuable insights and suggestions for the decarbonization development of the marine power industry, such as promoting the widespread application of green synthetic fuels like DME or DME-based fuel in this field.

## 1 INTRODUCTION

As global climate change intensifies, reducing greenhouse gas emissions has become an international consensus. Many countries and regions around the world have announced relevant laws requiring the shipping industry to pay carbon taxes or purchase GHG emission rights, and to reduce the greenhouse gas emission intensity of fuels, thereby accelerating the transformation of the global shipbuilding and shipping industries. Key points include the International Maritime Organization (IMO)'s decision in 2023 to advance the strategic goal of achieving net-zero greenhouse gas emissions or carbon neutrality in the shipping industry from 2100 to 2050. Based on their own technological innovation capabilities, energy endowments, industrial bases, and trend predictions, countries/regions such as the United States, Europe, and Japan have proposed various green fuel solutions, mainly focusing on fuels like green methanol, green ammonia, and biodiesel.

With the gradual promotion of these green fuel solutions, fossil fuels such as diesel will gradually fade into history, and competition among green fuel power technology products will become increasingly fierce. However, regardless of the type of green fuel used or the many challenges faced by these green fuel power technologies, internal combustion engines will remain the main power source for marine propulsion systems in the future. From the perspective of internal combustion engine principles, it is particularly important to conduct research on green fuel-related power technologies.

Internal combustion engines can be divided into two categories: spark-ignition and compression-ignition. Spark-ignition internal combustion engines, such as gasoline engines, require fuels with high octane numbers, i.e., good anti-knock properties, and methanol and ammonia are both suitable fuels for spark-ignition engines. Compression-ignition internal combustion engines, such as diesel engines, often have higher compression ratios and higher thermal efficiencies, and require fuels with high cetane numbers, i.e., they can be directly compressed and ignited. If a high-octane fuel is used in a compression-ignition internal combustion engine, a dual-fuel technology must be adopted. However, this requires two fuel systems, increasing manufacturing costs, system complexity, and operation and maintenance costs. At the same time, since diesel is used as the pilot fuel, it is difficult to achieve net-zero GHG emission.

In order to make marine green fuel internal combustion engines return to a level of economy, simplicity, and reliability similar to diesel engines, a high cetane number (capable of direct compression ignition) is obviously an important factor in fuel selection. After screening many high-cetane green fuels, CSSC Power (Group) Co., Ltd (CPGC) has chosen DME for in-depth research and preliminarily believes that DME power technology has the potential to become a new decarbonization solution for the shipping industry, in addition to methanol and ammonia.

## 2 DME PROPERTITIES

DME, serving as a clean-burning alternative to fossil fuels, can be derived from feedstocks (e.g. natural gas, coal, or biomass). It is commonly used as a propellant in aerosol sprays, a refrigerant, and a fuel for transportation, cooking, and heating. Its extremely low emissions make it a popular choice for industries and individuals seeking to reduce their environmental impact. Over the past few years, the global DME industry has experienced significant growth due to the increasing prominence of environmental issues and the growing demand for sustainable energy options.

### 2.1 Fuel Properties

DME, with the molecular formula C2H6O and a molecular weight of 46, is a non-toxic oxygenated fuel that has a slight ether-like odor. It is gaseous at room temperature and pressure but can be liquefied by pressurizing to 5 bar (gauge pressure), making it easy to store and transport. A comparison of the main physical and chemical properties of DME with diesel, methanol, and ammonia is shown in Table 1 below.

Table 1 Basic physical and chemical properties of some fuels

| Item | DME | Diesel | $CH_3OH$ | $NH_3$ |
|---|---|---|---|---|
| Boiling Point (℃) | -25 | 180-360 | 65 | -33.5 |
| Flash Point (℃) | -41 | 55~120 | 11-12 | -54 |
| Ignition Point (℃) | 350 | 220 | 464 | 651 |
| lower heating value ($MJ \cdot kg^{-1}$) | 28.9 | 42.5 | 19.9 | 18.6 |
| Heat of Vaporization (kJ • kg-1) | 410 | 230~250 | 1089 | 1370 |
| Octane Number | 20 | 35~60 | 109 | >130 |
| Cetane Number | 55-66 | 40-56 | 5 | 0 |

It is known that DME has a cetane number exceeding 55, exhibiting excellent compression ignition performance, and is therefore particularly suitable for compression ignition internal combustion engines. DME's higher low heating value reduces onboard storage requirements compared to methanol and ammonia. Early research has already shown that DME, as an engine fuel, not only burns rapidly and efficiently but also adapts well to low-temperature starting conditions[1],[2].It is worth mentioning that the molecular structure of DME contains only C-H bonds and C-O bonds( no C-C bonds), resulting in combustion prodcuts of carbon dioxide and water. Green DME use achieves lifecycle net-zero GHG emissions. Therefore, utilizing DME as an engine fuel is of great significance for mitigating environmental pollution and reducing greenhouse gas emissions[3],[4].

### 2.2 Global Production Capacity

According to Mordor Intelligence's forecast[5], the global DME market is expected to reach 8.02 million tons in 2024, and by 2025, this number is projected to climb to 8.72 million tons. Looking further ahead, the global DME market size is forecast to grow to 12.81 million tons by 2030, with a Compound Annual Growth Rate (CAGR) exceeding 8% during the forecast period (2025-2030), demonstrating robust growth trend.

The main factors driving the continued growth of this market include the increasing demand for aerosol propellants across various industries. Additionally, the growing global trend towards reducing GHG emission and emphasizing clean energy and fuels, along with the wide availability of renewable raw materials, also contribute to this growth. Currently, the Asia-Pacific region dominates the global DME market, driven by the rapid expansion of its manufacturing sector.

### 2.3 Production Process

DME has a wide and abundant source, and its production cost is relatively low. It can be produced on a large scale from various raw materials such as natural gas, coal, municipal waste, and biomass[6]. Currently, the industrial production of DME mainly adopts the two-step synthesis gas method: firstly, converting synthesis gas into methanol; subsequently, converting methanol into DME through a catalytic dehydration reaction. The reaction equation for the second step is as follows:

$$2CH_3OH \xrightarrow{\text{Electricity \& Steam}} CH_3OCH_3 + H_2O \qquad (1)$$

Specifically, producing 1 kg of DME requires 1.4 kg of methanol, along with a certain amount of electricity and steam.

When evaluating the value of methanol and DME as fuels, their lower heating values must be considered. According to Table 1, the lower heating value of 1 kg of DME is 28.9 MJ, while the lower heating value of 1.4 kg of methanol is 27.9 MJ. **This shows that the process of producing DME from methanol effectively stores useful energy.**

Similarly, the theoretical GHG emission for producing 1 ton of DME can be calculated using Equation 1, as shown in Table 2. According to the EU's Renewable Energy Directive (RED), the GHG emission of green methanol should be less than 28.2 g CO2/MJ. Calculating based on the lower heating value of methanol at 19.9 MJ/kg, the

GHG emission for producing 1 ton of green methanol should be less than 561 kg. Therefore, the maximum GHG emission for producing the 1.4 tons of green methanol needed for 1 ton of green DME would be 561×1.4 =785.4 kg CO2.

The electricity required to produce 1 ton of DME can come from wind power, solar power, or fossil fuel power generation, while steam can be obtained through thermal conversion of electricity or fossil fuels. According to research, the GHG emission generated by different production processes range from approximately 0 to 252 kg. **Based on this, the total GHG emission for producing 1 ton of green DME, by green methanol with a GHG emission limit of 28.2g CO2/MJ, range from 785.4 to 1037.4 kg CO**2. **When converted based on the lower heating value of DME, this is equivalent to 27.2-35.9 g CO2/MJ.** This result can provide some support for defining the GHG emission limit for green DME.

Table 2 Theoretical CO2 emissions for producing 1t of DME

| Item | GHG emission kg CO2/t | Coefficient | GHG emission kg CO2/t |
|---|---|---|---|
| CH3OH | 561 | 1.4 | 785.4 |
| DME production | 0~252 | 1 | 0~252 |
| Total | | | 785.4~1037.4 |

## 3 DME ENGINE DESIGN CONCEPTS

In view of the significant advantage of DME direct compression ignition, as well as its potential economic advantages that will be elaborated later in this article, CPGC is focusing its efforts on the technological research and development of DME fuel in the field of ocean-going low-speed engines. Currently, the company has successfully developed key components such as the DME supply system, injection system, control system, and cylinder head based on a low-speed test engine with a 340mm bore. In addition, the company has completed the single-cylinder modification of the low-speed test engine and successfully conducted the first phase of testing. Figure 1 shows a partial view of the DME test engine. The DME cylinder is on the far left, and the others are diesel cylinder.

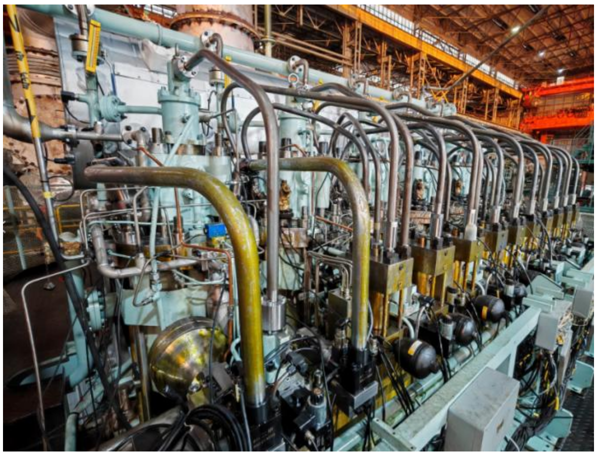


Figure 1 EX340 low-speed DME test engine

### 3.1 DME supply system

Figure 2 presents a simplified diagram of the DME supply system (DME SS) for the test platform, which primarily consists of several core components: the DME supply tank, recycling tank, supply system, valve unit, and buffer tank. The piping connecting the valve unit to the DME SS adopts a single-wall design, while the piping connecting to the engine employs a safety double-wall design.

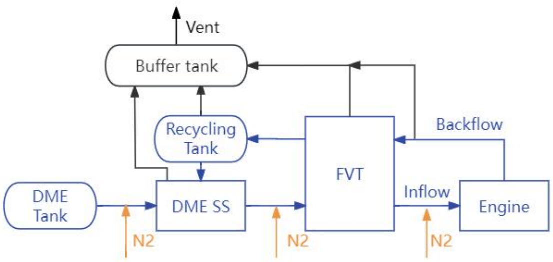



Figure 2 DME supply system principle diagram of EX340 test engine

The actual DME SS, as shown in Figure 3, mainly includes components such as a DME booster pump, heat exchanger, flow meter, valves, control cabinet, etc. This system is responsible for regulating the supply pressure, controlling the temperature, and accurately measuring the DME to ensure stable operation of the test platform and the accuracy of the data.


Figure 3 Dimethyl ether supply system

CPGC follows this fuel supply procedure: low-pressure DME flows out of the storage tank and enters the DME SS skid, where it is pressurized to medium pressure before flowing into the valve unit. The valve unit automatically performs a leak check, and once confirmed to be error-free, the DME enters the engine through the double shut-off valve for combustion and work. Some of the DME flows back from the engine, passing through the double shut-off valve in the valve unit, and returns to the recycling tank for the next supply cycle.

The inerting and purging process varies depending on the operating conditions of the supply system and the engine, and is mainly divided into three categories: pre-start purging, post-shutdown purging, and independent purging. Pre-start purging aims to remove any impurities that may be present in the DME flow path, ensuring the cleanliness of the supply system. Post-shutdown purging includes normal shutdown purging and emergency shutdown purging, which can blow the residual liquid DME in the DME SS, valve unit, engine, and related pipelines back into the recycling tank, and then further into the buffer tank, ensuring system safety. Independent nitrogen purging is designed for specific on-site requirements and is generally performed manually. Purging inlets are set before the DME SS skid, before the valve unit, and before the engine's double-wall pipe, ensuring that all pipelines are thoroughly purged.

### 3.2 DME injection system

Figure 4 presents the GT-power model of the DME test engine. DME would be sprayed from cylinder 1 to cylinder 6, then the cylinder with the least impact on cylinder pressure, exhaust flow rate and exhaust manifold pressure will be used to spray dimethyl ether. As shown in Figure 5, it can be seen that cylinder 6 sprays DME would not cause significant difference.

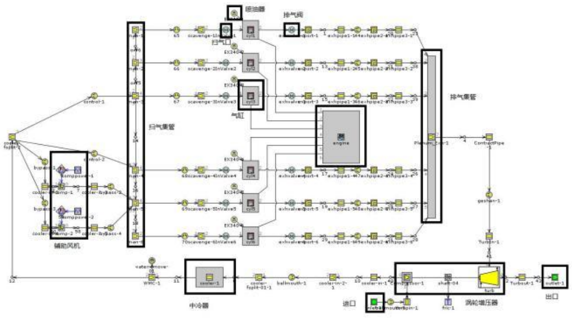


Figure 4 Test engine GT-power model

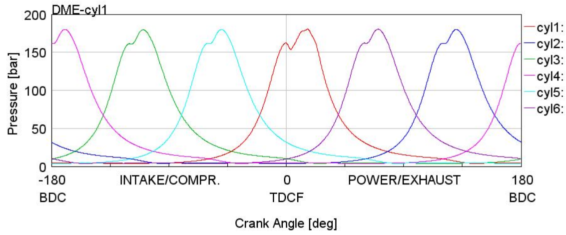



Figure 5 Pressure curve of different cylinders

The spray characteristic is also very important for engine operation and injector design. Therefore, the injector One-dimensional (1-D) performance model and Three-dimensional (3-D) computational fluid dynamics (CFD) model had been established in according to the detailed injector design scheme.Figure 6 shows the DME spray morphology predicted by Large eddy similation (LES) model. It used to analysis the cavitation, the flow rate coefficient, cone angle and peneration when DME need to be sprayed into a large bore and high pressure cylinder.

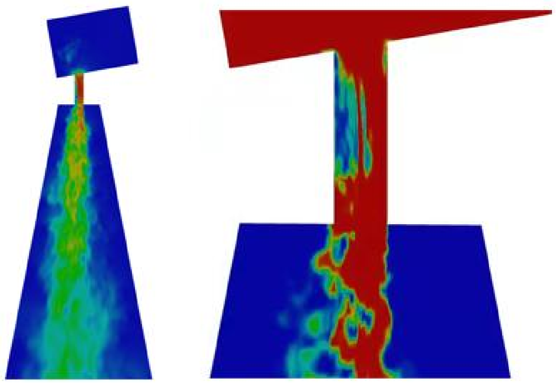


Figure 6 DME spray prediction by LES

Figure 7 presents the appearance of the DME injector and the scenario of its testing on a specialized test bench. Currently, the first batch of injectors have successfully passed the specialized platform tests, with all parameters, especially safety indicators, meeting the testing requirements of real engines.

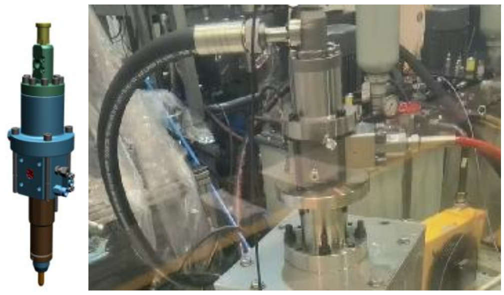


Figure 7 DME injector and the rig testing

The DME injector employs advanced servo oil pressurization technology, equipped internally with a pressurization piston that boosts the DME to the target injection pressure through servo oil, ensuring that the injection quantity and duration can adapt to the varying operating conditions of the engine. The injector incorporates a specialized coupling assembly that not only facilitates pressure build-up at the start of injection but also suppresses the occurrence of negative pressure (vacuum) conditions at the end of injection. Additionally, by setting a specific proportion of fuel return, the temperature of the DME fuel in the pressurization chamber is reduced, further enhancing the safety and reliability of the system.

Furthermore, the DME injector adopts a unique sealing and ventilation design. Utilizing servo oil with a pressure significantly higher than the DME supply pressure, combined with DME-resistant seals, a seal barrier for DME is jointly established. The injector is internally designed with special flow channels that penetrate potential leakage end faces and are tightly connected to the double-walled tube interlayer, forming an effective leakage path. By continuously sucking and monitoring hydrocarbons in the double-walled tube interlayer, DME leaks within the injector can be promptly detected and addressed, ensuring the safe and stable operation of the system.

Figure 8 illustrates the principle diagram of the DME injection system. After entering the engine through the valve group unit, DME flows through the DME on-off valve and ultimately into the DME injector. Within the injector, the DME is pressurized by high-pressure servo oil from the servo oil common rail. Once the pressure reaches the set value, DME is immediately injected directly into the cylinder, achieving diffusive combustion and driving the piston to perform work. The servo oil control valve is responsible for controlling the injection timing and duration of the DME injector. The pressure in the high-pressure servo oil common rail originates from the engine's own servo oil booster pump.

Due to the return flow design in this injection system, the returned DME is directed back to the DME recycling tank via the fuel valve train (FVT) and re-enters the supply cycle.

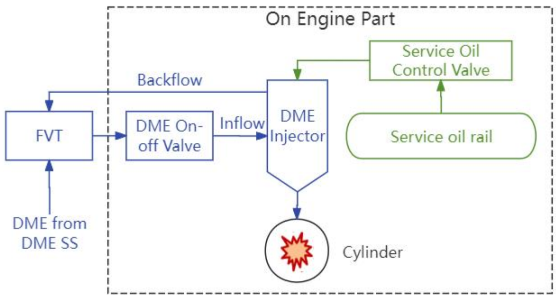



Figure 8 DME injection system principle diagram of EX340 test engine

### 3.3 Safty design

DME has a density greater than air and relatively low boiling and flash points. Therefore, when mixed with air, DME can easily form an explosive mixture, posing a safety hazard. When designing and constructing DME supply systems and DME engines, some safety design concepts and measures had been implemented to prevent explosive mixtures formation, ensuring the safe and reliable operation of the system. The considerations are mainly as follows:

**1) Leak Prevention:** Generally adopting methods similar to those for LNG fuel, including installing emergency shut-off valves in fuel filling pipelines, equipping valve units with emergency shut-off functions, and designing double-walled piping after the valve unit.

**2) Gas Detection System:** Installing gas detection sensors at appropriate locations to promptly detect leaked gas, initiate audible and visual alarms, and automatically take emergency security measures

**3) Prevention of Explosive Mixture Formation:** This includes ventilation, inerting, and operating equipment outside the explosion limit range (monitoring and alarming of flammable mixture concentration).

**4) Elimination of Ignition Sources:** Ensuring the absence of hot surfaces above the ignition temperature, electrostatic and electrical ignition sources, sparks, and open flames.

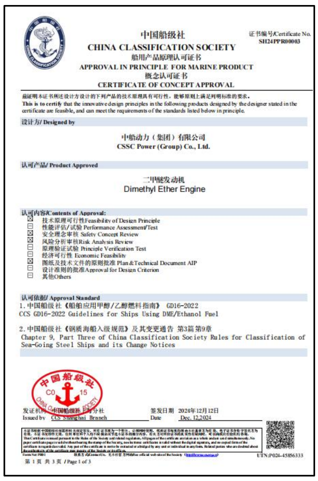
**5) Limiting the Impact of Explosions:** Employing safety measures to prevent the generation of destructive explosion pressure waves, including safety valves, explosion-proof designs, and fire-fighting devices specific to DME.

**6) Setting Up Explosion-Proof Control Zones:** As shown in Table 3, the control zones are designed and operated according to corresponding explosion-proof and flame-retardant requirements. Zone 0: Flammable and explosive gases are present continuously or for extended periods; Zone 1: Explosive gases may occur or exist during normal operation of equipment; Zone 2: Explosive gases are generally absent and, if they occur occasionally, their presence is short-lived

Table 3 Explosion-proof control zone

| System/Area | Zone |
|---|---|
| DME tank | Zone 0 |
| Recycling tank | Zone 0 |
| In-cyinder | Zone 0 |
| Scavange air box | Zone 1 |
| Exhaust manifold | Zone 1 |
| Buffer tank | Zone 1 |
| Within 3 meters of the relief outlet of the buffer tank | Zone 1 |
| Between 3 and 4.5 meters from the relief outlet of the buffer tank | Zone 2 |
| Exhaust receiver | Zone 2 |
| Ship side exhaust system | Zone 2 |
| Installation area of tanks, skids, and engines | Zone 2 |

CPGC has completed the principle design of a DME low-speed engine based on the aforementioned design concepts and obtained a principle approval certificate issued by China Classification Society (CCS), as shown in Figure 9.


中国船级社
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船用产品原理认可证书
APPROVAL IN PRINCIPLE FOR MARINE PRODUCT
概念认可证书
CERTIFICATE OF CONCEPT APPROVAL

证书编号/Certificate No.
SH24PPR00003

兹证明本证书所述设计方设计的下列产品的技术原理具有可行性，能够原则上满足列明标准的要求。
This is to certify that the innovative design principles in the following products designed by the designer stated in the certificate are feasible, and can meet the requirements of the standards listed below in principle.

设计方/ Designed by

中船动力（集团）有限公司
CSSC Power (Group) Co., Ltd.

认可产品/ Product Approved

二甲醚发动机
Dimethyl Ether Engine

认可内容/Contents of Approval:

- ☒ 技术原理可行性Feasibility of Design Principle
- ☐ 性能评估/试验 Performance Assessment/Test
- ☒ 安全理念审核 Safety Concept Review
- ☒ 风险分析审核Risk Analysis Review
- ☐ 原理验证试验 Principle Verification Test
- ☐ 经济可行性 Economic Feasibility
- ☒ 图纸及技术文件的原则批准 Plan&Technical Document AIP
- ☐ 设计准则的批准Approval for Design Criterion
- ☐ 其他Others

认可依据/ Approval Standard

1. 中国船级社《船舶应用甲醇/乙醇燃料指南》 GD16-2022
CCS GD16-2022 Guidelines for Ships Using DME/Ethanol Fuel

2. 中国船级社《钢质海船入级规范》及其变更通告 第3篇 第9章
Chapter 9, Part Three of China Classification Society Rules for Classification of Sea-Going Steel Ships and its Change Notices

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第 1 页 共 3 页 / Page 1 of 3

Figure 9 Principle approval certificate issued by China Classification Society

## 4 SINGLE CYLINER TESTING

Relying on its self-developed EX340 test engine, CPGC has carried out a series of in-depth and meticulous experiments aimed at validating the feasibility and effectiveness of DME as a marine propulsion fuel, and has conducted a comprehensive and thorough assessment of its vast application potential.

The first phase of testing primarily focused on verifying whether each system met the design requirements, with particular emphasis on safety validation. Specifically, functional testing of the software was conducted to ensure its stability and accuracy in executing various control commands. Cycle testing was implemented on the DME supply system to evaluate its reliability and stability in real-time operating environments. Rigorous leakage monitoring was performed on the DME piping to promptly detect and address any potential leakage issues. Additionally, automatic emergency operation tests were carried out to examine the system's emergency response and handling capabilities in sudden situations.

The second phase of testing aimed to explore the DME ignition performance and achieve a low-load operation.The test results indicate that DME can be directly ignited after being injected into the cylinder, releasing energy comparable to that of a diesel cylinder, thereby the DME cylinder can maintain a stable operating state.

CPGC continues to carry out related experimental work, aiming to precisely optimize the performance of DME across all operating conditions of the engine and to delve deeper into its emission characteristics to ensure that NOx emissions comply with current regulatory standards. Simultaneously, the Group is also dedicated to collecting temperature field distribution data for key heated components such as cylinder heads, pistons, and valves under various operating conditions, aiming to further enhance researchers' comprehensive understanding and knowledge of DME as a fuel for low-speed engines.

## 5 FUEL ECONOMY

By conducting a comparative analysis of the operating costs of typical ships using different fuel types, we can further assess whether the economic performance and other indicator requirements of DME as a fuel meet actual demand. To this end, an economic calculation model for marine engines using different fuels has been established, with some important calculation parameters shown in Table 4. It should be noted that, in Table 4, the production cost of Diesel including Intermediate Fuel Oil (IFO) and Marine Gas Oil (MGO), IFO with 380cst is considered as the main fuel, MGO is considered as the pilot fuel, and the production cost of green methanol and green ammorina are from the estimation of International Renewable Energy Agency, it could be adjusted in accordance with future technological developments and market changes. The production cost of green DME is calculated by 1.4 × the production cost of green methanol and the cost of steam and electricity, it’s a theoretical value. Therefore, the relevant analysis results are for reference only.

Table 4 Key factors for fuel economy calculations

| Item | Diesel | Green $CH_3OH$ | Green $NH_3$ | Green DME |
|---|---|---|---|---|
| Stroage mode | Normal Tank | | C Tank | |
| Stroage pressure | Atmospheric pressure | | | |
| Filling rate | 0.98 | | 0.95 | 0.95 |
| Stroage Temp.(℃) | 25 | | <-34 | <-25 |
| Main fuel cost ($/t) | 530 (IFO380) | 410[7] | 475[8] | 616 |
| Pilot fuel cost ($/t) | 642(MGO) | | | |
| Carbon tax ($/t) | 150 | | | |
| Main fuel carbon factor | 3.206 | 1.375 | 0 | 1.913 |
| Pilot fuel carbon factor | 3.206 | | | 0 |

Subsequently, three typical ship types were selected for analysis: an 82,000 DWT bulk carrier, an Aframax tanker, and a 15,000 TEU container ship. Based on the following assumptions, the parameters provided by ship owners, including the annual operating time, operating load, and voyage information of the marine main engines, were analyzed. The fuel economy of the marine main engines and the bunker capacity requirements are shown in Figure 10 and Table 5, respectively.

Assumption 1, the thermal efficiency of engines using different fuels is the same.

Assumption 2, methanol, ammonia, and DME fuels can cover all operating points of the engine, meaning that the dependence of methanol and ammonia engines on diesel mode during the startup phase and low-load operation is not considered.

Assumption 3, both green methanol and green ammonia engines use an energy proportion of 10% for pilot fuel.

Assumption 4, Green fuels achieves lifecycle net-zero GHG emission, and the carbon tax on green fuels is not taken into account.

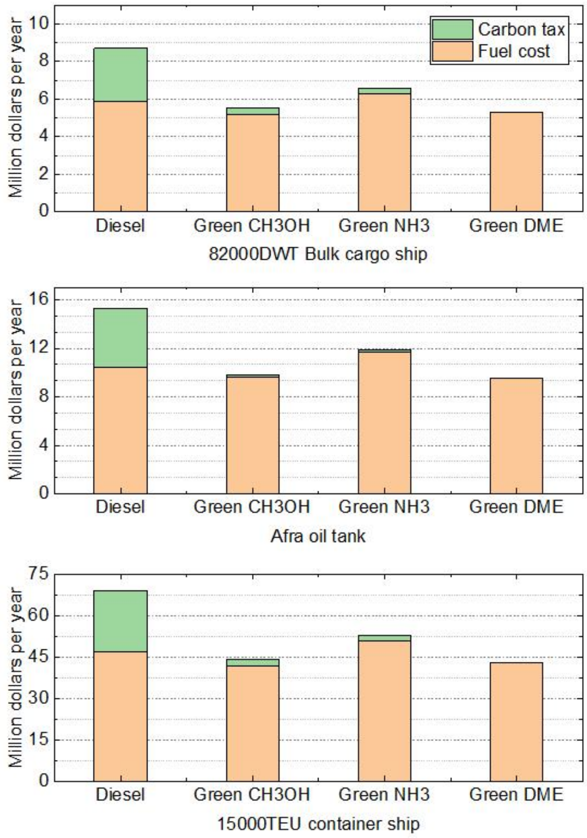


Figure 10 Predicted fuel economy comparsion

Table 5 Main fuel tank capacity (m³) for different ship types

| Item | Diesel | Green $CH_3OH$ | Green $NH_3$ | Green DME |
|---|---|---|---|---|
| 82000DWT bulk cargo ship | 1541 | 3197 | 4099 | 2734 |
| Afra oil tank | 2367 | 5464 | 7395 | 4507 |
| 15000TEU container ship | 9386 | 19569 | 26307 | 17873 |

Based on this, the following results can be drawn.

1) **If the cost production of green fuels reaches the predicted level in the future, they will have a cost advantage compared to diesel**, especially when considering the impact of carbon taxes. The operational difference between diesel and green fuels will further widen.

2) DME can be ignited directly by compression without pilot fuel, and therefore does not require the payment of carbon taxes. This is a key advantage of green DME as a fuel. Especially for 82,000 DWT bulk carriers and 15,000 TEU container ships, the total expenditure for DME fuel is slightly higher than that for methanol. However, after adding carbon taxes to the methanol engines, the total operating cost exceeds that of DME. In the future, with the decrease in green electricity prices and the continuous improvement of the industrial chain, the production cost of green methanol may further decrease. Furethemore, as the production cost of green methanol decreases and the production cost of carbon taxes increases, the economic advantages of green DME as a marine fuel will become more pronounced.

3) Due to its high energy density, DME requires less storage capacity compared to methanol and ammonia fuels. This can effectively increase the cargo space of ships and improve their operational economy.

## 6 REGULATORY COMPLIANCE

Currently, the global marine propulsion industry is facing increasingly stringent regulations concerning green fuels. Unfortunately, there is a lack of adequate regulatory support for the use of green DME as a fuel in the shipping industry. To promote the application of DME in marine fuels, this article emphasizes the following three key points:

1) DME, as a clean fuel, exhibits extremely low toxicity and corrosion, but its high flammability necessitates extremely stringent safety measures in ship design and operation. Therefore, the

development of a dedicated set of safety design specifications is crucial. This will not only effectively prevent safety incidents such as fires and explosions, ensuring the safety of crew members and ship property, but also further promote continuous innovation and improvement of related technologies, thereby enhancing the application level and competitiveness of DME fuel in the marine domain.

2) Compared to methanol, DME has lower toxicity and is far less toxic than ammonia. Therefore, when exploring the application path of DME as a fuel, we must thoroughly consider how to break through the existing restrictions in the International Maritime Dangerous Goods (IMDG) Code regarding the "prohibition of toxic goods as fuels" to pave the way for the legal and safe use of DME.

3) Although DME has the ability to ignite directly under compression, this alone is insufficient to prove that it can meet diesel fuel safety standards when used as a marine fuel. Therefore, DME should not be used solely as a marine fuel but must be considered in conjunction with intrinsic safety designs. In light of this, technically, the DME injection system theoretically has the potential to be compatible with diesel injection systems. This means that two independent fuel supply systems for diesel and DME can be set up to supply fuel to the engine, with diesel only used as a backup fuel in emergencies. However, it is worth noting that when the DME injection system is used to inject diesel, the engine's performance will not be optimized. Nevertheless, this approach at least ensures that the ship will not lose power at critical moments. This operational mode, which lies between single-fuel and dual-fuel operation, currently lacks a clear definition and corresponding regulatory guidance.

## 7 CONCLUSION

This article explores the practical application potential of DME as a green synthetic fuel in the decarbonization development of the marine propulsion industry. By conducting an in-depth analysis of DME's physicochemical properties, global production capacity, production methods, marine engine design concepts, operational testing, fuel economy, and regulatory compliance, it uncovers the significant advantages of using DME as a marine propulsion fuel. Additionally, the article points out potential issues and challenges associated with its use.

In terms of fuel characteristics, DME presents a high cetane number, ensuring excellent compression ignition performance, particularly suited to the requirements of compression ignition internal combustion engines. Its higher low heating value effectively reduces the space occupied by marine fuel tanks, enhancing space utilization efficiency. After combustion, DME mainly produces carbon dioxide and water, demonstrating its environmentally friendly nature. Globally, the market size of DME continues to expand, with more efficient energy storage achieved through the conversion of methanol to DME. Green DME produced from green methanol with a GHG emission level of 28.2g $CO_2$/MJ has a GHG emission range of 27.2 to 35.9 g$CO_2$/MJ.

In terms of engine design concepts, the application of DME in low-speed internal combustion engines for ocean transportation necessitates addressing key technical issues related to the fuel supply system, injection system, and other aspects, while also requiring further optimization and improvement of engine safety design concepts. Currently, CPGC has completed the relevant modification design and development of components related to the DME supply system and injection system for an EX340 test engine, and has obtained a DME low-speed engine principle approval certificate from CCS.

In terms of operational testing, CPGC has conducted combustion predictions and actual tests on DME internal combustion engines to assess whether their performance and other indicators meet actual requirements, and to provide continuous support for subsequent optimization and improvement efforts.

In terms of fuel economy, DME as a fuel demonstrates superior operational economic performance advantages during typical ship operations, which helps accelerate the decarbonization development process in the marine propulsion industry.

In terms of regulatory compliance, the application of DME as a fuel in the shipping industry lacks comprehensive regulatory support, and there is an urgent need to formulate or adjust relevant regulations and standards to ensure the widespread use of DME in the marine propulsion industry.

In conclusion, DME holds significant promise for decarbonizing marine propulsion. However, achieving large-scale application requires overcoming a series of challenges and issues. In the early stages of DME's application as a marine fuel, when related technologies and experience are still immature, it is recommended to issue some temporary guidelines or recommendations to guide manufacturers, operators, and regulatory bodies related to ships and propulsion systems on how to safely and effectively use this new fuel. These guidelines should not be mandatory but provide basic safety and technical guidance principles, which will help promote the application and development of DME fuel in the marine domain.

## DEFINITIONS, ACRONYMS, ABBREVIATIONS

**IMO**: International Maritime Organization
**DME:** Dimethyl ether
**CPGC:** CSSC Power (Group) Co., Ltd
**CCS**: China Classification Society
**CAGR:** Compound Annual Growth Rate
**RED:** Renewable Energy Directive
**DME SS:** Dimethyl ether supply system
**FVT:** Fuel valve train
**1-D:** One-dimensional
**3-D:** Three-dimensional
**CFD:** Computational fluid dynamics
**LES:** Large eddy simulation
IFO : Intermediate Fuel Oil
MGO: Marine Gas Oil

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