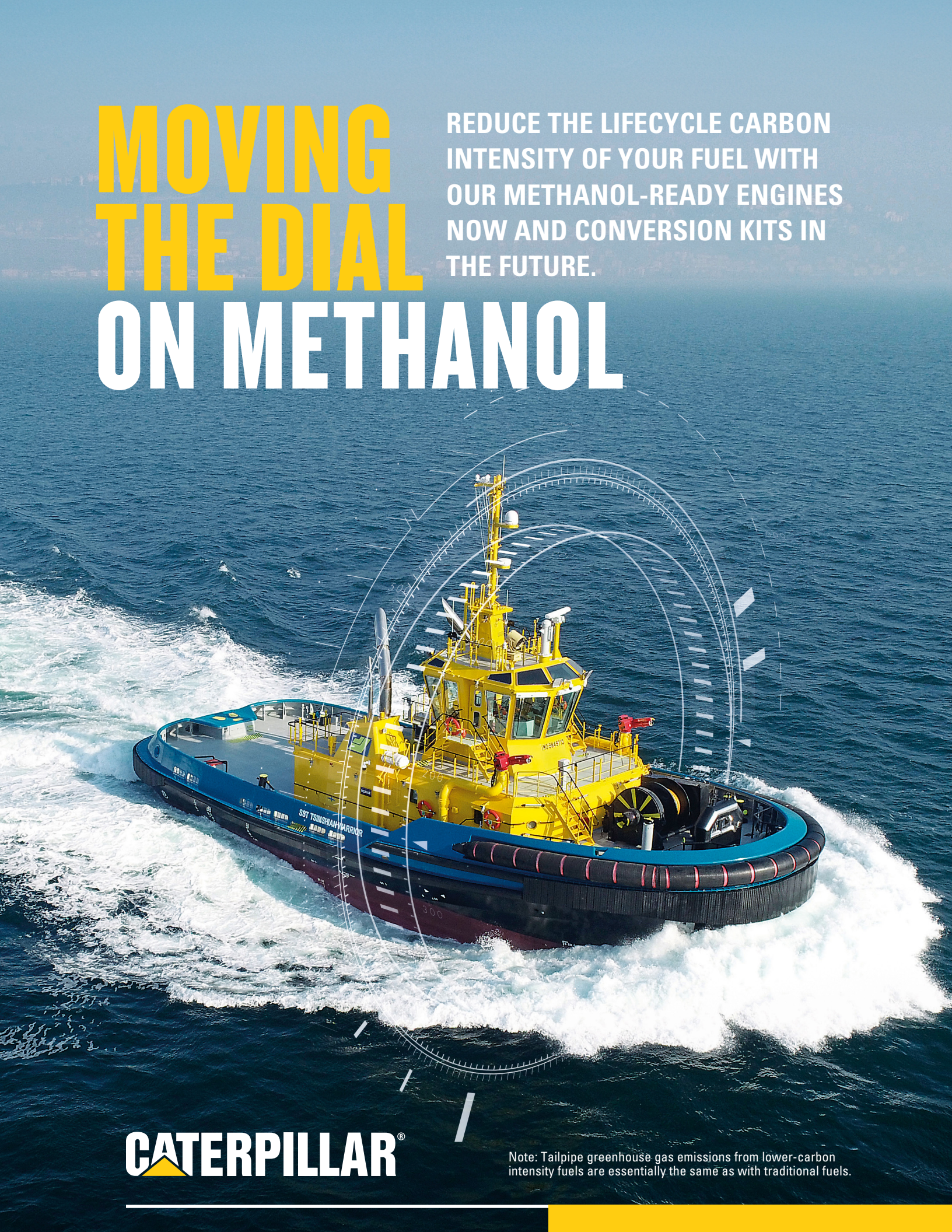
MOVING THE DIAL ON METHANOL

REDUCE THE LIFECYCLE CARBON INTENSITY OF YOUR FUEL WITH OUR METHANOL-READY ENGINES NOW AND CONVERSION KITS IN THE FUTURE.



CATERPILLAR®

Note: Tailpipe greenhouse gas emissions from lower-carbon intensity fuels are essentially the same as with traditional fuels.

FUELING A LOWER-CARBON FUTURE

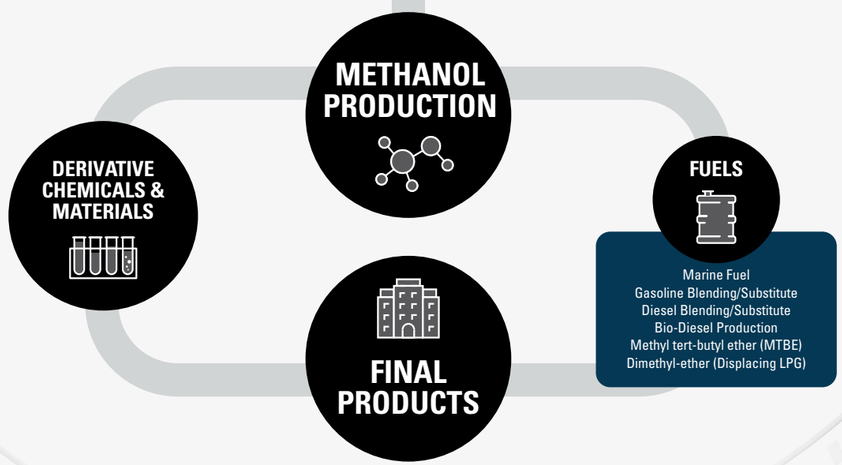
METHANOL AND OTHER ALCOHOL-BASED FUELS ARE GROWING IN POPULARITY due to the ease of transport and relative energy density compared to other lower-carbon fuels. Methanol is gaining traction among vessel operators aiming to minimize the environmental footprint of their marine operations using their existing Cat® engines. Powering vessels with methanol instead of petroleum-based fuels significantly reduces lifecycle greenhouse gas (GHG) emissions in the fuel value chain. Methanol's lower emission profile, combined with its ease of storage and handling, makes it a preferred choice for marine operators seeking to balance operational efficiency with their climate-related objectives.

Note: GHG emissions at the tailpipe are essentially the same as with traditional fuels.

WHAT IS METHANOL?

METHANOL CAN BE PRODUCED FROM RENEWABLE FEEDSTOCK OR FROM RENEWABLE ENERGY using hydrogen and carbon capture. It is increasingly being recognized for its potential as a sustainable alternative to fossil fuels due to its unique properties and biodegradability. Methanol has a century-long history in industrial use and is now emerging as a promising, sustainable fuel option for the maritime industry.

METHANOL PRODUCTION PROCESS



TYPES OF METHANOL

BROWN METHANOL

Produced from coal through a process called **coal gasification.** This method produces significant carbon dioxide (CO_2) emissions during production, making it less sustainable compared to other types of methanol.

GRAY METHANOL

Produced from natural gas using a process called **steam methane reforming.** It is currently the most common form of methanol production. However, the natural gas combustion emits greenhouse gas emissions during the production process. These emissions will occur upstream in the fuel development process, often referred to as “well-to-tank” emissions.

BLUE METHANOL

Derived from **natural gas** but combined with **carbon capture and storage.** The addition of carbon capture and storage reduces the well-to-tank CO_2 emissions.

GREEN METHANOL

Also known as renewable methanol, is produced either from **renewable organic matter** (bio-methanol) or from **captured carbon dioxide and hydrogen** generated through renewable energy (e-methanol). The production process may result in zero greenhouse gas emissions.

MULTIPLE SUSTAINABLE PATHS TO METHANOL

Well-to-wake nitrogen oxide (NOx) emissions for methanol are significantly lower than those of traditional fuels. Methanol also offers a distinct advantage in terms of reduced particulate matter. The primary benefits, particularly from a carbon reduction standpoint, occurs during the production phase rather than onboard the vessel. Depending on the production method, the potential for significant reduction, up to zero well-to-wake greenhouse gas emissions, positions methanol as a long-term sustainable choice.

BENEFITS OF METHANOL

CAN BE STORED AS LIQUID AT STANDARD CONDITIONS	Ideal for space/storage on vessel
ENERGY DENSE (COMPARED TO HYDROGEN & BATTERIES)	Customers will not sacrifice vessel power/performance
MULTIPLE PATHS TO RENEWABLE ENERGY PRODUCTION	Can be produced from multiple sources and unlimited feedstocks (unlike biofuels) with the potential for up to zero well-to-wake GHG emissions
LOWER ENVIRONMENTAL IMPACT	Significantly lower stack emissions (NOx and particulate matter) when compared to diesel or biofuels Low impact to wildlife in case of spillage due to its biodegradable nature (unlike diesel) Up to zero well-to-wake GHG emissions depending on the production method

Note: Industry standards and specifications are still being formulated for methanol as a fuel.

WHY METHANOL IS THE FUTURE FUEL OF CHOICE

IN MARINE APPLICATIONS

	DIESEL	METHANOL	HYDROGEN
PRODUCTION SOURCE	Traditional petrochemical fuel derived from crude oil or biomass	Produced from natural gas, coal, biomass, and renewable energy ✓	Generated from various sources including natural gas, coal, biomass, and renewable energy ✓
SHELF LIFE	Stable	Very stable, similar to traditional fuels but better than other lower-carbon fuel options ✓✓	Stable, but requires specific conditions for storage to maintain its shelf life ✓
MISCIBILITY IN WATER	Low miscibility; tends to float on the surface of water and is not biodegradable	High miscibility; mixes readily in water and is biodegradable ✓	Does not mix with water (gas); biodegradability does not apply since hydrogen doesn't interact directly with the environment like fluids
STATE AT STANDARD CONDITIONS	Liquid, easy to store, very stable	Liquid, easy to store, very stable ✓✓	Stored as high-pressure gas or at very low temperatures as a liquid (-253°C / -423.4°F)
CARBON REDUCTION POTENTIAL	Baseline for most evaluations	Well-to-wake GHG emissions reduction up to 100% depending on the production method; can be carbon-neutral with capture technology[1] ✓	Well-to-wake GHG emissions reduction up to 100% depending on production method; can be carbon neutral when produced with biomass or renewable energy ✓✓
STORAGE VOLUME[1]	Baseline for most evaluations 1x	Requires 2.3 times the volume of diesel to deliver the same amount of energy 2.3x ✓	Needs significantly more volume, approximately 11.9 times that of diesel, to provide equivalent energy 10.1x
TRANSPORTATION COST	Low, due to high energy density	Higher than diesel but adaptable to existing infrastructure ✓	High, due to low energy density and slow refueling process for both compressed and liquid forms

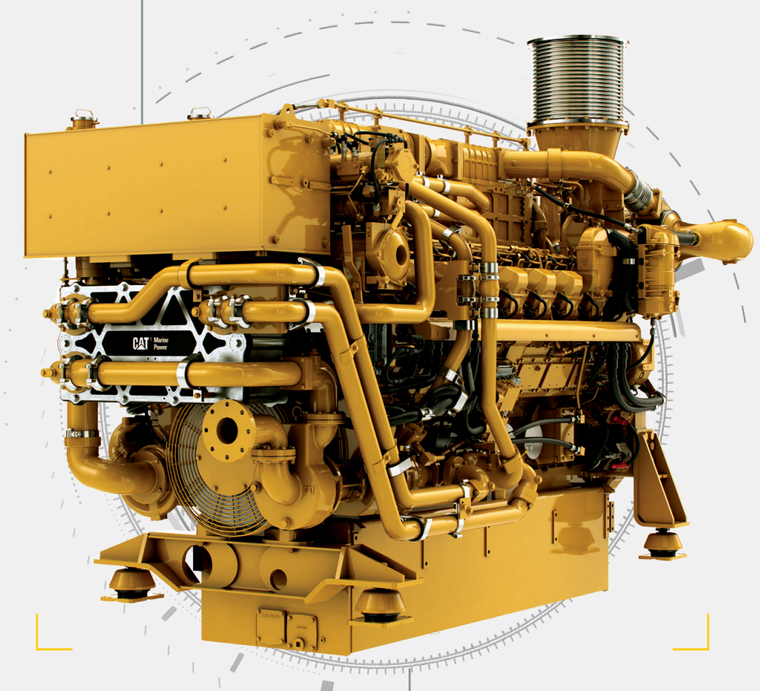
✓ advantage ✓✓ significant advantage

Note: Methanol's carbon reduction potential varies depending on production method (brown, gray, blue, or green).

[1] Graph not to scale

AVAILABILITY

Methanol is one of the most commonly traded chemicals globally, ensuring its availability. Gray methanol is currently widely available and can be used in existing engines. It provides flexibility for fuel switching based on price fluctuations. However, it has a higher carbon impact due to its fossil fuel origin. Green methanol is expected to become more available within the next few years. It can be blended with diesel fuel, allowing for a seamless transition without major infrastructure changes.



COST

Methanol is currently more expensive than diesel, but its cost dynamics could change favorably in the future, especially with the potential imposition of carbon taxes on diesel and the anticipated decrease in green methanol prices. Mixing green and gray methanol could provide a balanced approach to cost and emissions reduction.

STORAGE AND HANDLING

Methanol has lower energy content compared to diesel. Consequently, ships utilizing methanol would require cargo tanks approximately 2.3 times larger than their current size. However, methanol, regardless of production pathway, is a liquid at standard ambient conditions, making it easy to store, similar to diesel. It requires conventional storage solutions without the need for high-pressure or low-temperature systems. As methanol has a very stable shelf life, it is advantageous for long-term storage compared to other lower-carbon options.

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