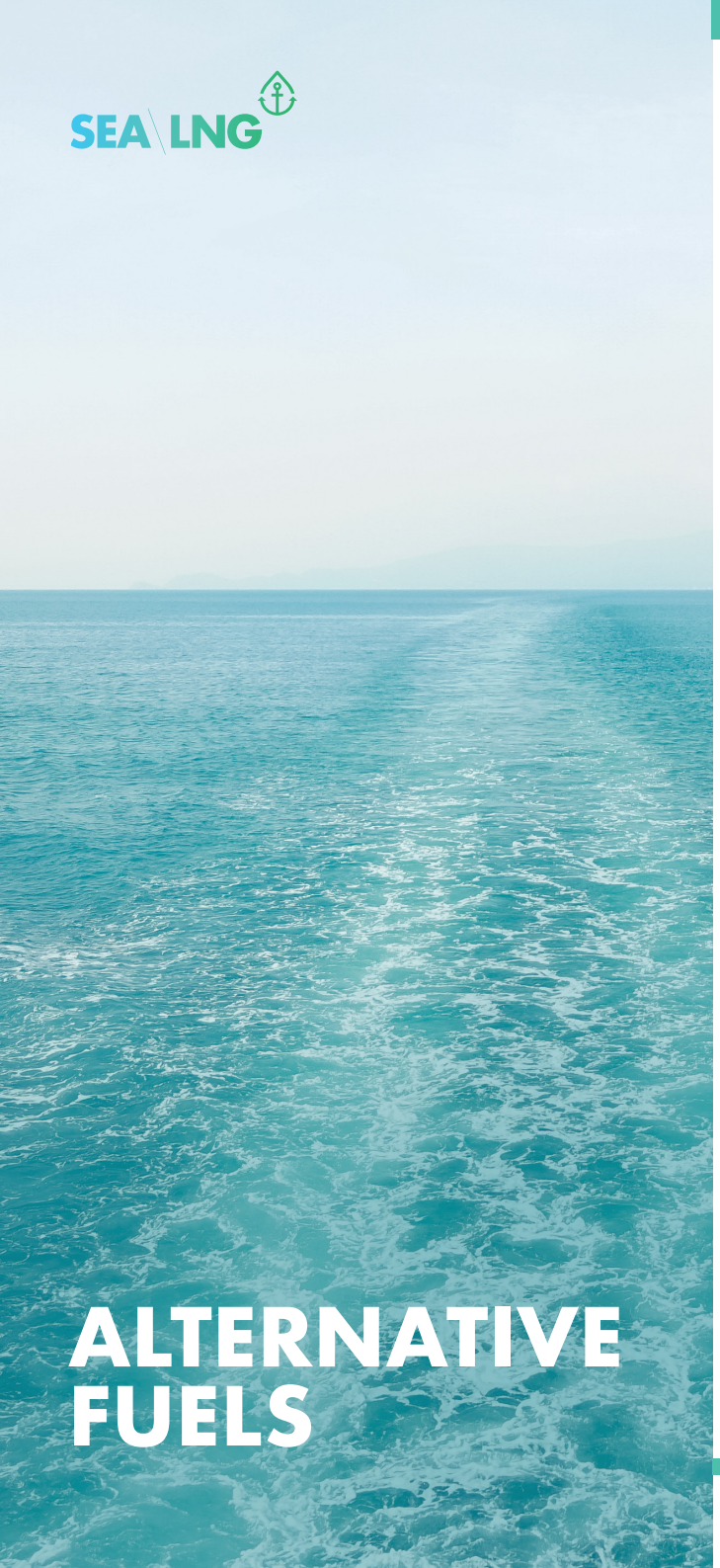

ALTERNATIVE FUELS

Environmental regulations controlling emissions of SOx, NOx and Greenhouse Gases (GHG) are transforming the global shipping industry. Carbon-intensive, polluting heavy fuel oil (HFO) can no longer remain the default option for ocean voyages. To comply with the International Maritime Organization's (IMO) 1st January 2020 SOx regulations and announced future environmental targets, ship owners and operators must change the ways in which they power and fuel their fleets.

Modern ships have a life expectancy of around a quarter of a century. Investors need to know how the capital expenditures for installed engines and their operational costs, including choice of fuel, will be impacted by current and future environmental legislation. There are several alternative marine fuel options to consider. Choosing which marine fuel to adopt is now a significant investment decision to be made amidst a range of uncertainties. Successful investment will require a genuine understanding of the alternative fuels options including their:

- energy density – how much energy is contained in each tonne or cubic metre of fuel
- technical maturity and proven operational performance in terms of safety and reliability
- local emissions of SOx, NOx and Particulate Matter which impact human health
- GHG emissions with associated global warming impact
- current cost of fuel and how this is predicted to change over time
- associated capital cost of engines and fuel storage onboard
- availability in terms of geographic bunkering and global production capacity
- flammability, toxicity and status of associated handling safety regulations

To support the industry in its decision-making process, SEA\LNG commissioned DNV GL to conduct a comprehensive study to assess the commercial and operational viability of alternative marine fuels. Based on existing academic and industry literature, the study evaluates how well six of the main alternative fuels (hydrogen, ammonia, methanol, LPG, biofuel, specifically Hydrotreated Vegetable Oil, and full battery-electric systems), perform compared to LNG and legacy HFO using a set of 11 key parameters.

Alternative fuels such as hydrogen and ammonia may have a role to play in ocean shipping in the future, but as this study indicates they are still operationally unproven, relatively expensive and require massive investments in supply chains and bunkering infrastructure. Although they have the potential to reduce GHG emissions, these alternatives require significant development to meet the industry's needs since many promising alternative fuels currently lack the regulatory framework, production capability, and bunkering infrastructure for widespread adoption.

LNG is already widely and safely used for power and heat generation and in industrial processes and as a fuel for heavy good vehicles. It is the only alternative fuel that is available now for the maritime sector in sufficient quantities and likely to be for the foreseeable future. LNG is proven, safe and compliant with both current and future emissions regulations. LNG addresses the air quality issues that directly affect human health. Human health concerns resulting from air quality issues was the driver which led to the IMO's 2020 rules limiting sulphur content in maritime fuels.

Separative independent studies commissioned by SEA/LNG and carried out by Opsiana have shown that LNG offers a better return on capital under a wide range of investment scenarios compared with low sulphur fuels and the use of exhaust gas abatement systems i.e. scrubbers Until technologies are developed, which are commercially viable, scalable and safe, **there are no other alternative fuel options beyond LNG for global shipping and the bulk of international trade**.

When combined with Energy Efficiency Design Index (EEDI) improvements to ship design, LNG is forecast to meet the IMO 2030 target for decarbonisation on new ships. This LNG advantage accrues in proportion to its representative mix within existing vessel fleets: the more LNG vessels the greater the benefits. Additionally, with expected developments in bio and synthetic methane, LNG also represents a pathway to 2050 and beyond.

In order to achieve GHG reductions and improve air quality NOW, ship owners and managers need to act decisively and invest in LNG capable vessels. Doing so will improve the long-term sustainability for the shipping industry while safeguarding a competitive advantage for the ship owners and operators who facilitate global trade.

KEY TAKE AWAYS

ENERGY SOURCE / FUEL	FOSSIL (WITHOUT CCS) HFO + SCRUBBER	LOW SULPHUR FUELS	LNG	METHANOL	LPG	BIO HVO (Advanced biodiesel)	RENEWABLE (3) AMMONIA	HYDROGEN	FULLY ELECTRIC
Highest priority parameters									
Energy density									
Technological maturity									
Local emissions									
GHG emissions			(2)						
Energy cost									(4)
Capital cost – Converter									
Capital cost – Storage									
Bunkering availability									
Commercial readiness (1)									(5)
Other parameters									
Flammability									
Toxicity									
Regulations and guidelines									
Global production capactity and locations									

(1) Taking into account maturity and availability of technology and fuel. (2) GHG benefits for LNG, methanol and LPG will increase proportionally with the fraction of corresponding bio or synthetic energy carrier used as drop-in fuel. (3) Results for anmmonia, hydrogen and fully-electric shown only for renewable energy sources since this represents long term solutions with the potential for decarbonizing shipping. Production from fossil energy sources without CCS (mainly the case today) will have a significant effect on results. (4) Large regional variations. (5) Needs to be evaluated case-by-case. Not applicable for deep-sea shipping.

KEY ADVANTAGES AND DISADVANTAGES

HYDROGEN

Key advantages

- Potential as a zero-emissions fuel **if** produced exclusively from renewables.

Key disadvantages

- Low energy density (50% of LNG) and large storage tanks cannibalize vessel cargo space limit application to short range coastal vessels,
- Extensive flammability range imposes the need for safety mitigating measures, at an added cost,
- Expensive CAPEX and OPEX around 3x greater than LNG and viable production likely decades away,
- Absence of supply, bulk storage and bunkering infrastructure.

AMMONIA

Key advantages

- Potential as a zero-emissions fuel **if** produced exclusively from renewables.

Key disadvantages

- High toxicity imposes the need for safety mitigating measures, at an added cost,
- Excessive high OPEX – green ammonia is up to 4x LNG cost,
- Absence of bunkering and bulk infrastructure along major cargo routes,
- Current production generates undesirable high GHG emissions.

METHANOL

Key advantages

- Liquid fuel that enables use of upgraded existing bunker systems.

Key disadvantages

- Expensive fuel close to or higher than LSFO/MGO in today's market,
- Absence of bunkering infrastructure,
- Fossil fuel derived – GHG emissions similar to conventional marine fuels.

LPG

Key advantages

- Low OPEX cost approaching LNG levels and low CAPEX costs.

Key disadvantages

- Limited operational experience,
- Lack of bunkering infrastructure and availability as a marine fuel,
- Fossil fuel derived – GHG emissions similar to conventional marine fuels.

HVO

Key advantages

- Drop-in fuel; direct substitute for conventional petroleum-based fuels

Key disadvantages

- Expensive,
- Extremely limited production capacity and bunkering availability,
- Quality and consistency of production varies; lack of agreed fuel standards,
- High NOx and Particulate Matter emissions.

FULLY ELECTRIC

Key advantages

- Zero emissions when using electricity from renewable sources

Key disadvantages

- Prohibitive CAPEX costs; battery technology not practicable for large ocean-going ships, battery costs could exceed newbuild cost of vessel,
- Applicability - limited to short range low-power coastal vessels.

LNG – THE REALITY

LNG engine technology is:

- safe, with 10's of millions operating hours experience,
- mature, used as a marine fuel for over 50 years ,
- commercially viable, as proven by a growing order book across most vessel types,
- readily available, with rapidly expanding supply of LNG globally,
- scalable, bunkering available or planned to be virtually all of the world's major bunker ports,
- fully compliant with existing legislation around the world,
- removes virtually all risk of ocean contamination in the event of a marine fuel spill accident,
- eliminates SOx pollution thereby preserving human health,
- reduces NOx emissions by 95%,
- drops Particulate Matter emissions by nearly 99%,
- Cuts GHG emissions by up to 21% on well-to-wake basis, 28% on a tank-to-wake basis,
- Offers a long-term pathway towards a zero-emissions shipping industry through bio and synthetic sources of LNG,
- Future-proof, ready NOW. Waiting is not an option if we are to clean the air and reduce GHG.