LNG – DELIVERING DECARBONISATION

SEA-LNG

A VIEW FROM THE BRIDGE

2022-2023

SEA-LNG.ORG

LNG AS MARINE FUEL – THE MOMENTUM CONTINUES

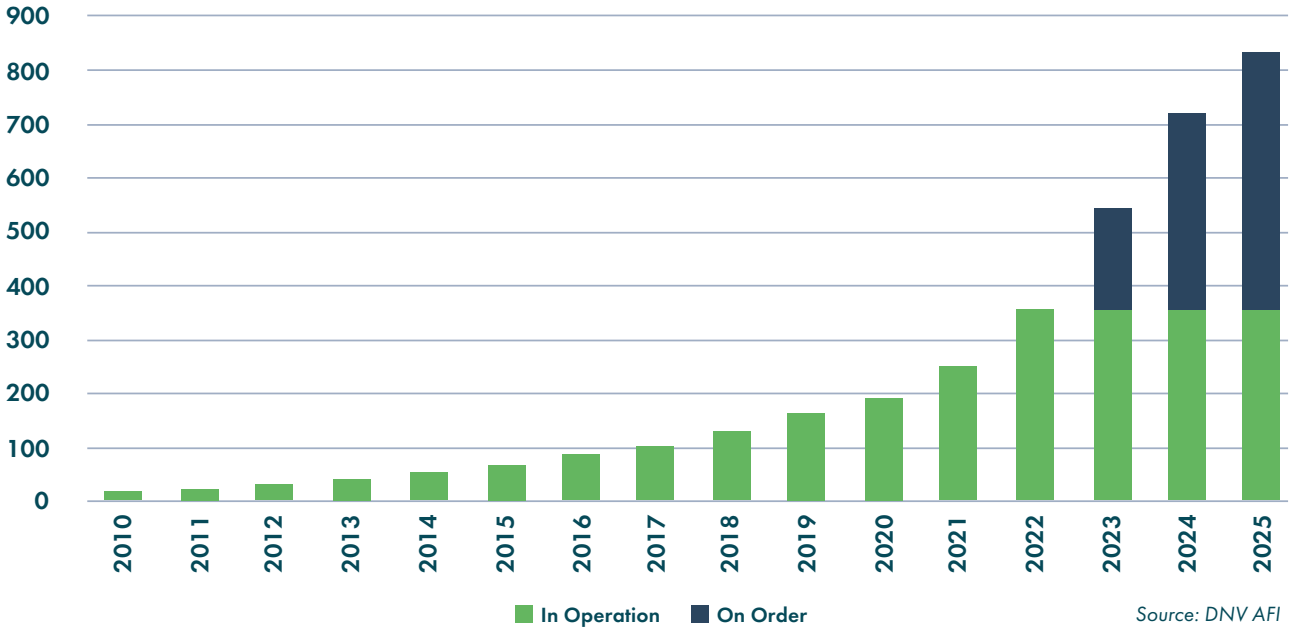
2022 was another very strong year for LNG-fuelled vessel orders, with numbers almost equalling those in 2021, the record year to date, despite exceptionally high LNG prices.

Approximately 20% of deadweight tonnage on the order book is LNG dual-fuelled and some sectors, such as car carriers, are seeing a remarkably high degree of LNG penetration – with the latest data from Clarksons showing that 93% are LNG DF.[i]

Based only on existing orders, DNV forecasts the number of LNG-fuelled ships will reach 876 by the end of this decade.[ii] However, if current growth trends continue, we can expect to see 2-4,000 LNG-fuelled ships in operation by 2030.

All of these vessels deliver immediate cleaner air locally and GHG emissions reductions globally. They provide a pathway to net-zero emissions shipping through the use of sustainable bio-LNG and renewable synthetic e-LNG.

GROWTH OF LNG-FUELLED FLEET



Source: DNV AFI

> **The only way of delivering on immediate decarbonisation is to go with LNG.**
>
> **Diego Paulizzi, Strategic Account General Manager, Wärtsilä**

BUNKERING INFRASTRUCTURE BUILD-OUT

Ship owners are investing in the LNG-fuelled fleet with the confidence that LNG infrastructure is already established in key bunkering locations and growing rapidly around the world.

By the end of 2022, there were 40 LNG bunker vessels operating in northern Europe, the Mediterranean, United States, Canada, South Korea, Japan, Malaysia, China, Singapore, Brazil, and Australia.[iii] 2022 saw commercial ship-to-ship bunkering of LNG taking place for the first time in China, the Caribbean and Russia.

In January 2022, LNG bunkering was available at 141 ports worldwide.

Today, according to Clarksons, LNG is available at 185 ports worldwide, with a further 50 facilities planned by 2025.[iv] This means LNG capable vessels have a myriad of LNG bunker locations available to them.

> **We need to effect sustainable change now – through the widespread use and investment into transitional fuels like LNG. While alternative fuels might be the right choice for specific projects today, they are not mature as a large-scale solution for our industry in the near future.**
>
> Kenneth Tveter, Head of Clarksons Green Transition team

SEA-LNG's Bunker Navigator [lviii] provides an 'at a glance' overview of the global LNG bunkering landscape. The map-based tool provides an overview of key LNG bunkering developments and how this growing infrastructure relates to major global shipping routes. It also shows the bulk LNG infrastructure which provides the foundation for bunkering services.

France's first bunker vessel came online in 2022 with **TotalEnergies'** ***Gas Vitality*** operating out of Marseilles-Fos. The vessel has a cargo capacity of 18,300 cbm.[v]

Canada-based **Seaspan** is expanding LNG bunkering solutions in the west coast of North America and the Pacific Northwest by ordering two 7,600 cbm LNG bunker vessels, with the option for a third. Chinese shipbuilder CIMC Sinopacific Offshore & Engineering has been awarded the contract, and the first vessel is expected to be delivered and in operation in 2024.[vi]

Mitsubishi Shipbuilding Co. concluded a contract with **KEYS Bunkering West Japan Co.** for the construction of an LNG bunker vessel, the first to operate in western Japan. The vessel will be built at MHI's Shimonoseki Shipyard & Machinery Works, with handover scheduled for March 2024.[vii]

The ***Clean Canaveral*** completed its inaugural bunkering in Jacksonville, Florida in March 2022. The vessel has a capacity of 5,500 cbm, making it the largest Jones Act LNG bunker barge. The vessel operates as an articulated tug barge unit ("ATB") and is owned **by Polaris New Energy LLC**.[viii]

Two additional LNG bunker vessels are under construction at Fincantieri Shipyard, one for **Polaris New Energy LLC** (5,500 cbm) and another for **Crowley** (12,000 cbm) (charter to **Shell**).[ix]

Avenir LNG took delivery of two newbuild LNG bunkering supply vessels, the 20,000 cbm ***Avenir Achievement*** and 7,500 cbm ***Avenir Ascension.***[x]

Singapore-based LNG bunker supplier **FueLNG**'s second LNG bunkering vessel was launched at Hyundai Mipo Dockyard. The 18,000 cbm vessel will be the largest LNG bunker vessel in Southeast Asia[xi]

TotalEnergies Marine Fuels is moving closer to starting its LNG bunkering services in Singapore with the 12,000 cbm ***Brassavola*** scheduled to be operational in the first quarter of 2023.[xii]

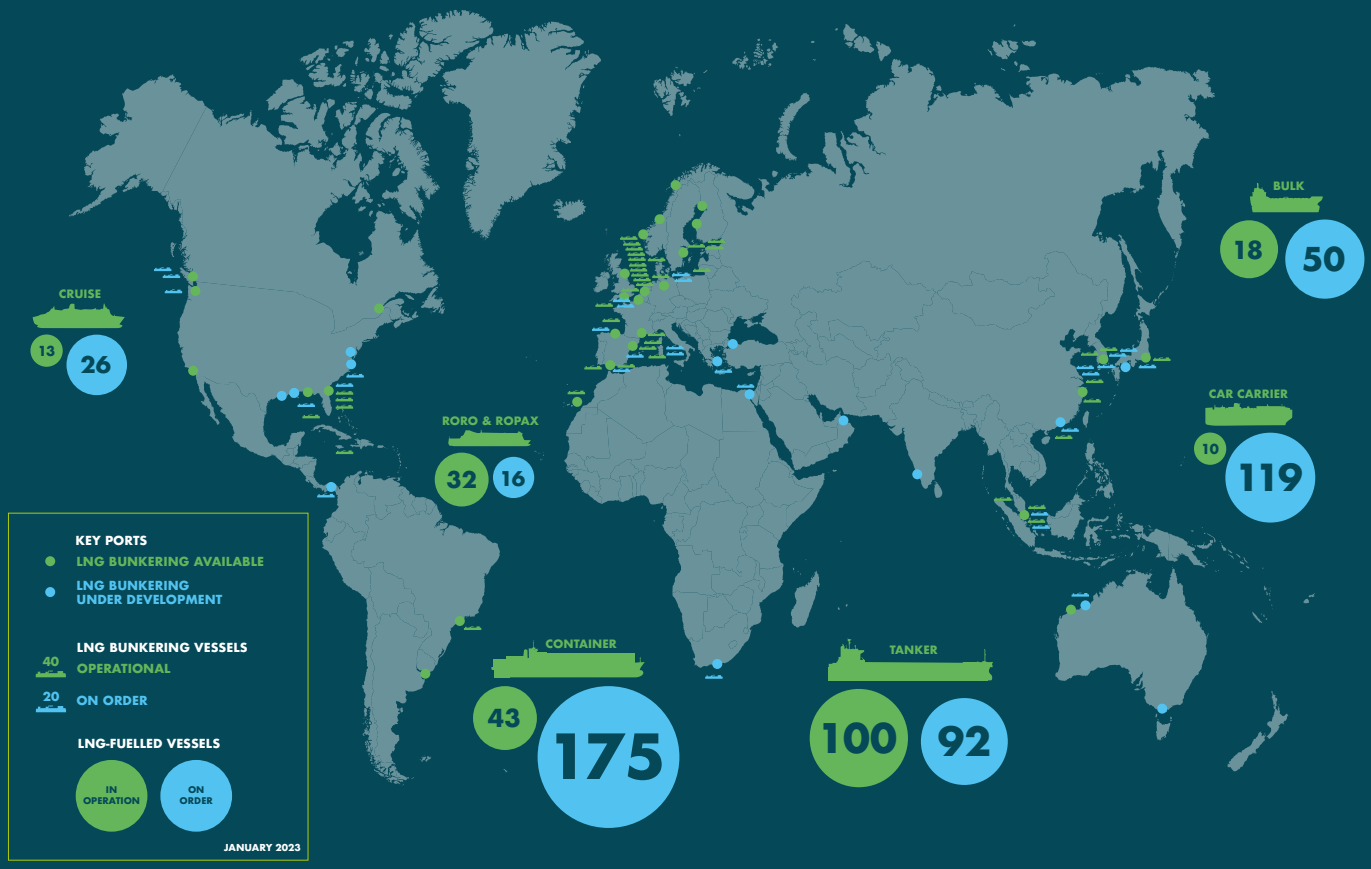
The 30,000 cbm ***Hai Yang Shi You 301***, described as the world's largest LNG bunker vessel, was officially put into operation by China State Shipbuilding Corporation's subsidiary **Guangzhou Shipbuilding International** following a conversion project for the China National Offshore Oil Corporation (CNOOC). China's first seagoing LNG bunker vessel ***Xin Ao Pu Tuo Hao*** was delivered in 2022 as was 20,000 cbm ***Hai Gang Wei Lai,*** previously known as ***Avenir Allegiance.***[xiii]

Korean shipbuilder, Hyundai Mipo Dockyard, delivered the 18,000 cbm LNG bunker vessel ***K Lotus*** to **Korea Line** on charter to Shell.[xiv]

Knutsen has partnered with Scale Gas on a 5,000 cbm newbuild, ***Haugesund Knutsen***, which will operate from the Port of Barcelona on charter to Shell.[xv]

Newport Shipping and Marine Service GmbH developed a containerised LNG fuel tank solution for newbuildings and existing container vessels as an alternative to traditional LNG bunkering. The LNG fuel tank container has a capacity of about 33 cbm.[xvi]

WORLDWIDE GROWTH IN LNG USE AND INFRASTRUCTURE



GOOD REASONS FOR INCREASED DEMAND

The growing orderbook is recognition from ship owners that LNG delivers immediate and important local air quality benefits and GHG compliance today and offers a low risk, incremental pathway to decarbonisation.

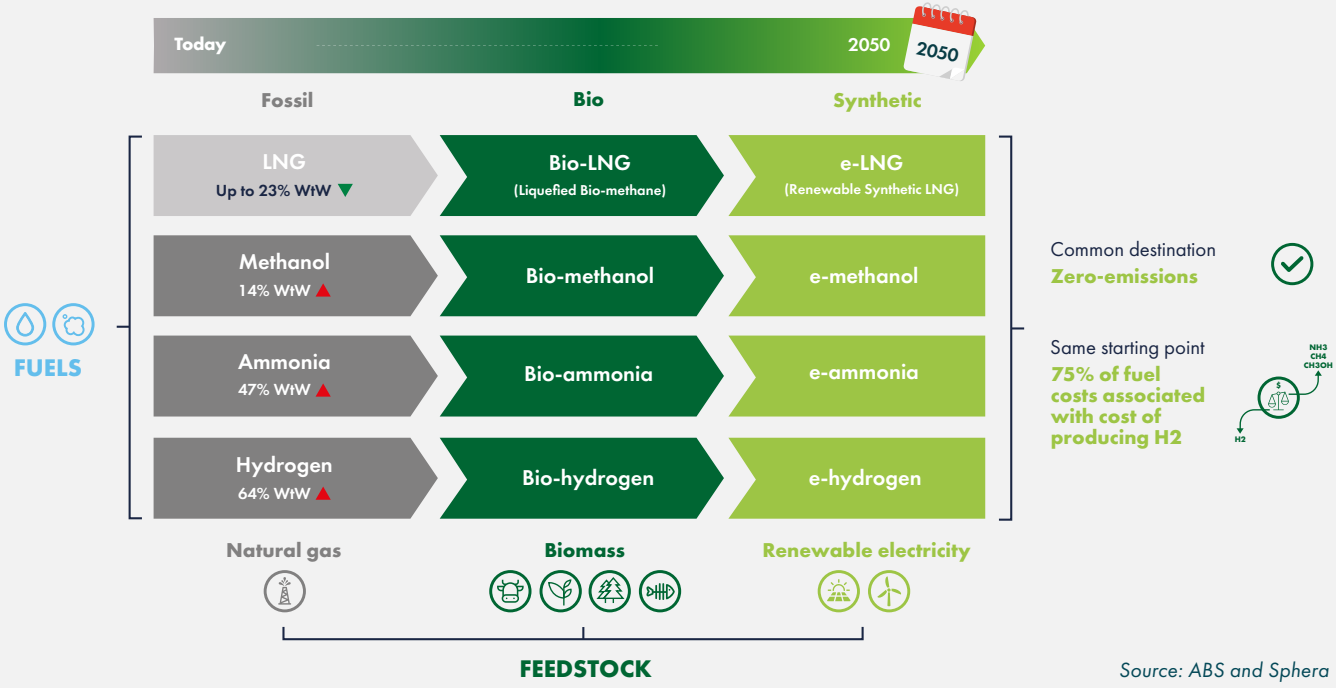
Existing infrastructure can transport, store and deliver carbon-neutral bio-LNG and renewable synthetic LNG (e-LNG). These fuels can also be used as a drop-in fuel for LNG-fuelled vessels or blended with fossil LNG without any additional investment.

It is imperative that we remember that air quality is still a major environmental issue around the world. Our health is directly related to the air we breathe, and LNG is the only scalable fuel available today that addresses these critical and ongoing health concerns.

COMPARING "APPLES WITH APPLES"

The shipping industry is making newbuild investment decisions now that will impact GHG emissions today and for the next 25-30 years, the typical lifetime of a deep-sea vessel. ***It is essential that assessments of alternative marine fuel pathways are made on a like-for-like, or "apples with apples" basis.***

Discussion of alternative fuels too often compares the green versions of, for example, ammonia and methanol, with fossil, or grey, LNG. The reality is that all fuels share a common pathway from fossil-based versions, produced from natural gas (often in the form of LNG) to hydrogen-based, renewably produced synthetic fuels. These synthetic fuels will only become available as and when sufficient renewable electricity and electrolysis capacity comes online to produce them.

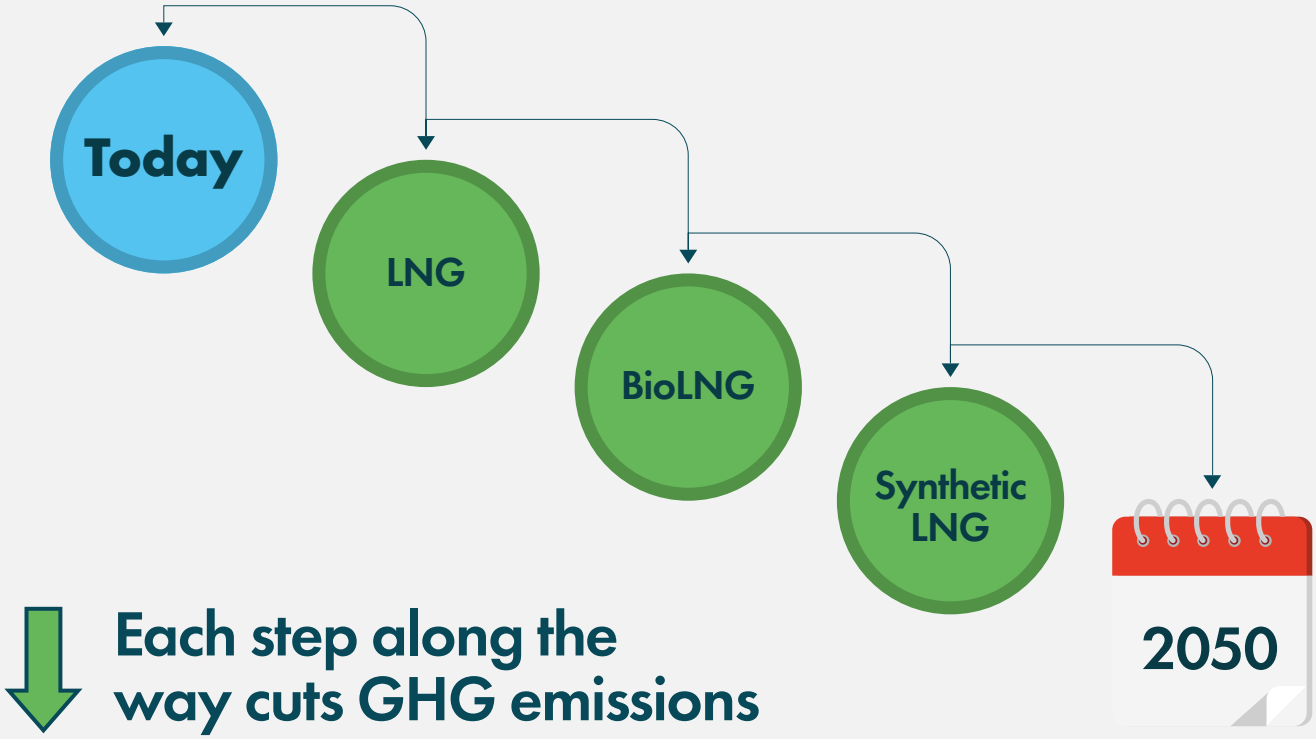


Source: ABS and Sphera

> **Apart from a select group of major shipping lines, the industry will not be blessed with government subsidies for "green" ammonia or methanol, neither of which are yet practical or safe.**
>
> **Richard Fulford-Smith, Affinity (Shipping) founder**

Many advocates of alternative fuels suggest that the shipping industry will be able to move in a single step from fossil to zero-emission, renewable fuels.[xvii] This is extremely unrealistic as the fuels and infrastructure needed to support them are likely to take many years to scale.

Decarbonisation is much more likely to take place incrementally as the carbon intensity of fuels are gradually reduced through the addition of low and zero-emission drop-ins.



THE PATHWAY, NOT SIMPLY THE DESTINATION

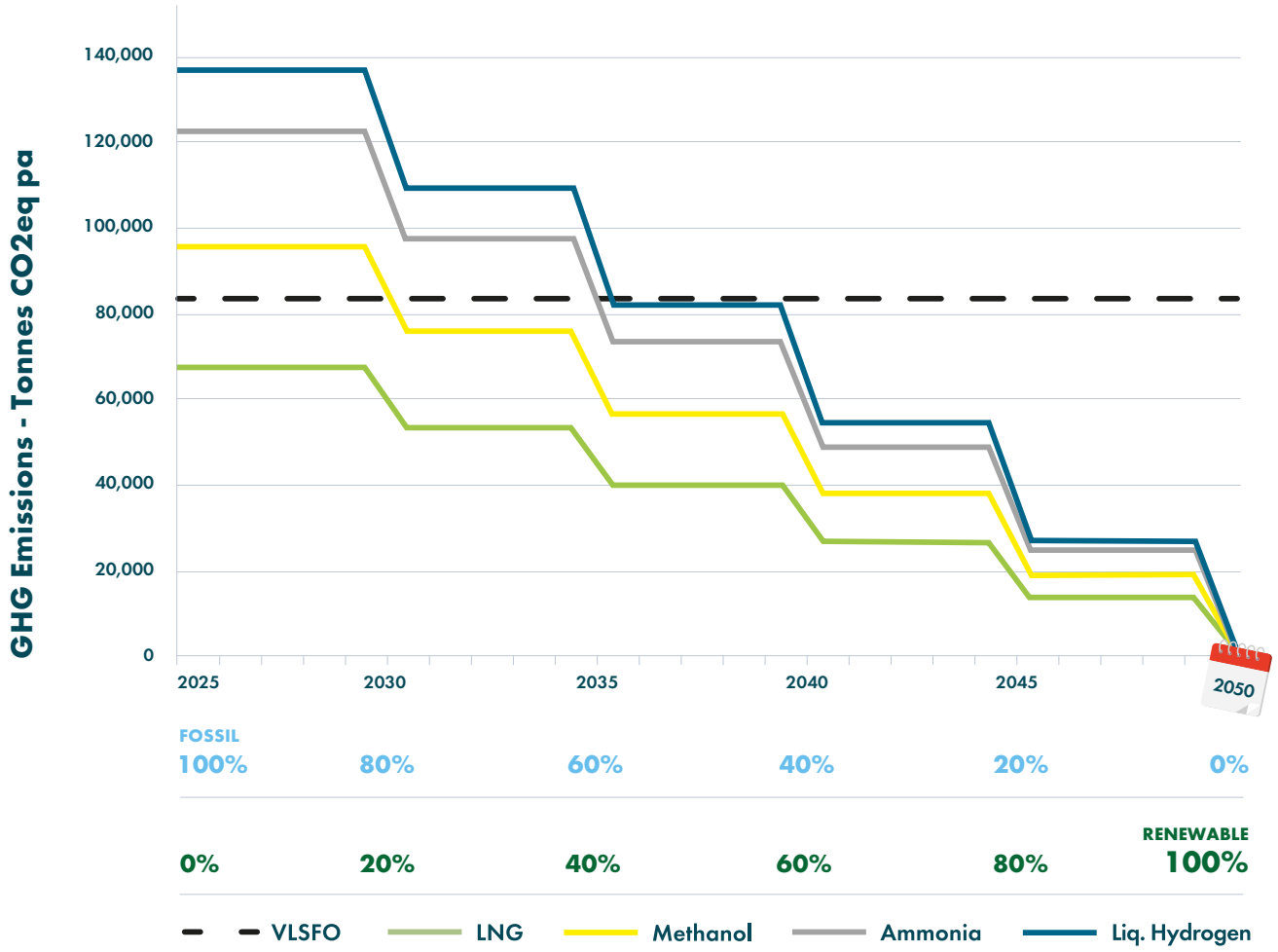
While regulators and industry are agreed on the net-zero emissions destination, the implications of the pathway are rarely discussed.

Almost all alternative fuels today, including LNG, are fossil-based. In fact, most are produced from natural gas. LNG is simply natural gas that has been cooled to the point it liquefies making it easier and cheaper to transport. Natural gas, and sometimes coal, is the feedstock for almost all current methanol, ammonia and hydrogen production.

Uniquely, fossil LNG offers significant GHG emissions reduction when used as a marine fuel compared with VLSFO – up to 23% on a full lifecycle (Well-to-Wake) basis.[xviii] By contrast, the use of fossil methanol, ammonia and (liquid) hydrogen results in emissions far higher than those associated with VLSFO because of the large amounts of fossil energy required for their production.

COMPARISON OF DECARBONISATION PATHWAY

14K TEU CONTAINER VESSEL: WELL-TO-WAKE GHG EMISSIONS OF DIFFERENT MARINE FUELS

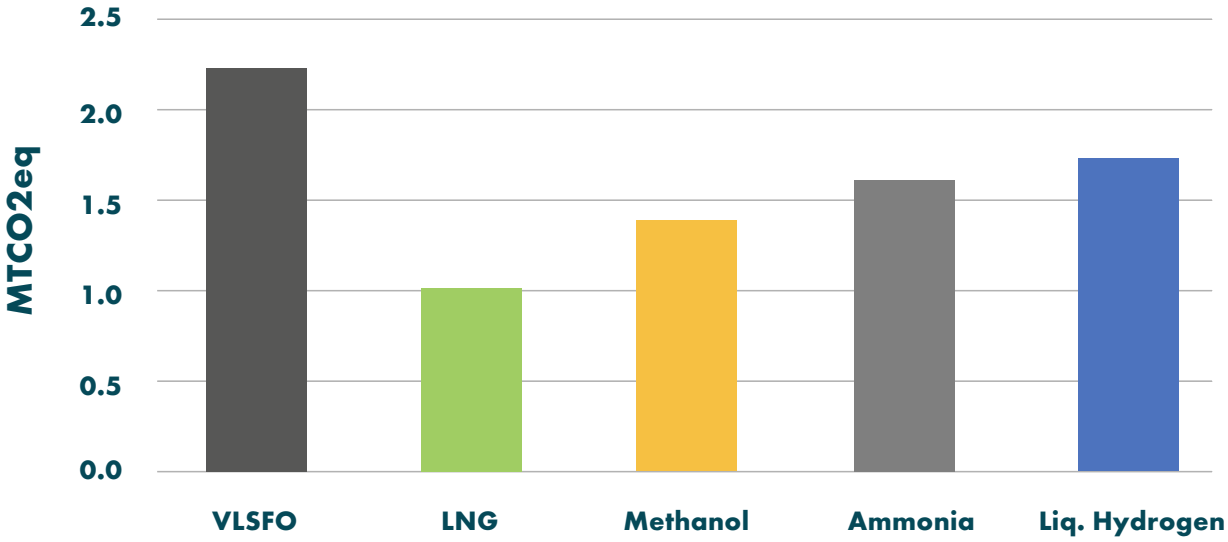


Source: Sphera, ABS & SEA-LNG analysis

The benefits of the LNG decarbonisation pathway are illustrated using simple calculations of GHG emissions over the lifetime of a mid-sized container vessel. The vessel comes into operation in 2025, is dual-fuelled with a 25-year lifespan, and renewable fuels are assumed to become available at increasing scale from about 2030 onwards. The graph illustrates how LNG offers immediate GHG reductions decreasing to zero-emissions by 2050.

Note, we use the example of a single container vessel for simplicity, whereas in reality the insights obtained apply at a fleet level.

LIFETIME GHG EMISSIONS 14K TEU CONTAINER VESSEL: VLSFO UNTIL PARITY



Source: Sphera, ABS & SEA-LNG analysis

The bar chart shows an overall emissions reduction for the LNG pathway of more than 50% over the lifetime of the vessel compared with VLSFO. The methanol and ammonia pathways also offer lifetime emissions reductions, but the reductions are significantly smaller – 37% and 28% respectively – as they start from a "worse" place. ***Fossil methanol emissions are 14% higher than VLSFO on a full lifecycle basis; for ammonia the corresponding number is 47%.*** This implies that ship owners and operators choosing methanol and ammonia pathways will be forced to continue using VLSFO until renewable versions of these fuels become available at scale i.e. not until about 2030, postponing emissions reductions for several years.

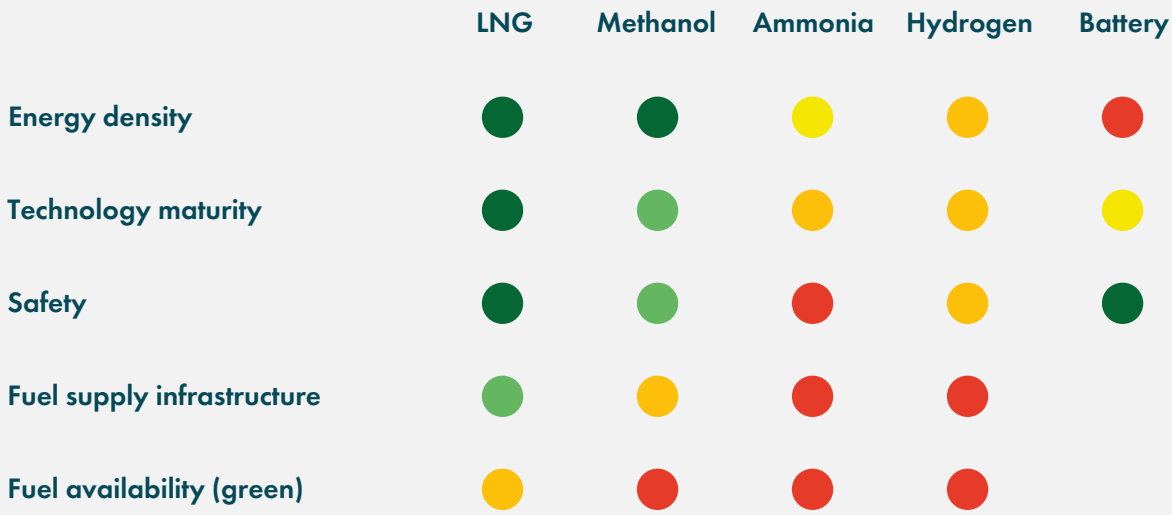
If methanol and ammonia are to achieve emissions parity with fossil LNG, then the grey versions of these fuels need to be blended with approximately 30% renewable or green methanol and 50% renewable or green ammonia. ***This implies higher costs to achieve the same emissions reductions.*** The fossil versions of methanol and ammonia are already significantly more expensive than LNG and the renewable versions are likely to cost multiples more than their fossil equivalents.

> **LNG offers an immediate 20% carbon reduction, enables the use of low-carbon drop-in fuels, and ultimately paves the way for new forms of low-carbon LNG using the same shipboard components and systems.**
>
> **Soren Toft, CEO of Mediterranean Shipping Company (MSC)**

DECARBONISATION – THE PRACTICAL CHALLENGES

Emissions and potential costs are only part of the picture. When making investments ship owners also need to consider other, practical factors. Pre-requisites for renewable and low-carbon fuel solutions include:

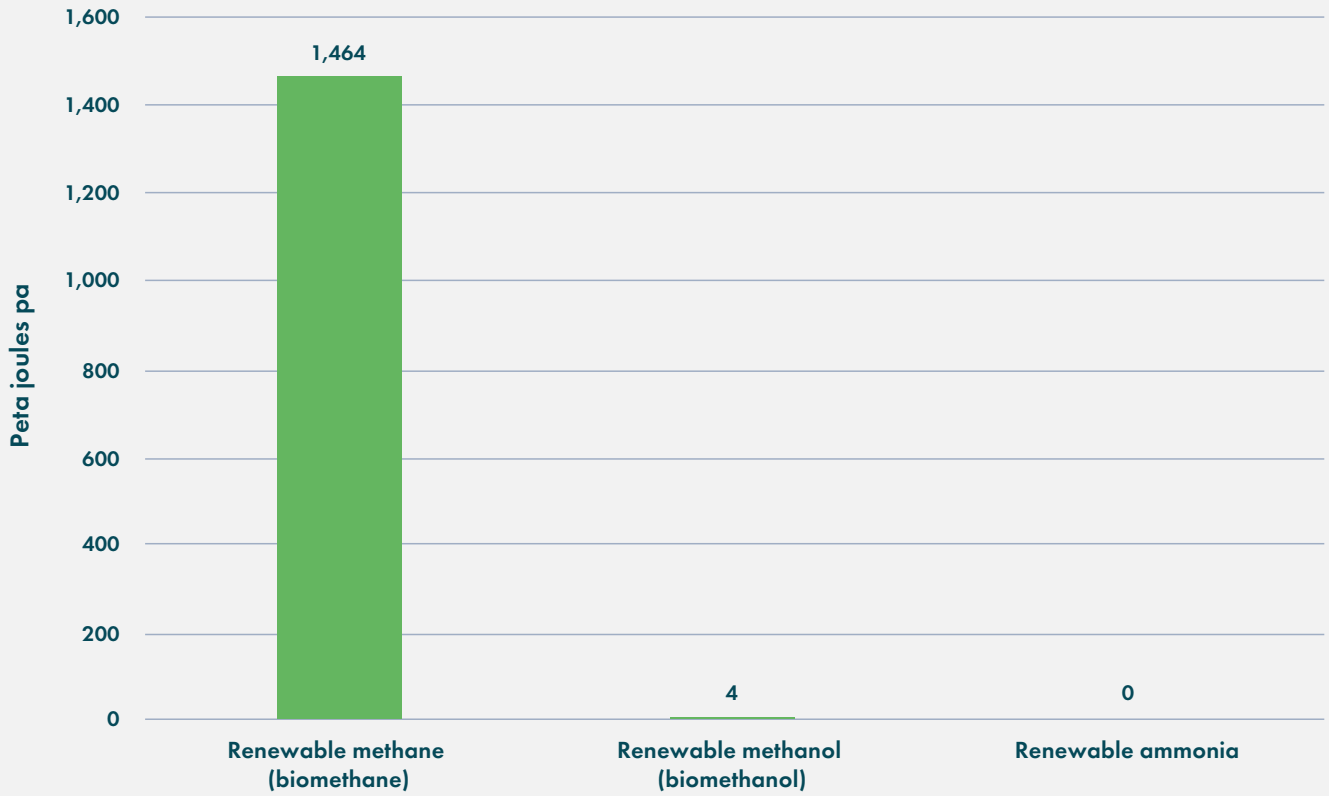
- High energy density – the more space required for fuel, the less space available for cargo
- Reliability – technologies that are proven to work in the maritime environment
- Safety – completely safe for crew, passengers and port communities
- Fuel supply infrastructure – how quickly fuel transportation, storage and bunkering infrastructure can be developed in the places it is needed
- Fuel availability – when the new "green" fuels will be available at scale



On this basis, ***LNG and its bio and synthetic derivatives offer significant advantages over alternative fuels and propulsion systems.*** Given time and money, the challenges associated with these alternative fuels are likely to be addressed, but decarbonisation timelines are challenging and money is clearly limited.

> **LNG is one of the single biggest ways to reduce emissions in current vessels and will enable the use of carbon neutral synthetic or bio-gas when it becomes available.**
>
> **Dominik Schneiter, WinGD Vice President Research & Development**

CURRENT RENEWABLE FUEL PRODUCTION



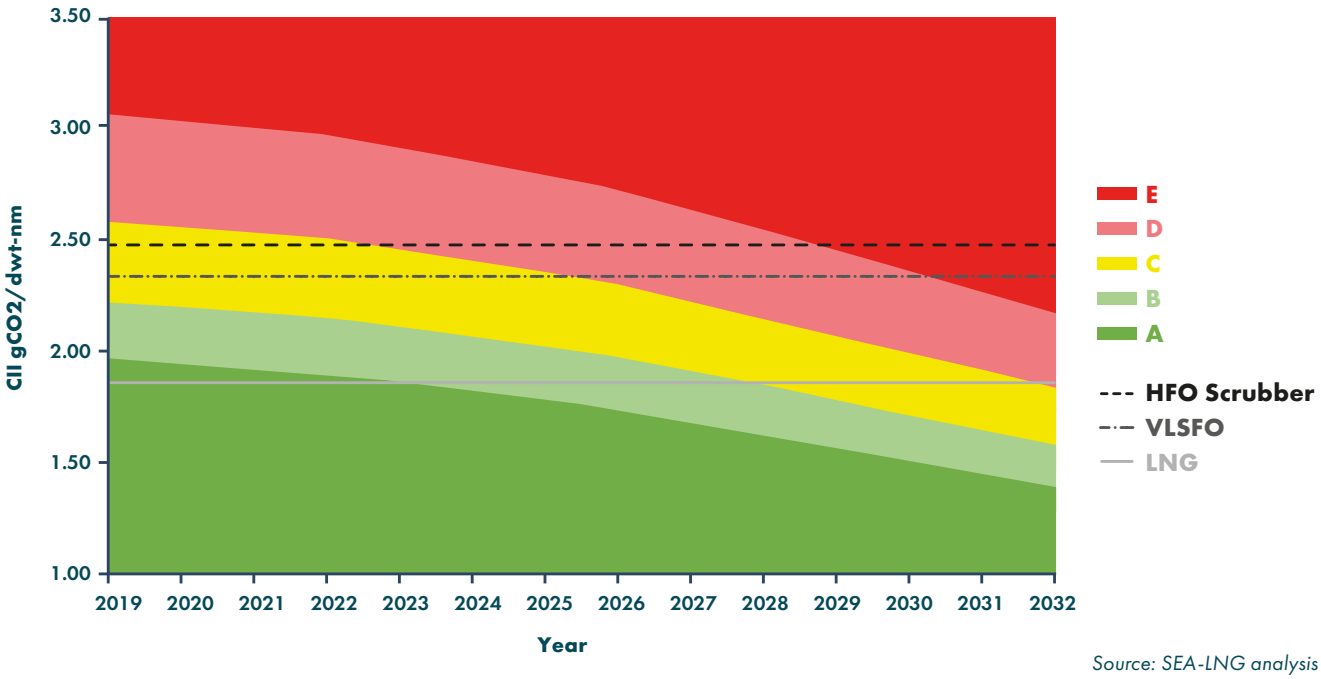
Source: IEA, Methanol Institute, Royal Society

The scale of the challenge is illustrated by the current levels of production for "green" marine fuels. No green ammonia or green methanol is available at scale to support maritime needs today or in the immediate future. By contrast, significant and growing volumes of biomethane production already exist and in its liquefied form bio-LNG is already commercially available for shipping in both Europe and North America.

LNG AND REGULATORY COMPLIANCE

The IMO and European Union are in the process of introducing a range of regulations aimed at decarbonising the shipping industry. This is work in progress, as the complexity of the shipping industry means that unintended consequences of proposed regulations still need to be understood and addressed. This is illustrated in the current discussions over the implementation of the IMO's Carbon Intensity Index (CII). Notwithstanding this, LNG and its associated bio and synthetic pathway will provide ship owners and operators with significant and immediate compliance benefits.

CII COMPLIANCE



Source: SEA-LNG analysis

LNG-fuelled vessels will be able to continue operating as normal under the CII system until after 2030, while fossil LNG blended with bio-LNG and e-LNG will further extend compliance to 2050 and beyond.

> **LNG is not the end game, but it is the starting point to carbon zero. With the IMO GHG reduction targets knocking at our doors, we cannot afford to wait.**
>
> **Dr Shahrin Osman, Regional Head of Maritime Advisory, Director of Maritime Decarbonization and Autonomy Centre of Excellence Asia – Pacific at DNV**

Analysis undertaken by SEA-LNG comparing emissions for two identical 180k DWT Capesize [lix] vessels – one using conventional, oil-based marine fuels, the other using LNG as a marine fuel – shows that the LNG-fuelled vessel immediately rates two grades higher than the conventionally fuelled vessel.[xix] ***LNG can be the difference between having a 'moderate' C-rated ship and having a 'major superior' A-rated ship on the IMO's CII scale.***

LNG is also the best fuel option for ship owners considering how to extend vessel life and secure CII compliance through retrofit. SEA-LNG's analysis underlines that there are significant benefits to businesses choosing an LNG retrofit [lx] over fuelling with VLSFO or retrofitting an HFO vessel with scrubbers, based on a ten-year payback period.

EU FIT FOR 55

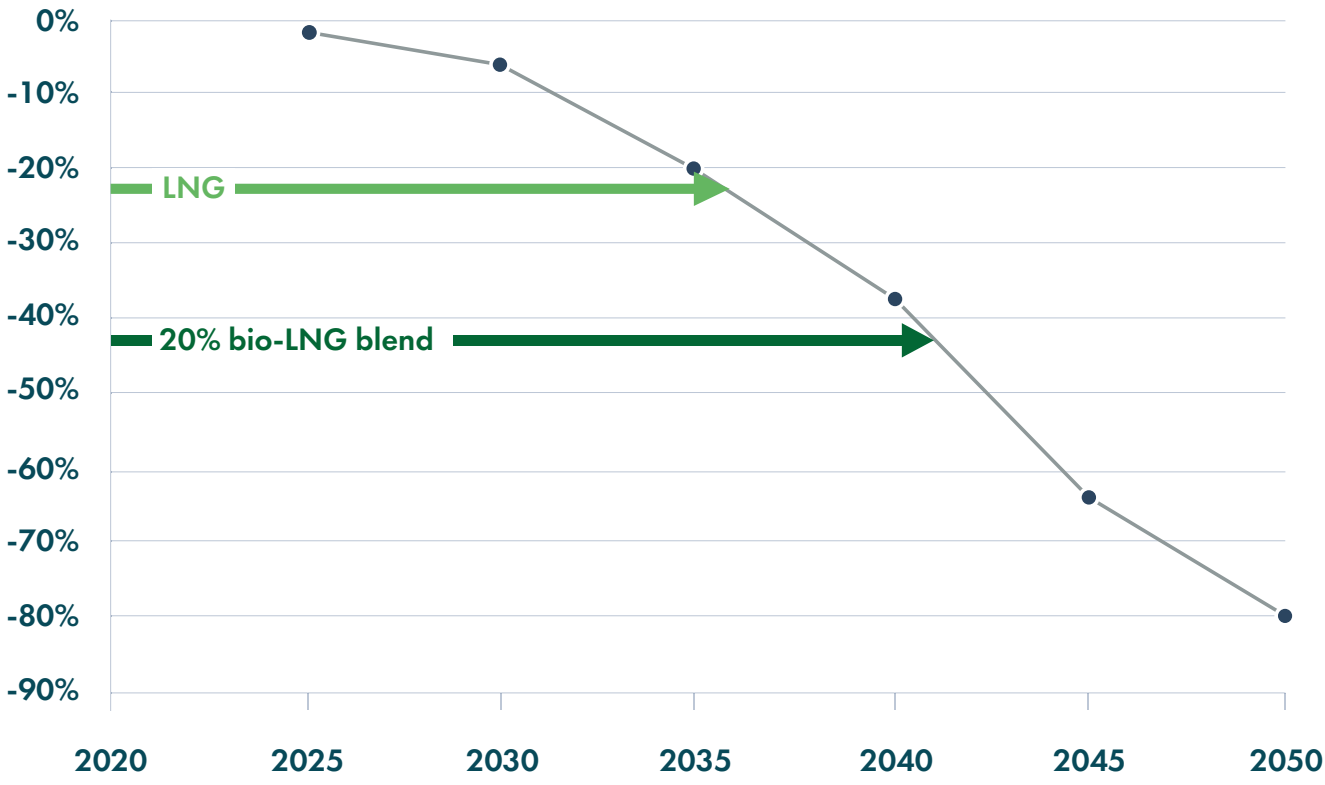
The EU's "Fit for 55" policy package sets out a range of measures targeting climate neutrality for Europe by 2050. FuelEU Maritime and the inclusion of shipping in the European Emissions Trading System (ETS) are key policy directives aimed at decarbonising shipping in line with this ambition.

FUELEU MARITIME COMPLIANCE

The FuelEU Maritime proposal has been designed to accelerate the maritime industry's decarbonisation through the adoption of renewable and low-carbon fuels and technologies. It does so by setting out increasingly stringent GHG intensity limits for the energy used on-board ships.

LNG enables vessels to be compliant with the GHG intensity targets (calculated on a Well-to-Wake basis) – proposed under the legislation until 2035. ***The use of a 20% drop-in blend of bio-LNG will extend compliance until beyond 2040.*** Thereafter, compliance can be achieved through the use increasing proportions of bio-LNG and e-LNG as and when it becomes available.

FUELEU MARITIME GHG INTENSITY LIMIT OF ENERGY USED ON-BOARD BY A SHIP



Source: SEA-LNG analysis

EU ETS BENEFITS

The extension of the EU ETS to shipping will be key in influencing fuel choice. LNG will give ship operators a competitive advantage over those using oil-based marine fuels when it comes into force in 2024 because of its lower levels of GHG emissions – up to 30% on a Tank-to-Wake basis – the methodology used to measure emissions. A ship operator using VLSFO will need to pay a CO2 'tax' of approximately €250 for each tonne of fuel used at current ETS market prices of €80/T. For LNG, the equivalent premium would be €220 per tonne. Given the higher energy content of LNG per tonne of fuel, then for a 14,000 TEU container vessel this would translate into a carbon tax exposure of about €27,000 per day if fuelled by LNG compared with €37,000 per day, if fuelled by VLSFO.

As bio-LNG is categorised as a zero emissions fuel on a Tank-to-Wake basis, it provides an opportunity to significantly reduce a ship operator's exposure to CO2 taxes.

> **With the preliminary agreement at the EU that shipping will be included in the EU ETS starting from 2024, all low-carbon options now make even more sense.**
>
> **Martin Wold, DNV Maritime's principal consultant**

BIO-LNG – PRODUCTION EXPANDING AND UPTAKE INCREASING

Today, bio-LNG produced from sustainable biomass resources i.e., waste biomass that does not compete with food, fodder or fibre, is the most readily available solution to support the pathway to decarbonisation in shipping, especially across Europe. Widely used as a net-zero fuel for heavy-duty vehicles within the EU, it is already being used as a marine fuel. Production is growing rapidly with 78 plants within the EU forecast to be operational in the next two years.[xx] Production is expected to expand tenfold by 2030.

Bio-LNG is carbon neutral, and potentially carbon negative depending on the feedstock used to produce it. It is produced from the reuse of waste from farming activities, industrial applications and households. It supports the circular economy, capturing methane that would otherwise be released into the atmosphere. It also helps the global economy begin to cope with another major concern - waste management - thereby promoting the circular economy. The benefits of the LNG decarbonisation pathway via bio-LNG are being recognised by increasing numbers of cargo owners, from car manufacturers to big box and internet retailers.

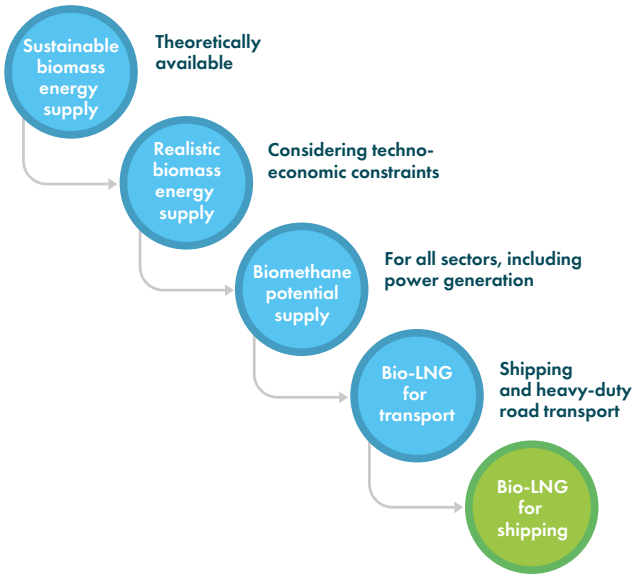
Bio-LNG can be utilised via existing infrastructure built up over decades for LNG. As sustainable sources of bio-LNG are often distant from the ports where it needs to be bunkered, mass balance / Guarantee of Origin regulatory systems are needed and are being introduced, for example in Europe.

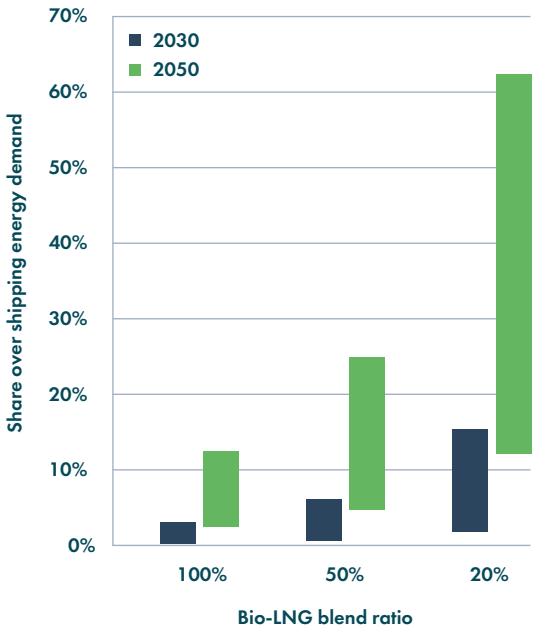
AVAILABILITY AND COST OF BIO-LNG

A study conducted this year by the Maritime Energy and Sustainable Development Centre of Excellence [lxi] (MESD CoE) at Nanyang Technological University, Singapore (NTU Singapore) explored the role of bio-LNG in shipping's decarbonisation.[lvii]

> **Our research concludes that bio-LNG, produced from sustainable biomass resources, has the potential to meet a significant proportion of future shipping energy demand.**
>
> **Associate Professor Jasmine Lam, Centre Director, MESD CoE, NTU Singapore**

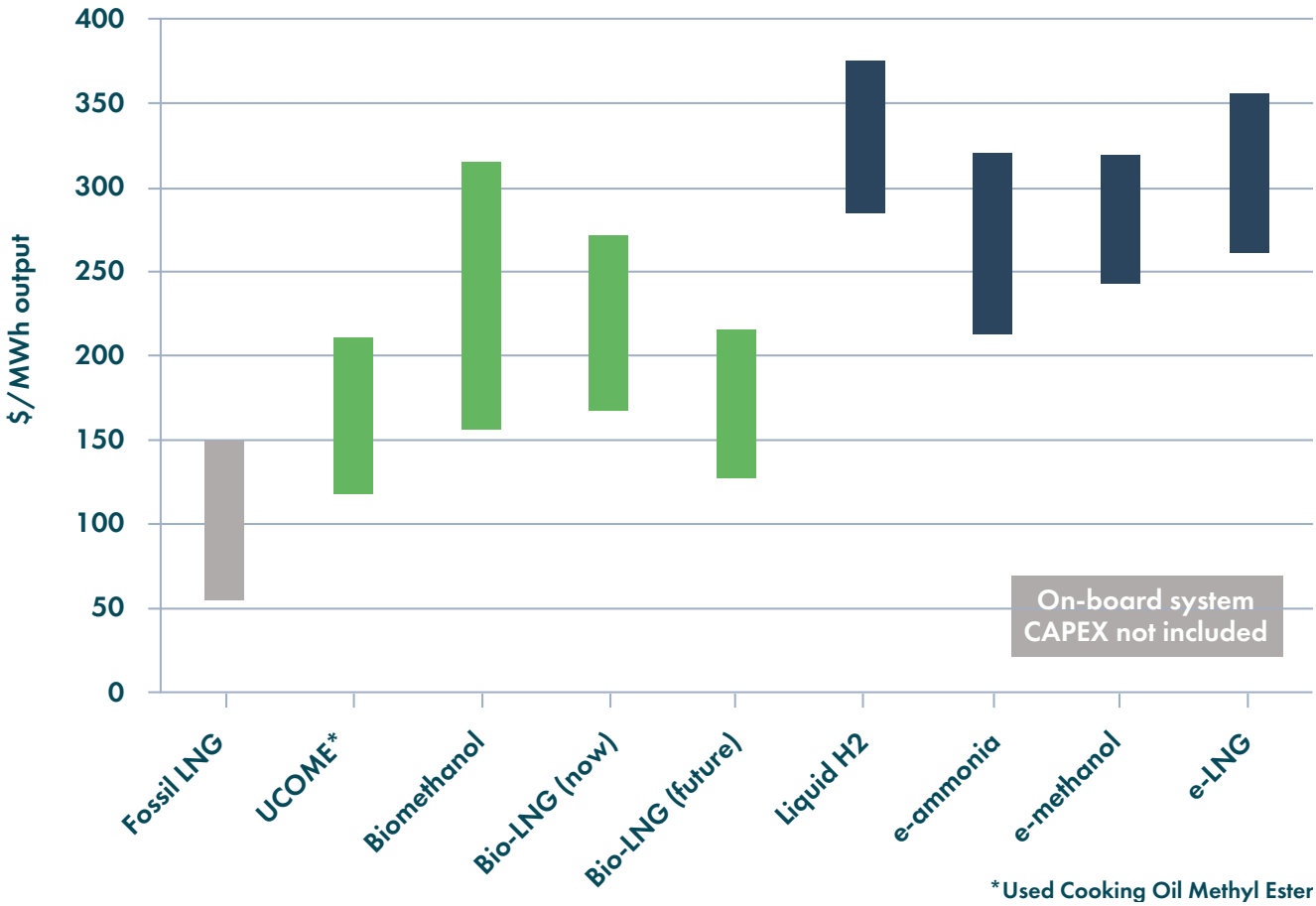
The findings suggest that pure bio-LNG could cover up to 3% of the total energy demand for shipping fuels in 2030 and 13% in 2050. If it is considered as a drop-in fuel blended with fossil LNG, bio-LNG could cover up to 16% and 63% of the total energy demand in 2030 and 2050, respectively, assuming a 20% blending ratio. In the long term, ship owners who have invested in the LNG pathway will need to shift to e-LNG.





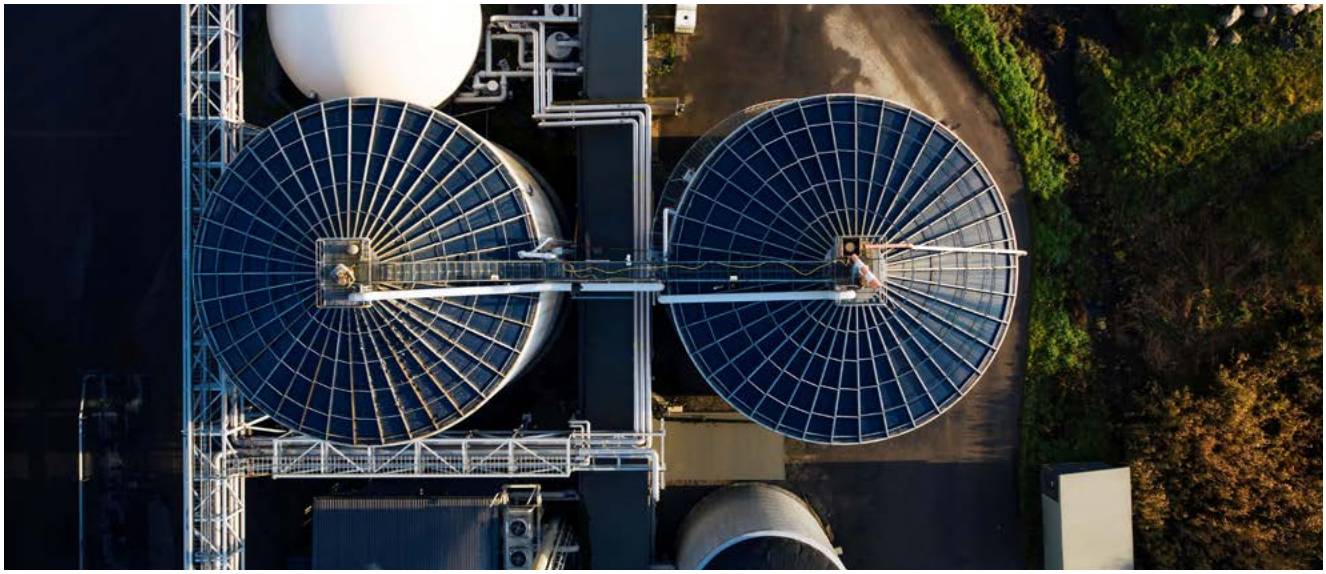
Source: MESD CoE

Currently, the cost of bio-LNG is around 3-4 times higher compared to the average fossil LNG bunker price. However, the average cost for delivered bio-LNG is forecast to decline by around 30% by 2050 compared to today's values, mainly driven by the reduced cost of producing biomethane in large-scale anaerobic digestion plants. ***It is key to note that although the cost of bio-LNG bunkers is relatively high compared to fossil fuels, it is cheaper than most other green alternative fuels such as biomethanol and electro-fuels, including e-ammonia and e-methanol.***



*Used Cooking Oil Methyl Ester

Source: MESD CoE



Titan has announced it will build the world's largest biomethane liquefaction plant in the Port of Amsterdam. Production is expected to commence in 2025. The company will operate the 200,000-tonne-per-year plant in partnership with biogas supplier BioValue and Linde Engineering, which will perform the basic engineering for the project. To put this in context, if blended as a 20% drop in fuel with LNG, the output of this plant alone could enable almost 25 14,000 TEUs container vessels to comply with FuelEU Maritime's decarbonisation trajectory for 2040.[xxi]

REEFUELERY, a joint venture between Erdgas Südwest and avanca Group, is building a bio-LNG plant which will be able to produce 63,000 tons of bio-LNG per year. Located in Burhaun, Germany, the plant will utilise biomethane from communal and agricultural waste materials as feedstock and is expected to become fully operational during the first quarter of 2024.[xxii]

In June, Nordic energy company Gasum delivered a blend of LNG and bio-LNG to Donsotank's hybrid tanker ***Prospero*** off Sweden's Gothenburg. Using its chartered 5,800 cbm LNG bunker vessel, ***Coralius***, approximately 25% of the total volume delivered was renewable and ISCC-certified bio-LNG. [xxiii]

During 2022 Gasum supplied liquefied biogas (LBG) to Island Offshore for usage trials in their offshore vessels. Island Offshore has found it a very positive experiment and is planning to offer their customers LBG as an option to lower emissions.

Gasum is commencing the process of consecutively constructing five large new biogas plants in southern Sweden. The construction of the first one will begin during 2023. The plants will use 1.8 million tons of different kinds of waste streams for feedstock and produce 55,000 tons of LBG (750 GWh of energy) per year. They will also produce 1.5 million tons of high-grade environmentally friendly fertilizer as a side stream.

CMA CGM and Engie announced a €150m investment scheme to establish a facility at the port of Le Havre fuelled by dry biomass from local wood-waste sources, along with solid recovered fuel, to produce 11,000 tonnes of biomethane annually. The project, dubbed Salamander, is the first step towards the companies' shared goal of producing up to 200,000 tonnes of renewable gas annually by 2028 for CMA CGM ships and the wider shipping industry.[xxiv]

Located at the Borås Energi och Miljö facility at Sobacken in Sweden, a new bio-LNG plant is expected to be fully operational by the end of 2023. The plant will take biogas from municipal waste and wastewater treatment plants and upgrade it into usable bio-LNG. When operational, the plant will be capable of producing 10 tonnes of bio-LNG per day. Finland energy company St1 Nordic is investing in the plant and has signed a long-term off-take agreement.[xxv]

RENEWABLE E-LNG – PROJECTS NOW PROVING FUTURE POTENTIAL

> **It is a fuel that can help us take the first steps to decarbonisation and can potentially future proof with bio and synthetic alternatives.**
>
> **Stam Achillas, Wärtsilä Head of Business Development and Sales, 2-stroke fuel conversions, said of LNG**

All synthetic fuels, such as e-LNG, e-ammonia, and e-methanol, are derived from the same building block – hydrogen produced from electrolysis using renewable electricity. Consequently, they all face the same challenge – the need for massive additional renewable electricity that does not exist today.

Only once sufficient renewable electricity exists to electrolyse hydrogen at scale will it be possible to produce e-LNG or, indeed, any of the other e-fuels being considered for shipping. It is important to note that around 70-80% of the cost of producing these e-fuels is associated with renewable hydrogen production. Therefore, it is anticipated that the ultimate cost differentials between the various e-fuels will be minimal.

The real differentiator in the long-term costs will be in the supply chain. Here LNG will dominate as the supply chain for e-LNG is the same as the supply chain for bio or conventional LNG. All other fuels need their own dedicated supply chains and the investments will be significant.

> **Shipping stakeholders are investing in LNG because it provides a low risk, incremental pathway for decarbonisation, starting now. Waiting is not an option.**
>
> **Peter Keller, Chairman, SEA-LNG**

MAN Energy Solutions reported that the 1,036 TEU containership, ***ElbBLUE*** (formerly ***Wes Amelie***) reduced its GHG emissions by 27% by operating on a blend of climate-neutral, synthetic natural gas (SNG) and conventional LNG, compared to LNG alone. GHG emissions were reduced by 34% compared heavy fuel oil (HFO). The data came from measurements initially carried out on board the ship in September 2021 when the ***ElbBLUE*** became the first containership worldwide to replace a portion of its bunkered gas fuel (around 50%) with SNG.[xxvi]

> **With this pilot project, we have proven that any LNG-powered ship can also operate with green SNG from power-to-X. Even with a blend of just 50% SNG, GHG and pollutant emissions are significantly reduced. When operated exclusively on SNG, we would expect a reduction of at least 80% in GHG emissions for modern ships.**
>
> **Stefan Eefting, Senior Vice President and Head of MAN PrimeServ Augsburg**

CMA CGM has 28 e-methane-ready dual-fuel, LNG-powered containerships and will have 44 vessels of this type in service by the end of 2024. By providing access to the results of its green hydrogen production, methanation and CO2 capture, the Jupiter 1000 project is expected to enable CMA CGM to accelerate the development of the production sector for synthetic methane. Piloted by the French natural gas transmission system operator, GRTgaz, the Jupiter 1000 project intends to provide solutions to the challenge of decarbonising gas networks and the intermittent nature of renewable energy. The idea is to convert a portion of renewable power, at times when it is abundant, into hydrogen and e-methane so it can be stored long-term on a large scale.[xxvii]

In summary, the LNG pathway is increasingly recognised as an attractive way of meeting net-zero targets. Being able to incrementally transition from LNG to bio-LNG, to renewable e-LNG means that ship owners will not end up with stranded assets. Additional investments in supply chains will also not be required as the transportation and storage systems and assets already exist and are being expanded almost daily.

PROGRESS IN ADDRESSING METHANE SLIP

Methane slip is a recognised problem that the maritime industry has been actively addressing for well over a decade.

It is important to recognise that methane slip represents a waste of energy and additional fuel cost, so engine manufacturers are incentivised to address it to improve overall efficiency and performance. The latest engine technologies already have virtually no methane slip, and these engines represent at least half the LNG new build order book, according to DNV data.[xxviii] Where methane slip still exists, engine manufacturers and fuel suppliers are accelerating their technological developments to address the issues. Levels have fallen four-fold since the early 2000s,[xxix] and ***engine manufacturers continue to identify technological pathways that will mean all LNG-fuelled engines have minimal levels of methane slip by 2030, if not sooner.***

Regulations are also being developed by the IMO and the EU to further reinforce this industry-led direction. The regulatory initiatives can be expected to make methane slip a compliance issue for the shipping industry.

The industry is also undertaking projects to improve on-board monitoring of methane slip and develop operational and technological solutions to the issue. Examples include:

The Methane Abatement in Maritime Innovation Initiative (MAMII), for example, was launched in 2022. The coalition includes Maran Gas Maritime, Mediterranean Shipping Company (MSC), Carnival Corporation, Seaspan, Shell, Lloyd's Register and Knutsen. In its first year, members will seek to identify and pilot new technologies to monitor and reduce methane slip from vessels fuelled by LNG. Once these solutions have been validated, the initiative will look to encourage widespread industry adoption.[xxx]

GREEN RAY - a five-year project, started in June 2022 which is aiming to develop three solutions to reduce methane slip from LNG in new and existing ships. The project, which received a EUR 7 million grant from the European Commission, is being coordinated by VTT Technical Research Centre of Finland and brings together partners from across the shipping value chain including Chantiers de l'Atlantique, CMA Ships, Wärtsilä, Shell, DNV, the Finnish Meteorological Institute and MSC.[xxxi]

Upstream emissions of methane are being addressed by a number of UN and industry initiatives. The most high profile being the Global Methane Pledge (GMP), launched at COP26 in November 2021 to catalyse action to reduce methane emissions. By joining the GMP, countries commit to work together to collectively reduce methane emissions by at least 30% below 2020 levels by 2030. Led by the United States and the EU, country endorsements of the GMP have grown from just over 100 last year to 150. More than 50 countries have developed national methane action plans or are in the process of doing so,[xxxii] substantial new financial resources are being directed to methane action, and partners have launched "pathways" of policies and initiatives to drive methane reductions in key methane-emitting sectors.

As industry continues to address the issue of methane slip and upstream emissions with almost daily technological improvements it is essential that we monitor the situation using current and accurate data. All too often detractors of the LNG pathway cite outdated information and studies that are no longer relevant.

CONCLUSION

2022 was another very strong year for LNG-fuelled vessel orders, with numbers almost equalling those in 2021, the record year to date, despite exceptionally high LNG prices. The majority of these will have low slip engines with the potential to cut GHG emissions by up to 23% as well as eliminate local air emissions in the air we breathe. LNG is the only scalable fuel available today for deep-sea shipping that addresses both climate and health challenges.

Ship owners are investing in the LNG-fuelled fleet with the confidence that LNG infrastructure is already established in key bunkering locations and growing rapidly around the world. The industry is making massive investments in new builds and energy supply infrastructure that will impact GHG emissions today and for the next 25-30 years, the typical lifetime of a deep-sea vessel. It is essential that assessments of alternative marine fuel pathways are made on a like-for-like, or "apples with apples" basis using accurate data.

While regulators and industry are agreed on the net-zero emissions destination, the implications of the pathway are rarely discussed. The total pathway emissions associated with many of the alternative fuels being discussed may be much higher than those associated with LNG and its bio and synthetic variants.

> **The choice of dual-fuel gas vessels powered by LNG for our new ships is part of our commitment to build a zero-carbon future.**
>
> **Xavier Leclercq, Vice-President of CMA SHIPS**

There is growing recognition that decarbonisation will not be a "big bang" process where the industry moves in a single step from fossil to zero-emission, renewable fuels. It is likely to take place incrementally as fuels are gradually decarbonised through the addition of low and zero-emission drop-ins. Being able to transition safely and easily from fossil LNG to bio-LNG, to renewable synthetic e-LNG means that LNG vessels ordered today will be able to continue operating within increasingly stringent GHG emissions regulations up to and beyond 2050.

Bio-LNG, produced from sustainable biomass resources, is commercially available today and production is growing; it is among the cheapest of the alternative fuels being discussed. The availability of renewable synthetic e-LNG will depend on the build out of renewable electricity, as is the case for other electro-fuels such as e-methanol and e-ammonia and it is likely to be competitive on price.

The IMO and European Union are in the process of introducing a range of regulations aimed at decarbonising the shipping industry. LNG and its associated bio and synthetic pathway will provide ship owners and operators with significant and immediate compliance benefits. While challenges exist, in relation to methane emissions for some LNG-dual fuel engine technologies and in the upstream, these are being addressed through multiple industry initiatives.

Shipping stakeholders are investing in LNG because it provides a low risk, incremental pathway for decarbonisation, starting now. Waiting is not an option.

ANNEX: MYTHS VS REALITY

MYTH	REALITY
LNG as a marine fuel offers no **GHG benefits** compared to conventional marine fuels	Sphera's 2nd Life Cycle GHG Emission Study on the Use of LNG as Marine Fuel, widely recognised as the most definitive analysis to date of the GHG emissions of LNG as a marine fuel, reports **emissions reductions of up to 23% in GHG emissions compared with conventional marine fuels.** The results are assessed on a full life cycle, well-to-wake, basis inclusive of methane slip and upstream methane emissions. The study is based on primary data from all major marine engine manufacturers and peer-reviewed by independent academics.
Methane slip is a fatal flaw for LNG-fuelled vessels	**Methane slip is a recognised issue by the industry and where it exists, is being addressed.** LNG-fuelled engines were first introduced to address local emissions of SOx and NOx at the turn of the century. Levels of methane slip have been reduced by a factor of four since then. Sphera's 2nd Life Cycle GHG Emission Study on the Use of LNG as Marine Fuel, reports that for technologies where methane slip is an issue, engine manufacturers have identified clear technology pathways to eliminate slip by 2030. Support from programmes such as Methane Abatement in Maritime Innovation Initiative (MAMII) and pressure from the Global Methane Pledge will also drive this change. Finally, DNV data on the LNG-fuelled vessel orderbook shows that it is dominated by engine technologies with low, or negligible levels of methane slip.
Upstream methane emissions more than offset CO2 emissions benefits of LNG as a marine fuel	Sphera's 2nd Life Cycle GHG Emission Study on the Use of LNG as Marine Fuel study analysed methane emissions from all major LNG supply chains and found that **upstream methane emissions account for a small fraction, 5% to 6%, of total, well-to-wake GHG emissions.** There are a number of UN, World Bank, European, US and industry led initiatives focused on reducing upstream methane emissions. Examples include the Global Methane Pledge announced at COP26 and co-convened by the US and European Union and the OGCI Aiming for Zero Methane Emissions Initiative,

Investing in LNG now will **divert resources** from true net-zero emission shipping solutions

Investing in LNG fuelled ships and bunkering infrastructure offers immediate GHG emission reductions and a **low risk, incremental pathway to net-zero emissions** through the use of bio and synthetic LNG as drop-in fuels.

This pathway is consistent with those set out for other alternative marine fuels, based on the use of sustainable biomass resources and synthetic fuels produced from renewable electricity, with the difference that with LNG emissions reductions start today.

By contrast, investing in assets with technologies for which green fuels do not exist today, will do nothing to reduce emissions in the short to medium term.

Bio-LNG availability is limited, and it will be **too expensive** for shipping to use

Liquefied biomethane, or bio-LNG, produced from sustainable biomass resources ie which does not interfere with production of food, fodder and fibres, can **meet a significant proportion of future shipping demand** even when considering growing demand for biomass from other sectors such as heat and power, industry, aviation and heavy-duty road transportation.

The October 2022 study by Singapore's Maritime Energy and Sustainable Development Centre of Excellence forecasts that could meet up to 3% of total energy demand from shipping in 2030 rising to 13% by 2050. If used as a 20% drop in fuel these numbers increase to 16% and 63%, respectively.

Bio-LNG is among the most cost-effective alternative marine fuels, cheaper than biomethanol and electrofuels, including e-ammonia and e-methanol.

Renewable synthetic LNG (e-LNG) will be far **too expensive** for use in maritime

In the long term it will be the relative price of alternative fuels that matters to customers. Approximately 75% of the cost of electro-fuels (e-fuels) such as e-LNG, e-methanol and e-ammonia are related to the cost of producing hydrogen from renewable electricity.

This means that the **production costs all e-fuels such as will be broadly similar.** It also means that the infrastructure costs associated transporting, storing and delivering these fuels to vessels will be a significant differentiator. Here e-LNG will have a clear advantage as most of the supply infrastructure is already built.

ANNEX: UPTAKE ACROSS EVERY SECTOR

CONTAINERSHIPS

- **Matson** signed a contract with MAN Energy Solutions (MAN ES) for the retrofit of the main engine onboard its 3,600 TEU containership, ***Daniel K. Inouye***, which was delivered in 2018. The retrofit will make it capable of operating on LNG and fuel oil.[xxxiii]

- **ZIM** penned a deal with a shipping player affiliated with Idan Ofer's Kenon Holdings to charter three new 7,000 TEU LNG dual-fuel containerships. Israeli carrier ZIM subsequently chartered another new 15,000 TEU LNG-fuelled containership from Seaspan to further add to its LNG-fuelled fleet.[xxxiv]

- **Pacific International Lines (PIL)** ordered four new LNG-fuelled 14,000 TEU containerships. The dual-fuel ships will be delivered by China's Jiangnan Shipyard in 2024-25. In the announcements, PIL highlighted its recognition of the LNG pathway to net-zero shipping.[xxxv]

- **Mediterranean Shipping Company (MSC)** approached shipyards for up to 24 LNG dual-fuelled, 8,000 TEU containership newbuildings worth an estimated $2.8bn in total. This was part of a broader trend of containership owners spending their recent profits on green fleet renewals.[xxxvi]

BULK

- The first LNG-fuelled Newcastlemax bulk carrier, in an order of 13 ABS-classed vessels for **Eastern Pacific Shipping (EPS)**, took on its first load of LNG bunker fuel in Singapore. The 209,936 DWT dual-fuel vessel, ***Mount Tourmaline***, was built by Shanghai Waigaoqiao Shipbuilding Co. and delivered to EPS in January 2022.[xxxvii]

- **NYK Line** ordered four new LNG-fuelled bulkers due for delivery in 2024-5. The ships will be built by Japan Shipyard, Namura Shipbuilding and China State Shipbuilding Corporation. Subsequently, NYK Line announced that one of its bulkers received its green certification from the Japanese government.[xxxviii]

- **Kawasaki Kisen Kaisha (K Line)** applied for the Specified Vessel Introduction Plan with Japan Marine United Corporation (JMU) to build a more environmentally-friendly LNG-fuelled large scale dry bulk vessel with approximately 209,490 DWT. Intended mainly for the bulk cargo business between Australia and Japan, the vessel is scheduled for delivery in March 2024.[xxxix]

- **Mitsui O.S.K. Lines (MOL)** placed an order for four Capesize bulkers powered by LNG as their main fuel, cementing its efforts in having 90 LNG-fuelled ships by 2030. These new bulkers joined two very large crude carriers (VLCC), powered by LNG, that MOL also announced this year.[xl]

TANKERS

- **Total Energies** broke new ground by chartering its first newly built LNG-fuelled VLCC. The ***Eagle Valence*** was chartered under a long-term agreement with AET and is just one of a broader Total Energies programme including six new LNG-fuelled tankers. The charter of the second ship from AET, ***Eagle Vallery***, was also subsequently announced in 2022.[xli]

- **Furetank** ordered two more LNG-fuelled tankers. The 17,999 DWT tankers are scheduled to be delivered by China Merchants Jinling Shipyard in the autumn of 2024 and the spring of 2025.[xlii]

- **Fairfield Chemical Carriers** exercised the option it had to build two additional dual-fuel tankers at Japan's Fukuoka Shipbuilding. The four 26,300 DWT vessels now on order are to be delivered between 2023 and 2025.[xliii]

- **NYK Offshore Tankers AS (KNOT)**, an affiliate of NYK, took delivery of its LNG-fuelled shuttle tanker ***Frida Knutsen***. Ordered by Knutsen, it was delivered in August 2022 at Daewoo Shipbuilding & Marine Engineering.[xliv]

PCTCS

- **Norway's SFL Corporation Ltd** witnessed the steel-cutting at Guangzhou Shipyard (GSI) for its first LNG-fuelled pure car and truck carrier (PCTC) which will carry 7,000 vehicles. It was reported in February 2022 that GSI holds eight orders for LNG-powered PCTCs.[xlv]

- **Mitsui O.S.K. Lines (MOL)** reached an agreement with Nihon Shipyard and Shin Kurushima Dockyard for the construction of four 7,000-unit capacity LNG-fuelled car carriers. The new ships are scheduled for delivery in 2024 and 2025. These orders bring MOL's total orders for LNG-fuelled car carriers to eight.[xlvi]

- Construction also began on the world's largest dual-fuel LNG car carrier for **SAIC Anji Logistics**, a subsidiary of China's automobile manufacturer SAIC Moto. It is one of two ships capable of carrying 7,600 units that is expected for delivery by Jiangnan Shipbuilding in March and September 2024, respectively.[xlvii]

- **Deltamarin and GTT** received an approval in principle from DNV for a new design of LNG-fuelled PCTC. The design optimises carrying capacity and allows the ship to carry 8,000 CEU. The approval confirms that the design is feasible and that the concept could be built and operated.[xlviii]

CRUISE

- **Carnival Cruise Line's** second of three LNG-fuelled cruise ships, ***Carnival Celebration***, was delivered in November 2022 from Meyer Turku shipyard and will become the first LNG-fuelled cruise ship to be based in Miami. The ship is the second in the company's Excel Class and is also a part of the company's drive to reach zero emissions by 2050. The third Carnival LNG-fuelled cruise ship is due for delivery in late 2023.[xlix]

- **Disney Cruise Line's** 144,000 GT, LNG-fuelled ***Disney Wish*** left Meyer Werft in February and made its maiden voyage in July 2022. It is the first new cruise ship that Disney has built in a decade with three more vessels to follow. Disney has also announced details of its second LNG-fuelled cruise ship, which will be named ***Disney Treasure*** when it enters service in 2024.[l]

- **P&O's** second LNG-fuelled cruise ship, ***Arvia***, was delivered by Meyer Werft in December 2022. The yard is also building an additional ship, ***Carnival Jubilee***, which is due for delivery in late 2023.[li]

- **MSC** christened its first LNG-fuelled cruise ship, ***MSC World Europa***, in November 2022. The vessel completed its first LNG bunkering in the French port of La Rochelle. At 215,863 gross tons, it becomes one of the world's largest cruise ships. In addition, Chantiers de l'Atlantique has floated out the ***MSC Euribia***, a sister ship in the Meraviglia Plus class that is the first being built to operate on LNG. MSC is also investing more than $3.14 billion in three LNG-powered cruise ships.[lii]

FERRY

- The 1,015-passenger cruise ferry ***Salamanca***, built at China Merchants Jinling and powered by LNG, will be operated by **Brittany Ferries** on its route between Portsmouth, in the UK, and Bilbao and Santander, in Northern Spain. The ***Salamanca*** is the second E-Flexer series vessel to enter service with Brittany Ferries as part of the company's commitment to introduce cleaner and more efficient ships to its fleet in the next five years.[liii]

- Two new LNG-fuelled ferries have been launched in Japan, the 17,300 GT ***Sunflower Kurenai*** and sister ship ***Sunflower Murasaki***. The ferries were built for Mitsui O.S.K. Lines' Oita-based **Ferry Sunflower Limited** to operate between Osaka and Beppu.[liv]

- French ferry operator **Corsica Linea's** first roll-on/roll-off passenger (RoPax) ferry powered by LNG, ***A Galeotta***, was delivered in Q4 2022. The LNG-fuelled vessel will contribute significantly to the company's emissions reduction targets.[lv]

- Germany-based ferry owner and operator **TT-Line** took delivery of its second green ship, the LNG-powered RoPax ferry, ***Peter Pan***. Chinese shipyard Nanjing Jinling delivered the 230-meter-long ship with dual-fuel engines produced by MAN Energy Solutions.[lvi]

[i] https://www.offshore-energy.biz/clarksons-93-pct-of-car-carrier-newbuilds-lng-capable-23-pct-ammonia-methanol-ready/

[ii] https://www.tradewindsnews.com/gas/march-of-lng-and-methanol-fuelling-uptake-set-to-roll-on-in-2023-dnv-says/2-1-1381914

[iii] https://lngprime.com/europe/dnv-222-lng-powered-ships-ordered-in-2022/70166/

[iv] https://www.clarksons.com/research/

[v] https://www.tradewindsnews.com/gas/france-gets-its-first-lngbv-as-totalenergies-chartered-ship-arrives/2-1-1133668

[vi] https://www.bunkerspot.com/americas/56273-americas-seaspan-ulc-inks-contract-for-lng-bunker-vessel-pair

[vii] https://www.marinelink.com/news/mitsubishi-shipbuilding-build-lng-495382

[viii] https://gcaptain.com/clean-canaveral-performs-inaugural-barge-to-ship-lng-bunkering-operation/

[ix] https://www.offshore-energy.biz/fincantieri-starts-building-largest-lng-bunker-barge-in-us/

[x] https://lngprime.com/asia/avenir-lng-takes-delivery-of-small-scale-newbuild/30697/

[xi] https://www.offshore-energy.biz/fuelngs-2nd-lng-bunker-vessel-hits-the-water-at-hmd/

[xii] https://www.offshore-energy.biz/totalenergies-to-expand-lng-bunker-services-in-singapore-with-12000-cbm-ship/

[xiii] https://www.offshore-energy.biz/worlds-largest-lng-bunker-vessel-is-here/

[xiv] https://www.bunkerspot.com/asia/55727-asia-pacific-hyundai-mipo-delivers-lng-bunkering-ship-to-korea-line

[xv] https://lngprime.com/europe/knutsen-takes-delivery-of-lng-bunkering-newbuild-in-spain/70049/

[xvi] https://splash247.com/containerised-lng-rolls-out-as-alternative-to-traditional-bunkering/

[xvii] https://www.ucl.ac.uk/bartlett/energy/news/2021/oct/shippings-need-hydrogen-derived-fuels-creates-range-opportunities-energy-sector

[xviii] https://sphera.com/research/2nd-life-cycle-ghg-emission-study-on-the-use-of-lng-as-marine-fuel/

[xix] https://sea-lng.org/2022/02/lng-pathway-a-long-term-response-to-cii-game-changer/

[xx] https://www.gie.eu/wp-content/uploads/filr/7069/BioLNG%20report_2022_compressed.pdf

[xxi] https://www.porttechnology.org/news/titan-to-build-the-worlds-largest-biomethane-liquefaction-plant-at-amsterdam/

[xxii] https://www.bioenergy-news.com/news/wartsila-to-build-major-bio-lng-plant-in-germany/

[xxiii] https://shipandbunker.com/news/world/939561-gasum-supplies-tanker-with-lng-and-bio-lng-off-gothenburg

[xxiv] https://splash247.com/cma-cgm-looks-to-set-up-biomethane-production-in-france/

[xxv] https://bioenergyinternational.com/st1-and-boras-energi-och-miljo-in-biolng-partnership/

[xxvi] https://www.motorship.com/lng/synthetic-natural-gas-cuts-ghg-emissions-on-container-ship/1470266.article

[xxvii] https://www.cma-cgm.com/news/4089/cma-cgm-becomes-partner-to-the-jupiter-1000-project-france-s-first-industrial-demonstrator-of-hydrogen-and-e-methane-s-production-piloted-by-grtgaz

[xxviii] https://www.dnv.com/services/alternative-fuels-insight-128171

[xxix] https://www.wartsila.com/insights/article/mind-the-methane-gap

[xxx] https://splash247.com/methane-abatement-in-maritime-innovation-initiative-launches/

[xxxi] https://www.marineinsight.com/shipping-news/green-ray-project-to-develop-solutions-for-reducing-methane-slip-from-lng-fueled-engines/

[xxxii] https://www.state.gov/global-methane-pledge-from-moment-to-momentum/

[xxxiii] https://www.man-es.com/company/press-releases/press-details/2022/06/24/matson-signs-contract-for-me-gi-retrofit

[xxxiv] https://splash247.com/zim-adds-to-its-7000-teu-charter-spree/

[xxxv] https://www.seatrade-maritime.com/shipbuilding/pil-orders-four-14000-teu-lng-dual-fuel-containerships

[xxxvi] https://www.tradewindsnews.com/containerships/msc-taps-yards-for-24-lng-dual-fuelled-container-ships-worth-2-8bn/2-1-1176827

[xxxvii] https://www.manifoldtimes.com/news/abs-celebrates-historic-first-bunkering-operation-for-lng-fuelled-newcastlemax-bulker/

[xxxviii] https://shipandbunker.com/news/apac/944777-japans-nyk-line-orders-four-lng-fuelled-bulkers

[xxxix] https://www.offshore-energy.biz/k-line-introduces-plan-for-lng-fueled-large-scale-dry-bulk-vessel/

[xl] https://www.marinelink.com/news/mol-orders-six-lngfueled-vessels-499047

[xli] https://www.bunkerspot.com/global/55545-global-totalenergies-charters-its-first-lng-fuelled-vlcc

[xlii] https://www.ship-technology.com/news/furetank-repeat-order-vinga-tankers/

[xliii] https://www.tradewindsnews.com/tankers/fairfield-chemical-carriers-exercises-options-for-lng-fuelled-newbuildings/2-1-1332437

[xliv] https://www.manifoldtimes.com/news/knot-takes-delivery-of-first-lng-dual-fuel-shuttle-tanker-frida-knutsen/

[xlv] https://lngprime.com/asia/gsi-kicks-off-work-on-first-lng-pctc-for-sfl/43209/

[xlvi] https://www.naturalgasworld.com/japans-mol-orders-4-more-lng-fuelled-car-carriers-98083

[xlvii] https://www.autoevolution.com/news/a-saic-motor-subsidiary-will-operate-the-worlds-largest-dual-fuel-car-carrier-196731.html

[xlviii] https://www.offshore-energy.biz/dnv-approves-lng-fueled-pctc-new-design-by-gtt-deltamarin/

[xlix] https://www.offshore-energy.biz/meyer-turku-hands-over-lng-fuelled-carnival-celebration/

[l] https://maritime-executive.com/article/meyer-werft-floats-out-first-new-disney-lng-fueled-cruise-ship

[li] https://www.cruisehive.com/po-cruises-takes-delivery-of-second-lng-cruise-ship/90528

[lii] https://www.cruiseandferry.net/articles/msc-cruises-christens-msc-world-europa-in-qatar

[liii] https://allaboutshipping.co.uk/2022/01/06/brittany-ferries-new-lng-fuelled-salamanca-cruise-ferry-enters-bureau-veritas-classification/

[liv] https://www.mhi.com/news/22083002.html

[lv] https://www.offshore-energy.biz/corsica-lineas-first-lng-powered-ropax-ferry-delivered/

[lvi] https://lngprime.com/asia/germanys-tt-line-takes-delivery-of-second-lng-powered-ferry-in-china/67565/

[lvii] https://www.ntu.edu.sg/mesd-coe/publications#Content_C066_Col00

[lviii] https://sea-lng.org/bunker-navigator-introduction/

[lix] https://sea-lng.org/2022/02/lng-pathway-a-long-term-response-to-cii-game-changer/

[lx] https://sea-lng.org/2022/08/lng-retrofits-will-rate-higher-under-cii-than-hfo-scrubber-or-vlsfo-alternatives/

[lxi] https://sea-lng.org/2022/10/new-independent-study-confirms-bio-lngs-role-in-shippings-decarbonisation/

Visit sea-lng.org/2023/01/lng-delivering-decarbonisation to download all the infographics used in this report and access the online version

SEA–LNG

Contact us via:
communications@sea-lng.org
sea-lng.org
twitter.com/SEALNGcoalition
linkedin.com/company/sealng/