THE JOURNEY:
A DECADE MOVING TOWARDS A CLEANER FUTURE

SEA-LNG

A VIEW FROM THE BRIDGE

2025-2026

SEA-LNG.ORG

EXECUTIVE SUMMARY

Since SEA-LNG was founded in 2016, LNG has gone from a niche to a mainstream solution for maritime with numbers of vessels using LNG as a marine fuel increasing 10-fold to 850 vessels in operation with a further 642 on order. With inclusion of the LNG carrier fleet, this equates to 10% of global DWT. Since LNG is a fuel in transition to biomethane and e-methane, and biomethane is now bunkered regularly, this growth means the methane decarbonisation pathway is now a clear runway to the future.

Regulatory and market uncertainties combined with a lack of shipyard capacity has slowed the adoption of alternative fuels with the order book falling from 551 vessels in 2024 to 275 in 2025. However, within this LNG's relative position has strengthened, representing 79% of alternatively fuelled tonnage ordered focused on ultra large container vessels.

LNG bunkers are now available in **222 ports** with plans for a further 62. There are now **62 LNG bunker vessels in operation** in hubs such as Rotterdam, Zeebrugge, Barcelona, Singapore, Shanghai, and the US East Coast, with orders for a further 38. LNG bunker volumes also continue to grow strongly with the focus of growth shifting from Singapore to China, in 2025, which accounted for almost a quarter of bunker sales in 2025.

Investment in LNG dual fuel vessels and the associated fuel supply chains over the past 10 years has amounted to more than **$150 billion**. Investment continues to grow driven by the recognition that LNG and the methane decarbonisation runway is a safe, practical and realistic solution to the emissions challenges facing maritime.

The methane molecule's advantages over other alternative marine fuels such as methanol and ammonia include higher energy density, widespread fuel availability, lower costs of regulatory compliance and the commercial optionality it offers, "inoculating" itself against regulatory uncertainty.

Notwithstanding the uncertainties caused by the IMO's decision to delay the adoption of the Net Zero Framework, the shipping industry has shown how quickly it adapts to new regulation. Bunkering of liquefied biomethane (LBM) has exploded over the past year in Europe, driven by increasingly stringent EU regulations and voluntary, customer-related commitments. LBM bunkering operations have already taken place in key ports across Belgium, France, Finland, Italy, Lithuania, the Netherlands, Norway, Spain, Sweden and the UK, involving at least 10 major bunker suppliers.

> **2025 is the year the methane decarbonisation pathway became a clear runway. The year our advocacy for LNG as a fuel in transition from fossil LNG through liquefied biomethane (LBM) to liquefied e-methane took off, with record amounts of LBM powering global shipping today and growing strongly into the future.**
>
> **Steve Esau, COO, SEA-LNG**

E-methane project development continues in Europe, North America, South America, Australia and Asia driven by demand from utilities. Some 150kt pa of capacity is in FEED and a further 1 Mtpa at a pre-feasibility / feasibility stage.

Methane emissions from the ongoing use of LNG as a marine fuel continue to fall. Ongoing technology innovation by engine manufacturers and the development of abatement solutions mean that methane slip will no longer be an issue by the end of the decade. Eliminating fugitive emissions from the LNG supply chain is a major focus for the oil and gas industry. The global average in now 13.9g CO2e/MJ , significantly lower than the EU WtT default of 18.5 gCO2e/MJ, used in FuelEU Maritime,

The IMO's decision in October 2025 to delay the adoption of the Net Zero Framework while frustrating for many, provides an opportunity to pause for thought. SEA-LNG is calling for a single global decarbonisation framework based on regulations which are goal-based and technology neutral, which protect first movers and which incentivise solutions that are practical, scalable and investable.

PATHWAY TO RUNWAY – LNG HAS GONE MAINSTREAM

SEA-LNG was established 10 years ago, and it is time to take stock. From initial concerns to cut sulphur emissions by 2020, SEA-LNG's focus today is on reducing Greenhouse Gas (GHG) emissions. In 2016, excluding LNG carriers, there were just 81 dual-fuel vessels in operation capable of utilizing LNG, (or methane since 98% of marine fuel liquefied natural gas is made up of methane molecules), as an energy source. These few vessels have increased 10-fold, to the point where today there are almost 850 dual fuelled vessels in operation with a further 642 on order. From a niche fuel in Northern Europe, it is now a mainstream, global solution. Currently, the LNG-powered global fleet (operating and on-order), including LNG carriers, equates to about 10% of the global vessel tonnage by deadweight[1]. By 2029, 2,500 ocean going vessels comprised of about 1,450 vessels using LNG, or biomethane, as a fuel plus an additional 1,050 or so LNG carriers will be plying the World's oceans. This number will continue to increase as maritime tonnage is retired and replaced with newer, more efficient vessels. As a result, the methane decarbonisation pathway has become a runway to the future.

> **"Moving forward, it is abundantly clear that LNG has both a short-term and long-term role to play in shipping's transition strategy. This is reinforced by added safety advantages not yet enjoyed by other low-greenhouse gas fuels."**
>
> **Knut Orbeck-Nilssen, DNV Maritime Chief Executive Officer**

2016

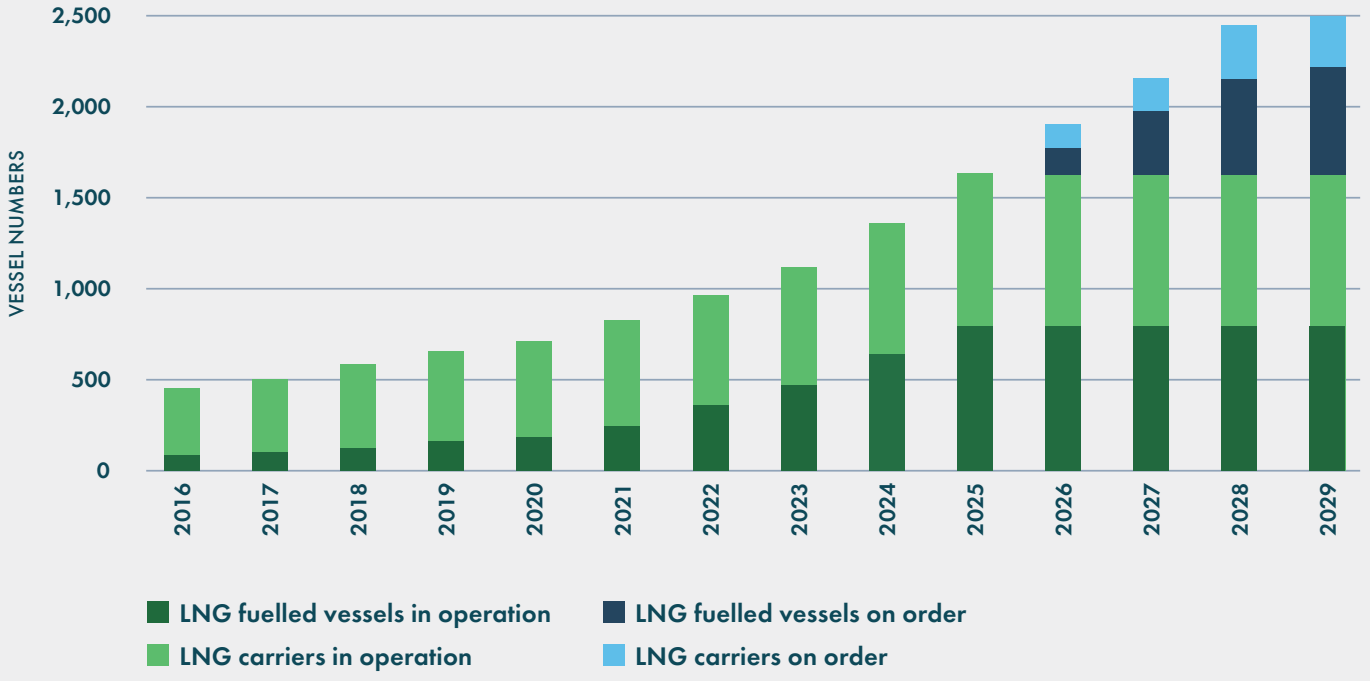
Initial truck-to-ship bunkering of TOTE Maritime's *ISLA BELLA* – the first LNG container vessel

1. Including the LNG carrier fleet – data from DNV AFI and https://www.gov.uk/government/statistics/shipping-fleet-statistics-2024/shipping-fleet-statistics-2024

2016

Delivery of first LNG RORO vessel to UECC, the *AUTO ECO*

DEVELOPMENT OF LNG-FUELLED FLEET INCLUDING LNG CARRIERS



Source SEA-LNG DNV AFI

In 2025, while regulatory and market uncertainties combined with a lack of shipyard capacity have slowed the adoption of alternative marine fuels, investment in LNG dual fuel vessels and the methane decarbonisation runway has remained robust. According to DNV, 275 alternatively fuelled vessels, including LNG, methanol, ammonia, LPG and hydrogen, were ordered in 2025, down from 551 in the record year of 2024, representing a fall of about 31% on a DWT basis. Within this however, LNG's relative position strengthened, as the 188 vessels ordered represented 79% of alternatively fuelled tonnage, up from 67% in 2024.

> **We are taking delivery of some 150+ LNG dual fuel container vessels and we have about 40 such vessels in operation running on LNG. Looking ahead, our intention is for these LNG dual-fuel container vessels to switch from fossil LNG to Bio-LNG and Synthetic LNG - or e-LNG - as these fuels become available in affordable quantities at scale.**
>
> **Soren Toft, CEO MSC, at the European Shipping Summit, March 2025**

Orderbook growth in 2025 was dominated by the container sector, which accounted for 88% of LNG dual fuel orders, or 93% of DWT. 61% of container orders were for ultra-large container vessels with a capacity of 14,500 – 24,000 TEUs. Encouragingly, 2025 saw the first orders of LNG dual fuelled vessels by a number of major container fleet owners and operators, including Capital Maritime & Trading, COSCO, Evergreen, HMM and ONE. Today all the top ten container lines have chosen LNG powered vessels.

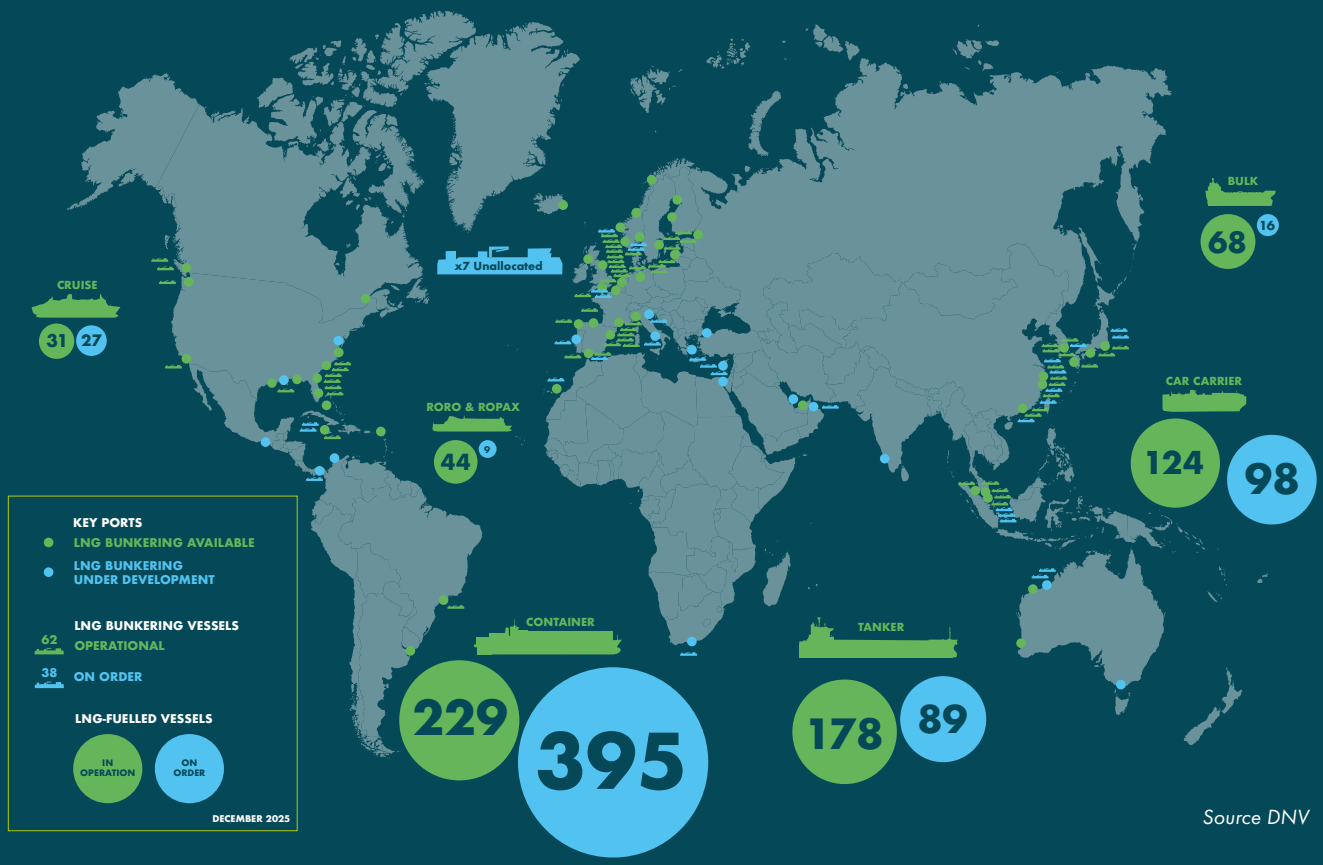
COMPANIES ORDERING FIRST DUAL-FUEL LNG CONTAINER VESSELS IN 2025

CAPITAL MARITIME & TRADING	COSCO	EVERGREEN	HMM	ONE
6x 8,800K TEU with HD Hyundai	12x 18,000K TEU with Shanghai's Jiangnan Shipyard	11x 24,000K TEU with CSSC Guangzhou Shipyard International (GSI) and Hanwha Ocean 14x 14,000K TEU with GSI and Samsung Heavy Industries (SHI)	8x 13,400K TEU with HD Hyundai 12x 13,000K TEU with HD Hyundai and Hanwha Ocean	8x 16,000K TEU with HD Hyundai

Twenty foot Equivalent Unit = size measurement for container vessels, 1 TEU = 1x 20 foot container.

On the supply side, LNG bunkers are available in 222 ports worldwide with plans underway in a further 62[2]. In 2016 only a single dedicated LNG bunker vessel, the Seagas, was in operation, in Sweden. By the end of 2025 this had increased to 62 LNG bunker vessels with bunkering focused on hubs such as Rotterdam, Zeebrugge, Barcelona, Singapore, Shanghai, and the US East Coast. In addition, there were 38 LNG bunker vessels on order at the end of 2025.

WORLDWIDE GROWTH IN LNG USE AND INFRASTRUCTURE

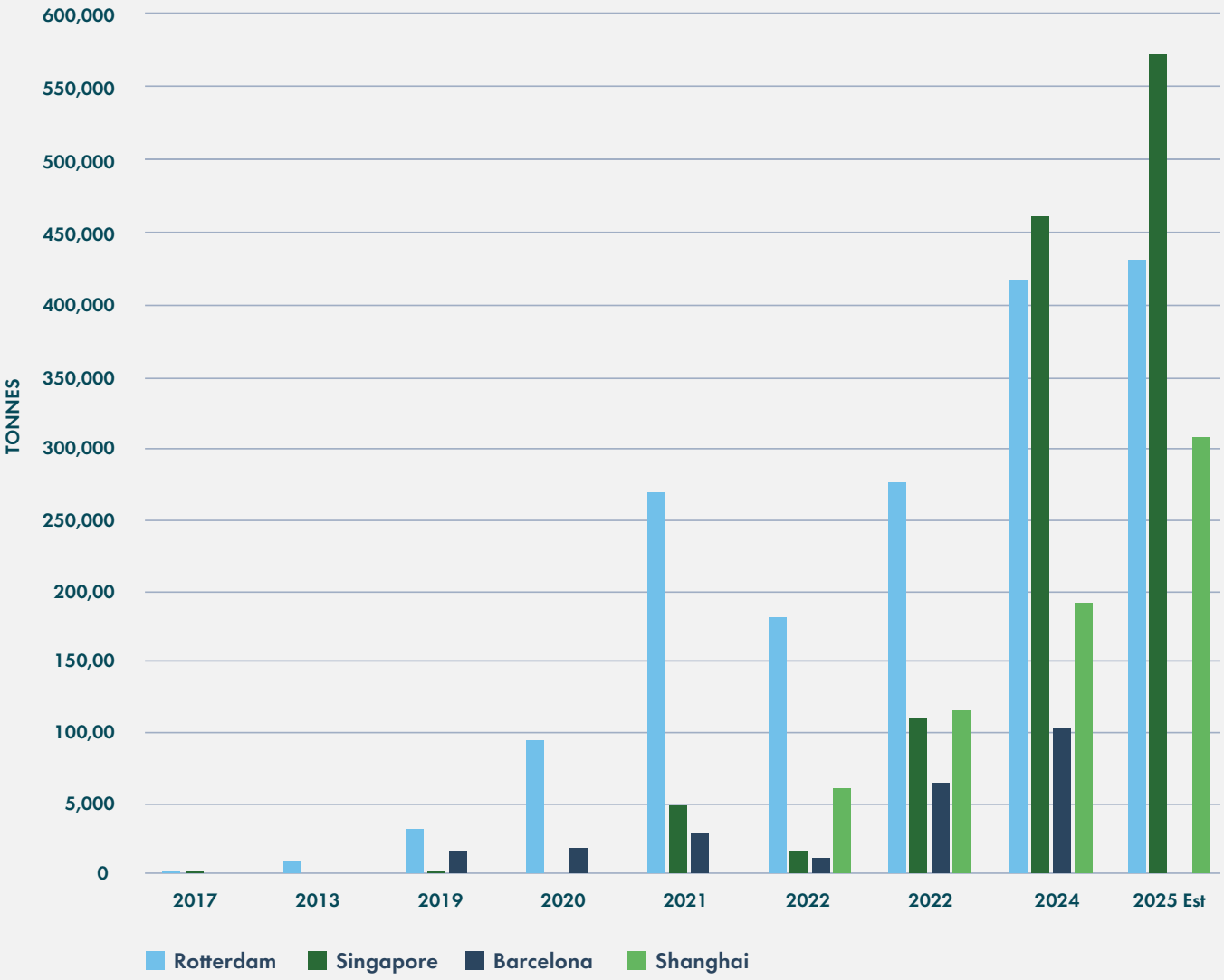


Source DNV

In 2024, the industry witnessed a record growth in LNG bunkering volumes, with estimated volumes reaching 3-4 million tonnes. This has continued into 2025. All of these new bunker assets are future proofed as the industry gravitates to the lower carbon intensity methane decarbonisation runway, as handling and bunkering of LNG is identical in every way to handling biomethane or e-methane products, regardless of whether these are physical or mass balanced molecules.

2. https://www.clarksons.com/research/

ANNUAL LNG BUNKER SALES: ROTTERDAM, SINGAPORE, SHANGHAI & BARCELONA



Source: MPA and Ports of Barcelona, Rotterdam and Shanghai

While the growth of LNG bunkering in Singapore was the big story in 2024, in 2025, the focus shifted to China, which by some estimates accounted for almost a quarter of LNG bunker sales. Growth remained strong in Singapore, with bunker volumes increasing by 24% in the period from January to November 2025 compared with the same period in 2024 while Rotterdam showed steady growth at 3%, due to the expansion in LNG bunkering being spread across the ZARA ports (Zeebrugge, Antwerp, Rotterdam and Amsterdam). LNG bunkering continued to develop elsewhere in Europe, particularly in the Western Mediterranean and in North America, where bunkering has been surging on the US East Coast and the Gulf.

Demand for LNG as a marine fuel has grown significantly over the past year, driven not only by regulatory developments like FuelEU Maritime but also by the growth of the LNG dual-fuel fleet.

Michael Schaap, Commercial Director, Titan Clean Fuels

2017

First Ship-to-Ship LNG bunkering by LNG Bunker Vessel *ENGIE ZEEBRUGGE*

2017

First LNG bunkering in Singapore – the world's largest bunkering port

NOTABLE LNG BUNKERING FIRSTS IN 2025 INCLUDE:

- the first ship-to-ship LNG bunker operation in the Middle East (Dubai) in January, with Monjasa supplying LNG to the Costa Smeralda cruise line vessel;
- the inaugural ship-to-ship LNG bunkering of a containership in Hong Kong took place in February with PetroChina's subsidiary, Kunlun Energy, supplying the Zim Aquamarine;
- the first bunkering of a PCTC in Western North America, with Seaspan supplying LNG via ship-to-ship to the MOL operated Lake Herman in Vancouver's English Bay in March; and
- the Port of Trieste hosting Italy's first ship-to-ship LNG bunkering operation involving a container vessel in December, involving Edison and CMA CGM.

Looking forward, Shell is forecasting an LNG bunker market size in excess of 15 million tonnes per annum by 2030, driven by the rapid growth in the LNG dual fuel fleet and projected falling LNG prices. Future LNG prices are forecast to drop with approximately 170 million tonnes per annum of new liquefaction capacity coming on stream by 2030, representing about a 42% increase in LNG supply. This is reflected in the Dutch TTF Natural Gas Future prices which currently are trading at €22.1/MWh for 2030 delivery compared with €32.2/MWh the current (mid-January 2026) spot market.

Investment in LNG bunker vessels is strong and growing. By the end of October 2025, 21 LNG bunker vessels had been ordered in the year to date, many by new market entrants such as the Celsius/Caravel JV, Continental Kapital, Ibaizabal, Evalend, Evergreen / MSC JV and Purus Marine. Most of these have a capacity of between 18,000 and 20,000 cubic metres, reflecting the volumes of fuel required by large container vessels. As a sign of the growing maturity of the market, we are seeing orders placed on a speculative basis i.e. not tied to a specific charter agreement.

NOTABLE LNG BUNKER VESSEL ORDERS IN 2025

CELSIUS/CARAVEL JV	CONTINENTAL KAPITAL	IBAIZABAL	EVALEND	PURUS MARINE
2x 20,000K m3	2x 20,000K m3 (options for +4)	2x 18,600K m3 2x 18,000K m3	4x 18,000K m3	2x 18,900K m3

THE PRACTICAL AND REALISTIC INVESTMENT OPTIONS

Investment in LNG dual fuel vessels and the associated fuel supply chains over the past 10 years is estimated at well over $150 billion[3]. Investment levels continue to grow driven by the growing recognition that LNG and the methane decarbonisation runway is a safe, practical and realistic solution to the emissions challenges facing the maritime sector. It is currently the only commercially scalable solution that eliminates SOx, NOx and Particulate Matter (PM) emissions, all of which are harmful to human health. It also provides immediate greenhouse gas reductions, and offers an incremental pathway to net-zero emissions using liquefied biomethane and e-methane.

> **When compared with methanol and ammonia on parameters such as energy density, infrastructure readiness, safety and cost, LNG is the only fuel that is scalable today and compliant with regulatory trajectories through to 2037.**
>
> **Can Murtezaoğlu, Business Development Manager, EMEAI, Commercial Division, GTT**

LNG, or more accurately, the methane molecule's commercial advantages over other alternative marine fuels such as methanol and ammonia include:

- **ENERGY DENSITY**
- **FUEL AVAILABILITY**
- **COST OF COMPLIANCE**
- **OPTIONALITY**

2018

Delivery of first LNG cruise ship to Carnival Corporation, the *AIDAnova*

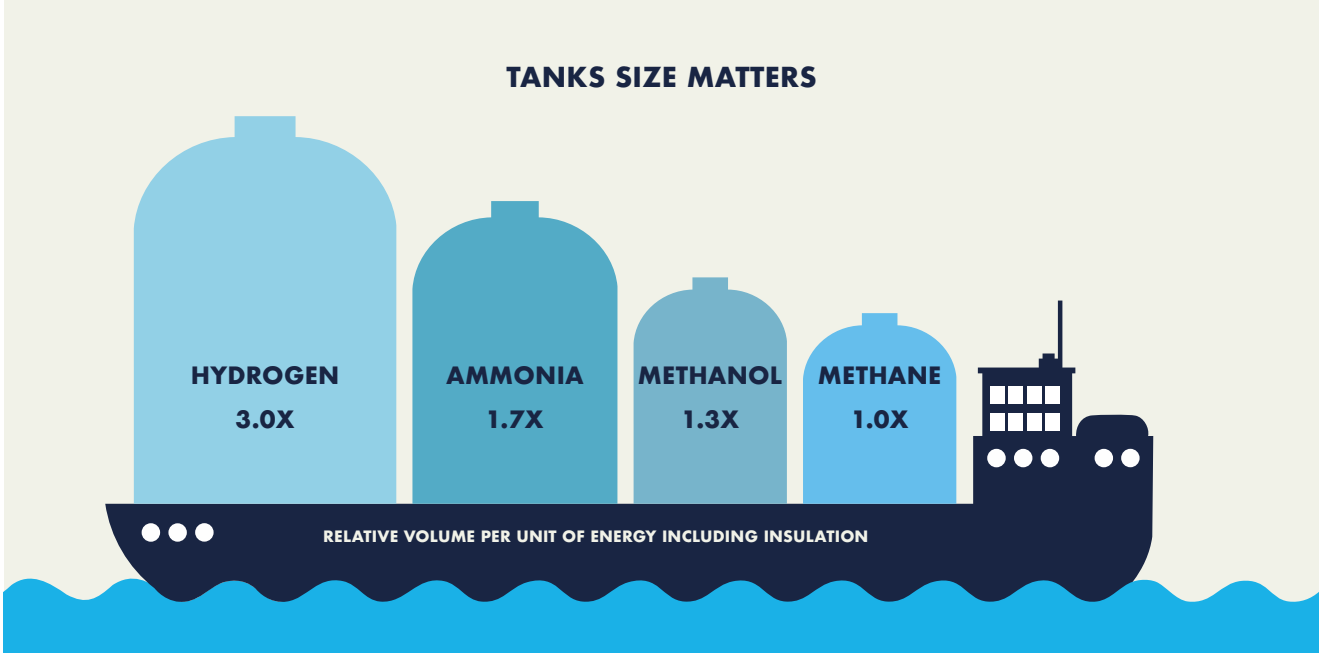
3. SEA-LNG calculation

2018

Initial Ship-to-Ship bunkering of TOTE Maritime vessels in USA by LNG bunker barge *CLEAN JACKSONVILLE*
Delivery of the first LNG bulk carrier to Ilshin Shipping, the *ILSHIN GREEN IRIS*

ENERGY DENSITY

Volumetric energy density is a key factor to consider for ship owners when considering vessel investment decisions. The less storage space required for fuel, the more space is available for cargo. Energy density has major commercial impacts through vessel design, deadweight tonnage, cargo volume and passenger space.



Source: SEA-LNG Analysis

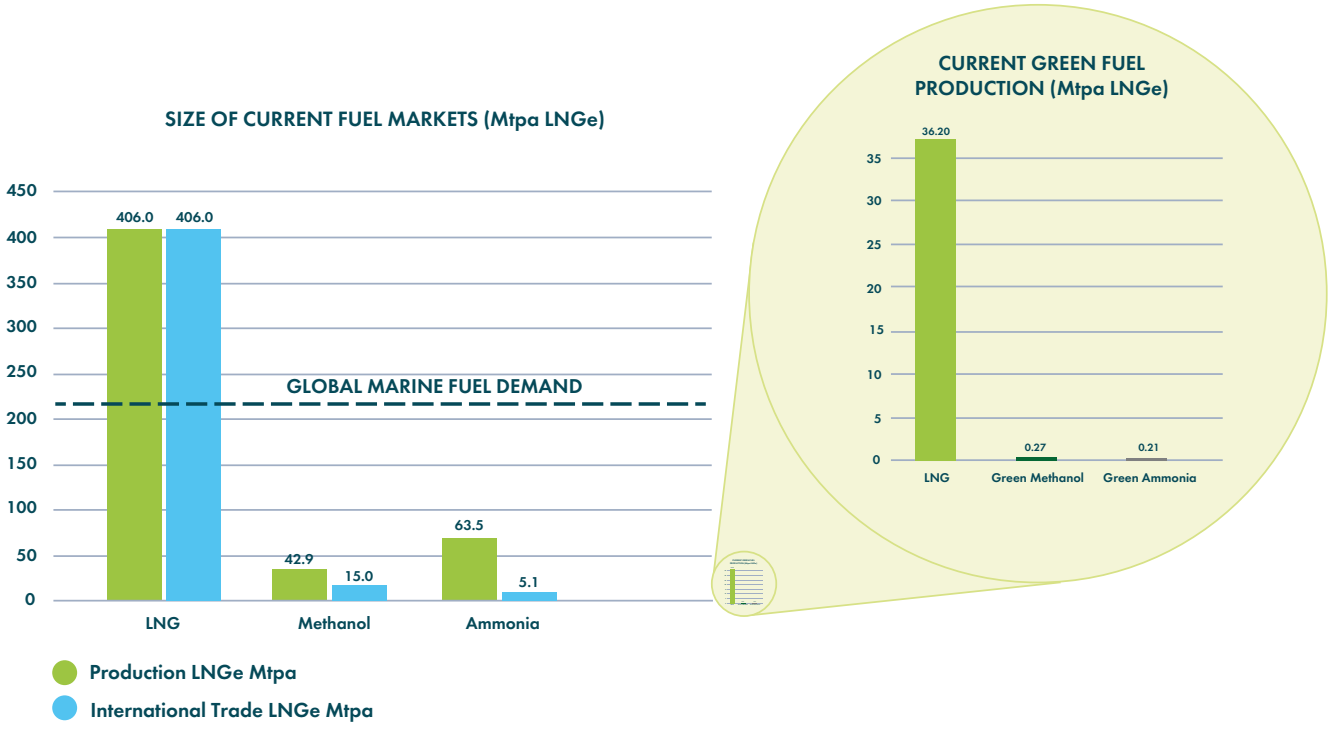
When comparing volumetric energy density, you need to take account of insulation requirements for cryogenic fuels such as LNG, ammonia and hydrogen and any safety issues.

Looking at the different alternative fuel molecules and taking insulation requirements into account, it can be seen that methane, in the form of LNG, has the highest energy density which gives it a significant commercial advantage. Methanol will require a tank 1.3 times larger, for the same amount of energy and the multiples for liquefied ammonia and hydrogen are 1.7 and 3.0 respectively.

FUEL AVAILABILITY

LNG is a globally traded commodity serving multiple sectors. In 2024, the LNG market size was some 406 million tonnes, or approximately 100 times the current consumption of LNG as a marine fuel. There is over one billion tonnes per annum of LNG import terminal capacity with terminals in, or near, all major bunkering ports. As demand from shipping grows for green methane, biomethane and e-methane, their production facilities can simply plug into the existing natural gas and LNG infrastructure.

GREY & GREEN FUEL MARKET SIZES

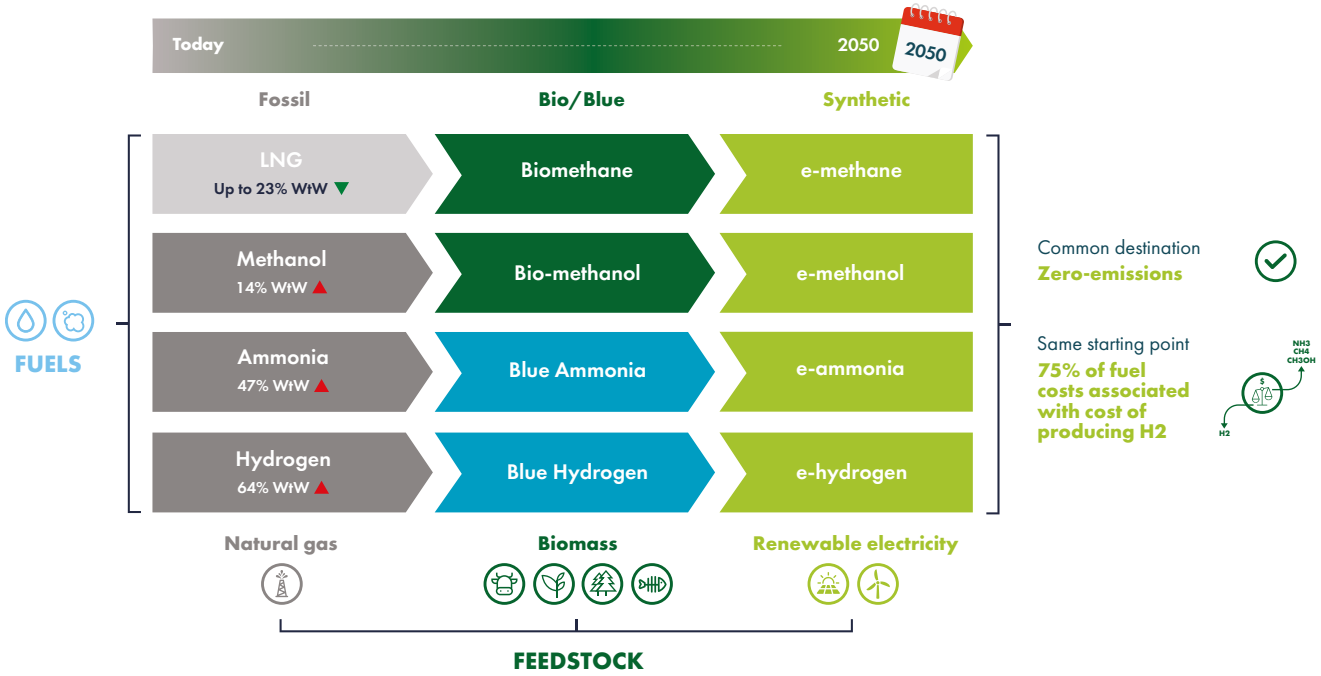


Sources: Ammonia Energy Association, GIIGNL, IEA, Methanol Institute & S&P Global

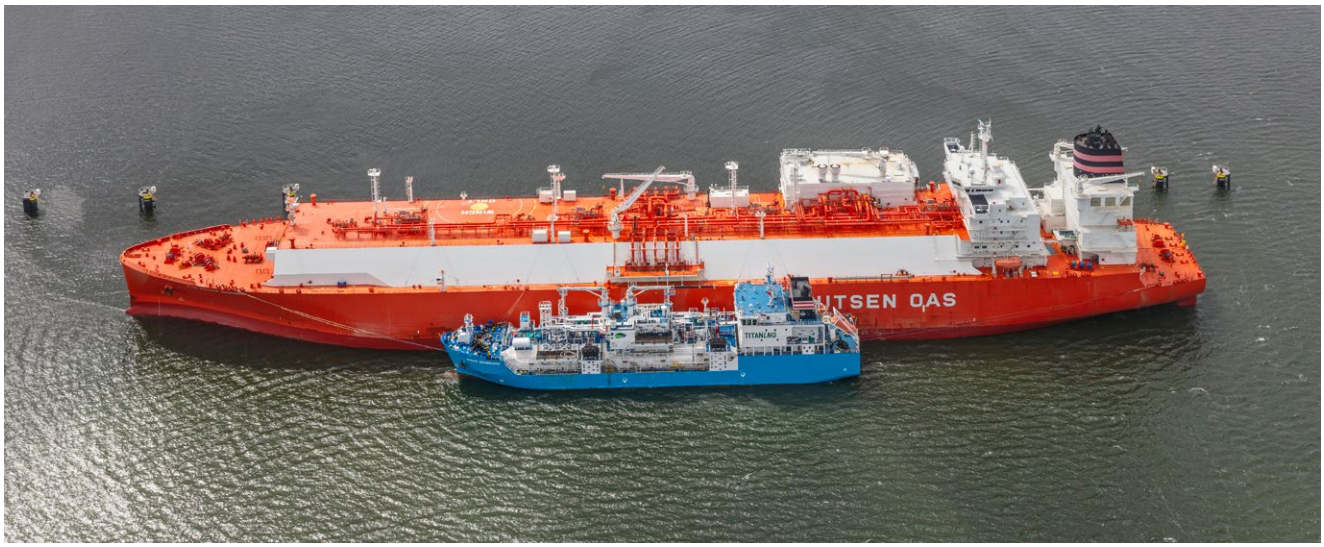
By contrast, ammonia and methanol are small, locally produced commodities serving primarily niche markets. The current size of the ammonia market is about 190 million tonnes, or 64 million tonnes LNG equivalent (LNGe) while the methanol market size is 120 million tonnes, representing 43 million tonnes LNGe. Ammonia and methanol are mainly locally produced from methane, with only about 8% of ammonia and 35% of methanol being internationally traded, meaning there is very limited global infrastructure. Consequently, ammonia and methanol face the double challenge of investment in green fuel production and the backbone infrastructure to move these fuels to where they are needed by shipping. Regulatory uncertainty and lower expected returns on investment mean that the financing of these new fuel supply chains has stalled, with less than 0.5Mtpa (LNGe) production of green ammonia and methanol combined.

COST OF COMPLIANCE

The methane decarbonisation runway offers the lowest cost of compliance with EU and potential future IMO decarbonisation regulations compared with other alternative marine fuel solutions. This is driven by the simple fact that methane, in its fossil form (ie LNG), offers greenhouse gas emission reductions compared with traditional marine fuels whereas other alternative marine fuels such as ammonia and methanol, which today are mainly produced from methane have higher emissions and are not green as often reported.



This means that to achieve emissions parity with fossil methane (LNG), traditional fossil ammonia and methanol require the addition of large volumes of very expensive green ammonia or green methanol. Translating this into typical investment metrics, methane, or LNG, offers a far shorter payback period than any other potential alternative marine fuel.



2019

First Ship-to-Ship LNG bunkering in Singapore

> **With bio-LNG, LNG is all of a sudden truly a long-term solution to decarbonise assets in the shipping sector [...] We are firmly convinced that bio-LNG, especially today, is the lowest cost of compliance option for shipowners.**
>
> **Stefan Dubbeldam, head of small scale at Vitol Group**

OPTIONALITY

Finally, it should be remembered that LNG is a solution that provides optionality, "inoculating" itself against regulatory uncertainty. LNG dual fuel vessels can fuel switch between LNG, liquefied biomethane and e-methane, traditional fuels and biofuels depending on regulations and relative fuel prices. As regards future optionality, LNG is particularly well-suited to onboard carbon capture technologies due to methane, as the cleanest hydrocarbon marine fuel, emitting purer carbon dioxide when burnt.

BIO/E-METHANE GROWTH ENSURES LONG TERM COMPLIANCE

Notwithstanding the current uncertainties caused by the IMO's decision in October to delay the adoption of the Net Zero Framework, the shipping industry has shown how quickly it adapts to new regulation. We saw the industry respond rapidly to the introduction of Emission Control Areas (ECAs) and the IMO's global sulphur cap in 2020. We are now seeing it rising to meet the challenges presented by the European Union's decarbonisation targets and associated regulations for shipping, in the form of EU ETS and FuelEU Maritime.

DEVELOPMENTS IN LIQUEFIED BIOMETHANE

Liquefied biomethane (LBM), often referred to as bio-LNG, or RNG in the USA, produced from sustainable biomass resources such as agricultural and municipal waste, is a central next step along the methane runway towards decarbonisation. It is virtually identical chemically to LNG, and fully compatible as a drop-in fuel in existing LNG engines with no blending issues, unlike biodiesel and fuel oils, which consist of a complex mix of hydrocarbons.

> **The technology and market are already in place. We need to catch the train. In the race to decarbonise shipping, that train is leaving the station and Bio-LNG may well be one of the fastest, most practical tickets on-board.**
>
> **Yiyong He, Founder/Director of Straits Bio LNG**

Bunkering of LBM has exploded over the past year in Europe. This has been driven by companies' response to increasingly stringent EU regulations with large financial penalties, and important and innovative voluntary, customer-related commitments. LBM bunkering operations have already taken place in key ports across Belgium, France, Finland, Italy, Lithuania, the Netherlands, Norway, Spain, Sweden and the UK, involving at least 10 major bunker suppliers. Use of LBM is widespread with bunkers being delivered to the cruise sector, container lines, ferries, OSVs, car carriers, tankers, bulkers and small-scale LNG carriers over the past 12 months.

> **Bio-LNG is a scalable solution we can use today... Bio-LNG's increasing availability and commercial viability gives our customers confidence that their dual-fuel LNG fleets are ready to further reduce emissions.**
>
> Dexter Belmar, Vice President of Shell Downstream LNG

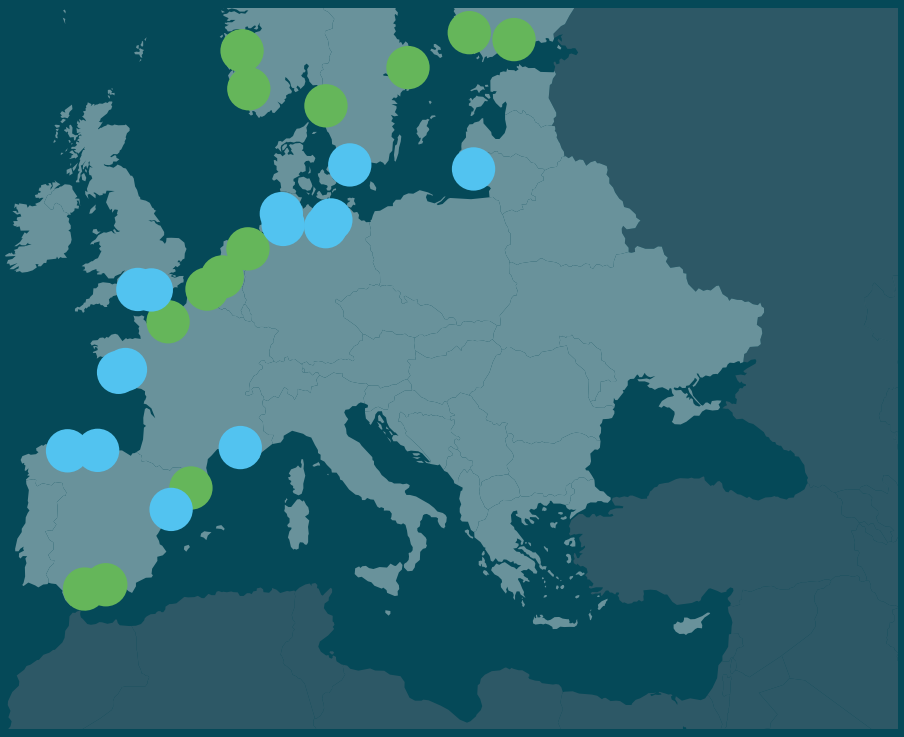
BIOMETHANE BUNKERING MAP

KEY PORTS

- PORTS WITH REGULAR BIOMETHANE BUNKERING OPERATIONS
- PORTS WITH AD HOC BIOMETHANE BUNKERING OPERATIONS

DECEMBER 2025

Source: SEA-LNG Analysis



2020

First liquefied biomethane (LBM) bunkering by UECC

Delivery of the first LNG ultra large container ship (ULCS) *CMA CGM JACQUES SAADÉ*

2020

First Ship-to-Ship LNG bunkering in Japan by the *KAGUYA*

The table below highlights several long-term agreements shipping companies have entered into with LBM suppliers.

In September 2025, Hapag-Lloyd and Shell signed a multi-year agreement for the supply of LBM starting with immediate effect. Since 2024, Shell has expanded its offering to include LBM, available at 22 strategic locations within its global LNG bunkering network. This agreement followed the September 2024 announcement that Gasum was supplying Hapag-Lloyd with LBM to fulfil the requirements of their ZEMBA tender. ZEMBA being a first-of-its-kind buyers' group within the maritime sector with the mission to accelerate the commercial deployment of zero-emission (ZE) shipping solutions. The LBM is used throughout 2025 and 2026 on a route between Rotterdam and Singapore.

Expanding upon their MOU with Shell in 2022, that encompassed the advancement of low-carbon marine fuels, such as LBM, in August 2025 CMA CGM formed a strategic partnership with the U.S.-based renewable natural gas (RNG) provider Vanguard Renewables, to support the decarbonisation of its shipping activities, through which Vanguard will dedicate up to four projects to the production of RNG (LBM) to be delivered to CMA CGM.

Since August 2025 Viking Line has run its two RORO vessels VIKING GLORY and VIKING GRACE operating between Turku in Finland and Stockholm Sweden on LBM to generate compliance for Gasum's FuelEU Maritime pool. The collaboration enabled a substantial increase in compliance supply as demand for FuelEU Maritime pooling built up at the end of the year. This LBM agreement built upon Gasum's earlier agreement with Equinor in February 2025 to supply its two tugboats BORGØY and BOKN with LBM throughout 2025.

> **The WILHELMSHAVEN EXPRESS and its eleven sister vessels... are not just the largest in our fleet – they are a symbol of our unwavering commitment to continuously lower emissions, to quality leadership, and to long-term strategic growth.**
>
> **Rolf Habben Jansen, CEO of Hapag-Lloyd at the LNG-powered vessel's christening ceremony October 2025**

Some fleet operators have gone beyond LBM blends and have committed to using 100% LBM bunkers for certain of their operations.

In December 2024, United European Car Carriers (UECC) announced that since July 2024 over 95% of the LNG used was LBM, avoiding 75,000 tonnes of GHGs being emitted. Their agreement with Titan Clean Fuels enabled UECC to continue to run on LBM for most of 2025.

In April 2025, Avenir LNG, announced that its vessel AVENIR ASCENSION would be the first bunker vessel globally to run entirely on LBM for 2025.

In August 2025, Swedish shipping firm Furetank announced it would be running its EU fleet on mass-balanced LBM for the remainder of the year, moving closer to its long-term goal of fossil-free shipping.

While Spanish ferry operator Balearia moved three of its dual-fuel ferries MARGARITA SALAS, ABEL MATUTES and RUSADIR to run exclusively on LBM from September to December 2025. To facilitate this, the company secured 132 GWh of LBM, the equivalent of 13% of all LNG consumed by Balearia's LNG-powered fleet in 2024.

Mass balancing is the most common chain of custody, as it is more efficient by avoiding separate investments in transportation and storage infrastructure, using existing infrastructure to connect buyers and sellers. It tends to be favoured by regulators as it is lower cost, allows utilization of LBM without increasing lifecycle GHG emissions due to avoiding unnecessary infrastructure and transportation, and enables the market for green fuels such as liquefied biomethane market for maritime to scale more quickly.

Read more in SEA-LNG's Chain of Custody Fact Sheet

FuelEU Maritime allows for pooling by fleet operators to meet their GHG intensity targets. The use of LBM can generate credits within this pooling mechanism which can be used directly by fleet operators for compliance purposes or can be sold to other fleet operators. Having the flexibility to utilise biogas with highly negative GHG emission factors is a key component in making pooling work. At least four commercial FuelEU Maritime Pools are in operation in Europe: Gasum Pool, Ahti Pool, BetterSea & OceanScore. This is an important feature of the regulations and should continue to be encouraged and expanded.

The growing liquidity of the market in Europe is demonstrated by the recent introduction of LBM bunker price assessments by price reporting agencies S&P Platts and Argus. Outside Europe we are seeing the emergence of LBM bunkering for voluntary commitments, for example in the US.

> **The U.S. still overlooks the enormous value in food processing scraps and inedible food... Biogas facilities can convert this waste into enough home-grown energy to supply the needs of millions of Americans, while creating jobs and catalyzing new, local investments. We hope more municipalities and industrial food processors will choose to invest in biogas systems to recycle their resources locally.**
>
> **Patrick Serfass, American Biogas Council Executive Director**

These are very promising developments for the methane decarbonisation runway but what of the long-term potential of the use of LBM as a marine fuel? The IEA's May 2025 report, Outlook for Biogas and Biomethane[4] states that biomethane is an underutilised resource in the energy transition. It is currently growing at a rate of 20% per annum and the IEA estimates some one trillion cubic metres of biomethane could be produced every year using organic waste streams (this would be the equivalent of around 25% of the total global natural gas demand today) yet only around 5% of the total potential for biogas and biomethane production is currently being utilised. The opportunities for greater production of LBM are significant and will be exploited given the obvious commercial and environmental benefits outlined above.

Read more about progress in SEA-LNG's Liquefied Biomethane Fact Sheet

4. https://www.iea.org/reports/outlook-for-biogas-and-biomethane

DEVELOPMENTS IN E-METHANE

The next stage of the methane decarbonisation runway extends beyond biomethane to e-methane, a synthetic fuel produced using renewable electricity and green hydrogen.

With the potential to deliver net zero emissions on a lifecycle basis, e-methane is increasingly recognised as a credible route for meeting the IMO's 2050 climate ambitions. Its emergence aligns with growing industry interest in synthetic fuels as long-term, scalable decarbonisation solutions.

E-methane can be adopted using existing LNG-ready infrastructure, including bunkering, making it a commercially viable investment for long-term compliance.

The New Energies Coalition's recent study[5] reinforces this trajectory, identifying e-fuels as one of the most promising pathways for deep GHG reductions using renewable electricity and green hydrogen.

E-methane offers significant advantages. It retains the energy density, storage properties, and handling characteristics of conventional LNG, ensuring that vessel performance and safety procedures remain unchanged. This, together with LBM, ensures methane investments are future proofed.

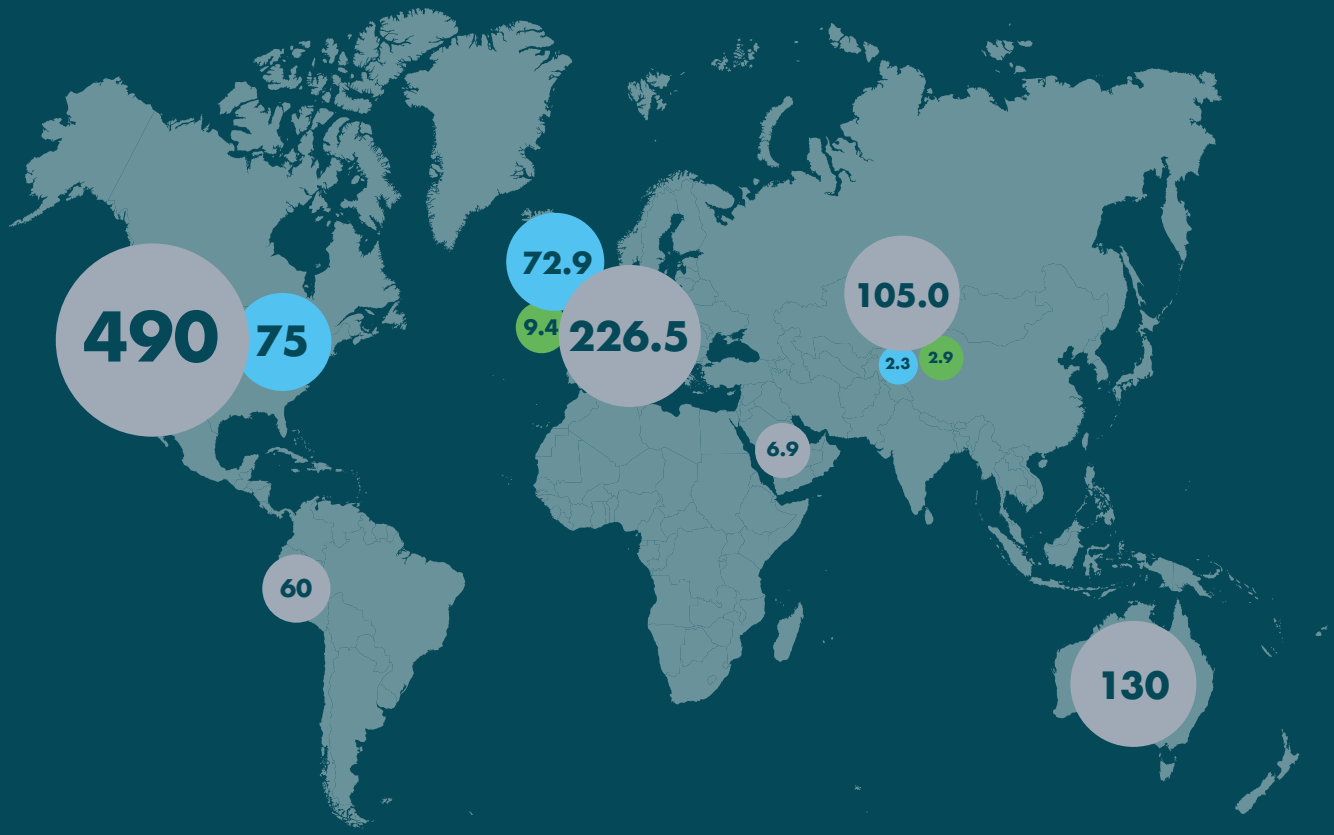
E-methane project development is currently being driven by demand from the utility sector, particularly in Japan, Europe and America. Clearly this is a product that will see significant investment as the "hydrogen economy" develops over the coming decades.

In December 2025, TotalEnergies, TES, Osaka Gas, Toho Gas and ITOCHU signed a joint development and operating agreement to develop the Live Oak Project for e-NG Production in Nebraska. The partners are now preparing the Front-End Engineering Design (FEED) phase, targeting a capacity of approximately 250 MW of electrolysis and 75 ktpa of methanation. The project, subject to a Final Investment Decision in 2027, is scheduled to begin commercial operations by 2030, with plans to export e-NG to Japan. The Live Oak project will leverage Nebraska's abundant biogenic CO2 resources, captured from bioethanol plants, and the growing renewable power generation capacity in the United States.

5. https://www.ricardo.com/en/news-and-insights/industry-insights/the-role-of-e-fuels-in-maritime-decarbonisation-insights-from-the-new-energies-coalition-study

E-METHANE PRODUCTION FACILITIES

The map, below shows the location of key e-methane projects.



Source: e-NG Coalition

There are 13 e-methane projects currently in operation, mainly pilot projects in Europe, with a total production capacity of just over 12 kilotonnes (kt pa) of LNG equivalent per annum. Four small projects, in Japan, Italy and France, are currently under construction and scheduled for start-up this year (2026). Three large scale projects, with a capacity of approximately 150 kt pa are currently in FEED and due to come on stream in the US and Finland between 2028 and 2030. Over one million tonnes per annum capacity, is at a pre-feasibility, or feasibility stage, in the USA, Peru, Canada, Australia, Oman, China, Japan, Italy, France and Finland with project start dates ranging from 2027 to 2031.

In terms of e-methane for shipping a number of SEA-LNG members including Gasum[6] and Galveston LNG Bunker Port[7] have already announced that they are exploring pathways to commercialise e-methane, incorporating it into future supply offerings.

Read more about progress in SEA-LNG's Liquefied E-methane Fact Sheet

FUTURE REGULATIONS

The IMO's decision in October 2025 to delay the adoption of the Net Zero Framework while frustrating for many, provides an opportunity to pause for thought. What is clear is that the industry is calling for a single, global regulatory system for decarbonisation that avoids the development of multiple, fragmented regulatory regimes with differing compliance requirements and "double" compliance costs.

> **After a year of regulatory drama exposing the complexity of the task faced by the IMO, the need for a single global decarbonisation framework is greater than ever. This framework must be goal-based and technology-neutral. It must allow some flexibility so companies can plan their fleet modernisation. We need a framework which is practical and realistic, incentivising solutions that are scalable and investable.**
>
> **Peter Keller, Chairman SEA-LNG**

6. https://sea-lng.org/2024/01/sea-lng-member-gasum-announces-renewable-e-methane-e-lng-deliveries-from-2026/

7. https://sea-lng.org/2025/07/sea-lng-member-galveston-lng-bunker-port-and-loa-carbon-sign-letter-of-intent-to-produce-e-lng-fuels/

What is also clear, is the complexity of the task the IMO faces in seeking to reconcile a myriad of stakeholder positions on difficult techno-economic issues coupled with a challenging geo-political environment. It is SEA-LNG's view that any decarbonisation framework should be informed by the following principles:

- There can only be **one global decarbonisation framework** for maritime, and all Member States should act accordingly. Any local or regional regulations should converge with IMO regulations with no double compliance costs.
- **Regulations should be goal-based and technology neutral** and not be prescriptive.
- **Early adopters should not be penalised** for taking a leadership role. In particular, regulations should recognise that the life of a capital vessel often exceeds 20-25 years.
- **Regulations should incentivise solutions that are practical, scalable and investable** given current technologies and realistic technology pathways, and levering existing infrastructure.
- **Regulations should allow for flexibility**, recognizing the need for shipping companies to consider fleet planning and to allow compliance pooling mechanisms.
- **Non-compliance** with any established regulations must be **dealt with in a realistic manner** without creating undue financial burdens on the maritime industry. If funds are raised through compliance mechanisms they should be hypothecated for re-investment in the maritime sector.

2021

First e-methane methane bunkering to the *ElbBLUE, in Brunsbüttel, Germany*

METHANE EMISSIONS CONTINUE TO FALL

While the use of LNG as a marine fuel effectively eliminates local emissions such as SOx, NOx and Particulate Matter while reducing CO2 emissions by more than a quarter, concerns are frequently raised about the issue of methane emissions. Methane can be emitted because of incomplete combustion in LNG-fuelled engines, so-called "methane slip", and also in the LNG fuel supply chain, often referred to as "fugitive emissions".

METHANE SLIP

SEA-LNG has consistently maintained that methane slip must be resolved if LNG is going to become a long-term, viable solution towards net zero. Slip is an issue that its members and other industry stakeholders have been proactively addressing.

2-stroke diesel cycle engines have essentially eliminated methane slip already. These account for around 75% of LNG-fuelled ships on order today, and some 90% of the installed onboard power capacity.

For low-pressure Otto cycle engine technologies where methane slip remains an issue, between 2019 and 2025 manufacturers have cut emissions from 1.5% to 0.8% for 2-stroke engines and 2.5% to less than 1.4% for 4-stroke engines.

In addition to ongoing developments by engine manufacturers, a number of industry initiatives have been set up to address methane slip. In 2022, the Methane Abatement in Maritime innovation initiative (MAMII) was established with the objective of advancing technologies to monitor, measure and mitigate methane emissions in the maritime sector. It is collaborating with regulators on developing methane emission measurement, certification and validation protocols. Three MAMII-member after treatment trials have been undertaken using plasma-catalytic and methane oxidation catalysts showing positive early results. Commercial aftertreatment solutions are anticipated soon as 2027.

2022

Delivery of first LNG VLCC to COSCO, the *YUAN RUI YANG*

First Ship-to-Ship bunkering in China

First Truck-to-Ship in Los Angeles/Long Beach (LA/LB) – the USA's largest container port

> **Methane abatement is both a climate obligation and a strategic opportunity for technology development. It is a great example for the industry to demonstrate action and compliance. It can offer substantial emissions reductions, generating positive cash flows and balance, in carbon cost measures.**
>
> **Panos Mitrou, MAMII chair and Lloyd's Register Senior Vice President - Shipping Strategy**

Additionally, while MAMII is trialling post-combustion technologies, companies such as ROTOBOOST, are already focusing on pre-combustion solutions in which LNG is converted into hydrogen and solid carbon, thereby fuelling engines with a blend of hydrogen and methane, which reduces methane slip.

The EU-funded Green Ray project, set up in 2022, targets methane slip reductions in low pressure dual fuel engine technologies. It is exploring solutions to reduce methane slip in two- and four-stroke engines, as well as tackling the remaining methane slip through the development of an aftertreatment technology. It has pioneered reliable onboard measurement solutions, through trials on ferries and cruise vessels. A recent trial on the AURORA BOTNIA RoPax ferry successfully reduced methane slip by up to 56% in Wärtsilä's most popular – and already emission-efficient – dual fuel low pressure four-stroke engine.

The Japanese government-backed NEDO initiative, which began in 2021, reported massive reductions in methane emissions during tests on a bulk carrier operated by Mitsui O.S.K. Lines in 2025. The trial of a methane oxidation catalyst system on the Reimei, operating between Australia and Japan, delivered a 98% reduction in methane slip. Recent operational data also confirms further progress. For example, a year-long independent study on Brittany Ferries' LNG-powered ship Salamanca, published in September 2025, showed that levels of methane slip were around 50% less than the default values used as a benchmark for European shipping emissions regulations.

> **We have invested significantly in LNG as a cleaner, greener fuel with four new ships. It is important that we are recognised for our sector leading approach to sustainability, and that we are not penalised for phantom emissions that exist only on a spreadsheet.**
>
> **Christophe Mathieu, CEO Brittany Ferries**

Across the global LNG-fuelled fleet, methane slip in the latest low pressure engine technologies has fallen by roughly 60% in under a decade. SEA-LNG has repeatedly stated since the start of the 2020s that methane slip will be effectively resolved by 2030. The actions to date, and the trajectory forward, support this position.

2023

Large cruise ship *MSC EURIBA* completes maiden voyage on LBM

FUGITIVE METHANE EMISSIONS

Fugitive methane emissions in LNG supply chains account for approximately 5%[8] of the total Well-to-Wake GHG emissions associated with the use of LNG as a marine fuel. However, the situation is confusing. Different studies from different locations using different assumptions report a wide range of results. What had been missing is a definitive study on the GHG emissions associated with LNG bunker supply chains, including a breakdown of the contribution of fugitive methane emissions. To address this gap, in 2025 SEA-LNG commissioned Rystad Energy to undertake a bottom-up study of all global marine fuel LNG supply chains.

> **Our analysis is based on asset-level data that ties specific gas fields to liquefaction facilities. This approach, supported by satellite-detected methane plume data and reported asset information, gives a more accurate picture of the LNG actually used for bunkering, rather than relying on outdated, hypothetical or overly broad averages.**
>
> **Patrick King, Vice President Emissions Research, Rystad Energy**

The study analyses emissions originating from the five key fuel lifecycle stages of LNG: upstream, transportation & processing, liquefaction, shipping, and distribution & bunkering operations. It aligns with the International Maritime Organization's (IMO) Well-to-Tank (WtT) lifecycle analysis guidelines, the Intergovernmental Panel on Climate Change's (IPCC) AR5 GHG definitions and is based on asset-specific 2024 data.

2024

First Ship-to-Ship LNG Bunkering on USWC and in Vancouver Canada

Record year for LNG newbuilding orders

1.1M tonnes of LNG bunkered by Shell

8. https://sea-lng.org/reports/independent-study-confirms-lng-reduces-shipping-ghg-emissions-by-up-to-23/

WELL-TO-TANK INTENSITY FOR LNG BUNKERED IN 2024

Value chain stage	Emissions intensity (g CO2e/MJ)	CH_4 Impact* (% of stage total)
Upstream	4.2	38%
Transport & processing	1.3	7%
Liquefaction	5.9	1%
Shipping	1.8	8%
Bunker operations/ distribution	0.7	37%
Well-to-tank	**13.9**	16%

CH_4 impact denotes the percentage that stages overall GHG emissions methane responsible for (i.e. a 10% value with an intensity of 10 g CO2/MJ, denotes a methane contribution of 1 g CO2e/MJ)

It found that the 2024 global WtT emissions intensity for LNG bunkering fuel is 13.9g CO2e/MJ (LHV). Carbon dioxide dominates global WtT emissions, responsible for 84% of emissions. Methane emissions were responsible for 16% of total WtT emissions, equivalent to 2.2 g CO2e/MJ. They were most prevalent in upstream gas production lifecycle stage, responsible for 38% of total emissions from that stage. On a global basis, upstream gas production and liquefaction were responsible for the majority of bunker supply chain emissions at 30% and 43% respectively.

Eliminating LNG supply chain emissions is a major focus of the oil and gas sector. Significant improvements have been seen over the past few years through initiatives such as the Oil and Gas Climate Initiative (OGCI) and the Oil and Gas Methane Partnership (OGMP 2.0). Improvements in liquefaction emissions have also been observed over recent years, tied to greater utilisation of more efficient technologies. This trend is likely to continue when coupled with key electrification projects using renewable energy, such as hydro and solar power.

The Rystad Energy study shows that the global average for LNG bunkering fuel is 13.9g CO_2e/MJ is lower than the EU WtT default of 18.5 gCO_2e/MJ, used in FuelEU Maritime, reflecting improvements that have been achieved by the upstream oil and gas industry. The study also shows wide variations between regions and cargoes, reflecting differences in gas sources, liquefaction technologies, and shipping distances. In some cases, emissions intensities differed by as much as 6.6 g CO_2e/MJ, highlighting that a single global average does not capture the full picture and risks leading to poorly informed regulatory choices.

The Rystad Energy study needs to be seriously considered as regulators set default standards for compliance. We must ensure that vessel owners and operators are not negatively impacted by the out- of-date default standards which do not account for improved performance.

Read more about progress in SEA-LNG's Methane Slip Fact Sheet

FASTER, LOWER, STRONGER-TOGETHER

Over the last decade SEA-LNG Members have led the maritime industry in moving towards a cleaner future. Working together, initial hurdles preventing the development of LNG as a marine fuel have been overcome so successfully that they are now almost forgotten. The issue of sulphur emissions has been solved by LNG, as has the significant reduction of nitrogen oxides and particulate matter. With LNG and the methane runway GHG emissions are being consistently reduced year on year.

Supplies of LNG as a marine fuel are available worldwide. Port infrastructure has grown to the extent that over 200 ports now offer LNG and increasing numbers now offer liquefied biomethane as well. Bunkering has grown from a single bunkering vessel in 2016 to over sixty in 2025. The rate of growth is increasing and the methane decarbonisation pathway is now a clear runway.

Demand for LNG as a marine fuel is greater than ever, while technical and engineering innovation to reduce methane emissions mean GHG emissions per tonne mile of cargo powered by LNG are lower than ever. LNG as a fuel in transition from fossil to bio and e-methane will extend these GHGs reductions still lower. As methane burns cleanly, local emissions have been cut benefiting the health of port communities and workers globally.

> **SEA-LNG's messaging is built upon sound science, and the professional expertise and experience of the coalition's members. So, despite the environmental and regulatory tumult experienced by the maritime industry, our voice has remained consistent over the last decade. In a world increasingly filled with AI content, being a credible and trusted advocate for a cleaner future is more important than ever.**
>
> **Ian Aitchison, Communications Director, SEA-LNG**

Throughout its existence, SEA-LNG has sought to be a voice of reason, basing its advocacy for LNG as a marine fuel on sound science, and the professional expertise and maritime experience of its members. Today, our practical and realistic mantra is being echoed in the industry as ideologically driven green claims are questioned for accuracy and impact. Whatever propulsion method is chosen by owners and operators, the maritime industry must consider fuel energy density, cost to propel the vessel, availability of fuels, optionality and increasingly the cost of compliance with ever developing regulations.

As we enter 2026, and approach the start of our second decade, the methane decarbonisation pathway becomes a runway to a cleaner future. While much has been accomplished, the transition is still in its infancy with some 90% of the world's deepsea vessel fleet yet to transition to alternative fuel sources. The most realistic and practical solution continues to be LNG and the methane runway. We look forward to working with existing and new members to go faster, lower, stronger-together.

2025

LNG powered fleet (operational and on order) exceeds 10% of the total current global fleet

2025

Gasum's new biomethane plant in Gotene Sweden.

FASTER

Growth of LNG-powered vessels

2019	2025
159	1406

Source: DNV

LOWER

GHG emissions

2019	2025
18.8g (Well-to-Tank CO2eq/MJ)	13.9g (Well-to-Tank CO2eq/MJ)
2019 4-stroke low-pressure slip 2.5%	2025 4-stroke low-pressure slip <1.4%
2019 2-stroke low-pressure slip 1.5%	2025 2-stroke low-pressure slip 0.8%

Source: thinkstep, Rystad Energy, Wartsila, WinGD

STRONGER - TOGETHER

as whole LNG value chain

2019	2025
OCCASIONAL USE OF LBM Liquefied Biomethane, or BioLNG	REGULAR USE OF LBM Liquefied Biomethane, or BioLNG

Source: Titan, Shell

CHAIN OF CUSTODY MODELS FACT SHEET

Tracking low-carbon marine fuels through the bunkering supply chain

SEA-LNG

What does Chain of Custody mean?

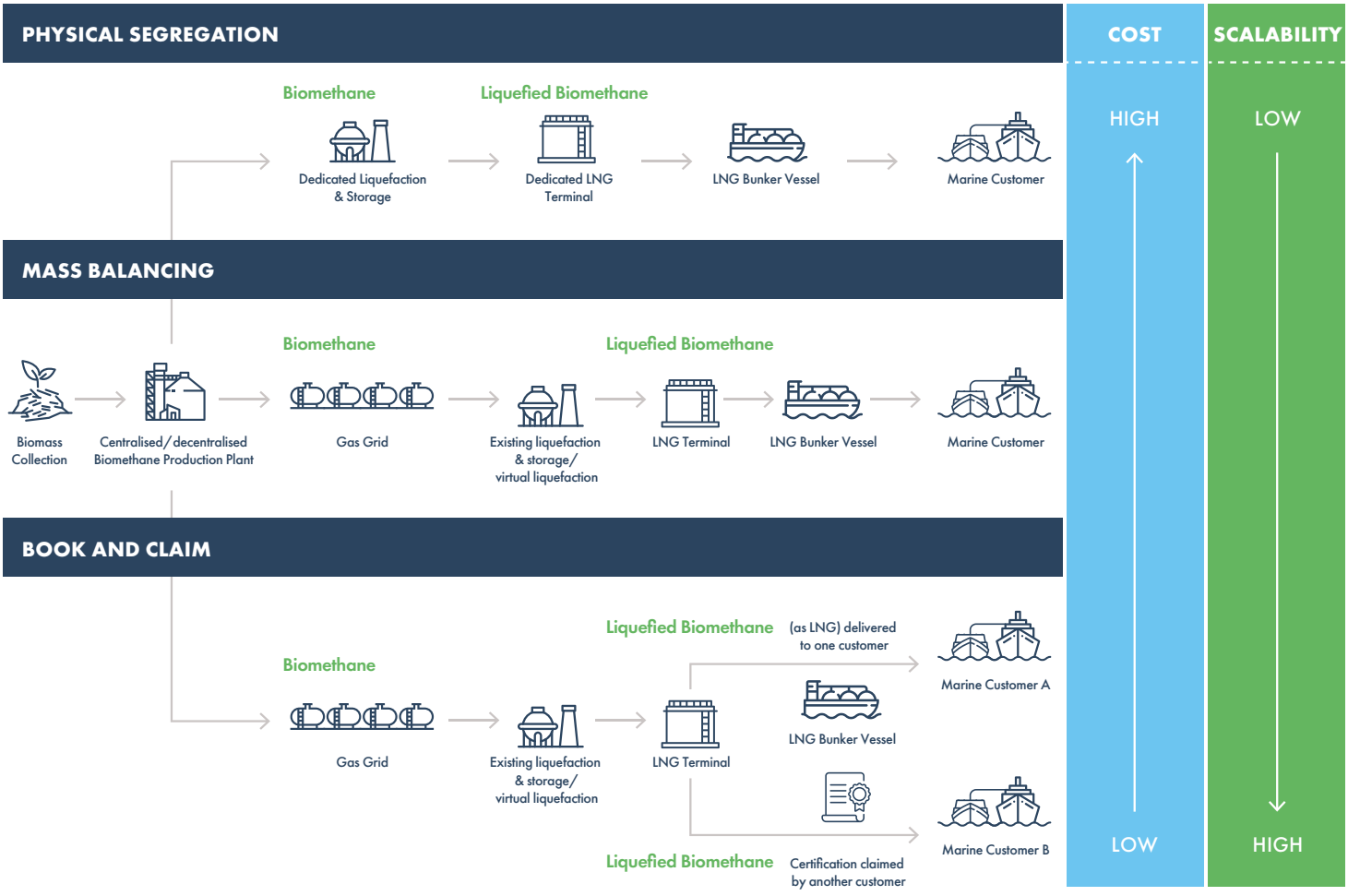
Chain of Custody refers to a transparent and verifiable way to track the greenhouse gas emission attributes of marine fuels throughout their lifecycle, from production to the end-use customer.

Why are chain of custody models important in decarbonisation?

Chain of custody models are important in maritime decarbonisation as they provide mechanisms to verify that the fuels used are low carbon. Such verification creates investor confidence in new fuel supply chains and accelerates the transition to low-carbon fuels, enabling early adoption in conditions of limited supply. They can create a market for green fuels by connecting buyers to fuel producers away from bunker ports enabling faster scaling and providing flexibility to shipping companies at lower cost.

What are the main chain of custody models being discussed in the maritime industry?

There are three relevant Chain of Custody models currently being discussed for low-carbon marine fuels such as liquefied biomethane (bio-LNG). These are Physical Segregation, Mass Balancing and Book & Claim.



What is Physical Segregation?

In the case of liquefied biomethane, Physical Segregation means that the biomethane molecule is produced, transported, stored, liquefied and delivered to the marine customer through a separate, dedicated infrastructure. The need for the supply chain to invest in this new infrastructure means that this is the most expensive way to supply liquefied biomethane and is also the most difficult to scale.

CHAIN OF CUSTODY MODELS FACT SHEET

Tracking low-carbon marine fuels through the bunkering supply chain

SEA-LNG

Why is Physical Segregation used?	Physical Segregation is sometimes preferred because some stakeholders see it as a more tangible and easily verifiable approach. Some cargo owners with voluntary decarbonization targets require it depending on the voluntary frameworks that they have signed up to. For example, the Science Based Targets initiative (SBTi) guidelines currently do not recognise Mass Balance and Book & Claim chains of custody.
What is Mass Balancing?	Mass Balancing allows biomethane producers to sell their fuel into existing natural gas grids and allows fuel customers to purchase this biomethane from the grid via a certificate.
Why is Mass Balancing used?	Mass Balancing uses existing infrastructure to connect buyers and sellers. It is favoured by regulators as it is lower cost and enables the market for green fuels such as liquefied biomethane market for maritime to scale more quickly. Mass Balancing has also been successfully used in other sectors such the chemicals and plastics industry. A growing number of key jurisdictions accept Mass Balancing for biomethane, including the EU, USA and Canada and regulators are exploring it in countries such as Japan, China and Australia.
What is Book & Claim?	In Book & Claim the greenhouse gas emissions of a low carbon fuel such as biomethane produced by a supplier are 'booked' in a central registry, and customers can 'claim' them without any connection to the physical biomethane molecule. Book & Claim is analogous to the system of renewable energy certificates used in the electricity sector whereby the electrons produced by a wind farm, aren't necessarily the same ones powering a green consumer's light bulb.
Why is Book & Claim used?	Book & Claim is the lowest cost Chain of Custody model as it decouples greenhouse gas emissions from the physical supply chain. As it can connect buyers to sellers anywhere on the globe it is also the most scalable and flexible Chain of Custody system. Book & Claim is being used in the voluntary carbon markets. The International Civil Aviation Organization (ICAO) is considering the implementation of a Book & Claim system for Sustainable Aviation Fuels (SAFs) and the International Maritime Organization (IMO) is actively exploring the potential of Book & Claim systems for maritime.
What is needed for a credible chain of custody system for marine fuels?	A credible chain of custody system requires the following: • clear and verifiable standards for greenhouse gas emissions attributes of the marine fuel; • certification of fuel supply chains by certification bodies such as ISCC (International Sustainability & Carbon Certification); • robust tracking and traceability of fuels using digital certificates as they pass through the supply chain; • independent verification of compliance by third party auditors; • and full transparency and disclosure.

LIQUEFIED BIOMETHANE FACT SHEET

SEA–LNG

What is liquefied biomethane?

Liquefied biomethane (LBM), also known as bio-LNG, is chemically identical to LNG (liquefied natural gas). In North America biomethane is sometimes also known as renewable natural gas (RNG).

How is liquefied biomethane produced?

Biomethane is mainly produced from anaerobic digestion of agricultural and human waste streams eg animal manure, silage, wastewater and landfill. It can also be produced through gasification of cellulosic waste, such as sawmill and forest harvest residues. This is a less mature technology.

Does liquefied biomethane compete with food production?

Biomethane is produced from sustainable biomass feedstocks, which are nationally, or regionally defined, for example by the EU (RED III)[1] in Europe and the EPA[2] (Renewable Fuel Standards) in the USA. This means that it does not compete with the production of food, fibre or fodder.

What emissions reductions does liquefied biomethane deliver?

Emissions reduction will depend on how the liquefied biomethane is produced and the engines in which it is used. In general, the use of liquefied biomethane as a marine fuel can reduce GHG emissions by up to 80% compared to marine diesel on a full well-to-wake basis. When produced from the anaerobic digestion of waste materials, such as manure, methane that would otherwise be released into the atmosphere is captured, resulting in negative emissions of up to -190% compared with diesel.

How much liquefied biomethane is available now?

Production of biomethane, is currently running at approximately 36Mt pa, or 15% of shipping's total energy demand.

What is the potential for liquefied biomethane the future?

Biomethane produced from sustainable biomass has massive global potential – up to 20 times current production levels by 2050. Once demand from other sectors is taken into account liquefied biomethane has the potential to play a significant role in decarbonizing shipping. If used in the form of a 20% blend with LNG, it could cover up to 16% of global shipping demand by 2030.

Is liquefied biomethane available to shipping?

Liquefied biomethane is an established bunker fuel and is commercially available in Europe, North America and Asia.

1. European Union Renewable Energy Directive III raises the share of renewable energy in the European Union's overall energy consumption to 42.5% by 2030, with an additional 2.5% indicative top-up to allow the target of 45% to be achieved.
2. The Renewable Fuel Standard (RFS) is a federal program that requires transportation fuel sold in the United States to contain a minimum volume of renewable fuels. The RFS originated with the Energy Policy Act of 2005 and expanded under the Energy Independence and Security Act of 2007.

How expensive is liquefied biomethane?	All biofuels and biogases such as liquefied biomethane are significantly more expensive than traditional marine fuels. However, negotiations are on-going in the International Maritime Organization (IMO) to introduce a global pricing carbon mechanism or economic measure that will effectively narrow the price gap.
How is liquefied biomethane typically sold?	Liquefied biomethane is typically sold as a blend with fossil LNG.
Are there any blending issues with liquefied biomethane?	Liquefied biomethane is pure, liquefied methane and effectively identical to the highest quality LNG, so there are no blending issues.
How is liquefied biomethane delivered to ship owners?	Liquefied biomethane can be delivered in the form of physical molecules from liquefied biomethane plants to a ship, or through a system of mass balancing and certified guarantees of origin, whereby biomethane is injected into the gas network and delivered from LNG terminals or liquefaction plants using existing infrastructure.
Does using liquefied biomethane impact methane slip?	Methane slip is a function of engine technology and is not impacted by the use of liquefied biomethane.

For more information on the role of liquefied biomethane in shipping industry decarbonization, please see the report published by the Maritime Energy and Sustainable Development Centre of Excellence in October 2022.

LIQUEFIED E-METHANE FACT SHEET

SEA–LNG

What is liquefied e-methane?

Liquefied e-methane, also known as e-LNG, is chemically identical to LNG (liquefied natural gas). It is an electro-fuel, or e-fuel, so called because it is produced from renewable electricity. It is also known as liquefied synthetic methane, or natural gas.

How is liquefied e-methane produced?

Liquefied e-methane is produced by combining hydrogen and carbon dioxide. For liquefied e-methane to be considered a zero-emission fuel, the hydrogen has to stem from electrolysis, using water and renewable electricity as inputs; the carbon dioxide has to be obtained from biogenic sources, or captured from the atmosphere.

How does liquefied e-methane relate to other green fuels?

Liquefied e-methane is one of a family of electro-fuels including e-methanol and e-ammonia which are being discussed for use in maritime. These fuels are all derived from the same renewable hydrogen feedstock. Liquefied e-methane and e-methanol are produced by combining hydrogen with carbon dioxide; ammonia is produced by combining hydrogen with nitrogen.

What emissions reductions does liquefied e-methane deliver?

Emissions reductions will depend on how the liquefied e-methane is produced and the engines in which it is used. In practice zero greenhouse gas emissions are achievable if liquefied e-methane is produced using renewable electricity and carbon dioxide obtained from biogenic sources, or captured from the atmosphere, and used in engines with no methane slip.

How much liquefied e-methane is available now?

Production of liquefied e-methane is currently limited to a number of pilot plants in Europe, but sizable production facilities are being developed in Europe, North America and Australia.

What is the potential for bio-LNG in the future?

Supplies of liquefied e-methane are potentially unlimited, dependent on the build out of renewable electricity and hydrogen electrolysis capacity. Liquefied e-methane has the advantage over other green marine fuels in that it can be delivered using existing natural gas and bunkering infrastructure.

Is liquefied e-methane available to shipping?

Liquefied e-methane has been successfully piloted in shipping. As with other e-fuels, it is currently only available in small volumes, but a number of bunker fuel suppliers are exploring pathways to commercialise e-methane, incorporating it into future supply offerings.

How expensive is liquefied e-methane?	All electro-fuels including liquefied e-methane are many times more expensive than traditional marine fuels and biofuels and biogases such as liquefied biomethane. However, negotiations are on-going in the International Maritime Organization (IMO) to introduce a global pricing carbon mechanism or economic measure that will effectively narrow the price gap.
How is liquefied e-methane typically sold?	Liquefied e-methane is in the early stages of commercialization. It is likely that it will initially be sold as a blend with fossil LNG.
Are there any blending issues with liquefied e-methane?	Liquefied e-methane is chemically identical to the highest quality fossil LNG, so there are no blending issues.
How is liquefied e-methane delivered to ship owners?	Liquefied e-methane can be delivered in the form of physical molecules from e-LNG plants to a ship, or through a system of mass balancing and certified guarantees of origin, whereby e-methane is injected into the gas network and delivered from LNG terminals or liquefaction plants using existing infrastructure.
Does using liquefied e-methane impact methane slip?	Methane slip is a function of engine technology and is not impacted by the use of liquefied e-methane.

For more information on the role of e-LNG in shipping industry decarbonization, please see the report published by the CE Delft on Availability and Costs of Liquefied Bio- and Synthetic Methane – the Maritime Shipping Perspective.

METHANE SLIP FACT SHEET

SEA–LNG

What is methane slip?

In LNG-fuelled marine engines, methane slip refers to the small amounts of the fuel that does not burn in the engine but escapes with the exhaust gases into the atmosphere.

Why is methane slip important?

Methane slip is important because methane is a powerful greenhouse gas, with a global warming potential of 28-36 times that of carbon dioxide on a 100-year timescale, according to the IPCC (Intergovernmental Panel on Climate Change). Methane slip reduces the benefit of lower carbon dioxide emissions offered by LNG-fuelled engines.

What determines levels of methane slip?

Levels of methane slip are dependent on engine technology and the way in which the engines are operated. High-pressure, diesel cycle dual fuel engines offer negligible levels of methane slip, while higher methane slip values are reported for low-pressure, Otto cycle dual fuel engines. Operations at lower engine loads tend to increase methane slip compared to higher engine loads where vessels operate for the majority (90%) of their voyage time.

Are all LNG-fuelled engines affected by methane slip?

No, high-pressure 2-stroke, diesel cycle engines have effectively eliminated methane slip. These engines account for approximately 75% of the LNG-fuelled vessel order book.

Does methane slip eliminate LNG's GHG emissions benefits?

No, independent analysis[1] based on data from all major engine manufacturers shows that once methane slip is taken into account, the use of LNG as a marine fuel offers significant GHG emissions reductions on a full lifecycle (Well-to-Wake) basis, compared with the use of traditional marine fuels. These reductions range from 6% to 14% for low pressure, 4-stroke engines and up to 23% for high pressure, 2-stroke engines which represent three quarters of the vessel order book.

Can methane slip be fixed?

Yes, for those low-pressure engine technologies for which methane slip is an issue, manufacturers have already cut the levels of slip from low pressure, 4-stroke engines by more than 85% over the past 25 years. It is worth noting that methane slip has been eliminated for the similar LNG dual fuel engine technologies used in the heavy-duty vehicle sector.

1. https://sea-lng.org/wp-content/uploads/2021/04/2021_Sphera_Study_Key_Findings_Document.pdf

What is being done to address methane slip?

Addressing methane slip is the focus of a number of industry initiatives including the Methane Abatement in Maritime Innovation Initiative (MAMII)[2] and the EU-funded GREEN RAY[3] project. These initiatives are accelerating the development of new engine technologies and exhaust stack abatement solutions which can be retrofitted to older engine technologies. Equipment manufacturers are confident methane slip will have been eliminated for all engine technologies within the decade.

What about the high levels of slip claimed by recent NGO studies?

Recent NGO studies reporting apparently high levels methane slip from LNG-fuelled vessels[4] use an experimental near-shore airborne measurement methodology which is not verified against industry standards. Putting the experimental nature of the measurement approach to one side, these studies were based on vessels using older engine technologies in atypical operating conditions ie vessels operating at low engine loads, manoeuvring in or near ports. These conditions are not representative of the vast majority of vessel activities.

What is the effect methane of emissions in the LNG supply chain?

Methane emissions in the LNG supply chain are responsible for a small fraction, approximately 5%, of the overall (Well-to-Wake) GHG emissions associated with the use of LNG as a marine fuel.

What is being done to address LNG supply chain emissions?

Eliminating LNG supply chain emissions is a major focus of the oil and gas sector. As a response to the Global Methane Pledge announced at COP26, the Oil and Gas Climate Initiative, whose members are responsible for one third of global oil and gas production, launched the Aiming for Zero Emissions Initiative[5] in March 2022. Existing emissions are below 0.2% and the goal is to reach near zero methane emissions from its members' operated oil and gas assets by 2030.

2. https://mamii.org
3. https://greenray-project.eu
4. https://sea-lng.org/2024/01/icct-fumes-study-risks-misleading-regulators/
5. https://aimingforzero.ogci.com/about/

SEA–LNG

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Back Cover: K-Line 7,000 CEU capacity Pure Car and Truck Carrier (PCTC) ODIN HIGHWAY being refuelled with LNG by Titan Cleanfuels LNG Bunker Vessel OPTIMUS in Zeebrugge. Photo credit: Titan

Front Cover: 11,500 TEU LNG dual-fuel container vessel MSC INSA departing Santos September 2025. Photo credit MSC.