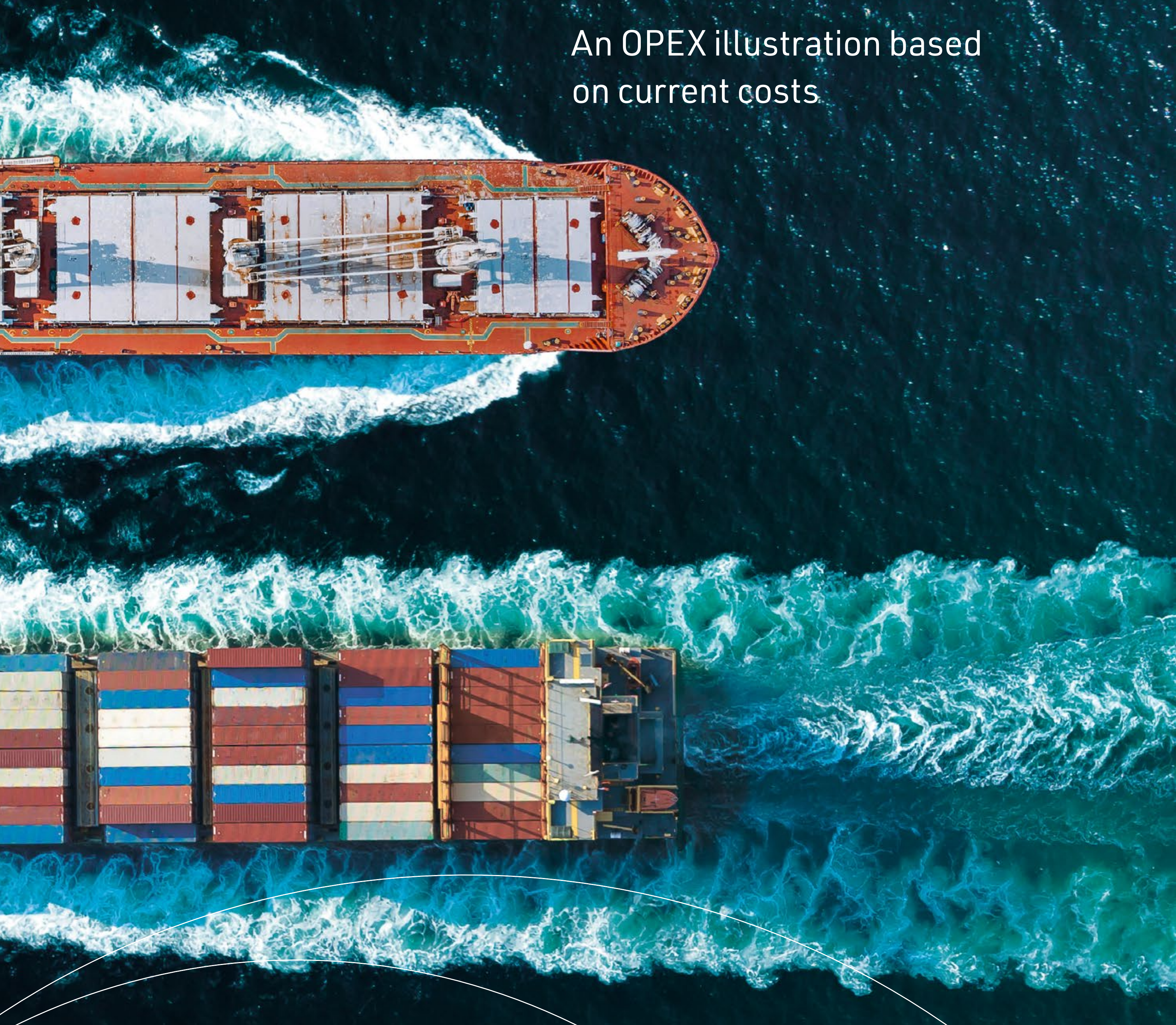
RENEWABLE FUEL ECONOMICS

An OPEX illustration based on current costs



WIN GD | Envision

Accelerating uptake of green ship fuels

Neither regulation nor ethics alone can push shipping to decarbonisation – what's needed is a clear business case.

Slowing climate change: moral imperative or regulatory necessity? At first glance today, it would seem neither. Outside of Europe, there is no carbon pricing scheme in effect for greenhouse gasses emitted by ships. And while morality – in its corporate guises of ESG reporting and reputation management – may offer some incentive to big, public facing companies, it is unlikely to move the smaller ship owners, operators and charterers that make up the backbone of the international shipping market.

Those companies face an increasingly challenging global economic environment, while flying under the radar of public expectations around sustainability. Why invest in expensive new fuels and technologies without a financial penalty to avoid or reward to accrue?

In the absence of a coherent global policy on pricing shipping's emissions, it won't be moral conscience that drives companies towards green fuels and zero-emission shipping – it will be a clear business case.

Is there a business case for green ship fuels without carbon pricing?

Motivated first movers are already confident they can make it work – evidenced by strong year-on-year growth in methanol- and ammonia-fuelled newbuild orders.

To explore the business case for the wider market, Swiss marine power company WinGD partnered with green fuel supplier Envision Energy to illustrate the current costs of using clean fuels, the cost gap between those fuels and their conventional cousins, and how that gap will be closed while a global regulatory framework is agreed.

The vessel cases shown are based on existing fuels and propulsion technologies at current prices. They show that, while the green fuels remain more expensive today, the gap is closing. It will close further with future price evolution, technology advances and – if there is a will – supportive global policy.

Crucially, the modelling also shows that at current green ammonia prices, only the surpluses and remedies element of the proposed IMO Net Zero Framework – without further reward – would be enough to make ammonia competitive against a conventionally fuelled vessel.

Building scale
Meeting shipping's green fuel needs

Green ammonia is no longer an optimistic ambition.

In July this year, Envision Energy commissioned the world's largest and most advanced green hydrogen and ammonia production facility.

Harnessing the vast wind and solar potential of its Gobi Desert location, the facility is powered entirely by the world's largest off-grid renewable energy system. The plant is also the first of its kind to be fully AI – enabled, achieving real-time optimisation of energy harvesting and a stable supply of renewable energy at scale.

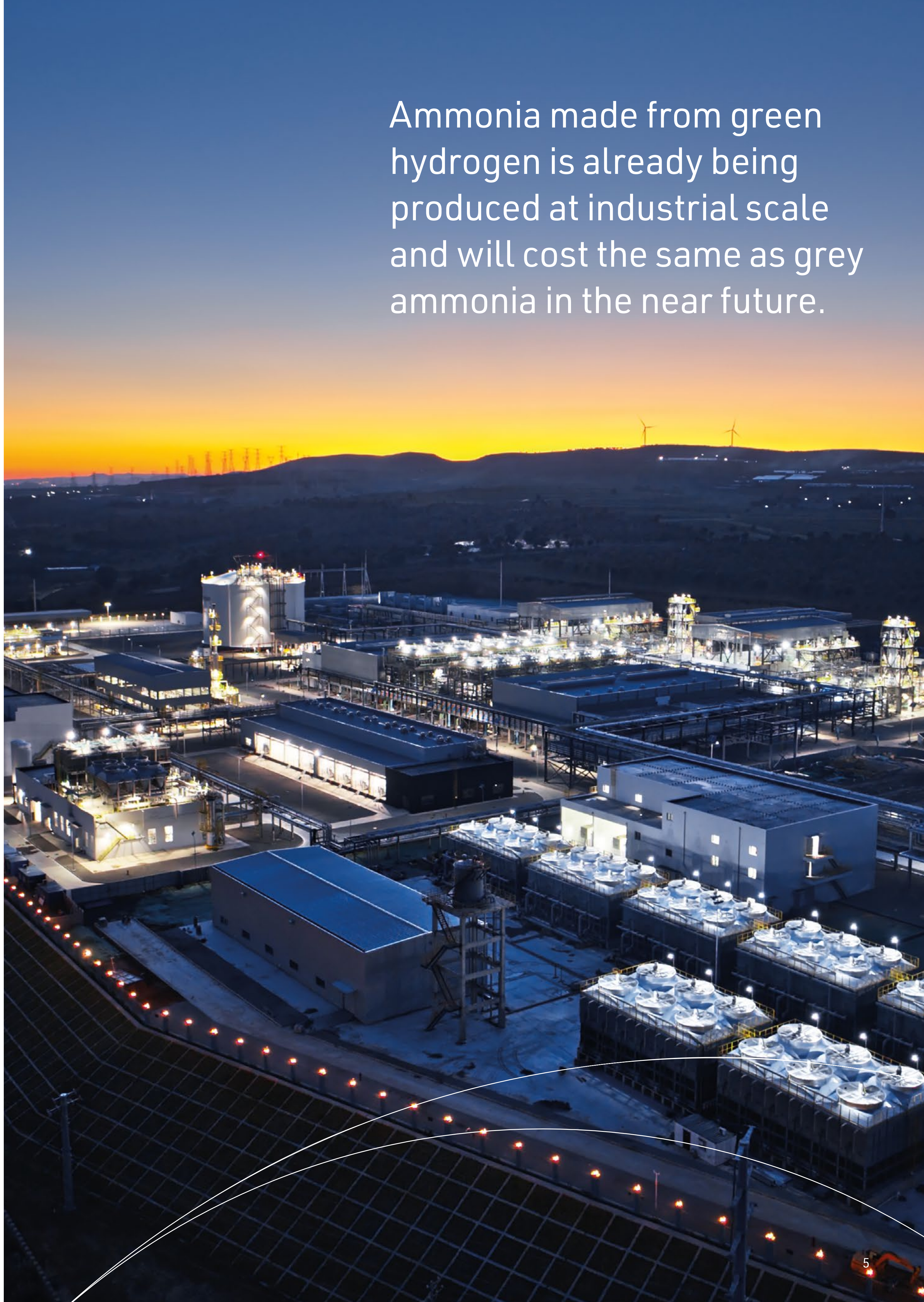
Located in the Chifeng Net Zero Industrial Park in Inner Mongolia, the facility starts by generating renewable electricity, which is then converted into green hydrogen. This can then be used to create other green fuels on site – starting with green ammonia, but with the capability of producing green methanol and e-methane in the future.

The first phase of the project will deliver 320,000 tons of green ammonia annually, with exports commencing in Q1 2026.

Using advanced wind turbines, grid-forming battery storage and predictive meteorological modelling, the plant dynamically balances wind and solar input with electrolyser and ammonia synthesis demands, ensuring continuous, cost-effective green fuel production without grid reliance. The facility has received Renewable Ammonia Certification from Bureau Veritas as well as under the ISCC PLUS and ISCC EU frameworks, affirming that it meets the highest global sustainability, safety and emissions standards.

Driven by that vision, commercial interest is already emerging. The green ammonia will be adopted in a range of sectors including power generation, hydrogen carrier, fertilisers, chemicals, and shipping – with long-term commitments that will be key to the scaling effort.

The park will produce 1.5 million tons of green ammonia per year by 2028 – helping green fuels become truly competitive and globally available.



Green fuel capability
Powering the future fleet

In July 2025, the first ammonia-fuelled engine built to WinGD's design was installed on a 46k cubic meter LPG/ammonia carrier being built for EXMAR LPG at HD Hyundai's Mipo shipyard. The vessel, which will enter operation in early 2026, is powered by an X52DF-A engine. It will shortly be joined by the first in a series of 210k DWT bulk carriers, under construction at CSSC Qingdao Beihai Shipbuilding, which will deploy larger X72DF-A engines.

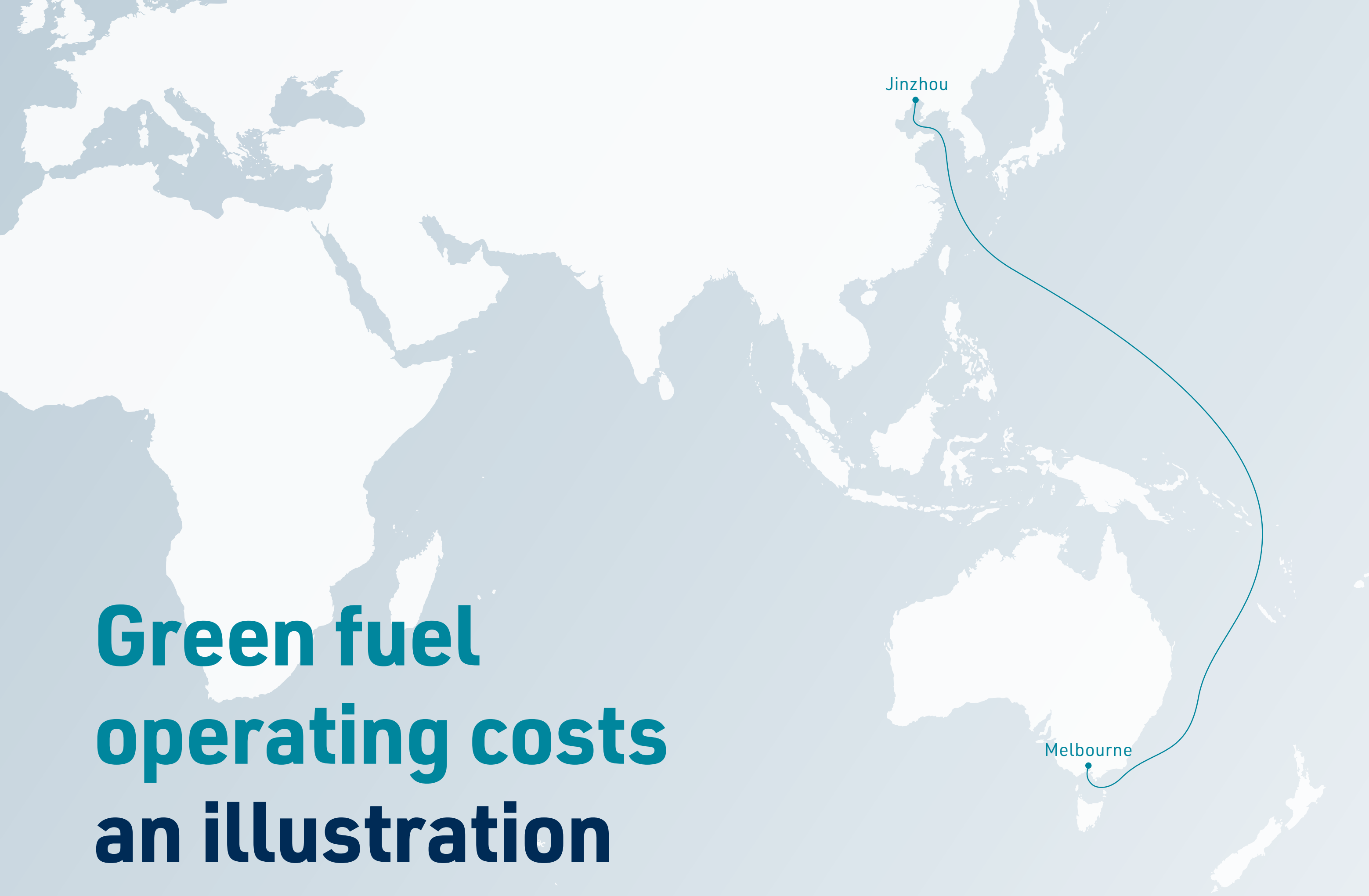
These vessels are the vanguard of more than 30 newbuilds ordered so far that will deploy WinGD's X-DF-A ammonia engines. The release of the engine design is a culmination of more than a decade of research, development and – crucially – collaboration with maritime and technology partners.

In early 2026, WinGD secured the first type approval and factory approval for an X-DF-A engine, in the 52-bore size. This follows class approvals for its safety concept, as well as cooperation on fuel supply, storage and integration design projects, and working with ship operators to develop crew training.

All to ensure that ship owners and operators are ready to deploy the technology safely and while realising the full benefits of using carbon-free green ammonia as a ship fuel.

Although the X-DF-A engine is the first from WinGD to run on a fuel with no carbon molecule, it is far from the first to enable the use of zero or near-zero emissions (ZNZ) fuels. Earlier in 2025, WinGD delivered its first methanol-fuelled X-DF-M engines, with nearly a hundred more on order. And since 2016 the company's X-DF dual-fuel LNG engine – also capable of running on e-LNG without modification – has become a market leader in the LNG carrier market and a mainstay of dual-fuel ocean-going vessels, with nearly 1,000 engines in service and on order.

> The first ocean-going ships fuelled by ammonia are hitting the water today, joining an existing fleet of vessels ready to deploy green methanol and e-LNG.



Green fuel operating costs an illustration

To examine the case for using green fuels today, WinGD and Envision Energy performed costing exercises for operating expenses – comprising fuels, consumables related to emission abatement and IMO penalties on two example applications:

- A 16k TEU containership with a service speed of 19 knots
- A 210k DWT bulk carrier with a service speed of 14 knots

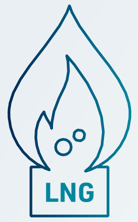
An annual operating time of 6,000 hours is considered, representing a single point-to-point voyage that is beyond the jurisdiction of European Union legislation (i.e., the EU Emissions Trading System and FuelEU Maritime).

The bunkering location is determined as Jinzhou in China – the nearest main port to Envision Energy's green ammonia production facility in Chifeng. A scenario where imported green ammonia is bunkered in Melbourne, the other end of the theoretical route, is also modelled to highlight the impact of bunker transport emissions on regulatory costs.

These fuel configurations are modelled across both vessel types. For the 16k TEU container vessel, a 92-bore engine is used in seven-cylinder configuration, except for the LNG-fuelled X-DF engine, where an eighth cylinder is required to match the power demand. For the 210k DWT bulk carrier, a 72-bore engine is used in six-cylinder configuration.

Fuel cases

VLSFO
As a reference case to illustrate the 'business as usual' case, operating costs were modelled for a vessel running with main engine fuelled by very low sulphur oil (VLSFO) and auxiliary engines running on marine diesel oil (MDO) – the conventional configuration for today's fleet. The main engine modelled is WinGD's X-Engine.



LNG
Liquefied natural gas (LNG) is produced by liquefying gas extracted from oil and gas fields. It is already widely used due to its low air pollutants and significant reduction in carbon dioxide in exhaust gas. Including an LNG case – where both the main and auxiliary engines run on the fuel, with a small amount of MDO used as pilot fuel – highlights vessel emissions using the most deployed alternative fuel. The main engine modelled is WinGD's X-DF engine.

e-LNG
Synthetic methane is produced by combining green hydrogen, created from renewable electricity, with captured biogenic carbon. Also known as e-LNG, this fuel can be used in LNG-fuelled engines without modification. In our e-LNG case, both the main engine and the auxiliary engines run on the fuel, with a small amount of MDO used for pilot fuel. The main engine modelled is WinGD's X-DF engine.

Green methanol
Like e-LNG, green methanol uses green hydrogen and captured biogenic carbon as feedstocks, with the added advantage of being liquid at ambient temperatures and thus not requiring cryogenic storage. In our green methanol case, while the main engine uses the fuel, the auxiliary engines run on MDO. This is representative of current methanol vessel configurations. The main engine modelled is WinGD's X-DF-M/E engine.

Green ammonia
With no carbon molecule, ammonia can be made directly from green hydrogen and combined with nitrogen from the air under the Haber-Bosch process – as in Envision Energy's production described above. In our case, the main engine uses green ammonia while auxiliary engines use MDO. This reflects the configuration in the first ocean-going ammonia-fuelled vessels. The main engine modelled is WinGD's X-DF-A engine.

Operating profile

The operating profile for each vessel is the same for each case, and is calculated based on three engine loads representative of standard vessel operations:

- Slow (40% engine load)
- Eco (60%)
- Continuous Service Rating (CSR) (85%)

For each condition, two modes represent operations inside or out of NO_X Emission Control Areas. (ECA) This determines additional power and consumables demand for emissions abatement.

- In the LNG and e-LNG cases, the X-DF engines deploy exhaust gas recirculation – WinGD's technology is known as iCER – to optimise engine performance and reduce methane slip. There is no difference between ECA and non-ECA power demand.
- For VLSFO, methanol and ammonia engines, which use SCR to limit NO_X in ECA zones, the additional power demand does not apply during non-ECA operations.

Table 1. 16k TEU container vessel

OPERATING PROFILE

Speed profile	Power (engine load, %)	Power (kW)	Non-ECA (hours)	ECA* (hours)
CSR	85	34,000	900	300
Eco	60	24,000	2,100	300
Slow	40	16,000	2,100	300

Table 2. 210k DWT bulk carrier

OPERATING PROFILE

Speed profile	Power (engine load, %)	Power (kW)	Non-ECA (hours)	ECA* (hours)
CSR	85	11,900	900	300
Eco	60	8,400	2,100	300
Slow	40	5,600	2,100	300

* Although there is no ECA on the theoretical route, ECA operation has been included in modelling to provide a comprehensive operating profile including NO_X emissions abatement measures.

Table 3. 16k TEU container vessel

AUXILIARY POWER DEMAND, (kWe)

	VLSFO	LNG	e-LNG	Green methanol	Green ammonia
Hotel load	4,000	4,000	4,000	4,000	4,000
VCR	-	13	13	-	-
SCR (Tier III)	200	-	-	200	200
iCER	-	151	151	-	-
Total	**4,200**	**4,164**	**4,164**	**4,200**	**4,200**

Table 4. 210k DWT bulk carrier

AUXILIARY POWER DEMAND, (kWe)

	VLSFO	LNG	e-LNG	Green methanol	Green ammonia
Hotel load	700	700	700	700	700
VCR	-	6	6	-	-
SCR (Tier III)	70	-	-	70	70
iCER	-	58	58	-	-
Total	**770**	**764**	**764**	**770**	**770**

Auxiliary engine demand

To calculate demand from auxiliary engines, power needed for both emissions abatement and hotel load is considered.

Emissions abatement power demand is derived based on the operating parameters above, depending on the engine load and whether the vessel is inside or outside of an ECA.

The hotel loads attributed to the bulk carrier and container vessel are different, with the container vessel's significantly higher, primarily to power reefer containers.

In all cases except for LNG and e-LNG, auxiliary engines use marine gas oil (MGO). This reflects current technology availability and marks a potential area of improvement for further reducing emissions from ships with main engines powered by green fuels.

VCR Variable Compression Ratio technology.

SCR Selective Catalytic Reduction.

iCER intelligent Control by Exhaust Recycling.

Fuel and consumables

The fuel consumption by mass presented below considers the fuel needed to meet the power demand specified by each operating profile, as well the performance of the respective main and auxiliary engines.

Fuel prices reflect WinGD and Envision Energy's best understanding of current costs as this paper was produced. In particular, the green ammonia price per tonne of US$710 reflects the bunker price of fuel currently being produced by Envision Energy, with bunkering on the coast of China.

Other consumables – urea, caustic soda and coagulant – are related to the use of either SCR or iCER systems.

In each vessel case VLSFO, under current pricing and regulatory regimes governing non-European Union voyages, is the most cost-effective fuel. Using e-LNG would be around five times as expensive, green methanol about four times, and Envision Energy's green ammonia just under three times the price. At current prices, the LNG case operates at a slight premium to the VLSFO case.

Table 5. Fuel and consumables

	US$/TONNE	US$/GJ
VLSFO	460.0	11
MGO	675.0	16
LNG	710.0	15
E-LNG	3,000.0	63
Green methanol	1,100.0	55
Green ammonia	710.0	38
NaOH	600.0	–
Urea	420.0	–
Coagulant	420.0	–

What happens when green ammonia reaches price parity with grey ammonia , as anticipated by Envision in a few years? Taking the 16k TEU container vessel case, if today's green ammonia price of US$710 were substituted with US$405.6 – the monthly average cost and freight price for a tonne of grey ammonia in East Asia in September 2025, according to Platts – then green ammonia-fuelled vessel OPEX for using green ammonia would be around US$22 million a year; less than twice the cost of using VLSFO.

Table 6. 16k TEU container vessel

FUEL AND CONSUMABLES CONSUMPTION (TONNES PER YEAR)

	VLSFO	LNG	e-LNG	Green methanol	Green ammonia
VLSFO	21,017	-	-	-	-
MGO	4,045	229	229	5,991	6,076
LNG	-	21,459	-	-	-
E-LNG	-	-	21,459	-	-
Green methanol	-	-	-	40,112	-
Green ammonia	-	-	-	-	43,629
NaOH	-	13	13	-	-
Urea	477	-	-	477	477
Coagulant	-	0.25	0.25	-	-

Table 7. 16k TEU container vessel

FUEL AND CONSUMABLES CONSUMPTION (US$ PER YEAR)

	VLSFO	LNG	e-LNG	Green methanol	Green ammonia
VLSFO	9,668,000	-	-	-	-
MGO	2,730,000	154,000	154,000	4,044,000	4,102,000
LNG	-	15,236,000	-	-	-
E-LNG	-	-	64,376,000	-	-
Green methanol	-	-	-	44,123,000	-
Green ammonia	-	-	-	-	30,977,000
NaOH	-	8,000	8,000	-	-
Urea	200,000	-	-	200,000	200,000
Coagulant	-	105	105	-	-
Total	**12,598,000**	**15,398,105**	**64,538,105**	**48,367,000**	**35,279,000**

Table 8. 210k DWT bulk carrier

FUEL AND CONSUMABLES CONSUMPTION (TONNES PER YEAR)

	VLSFO	LNG	e-LNG	Green methanol	Green ammonia
VLSFO	6,911	-	-	1,206	1,206
MGO	1,339	70	70	227	227
LNG	-	7,104	-	-	-
E-LNG	-	-	7,104	-	-
Green methanol	-	-	-	14,352	-
Green ammonia	-	-	-	-	15,685
NaOH	-	4	4	-	-
Urea	167	-	-	167	167
Coagulant	-	0.1	0.1	-	-

Table 9. 210k DWT bulk carrier

FUEL AND CONSUMABLES CONSUMPTION (US$ PER YEAR)

	VLSFO	LNG	e-LNG	Green methanol	Green ammonia
VLSFO	3,179,000	-	-	555,000	555,000
MGO	904,000	47,000	47,000	154,000	154,000
LNG	-	5,044,000	-	-	-
E-LNG	-	-	21,311,000	-	-
Green methanol	-	-	-	15,788,000	-
Green ammonia	-	-	-	-	11,136,000
NaOH	-	3,000	3,000	-	-
Urea	70,000	-	-	70,000	70,000
Coagulant	-	40	40	-	-
Total	**4,153,000**	**5,094,040**	**21,312,040**	**16,567,000**	**11,924,000**

Policy push

Incentivising green ship fuel uptake

Even with the anticipated steep reduction in the price of green fuels, some incentive will be needed to accelerate any transition away from conventional fuels.

In the European Union, this is achieved by the EU Emissions Trading System, pricing CO_2eq emissions, and the ratcheting energy intensity limits of FuelEU Maritime. Our sample route from China to Australia would not expose the vessel cases to these schemes – although both countries are understood to be considering the inclusion of shipping in emissions trading systems at a later stage.

For the global shipping market, the IMO has proposed but not yet adopted the Net Zero Framework, following a decision to postpone a vote on adoption until October 2026. The current draft includes a direct and base compliance target for the annual greenhouse gas fuel intensity (GFI) of a vessel, measured in gCO_2eq/MJ. The targets decline each year between 2028 and 2035 – now at least 2029 to 2036 after the delay – after which a continual trajectory will be established to 2050, by or around which time IMO's ambition is for net-zero emissions from shipping.

Vessels that exceed the direct compliance target will pay remedial units of US$100 for every excessive tonne of CO_2eq emissions, unless they further exceed the higher base compliance threshold, after which they will pay US$380 per tonne. Vessels that comply with the direct compliance target can collect surplus units, sellable to vessels that have failed to meet the base compliance target.

A reward for using zero- or near-zero emissions (ZNZ) fuels and energy sources has also been proposed. Fuels or energy sources need to emit less than 19 gCO_2eq/MJ on a well-to-wake basis initially to qualify. But no structure or value has been attached to the reward at this stage.

Is the IMO surplus/remedy scheme enough in its own right to give users of e-fuels a financial incentive? The vessel cases studied would indicate otherwise.

Tables 10 and 11 show the emissions and GFI of each vessel case across the five fuel options. For the green ammonia case, actual lifecycle emissions factors have been used based on analysis conducted for green ammonia produced in Chifeng. For the e-LNG and green methanol cases, representative emissions factors have been used to reflect a generic green fuel supply.

Here the environmental benefits of green fuels become obvious, with e-LNG and green methanol and ammonia all showing significantly lower well-to-wake (WtW) emissions than the VLSFO fuelled vessel or the LNG-fuelled case.

Both the fuels made using recycled carbon, e-LNG and green methanol, show big negative well-to-tank (WtT) emissions thanks to their use of captured carbon – even though tank-to-wake (TtW) emissions are only just below that of VLSFO. Meanwhile green ammonia's significantly lower TtW emissions, due to the absence of carbon dioxide and methane from its exhaust, more than offsets emissions involved in its production process, if any.

Table 10. 16k TEU container vessel

TOTAL CO_2eq EMISSIONS PER YEAR AND GHG FUEL INTENSITY

	VLSFO	LNG	e-LNG	Green methanol	Green ammonia
Well-to-Tank (tonnes CO_2eq)	17,605	19,228	-50,306	-46,635	5,989
Tank-to-Wake (tonnes CO_2eq)	79,647	65,944	65,944	76,625	19,779
Well-to-Wake (tonnes CO_2eq)	97,251	85,172	15,637	29,990	25,768
GHG Fuel Intensity (gCO_2eq/MJ)	93.6	81.9	15.0	28.5	24.1

Table 11. 210k DWT bulk carrier

TOTAL CO_2eq EMISSIONS PER YEAR AND GHG FUEL INTENSITY

	VLSFO	LNG	e-LNG	Green methanol	Green ammonia
Well-to-Tank (tonnes CO_2eq)	5,796	6,361	-16,658	-17,299	1,509
Tank-to-Wake (tonnes CO_2eq)	26,220	21,794	21,794	24,996	4,557
Well-to-Wake (tonnes CO_2eq)	32,016	28,155	5,136	7,697	6,066
GHG Fuel Intensity (gCO_2eq/MJ)	93.6	81.9	14.9	22.3	17.3

The GHG Fuel Intensity result in our cases is slightly skewed in favour of e-LNG, as this is the only vessel that can use its green fuel in both main and auxiliary engines. As mentioned above, this is because there is not well-established performance data for methanol- and ammonia-fuelled auxiliary engines, although concepts are being deployed. As a result the e-LNG fuelled vessel has a favourable GFI compared to those whose main engines are operating on green methanol and green ammonia.

Comparing the LNG-fuelled and VLSFO cases, the lower TtW emissions of LNG outweigh its more energy intensive production and distribution to deliver a CO_2eq saving of over 10%, and a corresponding reduction in GFI. Fossil LNG remains significantly above its green cousins, at just over four times the GFI of e-LNG.

IMO penalties

The lower GFI of e-fuels is reflected in penalties accrued under IMO's Net Zero Framework, should it come into effect. For the first eight years of the framework at least, vessels fuelled with any of the three e-fuels are not penalised, with emissions remaining below the direct compliance threshold for the duration of the period.

As a result, an e-fuelled 16k TEU container vessel avoids remedial unit requirements of around US$57 million for a VLSFO fuelled ship across the entire period, while the 210k DWT bulker avoids US$18.6 million in penalties.

Table 12. 16k TEU container vessel

IMO PENALTIES (US$), 2029-2036

	VLSFO	LNG
2029	2,851,000	464,000
2030	3,588,000	658,000
2031	4,324,000	852,000
2032	5,944,000	1,328,000
2033	7,565,000	2,950,000
2034	9,185,000	4,572,000
2035	10,805,000	6,194,000
2036	12,425,000	7,816,000
Total	**56,687,000**	**24,834,000**

Table 13. 210k DWT bulk carrier

IMO PENALTIES (US$), 2029-2036

	VLSFO	LNG
2029	935,000	153,000
2030	1,176,000	218,000
2031	1,418,000	282,000
2032	1,949,000	439,000
2033	2,480,000	976,000
2034	3,011,000	1,512,000
2035	3,543,000	2,049,000
2036	4,074,000	2,586,000
Total	**18,586,000**	**8,215,000**

IMO surpluses

These figures exclude revenue made from trading surpluses. The exact value of IMO surplus units will be dictated by the market, but we can assume that they will trade at a small discount to the Tier 2 remedial units (US$380 per tonnes of CO_2e emissions) that they will be bought to offset. Using a value of US$361, at 95% of the price of a remedial unit, all three e-fuels generate significant surpluses. Again it should be noted that the ability to use e-LNG in auxiliary engines brings a significant advantage.

Table 14. 16k TEU container vessel

IMO SURPLUS INCOME (US$)

	e-LNG	Green methanol	Green ammonia
2029	23,437,000	18,622,000	20,622,000
2030	22,737,000	17,912,000	19,900,000
2031	22,036,000	17,202,000	19,179,000
2032	20,495,000	15,640,000	17,592,000
2033	18,954,000	14,078,000	16,005,000
2034	17,414,000	12,516,000	14,417,000
2035	15,873,000	10,953,000	12,830,000
2036	14,332,000	9,391,000	11,243,000
Total	**155,278,000**	**116,314,000**	**131,788,000**

Table 15. 210k DWT bulk carrier

IMO SURPLUS INCOME (US$)

	e-LNG	Green methanol	Green ammonia
2029	7,766,000	6,863,000	7,619,000
2030	7,534,000	6,631,000	7,382,000
2031	7,302,000	6,399,000	7,146,000
2032	6,793,000	5,888,000	6,626,000
2033	6,283,000	5,377,000	6,106,000
2034	5,773,000	4,866,000	5,586,000
2035	5,263,000	4,355,000	5,066,000
2036	4,754,000	3,844,000	4,546,000
Total	**51,468,000**	**44,223,000**	**50,077,000**

* Surpluses were calculated using the Global Center for Maritime Decarbonisation's GFI calculator, available at https://gcformd.org/calculator/

An emerging reality?
Operating costs under a global framework

The inclusion of IMO surplus units has a significant impact on the net operating cost of green fuelled vessels, comprising fuel and consumables, IMO penalties and IMO surpluses.

The ammonia-fuelled bulk carrier vessel, with ammonia at US$710 a tonne, costs around US$6 million less than the VLSFO-fuelled vessel over the eight years. The ammonia-fuelled container vessel costs around US$7 million less than the similar VLSFO-fuelled vessel.

The reason for the growing appeal of LNG as a transitional, reduced carbon fuel – although by no means a ZNZ fuel – is apparent in this analysis. In both vessel cases, LNG offers a 5-6% OPEX saving on VLSFO-fuelled vessels over the eight years, thanks to reduced IMO penalties offsetting the current higher fuel price.

LNG is also competitive against green ammonia in the container vessel case, where the MDO-burning auxiliary engines of the ammonia-fuelled vessel push up GFI and therefore reduce the available surplus income. In the bulk carrier case, where auxiliary engine demand is lower, green ammonia still has an advantage.

The vessel illustrations here show that the operating cost gap between green-fuelled vessels and conventionally fuelled vessels is closing.

Table 16. 16k TEU container vessel

CONSUMABLES COSTS AND IMO PENALTIES (US$), 2029-2036

	VLSFO	LNG	e-LNG	Green methanol	Green ammonia
2029	15,449,000	15,862,000	41,101,000	29,745,000	14,657,000
2030	16,186,000	16,056,000	41,801,000	30,455,000	15,379,000
2031	16,922,000	16,250,000	42,502,000	31,165,000	16,100,000
2032	18,542,000	16,726,000	44,043,000	32,727,000	17,687,000
2033	20,163,000	18,348,000	45,584,000	34,289,000	19,274,000
2034	21,783,000	19,970,000	47,125,000	35,851,000	20,862,000
2035	23,403,000	21,592,000	48,666,000	37,414,000	22,449,000
2036	25,023,000	23,214,000	50,206,000	38,976,000	24,036,000
Total	**157,471,000**	**148,018,000**	**361,028,000**	**270,622,000**	**150,444,000**

Table 17. 210k DWT bulk carrier

CONSUMABLES COSTS AND IMO PENALTIES (US$), 2029-2036

	VLSFO	LNG	e-LNG	Green methanol	Green ammonia
2029	5,088,000	5,247,000	13,546,000	9,704,000	4,305,000
2030	5,329,000	5,312,000	13,778,000	9,936,000	4,542,000
2031	5,571,000	5,376,000	14,010,000	10,168,000	4,778,000
2032	6,102,000	5,533,000	14,519,000	10,679,000	5,298,000
2033	6,633,000	6,070,000	15,029,000	11,190,000	5,818,000
2034	7,164,000	6,607,000	15,539,000	11,701,000	6,338,000
2035	7,696,000	7,143,000	16,049,000	12,212,000	6,858,000
2036	8,227,000	7,680,000	16,559,000	12,723,000	7,378,000
Total	**51,810,000**	**48,968,000**	**119,029,000**	**88,313,000**	**45,315,000**

Modelling the future

Clean fuel OPEX from 2029 to 2050

Looking beyond the eight-year horizon of the initial phase of IMO's Net Zero Framework, it is useful to envision how penalties, surpluses and net operating costs would evolve as 2050 approaches.

By or around that time, IMO aims to reach net-zero emissions from international shipping. Considering these costs across the 21 years from 2029 to 2050 also more clearly illustrates operating expenses for (roughly) the lifecycle of a vessel.

To extend the illustrations beyond 2036, a trajectory for emissions reduction targets is plotted to reach net-zero by 2050. The trajectory also meets IMO's intended 2040 milestone of reducing emissions by 70-80%. The penalty and surplus scheme are assumed to remain as drafted in the first stage of the regulation.

Across the 21 years to 2050, the cost advantage of clean fuels – and particularly green ammonia – under a carbon pricing regime becomes even more apparent. While in the first phase of its life, 2029-2036, a green ammonia-fuelled container vessel would cost slightly more to operate than an LNG-fuelled vessel, by 2050 it would cost 3% less. For a bulk carrier, green ammonia outperforms LNG on a cost basis even in the first phase – a result of the outsized impact of surplus-gathering against relatively smaller fuel costs.

Green methanol and e-LNG remain substantially more expensive than LNG or VLSFO across the full period, despite gaining value as carbon pricing increases. To reach net cost parity with LNG, the fuel price of green methanol would need to be around 30% lower, and for e-LNG a full 40% lower than the modelled prices.

For shipowners, a key investment consideration will be whether the OPEX savings offered by any alternative fuel offset the premium incurred on building a vessel for that fuel type. At current newbuild prices, this may be a marginal call. A green ammonia-fuelled vessel would reduce OPEX by around US$21 million compared to an LNG-fuelled ship, or by more than US$50 million compared to a VLSFO-fuelled vessel. An ammonia-fuelled bulker would reduce OPEX by US$18 million against LNG and US$28 million against VLSFO.

Table 18: 16k TEU container vessel

NET OPERATING COSTS (US$), 2029-2036

	VLSFO	LNG	e-LNG	Green methanol	Green ammonia
Fuel and consumables, annual	12,598,000	15,398,105	64,538,105	48,367,000	35,279,000
% difference vs LNG	**-18**	**0**	**319**	**214**	**129**
Net operating costs, 2029-2036	157,471,000	148,018,000	361,028,000	270,622,000	150,444,000
% difference vs LNG	**6**	**0**	**144**	**83**	**2**
Net operating costs, 2029-2036	576,743,000	551,667,000	897,310,000	731,568,000	527,993,000
% difference vs LNG	**5**	**0**	**63**	**33**	**-4**
Net operating costs, 2029-2050	734,214,000	699,685,000	1,258,338,000	1,002,190,000	678,437,000
% difference vs LNG	**5**	**0**	**80**	**43**	**-3**

Table 19: 210k DWT bulk carrier

NET OPERATING COSTS (US$), 2029-2036

	VLSFO	LNG	e-LNG	Green methanol	Green ammonia
Fuel and consumables, annual	4,153,000	5,094,040	21,312,040	16,567,000	11,924,000
% difference vs LNG	**-18**	**0**	**318**	**225**	**134**
Net operating costs, 2029-2036	51,810,000	48,968,000	119,029,000	88,313,000	45,315,000
% difference vs LNG	**6**	**0**	**143**	**80**	**-7**
Net operating costs, 2037-2050	189,415,000	182,500,000	296,166,000	240,222,000	168,198,000
% difference vs LNG	**4**	**0**	**62**	**32**	**-8**
Net operating costs, 2029-2050	241,225,000	231,468,000	415,195,000	328,535,000	213,513,000
% difference vs LNG	**4**	**0**	**79**	**42**	**-8**

Conclusion

Green fuels can be competitive in the near future

The use of PTO, green-fuelled auxiliary engines and indeed other fuel types will be considered in future modelling by WinGD.

While a vessel fuelled by green ammonia currently costs nearly three times as much to operate as a VLSFO-fuelled vessel, that premium will decrease rapidly if prices evolve as expected – and if an effective global carbon pricing regime is placed on maritime emissions.

Although shape of any future carbon regime remains under discussion, using the most recent drafting of the IMO Net Zero Framework illustrates the potential impact. With IMO penalties and surpluses considered a green ammonia-fuelled vessel, using fuel priced in line with Envision's existing production, would have lower net operating costs than a VLSFO-fuelled vessel in the short-term (2029-2036), and lower than an LNG-fuelled vessel over the long-term (2029-2050).

For e-LNG and green methanol, which currently cost significantly more to produce than green ammonia, further incentivisation is needed. This is particularly evident when comparing the cost competitiveness of fossil LNG; even under a regime that penalises emissions intensity, LNG remains a cost-effective solution compared to those fuels, despite its far lower emissions reduction potential.

Any regulatory scheme that aims to encourage maritime decarbonisation will need to establish a structure that incentivises green fuels without making lower carbon but still fossil-based alternatives more attractive. This report does not factor in a reward for using zero or near zero (ZNZ) emissions fuels, but it would clearly reduce the net cost of all green fuels. A significant reward would be needed for e-LNG and green methanol to compete with VLSFO, while any reward whatsoever would further incentivise green ammonia.

One key area where technology evolution would support lower costs is in auxiliary engines. Today, although methanol and ammonia-fuelled four-stroke engines are promoted, many of the ships being built for these fuels still deploy auxiliaries that run on MDO. With green fuels used in auxiliary engines, the emissions and carbon costs related to those vessels will be reduced significantly.

Another configuration that is already being considered by operators of green fuelled vessels is the use of power take-off (PTO) on the main engine to meet electric power demand. An appropriately sized shaft generator can cover most if not all the auxiliary loads envisioned in this study, meaning that more green fuel is substituted for MDO, at the higher efficiency of the main engine, further reducing carbon exposure. This would also have a notable CAPEX benefit.

The use of PTO, green-fuelled auxiliary engines and indeed other fuel types will be considered in future modelling by WinGD.

The aim of this study has been to show what can be achieved today and in the near future using green fuels. More can be achieved with a global policy framework that recognises the need for such decarbonisation options. Combined with expected fuel price evolution and technology advances, those incentives will make green ammonia highly competitive as a marine fuel in the coming years.

Committed to the decarbonisation of marine transportation through our ensemble of sustainable energy systems

WinGD designs marine power ecosystems utilising the most advanced technology in emissions reduction, fuel efficiency, digitalisation, service and support. With our two-stroke low-speed engines at the heart of the power equation, WinGD sets the industry standard for reliability, safety, efficiency and environmental design.

Headquartered in Winterthur, Switzerland, since our inception as the Sulzer Diesel engine business in 1893, we are is powering the transformation to a sustainable future.

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