LNG-Fuelled Fleets
REDUCING EMISSIONS

VCR retrofitting as a ready solution

WIN GD

Executive summary

With stricter emissions regulations imminent, shipowners face mounting pressure to decarbonise.

WinGD's Variable Compression Ratio (VCR) technology, already available in new X-DF2.0 engines, offers a cost-effective and future-ready solution to upgrade existing LNG dual-fuel engines.

Delivering up to 25% fuel savings and 33% lower methane slip depending on fuel and engine load, VCR retrofits extend the life and compliance of today's X-DF powered fleet – by increasing overall performance.

The decarbonisation challenge

A rising tide of emissions regulations - chief among them the IMO's Net Zero Framework (NZF), the EU's FuelEU Maritime Regulation, and the expansion of the EU ETS to shipping - is collectively reshaping the commercial and compliance outlook for shipowners.

Together these frameworks introduce escalating pressure to decarbonise by placing a price on carbon emissions, mandating the use of cleaner fuels and improved GHG intensity, and setting a long-term pathway toward full decarbonisation by 2050. As it has across its 125 years, WinGD continues to pioneer new technology solutions to meet the real-world needs of shipowners.

Variable Compression Ratio technology enhances the environmental and operational performance of our popular X-DF low-pressure dual-fuel engine series so that a simple retrofit helps owners using LNG as fuel save money, stay compliant and sail into the future with confidence.

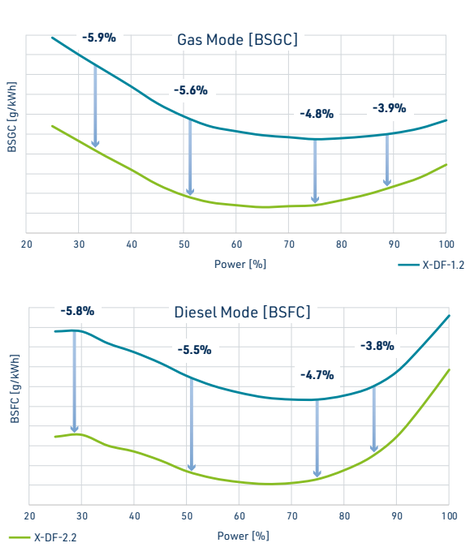
Engineering a response: the role of engine innovation

As the rules for shipping's net zero journey come into focus, and carbon pricing sharpens the financial incentives to invest in lower emission solutions, the industry is seeking practical solutions that can be implemented quickly and cost-effectively without compromising safety or reliability.

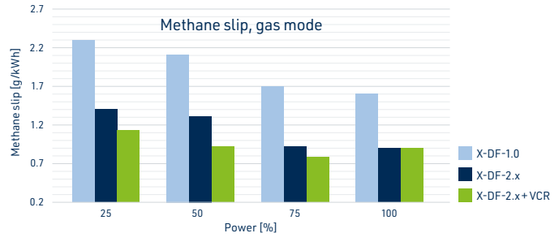
Given the remaining uncertainties—from new fuel availability to the still-emerging regulatory landscape, not to mention the significant costs of fleet decarbonisation—many owners are seeking to make incremental improvements that offer immediate emissions savings and quick payback on investment. Engine upgrades deliver on these aims, with engine manufacturers now set to play a key role in fleet decarbonisation.

WinGD's popular dual-fuel LNG X-DF engines have undergone continuous refinement since their launch in 2016, with two significant upgrades making a material impact on emissions performance: Intelligent Control by Exhaust Recycling (iCER) and Variable Compression Ratio (VCR) technology. iCER was launched in 2022 and has become an industry standard, boosting fuel consumption by approximately 8% in gas mode, 6% with diesel fuel, and delivering 50% less methane slip.

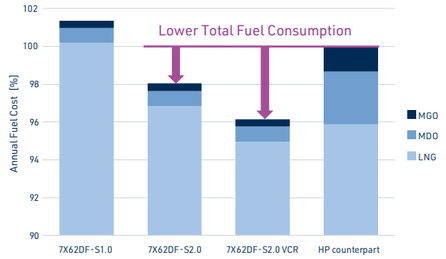
Variable Compression Ratio (VCR) technology was launched the following year and has quickly become a favoured option for new dual-fuel engines, with WinGD already receiving over 170 orders. While the order book is dominated by operators of LNG carriers, other market segments including pure car and truck carriers, bulk carriers and containerships are now turning to this technology to improve emissions compliance.



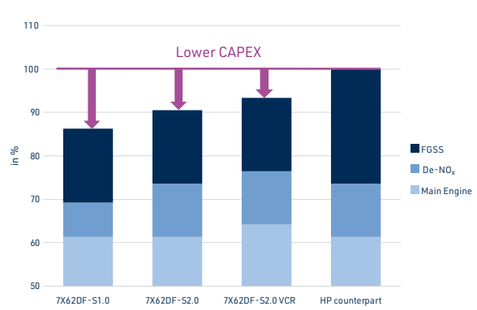
Fuel consumption improvements using iCER in gas and diesel modes



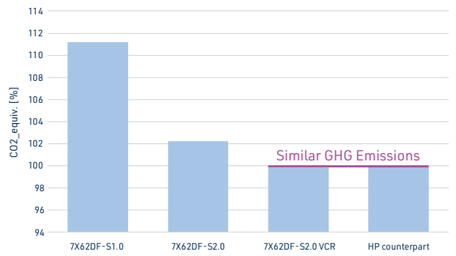
Methane slip emissions for X72DF type engines



Annual fuel costs, 7,000 CEU PCTC



Engine, fuel system and after treatment costs, 7,000 CEU PCTC



Annual total GHG emissions, 7,000 CEU PCTC

VCR technology dynamically adjusts the engine's compression ratio for fuel type, engine load and combustion behaviour, to deliver:

- **Fuel consumption savings of 5-25% in gas mode**
- **Fuel consumption savings of 7% in diesel mode**
- **Methane slip reduced by up to 33% at partial loads**
- **Future compatibility beyond LNG: 1-2% efficiency gain** for methanol/ammonia dual-fuel engines and complements energy efficiency measures such as air lubrication and wind assist systems.

By delivering industry-leading results when it comes to reduced fuel consumption, methane slip and emissions, VCR extends the window of compliance for existing and operationally sound assets. Across a fleet, these savings add up not only to a greener wake but also a material cost saving for owners and operators at a time when margins are under pressure.

VCR is also available for X-DF engines already in service. Successful retrofits deliver a quick payback on investment through reduced fuel costs, enhanced operational flexibility and extended compliance with emissions regulations.

Integrating a VCR retrofit into a scheduled dry-docking period converts maintenance downtime into a positive that will extend the operational lifespan of the vessel.

Enhancing the X-DF

WinGD's X-DF engines have been a popular choice for many shipowners, particularly those with LNG carriers or other LNG-fuelled applications.

When compared to competing high-pressure counterparts, the X-DF offers lower CAPEX, lower levels of air pollutant emissions ensuring Tier III NOx compliance without exhaust aftertreatment systems, and lower pilot fuel injection quantities.

Initial versions of the X-DF featured a design trade-off, with compression ratio limited to safeguard gas mode operation under worst-case conditions. This meant that diesel mode performance was also limited, as compression ratio has traditionally been a fixed design parameter.

The VCR system, however, eliminates this limitation—automatically optimising the compression ratio for actual operating conditions in both diesel and gas operating modes.

VCR technology delivers higher compression ratios when running on diesel, improving efficiency, while compression can also be tweaked during LNG use to optimise efficiency and reduce emissions.

This means X-DF engines can now perform as efficiently in diesel mode as a comparable diesel-only engine, providing the best of both worlds in terms of operational flexibility and emissions savings.

With close to 1,000 X-DF engines sold to date since launch in 2016, there is a large market for early adopters to improve their engine's performance, emissions and reliability by retrofitting VCR capability. VCR adds to engine lifespan by ensuring older models can reduce their carbon cost exposure, keeping engines profitable for longer.

Integrating a VCR retrofit into a scheduled dry-docking period converts maintenance downtime into a positive that will extend the operational lifespan of the vessel.

And with its network of experts and service partners, WinGD is well-placed to support retrofits, wherever and whenever needed to ensure ships are compliant with both existing and incoming regulations.

Retrofitting for results: Containerships Aurora

As French shipping line CMA CGM explored ways to reduce the carbon footprint of its current fleet, it partnered with WinGD for a pilot retrofit designed to prove the OPEX benefits, emission compliance and the performance of the VCR system.

The Containerships Aurora, a 1,400 TEU feeder container vessel with a WinGD 7RT-flex50DF engine sailing between the Baltic Sea and North Sea, was chosen for the pilot. Its combination of a controllable pitch propeller (CPP) and power take-off system allowed CMA CGM and WinGD to conduct a full exploration of the operational flexibility of VCR technology.

After six months of data collection prior to the conversion, the retrofit was planned for the ship's scheduled five-year dry dock, when it was due a major overhaul of all major machinery systems, as well as a repainting and installation of a new bulbous bow. The VCR system was installed during this work, with no extra time needed in dry dock.

Once the engine had been re-commissioned, safety tests complete and gas bunkering completed in Zeebrugge, the Containerships Aurora began commercial operations on time with a team of WinGD engineers onboard for tuning and optimisation during regular operations, which included a portion of low-load operation through the Kiel Canal and 75% load in the North Sea. These part-load operations at higher speed with a controllable pitch propeller result in lower engine torque, which allows the compression ratio to be increased to higher levels.

As a result, large gas consumption savings of 5% and 8.2% could be measured at 75% and 50% load respectively as a constant engine speed of 124 rpm. With power at 110 rpm, the VCR had a significant impact in low-load gas mode operation, with extreme savings of 24% at the 15% load point.

CMA CGM highlighted the ease of installing the system during dry dock and WinGD's onboard support in fine-tuning the system. This collaboration helped optimise energy efficiency, thereby reducing carbon emissions, achieving these improvements without affecting commercial operations.

Containerships Aurora, 1,400 TEU feeder container vessel

Containerships Aurora operating route (CMA CGM)

In diesel mode, the fuel savings were in line with predictions with more than 7% lower consumption compared to operation without the VCR system in use. These fuel and gas consumption savings were achieved while being fully compliant with NO_X emission limits.

The 3,000 hour field test on the Containerships Aurora was completed flawlessly with successful NO_X recertification, confirmed fuel savings in real operation, as well as fully validated component reliability. Meanwhile, the engine has accumulated more than 4,500 operating hours with VCR in use, and without a single failure on the system.

The VCR retrofit can be performed during a regular dry dock, with the engine then finetuned during completion operation at sea by WinGD experts and, once those experts leave, the system requires no interaction by the crew as it is fully integrated into the engine control system – where it requires no additional space or interface.

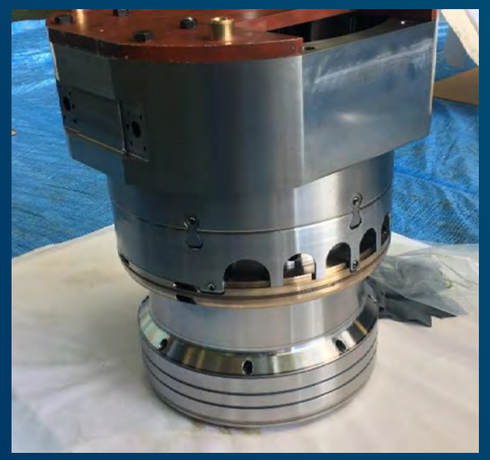
Given the significant fuel and gas savings over the load range, WinGD is confident that VCR technology offers a short payback on investment, both for newbuilds and retrofits.

How it works: inside the VCR system

The best marine engineering solutions tend to be simple, delivering real-world change through intelligent application of proven principles to deliver safe and reliable results that can be relied on to perform in the harshest conditions.

The VCR system involves simple hydraulic solution, involving a hydraulic piston, mounted on the lower end of the piston rod, which can vertically move into the crosshead pin. The amount of hydraulic oil in the lower chamber defines the piston rod position, which determines the compression ration based on inputs from sensors positioned in the piston underside space, which provide data on variables such as piston position, scavenge air temperature and O_2-concentration to determine the compression ratio and oil flow amounts.

The system has been designed for lowest possible maintenance: the hydraulic mechanism fitted in the crosshead pin, for example, does not include any wear parts and is expected to remain in the engine without the need for maintenance for the engine lifetime.

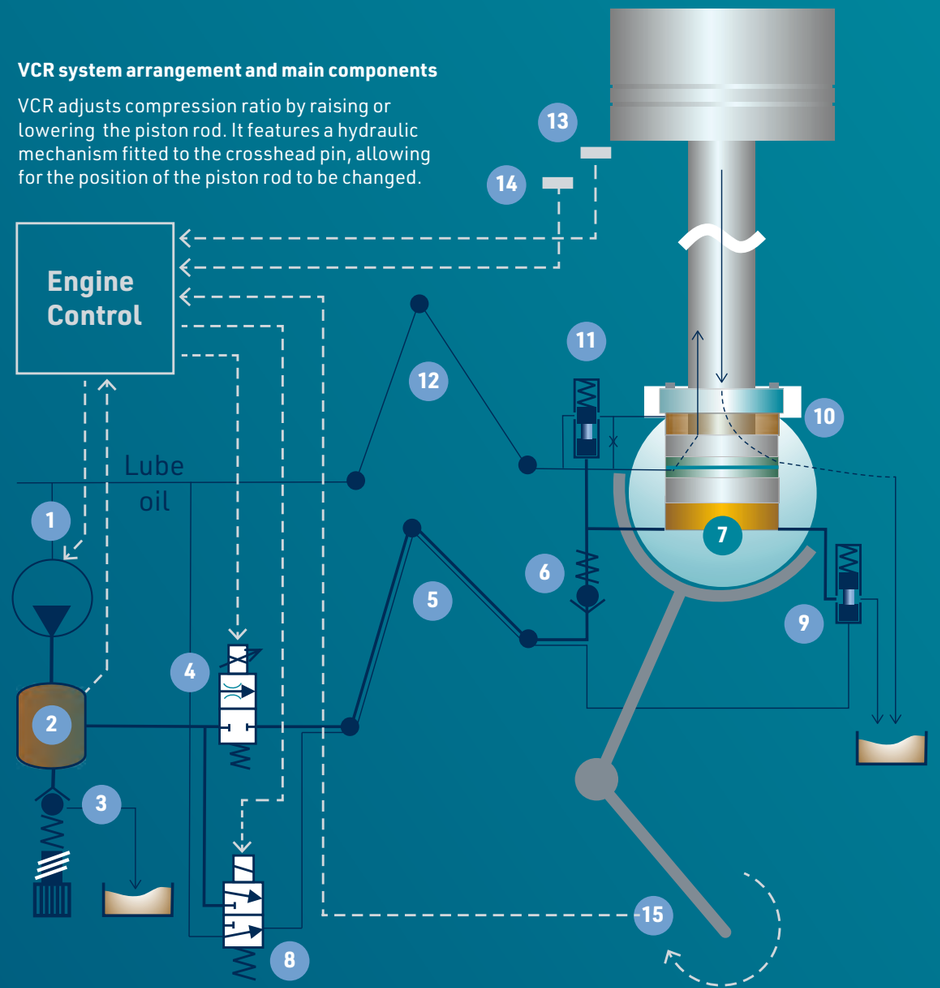


Hydraulic piston assembly

Installation of the crosshead pin

VCR system arrangement and main components

VCR adjusts compression ratio by raising or lowering the piston rod. It features a hydraulic mechanism fitted to the crosshead pin, allowing for the position of the piston rod to be changed.



1. **Feed pump**
   Electrically driven, it increases the engine lube oil pressure (4…5bar) to the feed pressure of 40…50bar. Variable motor speed to minimise power consumption.
2. **Feed manifold**
   Distributes the lube oil to all cylinders.
3. **Pressure control valve**
   Limits the pressure in the feed manifold.
4. **Solenoid proportional valve**
   (Inlet) Controls the flow of oil to the lower chamber of each cylinder.
5. **Knee lever of VCR**
   Connects the proportional valve with the lower hydraulic chamber.
6. **Delivery valve**
   Spring loaded non-return valve.
7. **Lower chamber**
   Lifts the piston rod depending on amount of oil in it.
8. **Solenoid relief valve**
   Controls opening and closing of outlet valve (9).
9. **Outlet valve**
   (Spring-loaded) Releases oil from the lower hydraulic chamber to lower the position of the piston rod.
10. **Upper chamber**
    Holds the piston down under any situation (e.g. engine start or malfunction of exhaust valve).
11. **Lift-off v/v with filling orifice**
    Retains oil volume in upper chamber in case of low oil pressure in lower chamber to avoid lift-off of piston.
12. **Knee lever for piston cooling**
    Existing knee lever for usual piston cooling.
13. **Sensor for piston position**
    Measures piston timing and enables control of piston rod position.
14. **Sensor for air temperature**
    In piston underside, measures scavenge air temperature close to the scavenging ports of each cylinder.
15. **Crank angle signal**
    Existing engine crank angle signal used also for the VCR control.

The VCR advantage: performance, savings, compliance

Even before the VCR step-change, the X-DF was a market leader for owners looking for a dual-fuel engine that offered lower CAPEX, emissions and maintenance requirements.

The introduction of VCR has now increased the attractiveness of this engine, improving fuel efficiency in all fuel modes, reducing GHG emissions and enhancing operational flexibility.

VCR engines are more adaptable to varying conditions, such as different load profiles, ambient conditions and the use of power take-out or other energy efficiency measures such as air lubrication or wind-assisted propulsion. While other engines usually operate off their design point, a VCR engine doesn't, as it continuously maximises performance for the given operating conditions.

Diesel mode operation

When operating in diesel mode, the compression ratio is increased to a similar level as on a comparable diesel engine. This leads to increased efficiency of the engine, delivering additional savings of 4.6% to 7%. Given that LNG-fuelled vessels may routinely operate on liquid fuels for some of their time, this is a significant advantage.

Gas mode operation

Unlike in diesel mode, the compression ratio in gas mode is not constant but varies according to engine load and other parameters.

When operating at full load the compression ratio is similar to a non-VCR engine but it's when the engine operates at part-load that the VCR kicks in, using the increased combustion margins to increase the compression ratio and maximise engine efficiency. This process further increases the amount of exhaust gas that can be recirculated. Taken together, the maximum EGR rate and compression ratio delivers the best engine efficiency.

Methane slip

Methane slip is a target of future emission taxation schemes, giving additional urgency to efforts to reduce the escape of unburned gas.

The X-DF was already an industry leader in methane slip levels for Otto-cycle combustion engines, with ongoing refinements of the design delivering significant reductions in methane slip: the introduction of iCER exhaust gas recirculation systems slashed methane slip by 40-50%, for example. VCR enhanced this impact because increasing the compression ratio in part-load operation allows higher exhaust recirculation rates while still maintaining combustion stability.

This combination of the two technologies, iCER and VCR, results in very low slip levels of around 0.9 g/kWh, which is less than 0.7% of total gas consumption across an IMO weighted average test cycle, beating by a significant measure the default factor of 1.7% set in the FuelEU Maritime or IMO regulations for low-pressure low-speed dual-fuel engines.

A complementary technology

VCR technology integrates with other efficiency measures, such as air lubrication that reduces hull resistance or wind assisted propulsion where high-tech sails generate additional propulsive force.

With the engine running at lower torque at a given power, the VCR automatically increases the compression ratio and thus enhances the part-load efficiency of the main engine. In turn, the vessel doesn't only benefit from a lower propulsion power need at a given speed, but also from the main engine running at higher efficiency.

Reduced fuel consumption

Optimised performance

Reduced emissions

X-DF VCR by WinGD

Dynamic control, system wide

Individually optimised compression ratio setting for both gas and diesel mode.

PTO power up

For vessels with power take-off systems, the engines typically operate away from the design point depending on whether the PTO is on or off. VCR automatically adjusts for this and uses any resulting margin to boost main engine efficiency, or it can increase available PTO power by reducing the compression ratio if necessary.

Future-ready

To date, the VCR has been used in LNG-fuelled applications but its use in methanol and ammonia dual-fuel engines is already under consideration. The savings are expected to be smaller than on LNG dual-fuel engines, at around 1-2% reduction in consumption, offering a rapid return on investment given the costs of operating on expensive green fuels. WinGD is already evaluating VCR on future iterations of its X-DF-M methanol and X-DF-A ammonia type engines.

Low maintenance by design

The VCR system has been designed for lowest possible additional maintenance, aligning with regular five-year drydock intervals.

Simple design

Existing users praise the simple hydraulic solution, which represents the first application of dynamic compression ratio adjustment in a marine engine.

No-fuss operation

Control of the VCR is fully integrated into the engine control system and does not require the crew to interact with it during operations. Its simple design allows for reliable operation, the VCR making its adjustments automatically.

Global Service by WinGD

Retrofit support

Staying ahead in a compliant future – with VCR, WinGD offers a proven, low-risk upgrade that reduces fuel costs, extends engine life, and futureproofs compliance with emerging regulations. Whether as part of a newbuild or retrofit, it represents a practical step toward net zero without compromise.

As regulatory deadlines for emissions performance approach, shipowners could face a scrabble for capacity to address their fleet's carbon footprint.

By moving early to retrofit existing X-DF to be VCR-enabled, owners can secure the drydock slot and support to be sure their engines are fully compliant ahead of time. And with Global Service by WinGD, the new lifecycle support model launched in 2025, owners can tap into a global network of spare parts, experts and customised insights wherever they are in the world to steam ahead with confidence.

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 powering the transformation to a sustainable future.

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