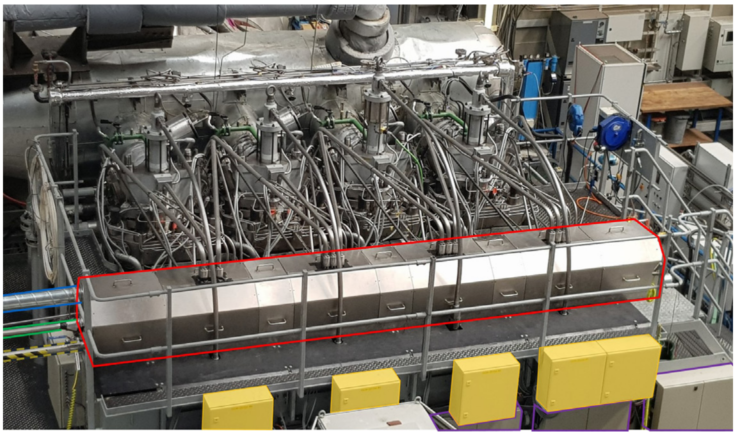
# Flexible Injector to Advance Alternative Fuels Research

2020

As shipping looks to eliminate carbon emissions from fuel, a whole new range of energy sources - both liquids and gases - are emerging as potential candidates.



Installation on RTX-6 Test Engine

WinGD has developed a flexible injection system that will allow it to investigate liquid fuels with the potential to reduce shipping's emissions. The system will also help the engine designer to develop new injection concepts allowing its two-stroke engines to burn emerging clean liquid fuels produced from biomass or renewable electricity.

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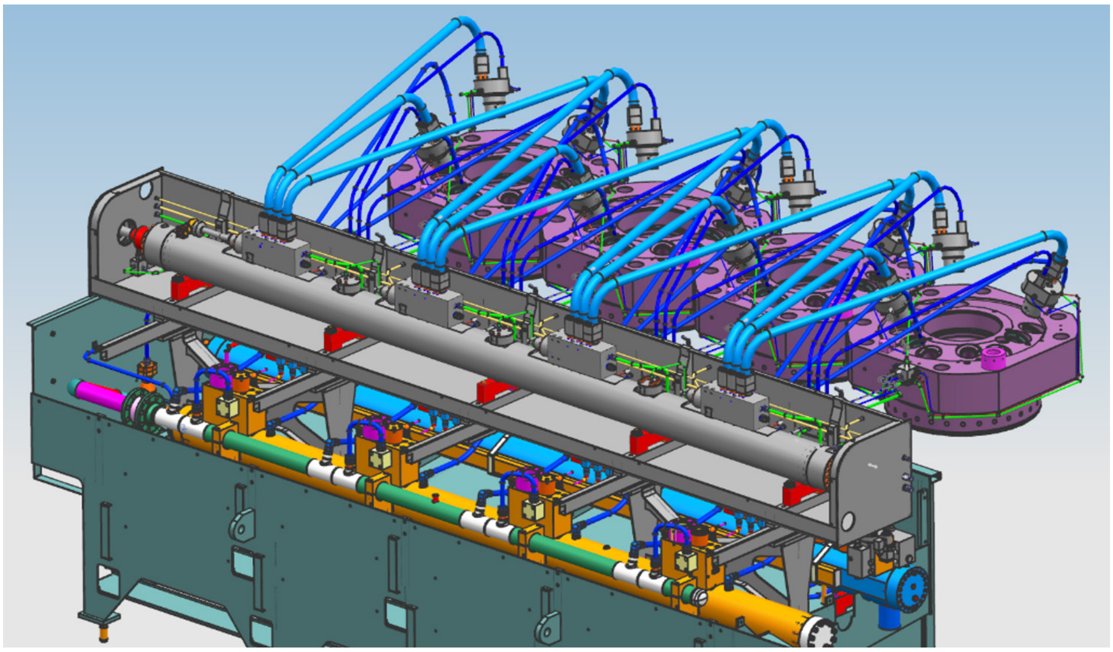
## Background

In April 2018, IMO agreed to an initial greenhouse gas reduction strategy that includes the target to at least halve total emissions from shipping by 2050, as well as reduce emissions per tonne-mile by at least 70%. Such a step will be impossible without the introduction of low, zero or net zero-carbon fuels.

For the first time, IMO's ambition brings a definite timeframe to the decarbonisation of shipping.

Long before then, a European consortium of engine designers and technology suppliers were already exploring how to prepare marine engines for low-carbon fuels. The long-running HERCULES series of projects, conceived in 2002, looked at advancing the performance of large marine engines. The last stage of the initiative, HERCULES 2 (2016-2018), targeted technology developments towards a fuel flexible engine capable of burning multiple environmentally sustainable fuels. Under one HERCULES 2 work package, WinGD led the design of a fuel flexible injector system that would allow new liquid fuels to be assessed.



CAD design of fuel flexible injector on RTX-6

## Why liquid fuels?

There has already been a lot of research into the use of gas fuels to improve the environmental performance of ship engines, which has resulted in the commercial introduction of gas-fuelled marine engines over the past decade. WinGD's own experience with liquefied natural gas (LNG) is a good example. LNG as fuel, used in WinGD's dual-fuel X-DF engines, almost eliminates sulphur and particulate matter emissions as well as cuts NOx (to within IMO Tier III limits without aftertreatment) and reduces GHG emissions.

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The company's first X-DF engines entered service in 2016. Since then, about 50 engines have followed and the company has gained more than 330,000 hours' field experience on those engines.

Research into low-carbon liquid fuels is a different matter. There are relatively few examples of commercial marine engines burning these fuels today. But many of shipping's potential future fuels are liquid. Alcohol fuels such as methanol and ethanol, for example, have potential. Although these fuels are expensive and relatively scarce today, they can be produced with biomass or using renewable energy and offer environmental advantages. If these fuels are made using captured carbon (either through biomass or through carbon capture and storage systems), they would offer net-zero GHG emissions

WinGD Team Leader, Future Technologies, Andreas Schmid, explains: "For todays' shipping sector, alcohols are interesting only in very special cases as their availability and price do not make them competitive. Further, they represent a fuel type on the far end of a wide spectrum of possibilities. A fuel injection system which can inject everything from residual fuels to methanol would likely be able to cover most of the possible liquid fuel alternatives in the future."

Because of the wide diversity of characteristics among liquid fuels and the large number of different fuels to be investigated, a fuel flexible injector would be a useful tool for studying liquid fuels. It would allow researchers to test several candidate fuels using the same injection concept, rather than tailoring an injector to each individual fuel. Flexibility would also be valuable in a commercial engine, enabling ship operators to choose from the most viable low-carbon liquid fuel depending on price and availability, rather than investing in an engine that burns just one type of fuel that may not be widely available.

# Technology development

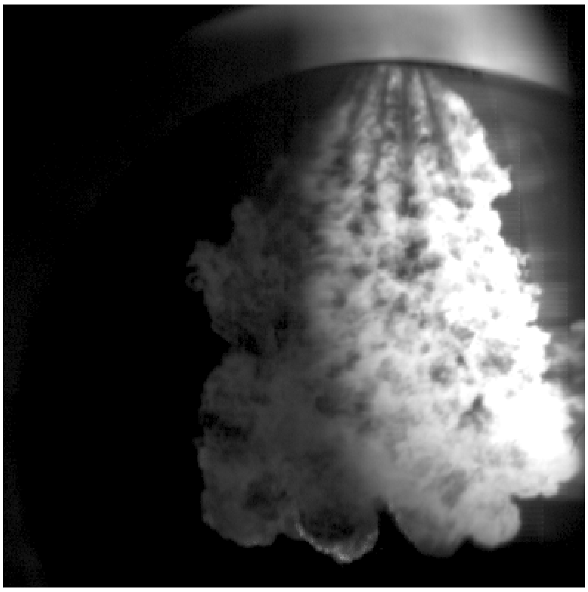
A fuel flexible injector is a considerable design challenge. The wide range of energy densities and viscosities of liquid fuels mean that different injection strategies are needed to begin combustion. Alcohols, for example, have half the energy density of traditional marine fuels. This means that injecting alcohols using conventional injectors would lead to long duration times in order to deliver the same amount of energy, directly affecting engine performance. Alcohols also lack the inherent lubricity of oil fuels, meaning that the long-term reliability of moving parts is a challenge. A new injection system would need to accommodate these widely varying capabilities.

To allow for fuels with different energy densities, the injector has a variable flow area. The needle has three positions:

- Closed: All orifices are closed by the needle;
- Medium lift: When traditional liquid fuels like HFO or marine diesel oil are to be used, the needle opens only the lower row of orifices;
- Full lift: Both rows of spray orifices are opened, increasing the injection rate and allowing the use of fuel with low energy density.

The mechanical layout of the injector components were adapted to cope with higher pressure peaks during opening and closing than those experienced when using classic fuels. Ethanol and methanol cannot be compressed as much as diesel and this leads to higher pressure peaks and therefore higher loads on components. In the first prototype, stainless steel was used to withstand the effects of alcohol fuel's chemical and fluid dynamic properties.

A prototype system was developed at WinGD and the injection concept was evaluated and its hydraulic performance tested on an injection rig. Spray morphology and combustion performance were assessed in WinGD's Spray Combustion Chamber (SCC), an experimental rig which allows the effect of various nozzle designs to be observed by taking optical, pressure and temperature measurements. Finally, WinGD's RTX-6 test engine was equipped with the new system and used to burn ethanol and diesel fuel as two representatives of a broad fuel spectrum.



Combustion

## Initial findings

WinGD's preliminary investigations revealed some interesting findings. On injection, methanol and ethanol are propogated into the combustion chamber faster than diesel, possibly due to their lower compressibility. On combustion, methanol and ethanol release heat faster and combustion chamber pressure peaks faster than diesel.

These observations and the different combustion characteristics of methanol and ethanol allowed WinGD to explore optimising combustion by adapting pilot fuel injection timing. The company observed that starting to inject ethanol just before the pilot fuel led to a more preferable combustion – with the highest pressure rise and shortest duration – than injecting diesel either before or much later than the ethanol. Those findings were used to input initial injection timings when the fuels were tested using the injector on WinGD's test engine.

Using the injector to test the fuels on the RTX-6 test engine allowed WinGD to measure fuel consumption and emissions. It was found the brake specific fuel consumption when operating the engine on ethanol was similar to that of diesel, once ethanol's lower heating value had been compensated for. At the same time, NOx emissions decreased slightly with ethanol due to the fuel's high vaporisation heat, which means that the charge air is cooled as the fuel evaporates. Due to the lower temperature at combustion, less NOx is formed.

Smoke emissions also decreased significantly with ethanol fuel. This is due to the oxygen within the ethanol molecule, which reduces the chance for rich zones (and therefore unburned fuel) and helps combustion of particulates, thus contributing to lower PM emissions. At the same time, the longer ignition delay of ethanol means that more of the fuel is evaporated and ready for combustion, further reducing the chances of fuel-rich zones.

The new injection system was proven to work reliably on the injection rig as well as in the SCC.

The RTX-6 research engine was run sucessfully on ethanol as well as diesel over the entire load range.

It was shown that switching from diesel to ethanol operation is possible at any engine load point.

# Future Steps

So far only one ethanol has been studied in an engine using the new injector. As WinGD continues to validate the new system, other possible fuel candidates will be considered. Once fully validated, the injection system will become an important addition to the company's toolbox for exploring low-carbon alternatives to help shipping meet IMO's ambitions.

The fuel flexible injector is just one element of WinGD's investigations into new liquid fuels. Among these is the EU-funded FALCON project to develop a carbon-neutral alternative to HFO from lignin, a wood component found in trees and plants. One of the objectives of the FALCON biorefinery project is the development, testing, standardisation and implementation of this low-sulphur, lignin-derived heavy fuel oil as a shipping fuel.

Promising gas fuels beyond LNG are also being examined. As one example, the company recently showed how volatile organic compounds (VOC) from oil cargoes can be burned in its dual-fuel engines. This will help shipowners – particularly those carrying crude oil – to reduce fuel bills while eliminating a big source of greenhouse gas emissions. The first VOC-capable X-DF engines will be deployed on a pair of shuttle tankers under construction for Teekay Corp at Samsung Heavy Industries.

The investigations into the fuel flexible injector have already highlighted potential benefits to ethanol fuel, including lower NOx formation and smoke emissions. Once other low-carbon liquid fuels are investigated further, WinGD will be well placed to identify which are most likely to help reduce shipping's emissions.

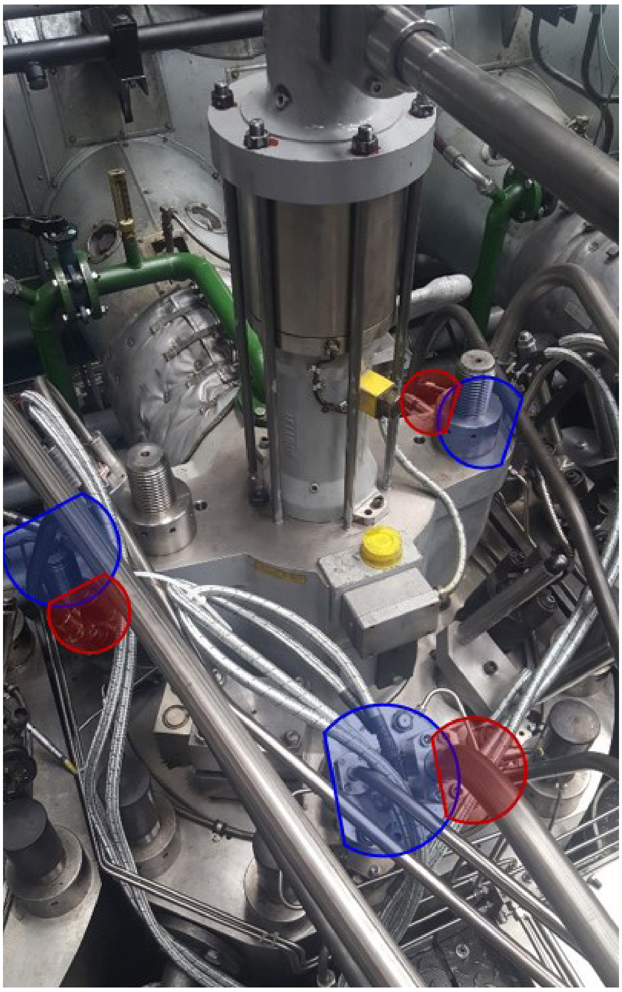
At that stage, the fuel flexible injector will be an important base from which to develop commercial injection concepts. So far, the experimental injection set-up has been optimised for research rather than for performance. For example, the system used for pilot fuel injection was not optimised in the tests. With a dedicated pilot injector and reduced diesel amounts, even better results might be possible. Further improvements will come when the type of fuels to be used can be narrowed down.

Andreas Schmid explains: "The fuel flexible injector is too general to be applied directly to a commercial engine. Once we know what fuels are likely to be used, we will be able to use this concept as a starting point to develop more tailored injection concepts. The injection system is the most challenging element of designing an engine for low-carbon fuels, so this experimental design will give us an important head start."

## Conclusion

The development of a fuel flexible injector represents a significant investment in the study of alternative fuels. The concept has been tested and validated using methanol and ethanol in experimental set-ups, and its use with ethanol in the RTX-6 test engine has already yielded interesting findings about alcohol fuels.

As the demand for decarbonisation in shipping becomes more urgent, ship operators will be faced with a wide range of alternative fuels promising to reduce emissions. Research into the fuel flexible injector, and the subsequent study of low-carbon liquid fuels, means WinGD will be well positioned to deploy the most promising of these fuels in its future engines.



Engine cover: blue areas indicate the position of the fuel flexible injectors, red incates the classic injectors

Acknowledgements

The fuel flexible injection system would not have been possible without the help and support of several partners.

Sincere thanks to:

- The European Union's HERCULES-2 project within the Horizon 2020 research and innovation programme.
- The Swiss Federal Government for their financial support during the INFLOSCOM project: SFOE Contract SI/501299-01, TP Nr. 8100075
- ETH Zürich
- PSI Villigen
- EMPA Dubendorf
- FHNW Brugg-Windisch
- IFPEN Paris
- NTUA Athens
- Chalmers University of Technology Gothenburg

The project has been presented in more detail in the following technical papers:

Schmid A., Bombach R. and Yildirim T., 2018. Experimental Analysis of Fuel Alternatives for Marine Propulsion Systems, 14th Triennial International Conference on Liquid Atomization and Spray Systems, Chicago, Il, USA.

Schmid A., Schmitz F., Yildirim T. and Yamada N., 2019. Fuel Flexible Injection System – How to Handle a Fuel Spectrum from Diesel-Like Fuels to Alcohols, CIMAC World Congress 2019, Vancouver, Canada.



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