GET READY FOR SUSTAINABLE FUELS WITH FLEXIBLE WÄRTSILÄ POWER PLANTS

In order to meet decarbonisation goals and limit the impacts of climate change, national power systems need to reach 100% renewable power generation in future. Renewables like solar and wind will be needed in vast amounts. To balance the intermittent nature of these renewable power sources, engine power plants and energy storage are ideal.

Wärtsilä power plants can already now run on carbon neutral fuels, and we will have solutions available for new sustainable fuels as those become available - both for new power plants and conversions of existing assets. Wärtsilä's continuous research on future fuels and engine technology will ensure reliable power generation with a wide range of sustainable fuels.

CONTENT

INTRODUCTION

The eyes of the world are on the greenhouse gas (GHG) emissions of the energy sector.

Global leaders expect power producers to deliver the lion's share of emissions cuts that are so vital for meeting national decarbonisation goals and limiting the impacts of climate change. According to the International Energy Agency's (IEA) 2050 roadmap, there is a viable pathway to a global net zero emissions energy sector by 2050 – but it's narrow and calls for a transformation in how energy is produced, transported, stored, and used globally.

It's also obvious that this change cannot happen overnight. Instead the transition is a stepwise process, where coal is replaced with cleaner fuels like natural gas and the share of carbon-neutral fuels in blends is increased as they become locally available. Not knowing which fuel will become predominant, or if there will be a variety of local sustainable fuels at hand in the future, investing in fuel flexibility brings certainty to an uncertain situation.

It's also very true that a power system cannot run on solar and wind power alone, due to their intermittent nature. Carbon-neutral fuels, gaseous and liquid, and perhaps even fossil fuels are needed for balancing purposes, especially in locations with power systems that are out of reach of the gas grid. Engine power plants can ramp up and down an unlimited number of times per day and reach full power in as little as two minutes, granting operational flexibility by short response times. Having sustainable fuels in storage will facilitate the long-duration backup that is needed to ensure a stable electricity supply.

In current discussions on decarbonisation, which often focus on CO_2 emissions, other emissions affecting local air quality tend to be put aside. However, it's important to consider and find a balance between both local and global emissions. Even the combustion of carbon-free fuels such as hydrogen or ammonia is not emission free and depending on how the emission limits are applied, exhaust after treatment for e.g. NOx reduction will be needed.

Dr. Reetta Kaila
Director, Sustainable
Fuels & Environment

The power plant solutions of today are future-proof investments, since the same engines will run on carbon-neutral sustainable fuels, either with tuning alone or through conversions.

These are the kind of issues that Wärtsilä deals with on a daily basis as we develop and deliver engine power plants with a unique combination of thermal efficiency, fuel flexibility and operational flexibility. We undertake continuous research on sustainable fuels produced from renewable energy, biomass and waste. We develop our engines in combination with emission aftertreatment systems to ensure that our power plants perform optimally with these new fuels and will play a role in decarbonising energy systems.

The power plant solutions of today are future-proof investments, since the same engines will run on carbon-neutral sustainable fuels, either with tuning alone or through conversions. For the transition phase, which we see happening through natural gas, the cleanest fossil fuel, we have developed our gas engines to operate with up to 25 vol% hydrogen blends. Future-proofing power generation assets and how our technology can use different fuels are crucial questions to our customers, which we aim to discuss in this paper. We understand it is difficult for our customers to commit to investments as there is no crystal-clear visibility into what the dominant future fuel will be. We want to demonstrate that our technology will be capable of adapting efficiently to any future fuel or their combinations.

THE TIME TO DECARBONISE IS NOW

The latest Intergovernmental Panel of Climate Change (IPCC) report from 2021 finds that unless there are immediate, rapid and large-scale reductions in greenhouse gas emissions, the opportunity to limit warming to close to 1.5 °C or even 2 °C will slip beyond our reach. It is paramount that we globally invest in decarbonisation of our optimised energy consumption, which has been fully embraced by energy leaders. The evolving regulatory landscapes need to push for viable sustainable investments that decarbonise the entire system.

Decarbonisation is feasible with current technologies – and does not cost more

Wärtsilä modelling* results show that the transition from fossil-based (e.g. coal) to 100% carbon-neutral electricity generation will not increase the cost of electricity in comparison to today.

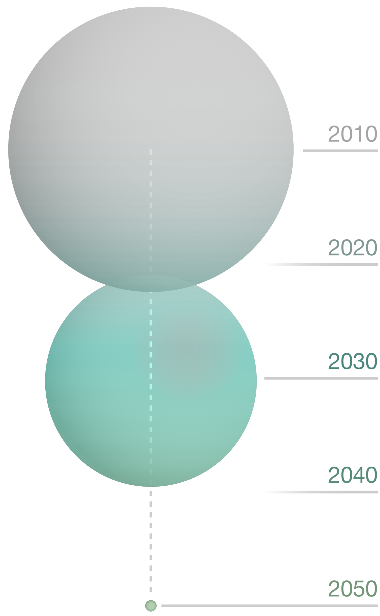
Currently, power generation is undergoing a rapid transformation towards cleaner energy sources due to huge additions of low-cost renewable electricity (wind and solar). To ensure a reliable and secure supply of electricity both short-term and long-term balancing is needed. The rapidly maturing battery storage technologies give great benefits short term. And there is a clear vision for the last piece of the decarbonisation puzzle: The Power-to-X-to-Power (P2X2P) concept, which enables long-term energy storage.

P2X2P turns excess and low-priced renewable electricity via electrolysis into hydrogen. This hydrogen is stored and converted back to electricity by balancing power plants when needed.

As wind and solar become the norm their intermittent character requires balancing thermal power to ensure adequate electricity during longer foreseen or sudden renewable "droughts" (no wind or sunshine). The running hours for thermal power plants will substantially decrease – long gone will be the days of only baseload operations. More dynamic operations are required overall. The positive effect is not limited to the total fuel consumption and costs to decrease but the GHG emissions reduction will be significant on system level.

It's important to use all available low-carbon fuels in the future energy mix to decarbonise the power generation sector and to gradually phase out the most carbon-intensive fuels by using natural gas as a bridge. Furthermore, biofuels and biogas can already be used to decarbonise thermal combustion – locally where available. By closing inflexible fossil assets and when flexible gas generation is converted to sustainable fuels the final push of decarbonisation of the energy generation is reached.

TO LIMIT GLOBAL WARMING TO 1.5 °C, GLOBAL CO_2 EMISSIONS SHOULD DECLINE BY 45% BY 2030 IN COMPARISON TO 2010 AND REACH NET ZERO BY 2050.



IN SIMPLIFIED TERMS, THE CAPITAL INVESTMENTS NEEDED IN NEW RENEWABLE ELECTRICITY GENERATION OUTPUT AND IN BALANCING POWER TO DEAL WITH RENEWABLE ELECTRICITY INTERMITTENCY ARE MORE THAN OFFSET BY THE SAVINGS IN FOSSIL FUEL USE.

* See the Front-loading Net Zero report

THE KEY STEPS TO FRONT-LOAD NET ZERO

Running hours of legacy power plants decrease.

Curtailment of RES increase due to system inflexibility.

Keep adding renewables supported by flexibility.

Utilise P2X and flexible thermal plants to provide carbon-neutral long-term storage.

1

ADD RENEWABLES
Build conditions that enable additions of renewable electricity sources as quickly as possible.

2

ADD THERMAL BALANCING AND STORAGE
Build conditions that enable investments in energy storage and thermal balancing power plants.

3

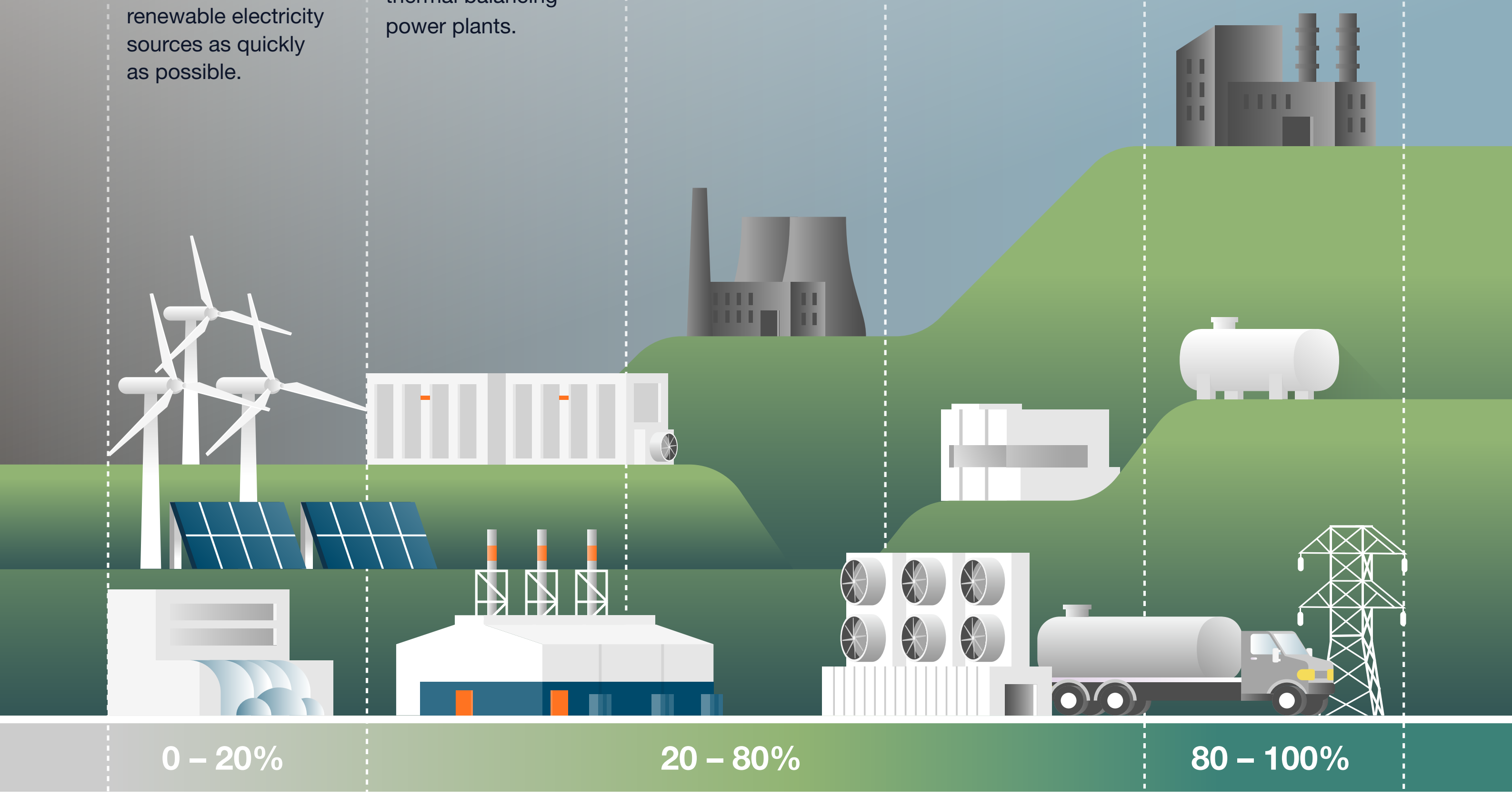
PHASE OUT INFLEXIBLE PLANTS
Once there is sufficient renewable output, battery storage and thermal balancing power plant capacity in the system, retire legacy inflexible plants, such as coal.

4

CONVERT TO SUSTAINABLE FUELS
Leaders must create the conditions to build new Power-to-X capacity for sustainable fuel production and convert thermal balancing power plants to run on that fuel.

5

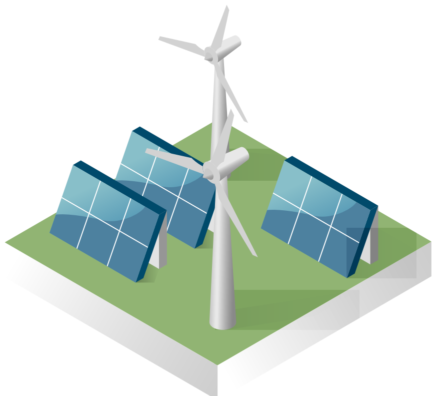
PHASE OUT FOSSIL FUELS
Phase out any remaining fossil fuel capacity.



SHARE OF RENEWABLE ENERGY SOURCES

THE MANY TYPES OF SUSTAINABLE FUEL

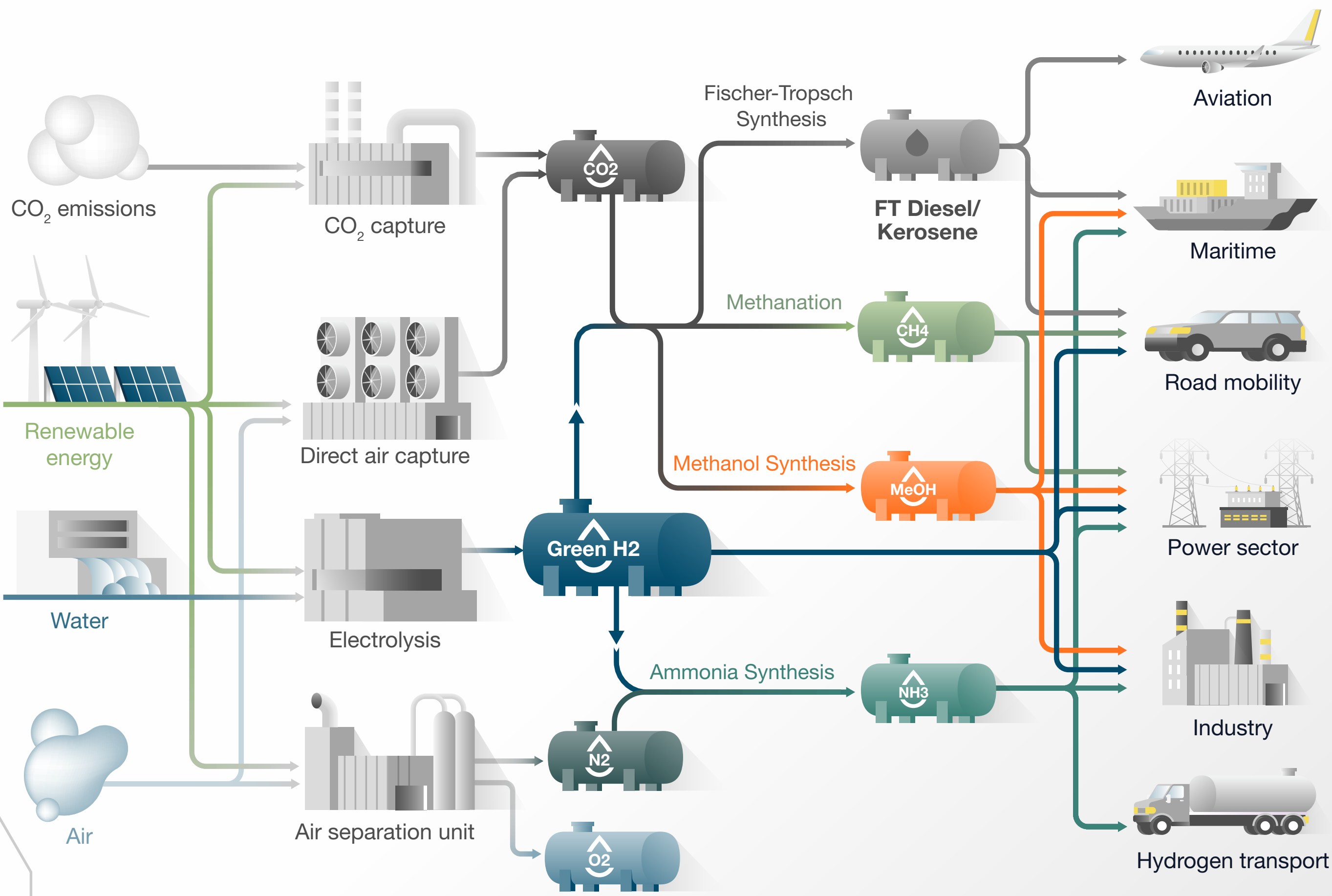
From hydrogen to biofuels to biogas made from waste, there is a wide array of different potential future fuels that can help to phase out fossil fuels in favour of renewable energy as part of the final push in decarbonising energy systems. These different types of sustainable fuels for future use can be broadly defined into three main categories based on source of energy.

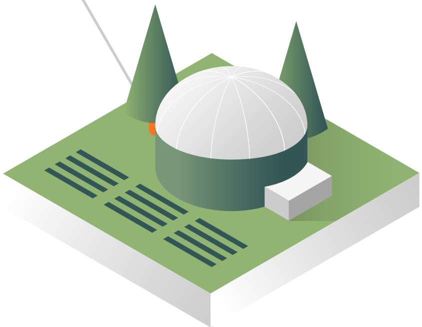


Power-to-X (P2X)

P2X (e-fuels) includes hydrogen (H_2) and its derivatives such as ammonia (NH_3), methanol (MeOH), methane (CH_4) and Fischer-Tropsch (FT) diesel/ kerosene. Green hydrogen is produced through electrolysis of water utilising renewable electricity. Hydrogen can then be further processed to its derivatives. Some of the hydrogen derivatives also need CO_2, which is provided by CO_2 capture, preferably from a biogenic origin. Each conversion step from hydrogen to other synthetic fuels adds energy losses to the value chain. With time there will be excess renewable electricity and thus costs will decrease, which will accelerate the production of P2X fuels.

SCHEMATIC OF P2X FUELS' PRODUCTION AND TYPICAL APPLICATION

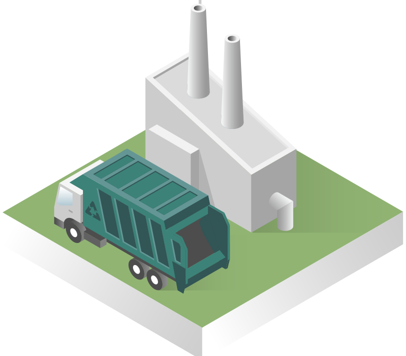




Bio-to-X (B2X)

B2X includes biofuels such as biomethane, -methanol or -ethanol, and liquid biofuels such as crude or hydrotreated vegetable oils (HVO) and fatty acid methyl ester (FAME). Biofuels are typically produced from agricultural and forestry side-products and residues or sustainable energy crops grown on “surplus land”, meaning land that is not used for the production of food, feed or fibres. If biomass is not utilised it will rot in nature or landfills and release methane, which will have a stronger greenhouse effect than the CO_2 emitted in combustion. Therefore these fuels are carbon neutral or even negative.

Biofuels are already commonly used as blends. The fuel volumes required for power plants are so large that there is seldom adequate amounts of biofuels therefore blending is foreseen to continue. The high transportation costs will push the biofuel production towards local solutions. Biomethane distribution, on the other hand, can widely benefit from existing gas grids which connect local smaller-scale production to large-scale consumers. Biomethane production also has the advantage of being able to utilise various watery sources such as, municipality waste, sewage and sludges. Decarbonising the existing gas grid is a smart and simple solution for decarbonising target of urban society – without conversion needs for existing assets. Furthermore, mixing biofuels into the conventional fuel supply does not need to wait for future development as the whole value chain and commercial industrial-scale fuel production is already in place and mature.



Waste-to-X (W2X)

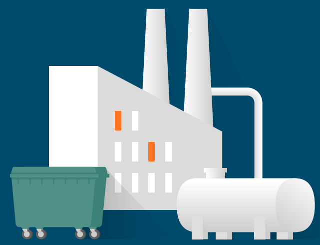
W2X fuels or recycled carbon free fuels include e.g. plastic or tyre pyrolysis oils or gasified municipality waste. Converting waste to fuels reduces or eliminates challenges in biodiversity, environmental and health issues of the waste fractions. For instance, pollution of rivers and oceans by plastic waste, uncontrolled fires and formation of malaria mosquito colonies in the tyre piles. These fuels support circular economy in societies and therefore they have value for sustainability and decarbonisation.

Sustainability and availability of future fuels

All fuels will emit greenhouse gases in their different processing stages including extraction, production, handling and transportation. These upstream emissions are related to, for example, how much energy is required in each step and whether this energy is from renewable sources. If the fuel contains carbon, its combustion will emit CO_2, whereas carbon-free fuels have no direct CO_2 emissions during combustion. As described above, it is not only about the exhaust when discussing global emissions; the whole value chain needs to be evaluated. If the production of fuel has captured CO_2 or prevented CH_4 leaks, the overall emissions of such fuels become carbon neutral or even negative.

The cost of transport and storage of a fuel will be an important factor of the total cost of the fuel and should be an integral part for power generation assets to consider. The cost and space requirements of fuel storage at a power plant will be determined by the volumetric energy density of the fuel and the storage conditions. All conventional fuels have high energy densities and heating values, which made them attractive initially for combustion. With sustainable fuels, and P2X fuels especially, the fuels need to be compressed or liquefied but even so more storage space needs to be reserved.

Although it seems that development today is focused on P2X fuels (hydrogen, ammonia and methanol), many alternative sustainable fuels such as bio/e-methane or liquid biofuels are promising and even more readily available for the energy sector. These fuels are similar in their chemical composition to fossil fuels and can therefore be used with current engine portfolios. These fuels can already today be used on their own or as blends with fossil fuels and are likely to play an important role in the coming 15 years before P2X fuels can be produced in the necessary volumes for the energy sector.



CASE

Power to synthetic methane

Wärtsilä and Vantaa Energy Ltd., a Finnish energy company, have signed an agreement on a joint concept feasibility study for a Power-to-Gas (P2G) facility at Vantaa Energy's waste-to-energy plant in the city of Vantaa.

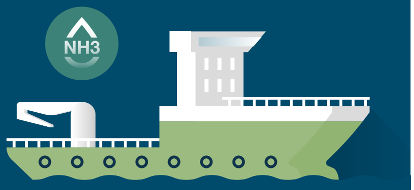
The P2G facility will produce carbon-neutral synthetic biogas using carbon dioxide emissions and electricity generated at the waste-to-energy plant. The purpose of the joint project is to demonstrate the first industrial scale P2G plant (in Finland), to build knowhow on operational integration of various new technologies (carbon capture, electrolysis and methanation) and to define boundary conditions for feasibility.

Execution is planned to start in 2023 and, when in operation in 2025-26, the plant should be producing approximately 80 GWh synthetic methane either injected into the gas grid or liquefied or compressed for road transportation use.

THE DIFFERENCES BETWEEN SUSTAINABLE FUELS

All future fuel options have advantages and disadvantages, as outlined in the following table:

Hydrogen	Bio/e-methane	Ammonia	Methanol	Bio/e-diesel
Chemical composition and specific features				
+ Carbon free – Explosive	+ Carbon neutral: pure methane + High Methane Number (MN 100)	+ Carbon free – Toxic and strong odour – Corrosive	+ Carbon neutral – Corrosive	+ Carbon neutral: biofuels (FAME, HVO) and synthetic Fischer-Tropsch (FT) diesel
Scale of production				
Large-scale production in piloting phase (electrolysers) driven by current industrial users of grey hydrogen	Biomethane production in industrial scale Synthetic methane production in scale-up phase, first pilots being developed especially for heavy transportation use	A green H_2-derivative and thus limited by H_2 availability	A green H_2-derivative and thus limited by H_2 availability	Commercial production from bio-oils or fats FAME produced with methanol HVO produced with hydrogen Development required to utilise green methanol and hydrogen FT diesel is produced from hydrogen and carbon monoxide (syngas)
Storage (volumetric energy density)				
Compressed or cryogenic storage Low energy density	Compressed or cryogenic storage High energy density	Liquid, easy to store Low energy density	Liquid, easy to store Low energy density	Liquid, easy to store High energy density
Infrastructure				
Plans on blending into current gas grid, however also plans to have pure hydrogen grid investments	Can utilise existing gas grid, grid maintenance required to minimise leakages	Can utilise existing infrastructure for global trade of grey ammonia (bulk chemical, fertilisers main use)	Can utilise existing infrastructure for global trade of grey methanol (bulk chemical, solvents main use)	Can utilise existing infrastructure for liquid fossil fuels
Transition phase				
Blends with natural gas	Ready to use	Blends with LFO	Blends with LFO	Ready to use
Internal combustion engine (ICE) power plants				
Blends up to 25 vol% available Conversion package needed for 100% H_2	Ready to use	Conversion package needed and requires pilot fuel	Conversion package needed and requires pilot fuel	Ready to use
Stack emissions from ICE plants				
Low NOx	Low NOx, CO2, CH4	High NOx, N2O, NH3	High NOx, CO2	High NOx, CO2
Regulatory aspects				
Under development Ensuring green electricity availability key	Existing rules and regulations for natural gas can be applied	Rules and regulations under development	Rules and regulations under development (transport sector)	Existing rules and regulations



CASE

Creating an engine that runs on ammonia

Wärtsilä and Norwegian ship owner Eidesvik Offshore ASA signed a cooperation agreement aimed at converting an offshore supply vessel to operate with an ammonia-fuelled combustion engine with required fuel supply, safety system and exhaust aftertreatment. This project will be the first of its kind in the world and is targeted for completion by the end of 2023.

The offshore supply vessel considered for a retrofit currently has Wärtsilä dual-fuel engines operating primarily with LNG fuel. The conversion will allow the vessel to operate with a 70% ammonia blend. The ultimate goal is to achieve operation with 100% ammonia and with a minimal ignition fuel requirement.

Emerging regulations and rules

Regulations and rules for sustainable fuels are being drafted and will play a central role in how quickly the production and utilisation of these fuels will ramp up. For example, in the EU the aim is to have regulations in place so that both the production and use of sustainable fuels can be viable technically and financially in a sustainable manner. Key legislation in the EU for hydrogen production will be the renewable energy directive (RED II and III), which targets high renewable fuel shares especially in the mobility sector.

While many of the details in the EU taxonomy and other regulations are still to be solved, the EU is clearly pushing for the decarbonisation of energy systems. The challenge is to cover the transition period in order to reach 2050 net zero scenarios in time. Many of the details – such as calculation methods and piloting/investment incentives – still need to be solved. This leaves some uncertainty on a national level over how power plant projects can be planned and financed. What is clear is that everybody agrees that decarbonisation is needed, and the regulation/financing rules will push for this change.

HYDROGEN IN POWER GENERATION?

At the moment, hydrogen is the most promising candidate of the P2X fuel for power plants. Hydrogen is carbon-free, has the highest production energy efficiency of the P2X fuels and with time it is predicted to become the most cost competitive due to low renewable electricity prices. Of course, there are several issues still to be tackled.

Important for green hydrogen production is access to renewable electricity and clean water. Locations with favourable conditions for these will become hydrogen production hubs.

For a sustainable power plant the access to the fuel will be crucial. Mode of fuel transport and distance will have a strong impact on costs and distribution emissions. Likewise, the storage volumes and capabilities need viable solutions. Hydrogen, being a gas, can be distributed via a gas grid which is the best option for both costs and distribution emissions. Hydrogen can be blended with natural gas. However, many industrial users (early adopters) prefer pure hydrogen, which pushes for dedicated hydrogen grids or on-site P2X production. One key concern with green hydrogen is how long it will take to build the needed infrastructure and ensure green hydrogen in adequate amounts.

THE MANY SHADES OF HYDROGEN

Hydrogen can be produced in many ways, each one labelled with different colours:

Green hydrogen is produced through electrolysis of water utilizing renewable electricity.

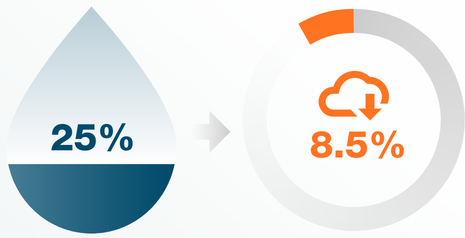
Pink hydrogen is otherwise the same, but the electricity used in the electrolysis is generated by nuclear power.

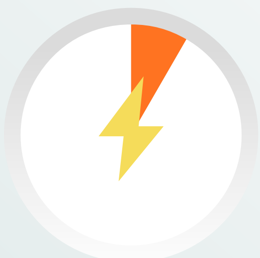
Blue hydrogen is produced by splitting fossil natural gas into hydrogen and CO_2 and then capturing and storing or utilising the CO_2.

Grey hydrogen is created in the same way as blue hydrogen, except the carbon dioxide is not captured but released into the atmosphere. This is how the majority of hydrogen is produced today.

COMBUSTION OF A 25 VOL% HYDROGEN/NATURAL GAS BLEND CORRESPONDS TO A GREENHOUSE GAS EMISSION REDUCTION OF

8.5%





A 10 MW ENGINE WILL RUN FOR APPROXIMATELY

ONE HOUR

WITH THE CAPACITY OF THE LARGEST HYDROGEN FUEL DELIVERY TRUCK AVAILABLE

ENSURING SAFETY WHEN USING HYDROGEN

While it's true that hydrogen use requires safety measures, it's worth remembering that any fuel does. Hydrogen molecules are very small and thus have a tendency to easily leak, but also dissolve into air. The explosive nature of concentrated hydrogen needs to be considered when designing hydrogen power plants. There is a safety-first approach when creating all power plant solutions, which for hydrogen engine solutions means:

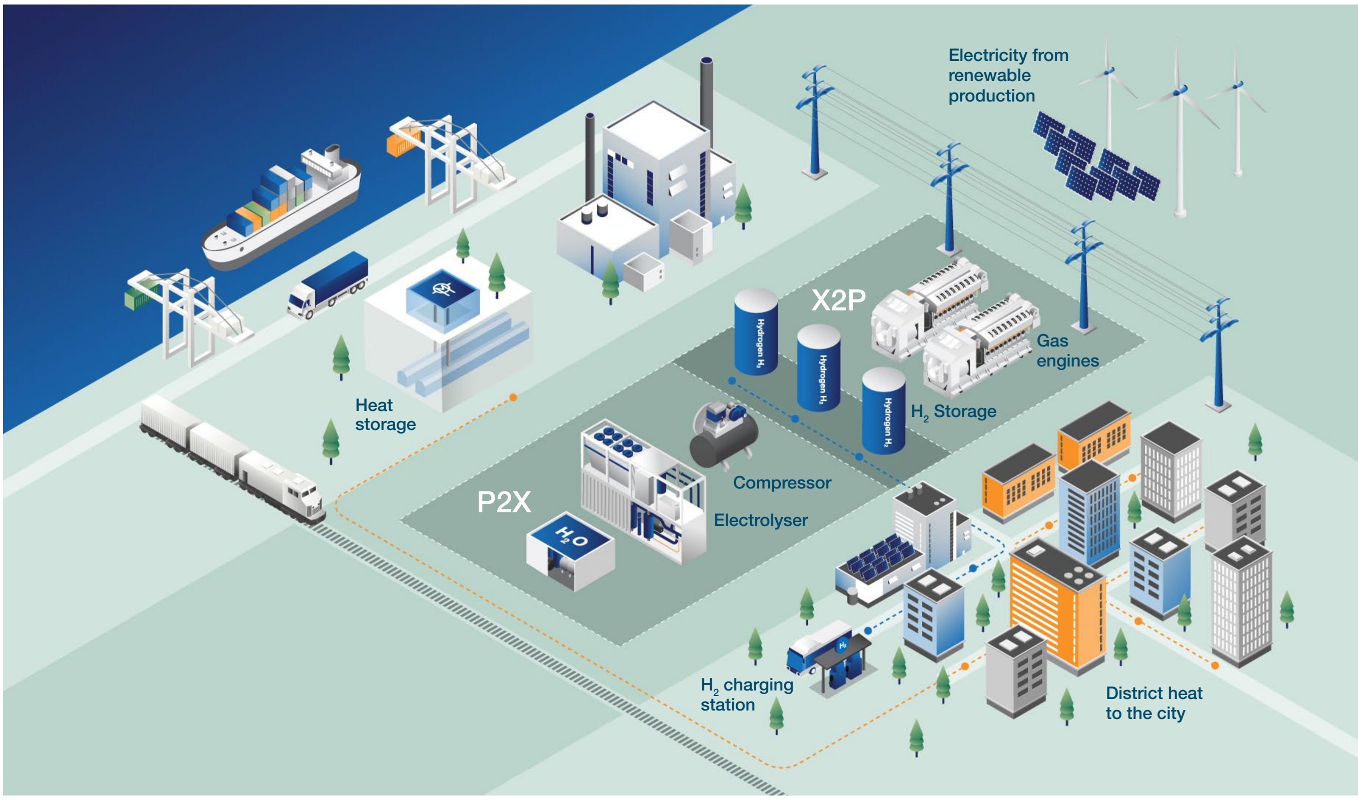
- **using welded pipes and double wall piping wherever possible**
- **utilising hydrogen sniffers at potential leakage points**
- **ensuring ventilation**
- **using inerting procedures for maintenance**

When it comes to which fuel will be used, availability and cost are of course important, but there are other parameters to consider such as footprint of production and storage, and operational safety. A natural gas blend with up to a maximum of 25 vol% hydrogen is still considered to be natural gas and thus rules and regulations for use are already in place. With higher hydrogen blends or pure hydrogen more attention is needed on material selections and designing the overall safety of the power plant solution.

On islands and other remote locations with no space to build dedicated renewable energy for hydrogen production, or locations that are not in the vicinity of gas networks, it's likely that other renewable energy sources will be used, such as liquid biofuels that are easy to transport and can be stored on site. Ammonia or methanol are also possible choices, especially when it comes to transportation.

During the transition period to P2X fuels, biomethane and biofuels can already be blended into their fossil twins, which takes off some of the pressure having the fuels in adequate amounts for the energy sector. As natural gas has the lowest GHG emissions of the fossil fuels it is the clear transition fuel especially as biomethane can be blended into the gas grid.

Wärtsilä is partnering with energy companies Vaasan Sähkö and EPV Energia to build a so-called Power-to-X-to-Power (P2X2P) system in the city of Vaasa, Finland. The system will use renewable energy to produce green hydrogen by electrolysis of water and the hydrogen will be further processed, stored and used for electricity and heat generation and road traffic applications. Energy production will take place in an engine power plant developed by Wärtsilä, using the latest technology.



Hydrogen fuel scenarios

Wärtsilä has studied various scenarios that go beyond a 25 vol% hydrogen blend.

High hydrogen blends (>50% of energy from H_2 corresponds to >78 vol% H_2-natural gas blend)

In scenarios where hydrogen becomes the dominant fuel, hydrogen-compliant materials will add approximately 15% to engine costs. The power density is expected to drop to 40% and efficiency to 84% compared to natural gas. CO_2-equivalent emissions (CO_2eq) are reduced by 46%. As the power density drops drastically, the levelised cost of electricity (LCOE) is increased up to threefold. For obvious reasons, this scenario is not attractive, and furthermore this high hydrogen blends are not expected to be available.

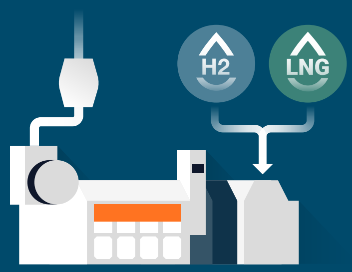
Pure hydrogen

For a spark-ignited gas engine to use 100% hydrogen, modification to the fuel injection and combustion chamber is required as well as ensuring hydrogen-compliant materials. The modifications are not expected to increase plant costs by more than 30%, which is in line with the EUGINE Hydrogen-Readiness Concept*. The power density is expected to be reduced to 73%. Our test results show that efficiency is expected to remain on same level as for natural gas, while CO_2eq emissions will be close to zero.

Hydrogen derivatives

Scenarios have also been calculated for the liquid P2X fuels. A medium-speed W31 diesel engine running on green ammonia or methanol, with various mixing ratios, will require fossil LFO (or HVO) as a pilot fuel. Power density and mechanical efficiency are not expected to drop, but the fuel supply system will add approximately 15% to plant costs.

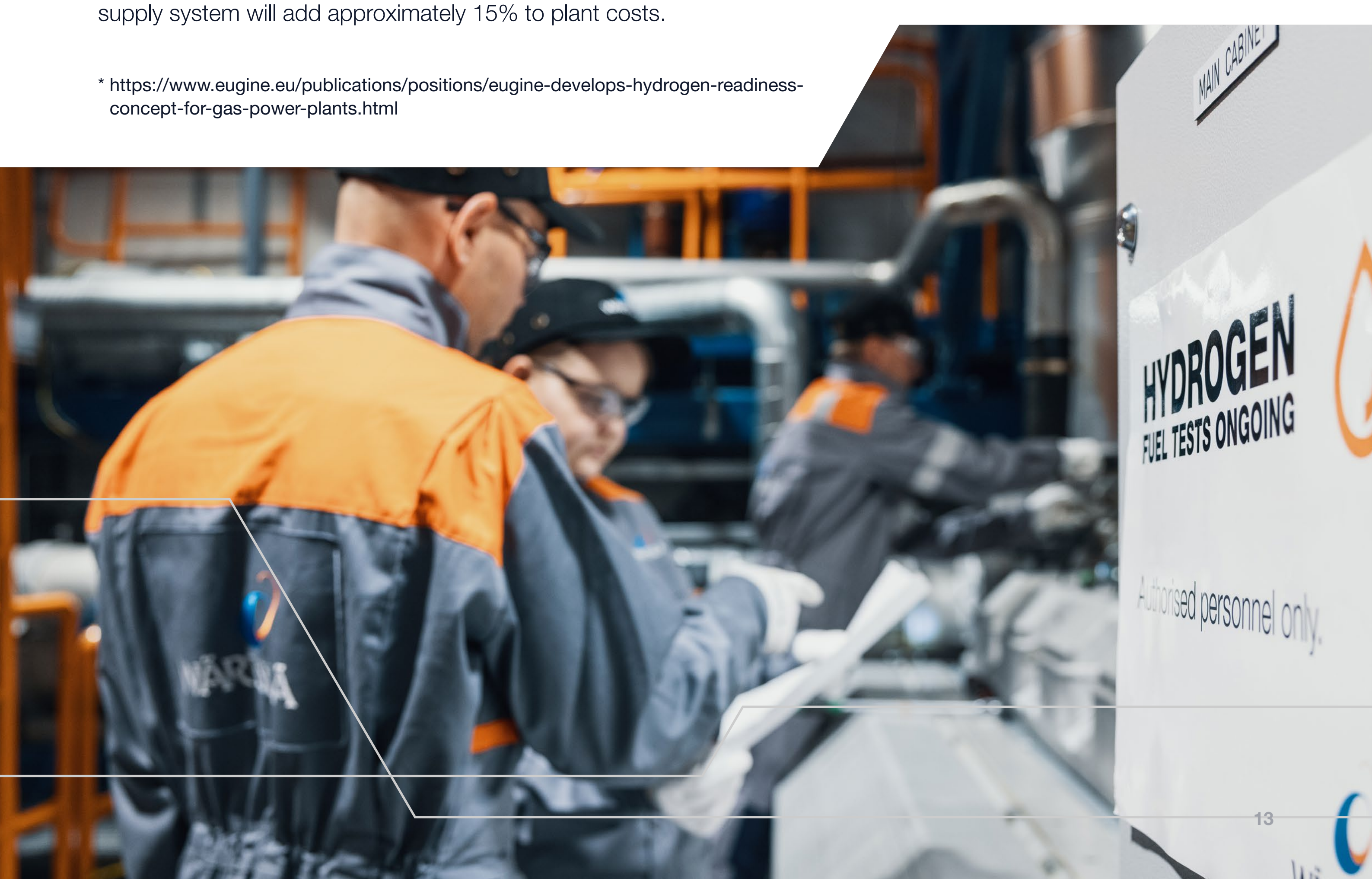
* https://www.eugine.eu/publications/positions/eugine-develops-hydrogen-readiness-concept-for-gas-power-plants.html



CASE

A test platform for hydrogen blending

Wärtsilä will provide engine generating sets, which will run on a hydrogen and natural gas blend, for Keppel Offshore & Marine's Floating Living Lab, an offshore floating testbed in Singapore. The Floating Living Lab is a floating barge with LNG bunkering facilities for harbour craft and small vessels. It will also house an embedded power generation system to power Keppel O&M's operations, with excess electricity to be exported to the national grid or stored in onboard energy storage systems.



OUR FUTURE FUEL RESEARCH

Wärtsilä is investigating a wide range of future fuels for engines, both as pure fuels and as blends:

- **Hydrogen**
- **Methane**
- **Ammonia**
- **Methanol**
- **Ethanol**
- **Biofuels** (by-products, residues or recycled feedstocks)
- **Plastic and tyre pyrolysis oils**

WÄRTSILÄ IS AT THE FOREFRONT OF RESEARCH AND DEVELOPMENT

The Wärtsilä Fuel Laboratory

As the need for decarbonisation and sustainability of engine power plants has grown, Wärtsilä has been researching various sustainable fuels (P2X, B2X and W2X) for quite some time. The lab staff has state-of-the-art competence for screening the behaviour of a variety of feedstocks as well as optimising combustion and ignition features related to engines. With these unique capabilities, they support customer projects to introduce new fuels and their blends to both new and existing power plant. Over the years, the lab has tested a wide range of fuels from conventional fuels to recycled vegetable oils such as cooking oil.

Compared to the well-known combustion features of conventional fuels, ammonia and methanol require a pilot fuel to ignite. Hydrogen combustion, on the other hand, is fast and happens at a high temperature. For these fuels, the whole combustion concept and emission aftertreatment need to be developed.

The laboratory equipment enables the analysis of fuel purity, quality and chemical composition, optical inspections, the testing of physical properties and thermal stability as well as the investigation of optimal combustion features, material selections and operability in fuel supply systems. The new world-class and wide-ranging testing facilities in the Smart Technology Hub in Vaasa, Finland enable all fuel tests to be done under one roof, meaning Wärtsilä can build complete fuel specifications to assess engine compatibility.

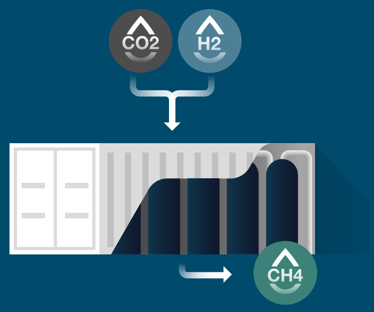
The Wärtsilä Engine Laboratory

Wärtsilä undertakes extensive engine testing in Vaasa, Finland, Trieste, Italy and Bermeo, Spain on P2X fuels (hydrogen, ammonia and methanol) and their various blends.

Based on the findings in the Wärtsilä Fuel Lab, the selected combustion concepts will first be tested and validated on a single-cylinder engine, which allows flexible fundamental investigations, faster and cost-efficient performance testing and shortens the time to market. Specific engine components, such as fuel injection, mixing systems or valve mechanisms, are pretested at component rigs to decrease the running-hours needed for multi-cylinder engine testing. This way of working reduces the total fuel consumption of testing.

Longer term engine performance and operational ranges are finally verified in full-scale lab engines to support market launches of new power plant solutions or conversion services. The new engine laboratory facilities in the Smart Technology Hub have ensured faster and broader testing capabilities that will cement Wärtsilä's position as the internal combustion engine (ICE) knowledge forerunner.

Wärtsilä's Smart Technology Hub enables Wärtsilä to undertake top-notch research and innovate, develop and pilot new solutions. The Hub is an agile testing facility that links together various centres of excellence to improve technology development. In this way, Wärtsilä is able to effectively put to use all of the know-how the company has across the globe.



CASE

Power to synthetic methane

Wärtsilä and Q Power Oy, a Finnish pioneer in biomethanation, have signed a cooperation agreement to accelerate the development and commercialisation of renewable fuels. The companies will work closely together to further develop the market and to find business opportunities for biomethanation and synthetic fuels globally.

Q Power's patented biomethanation concept is a P2X technology for producing synthetic methane, which is produced by taking CO_2 from the atmosphere or industrial processes and combining it with green hydrogen.

FUTURE-PROOFING FLEXIBLE WÄRTSILÄ ENGINE POWER PLANTS FOR DECARBONISED ENERGY SYSTEMS

As established, modern and flexible engine power plants are an ideal solution as balancing power, due to their flexibility in both fuels and operation profiles. This is needed as batteries alone cannot fulfill the balancing need for fluctuating renewable power sources. Flexible capacity must be ready to start quickly at any time and capable of quickly ramping up and down an unlimited number of times per day. Current Wärtsilä engine power plants can connect to the grid in 30 seconds and reach full load in just two minutes. With such fast ramp ups less fuel is consumed during start up and thus set-up emissions are lower.

Current Wärtsilä gas engine power plants can use up to 25 vol% hydrogen blends in natural gas and we are developing a concept for pure hydrogen operations to be launched in 2025.

There is benefits of having multiple medium-sized power plant units when dynamic power output levels are required. By switching units off and running the remaining units at highest efficiencies, overall fuel consumption and CO_2 emissions are minimised.

Current Wärtsilä gas engine power plants can use up to 25 vol% hydrogen blends in natural gas and there is ongoing development for pure hydrogen and other P2X fuels. A fuel change can require changing the combustion parameters of the engine and therefore potentially results in changed output. With hydrogen blends it is expected that there is no impact on component lifetime nor frequency of maintenance. Selection and testing of new materials and components are ongoing for the various P2X fuels concepts and the life cycle aspects are a vital part of that development.

Wärtsilä is working on future fuel development according to its initial timetable

There are good synergies between the Wärtsilä Energy and Marine business units in fuel development needs and Wärtsilä is testing and validating engines and new solutions for both markets.

Wärtsilä continues developing hydrogen power plant solutions and will launch a power plant design for hydrogen blends in 2022 and a concept for pure hydrogen in 2025.

SUSTAINABLE FUEL CAPABILITIES OF THE WÄRTSILÄ ENGINE TYPES

- Ready solution
- Industrialisation needed
- Research ongoing

Wärtsilä engine types	H2 Hydrogen	CH4 Bio/e-methane	NH3 Ammonia	MeOH Methanol	FAME HVO Bio/e-diesel
Gas	Research ongoing	Ready solution	Research ongoing	N/A	N/A
Dual fuel	Research ongoing	Ready solution	Research ongoing	Industrialisation needed	Ready solution
Liquid	N/A	N/A	Research ongoing	Industrialisation needed	Ready solution

Wärtsilä has proven track record in conversions

Power producers have always been concerned about their existing fleets becoming stranded assets due to changing market conditions and new fuels becoming available. The transition from carbon-intensive fuels e.g. coal or HFO to natural gas is a significant improvement step. Decarbonisation can already now be further enhanced utilising blends or pure biofuels. If the conversion is made to dual-fuel engines they can use an even wider range of fuels. For dual-fuel engines, a switch between liquid fuel and gas can effortlessly be made when the new fuel becomes available locally.

Conversion is generally a more economically viable way to implement future fuels than making greenfield investments. Wärtsilä will have conversion packages for hydrogen engine power plants and also have the capability to develop ammonia and methanol conversions when required. The current understanding is that the bulk of the engine will remain unchanged, while the fuel supply and control systems will be impacted.

Wärtsilä has an extensive track record of optimisations and conversions to new fuels for existing assets – over 100 engines worldwide are converted from HFO to run on gas. The main drivers for conversions from liquid fuels to gas have been the reduction of operational costs, local and GHG emissions. Local NOx emissions are reduced by 80-90%, and as natural gas contains almost no sulphur or ash, SOx and PM emissions are very low. The GHG emissions are reduced by 10-15%. By converting from HFO to natural gas, power producers can become more competitive and meet new emissions regulations – ensuring that they can continue to operate and get a return on their investment despite a changing business environment.

KEY FACTORS IMPACTING THE SWITCH TO SUSTAINABLE FUELS FOR ENGINE POWER PLANTS

Financing – many new rules need to be followed to ensure that the investment is sustainable

Fuel availability has to be secured on site depending on scale, mode of supply and local regulations

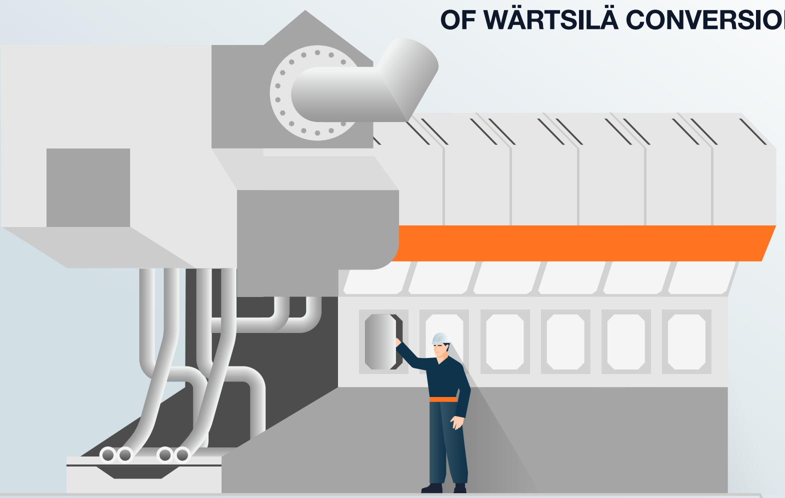
CapEx – conversion packages may include new and more expensive solutions compared to the current mature solutions such as safety, fuel supply and control systems, storage and emissions control

OpEx is higher due to novel and increased operational complexity

OVER
100
ENGINES CONVERTED TO RUN ON GAS

RESULTS TO
1.5 GW
TOTAL POWER GENERATION OF WÄRTSILÄ CONVERSIONS

REDUCING ANNUAL NOx EMISSIONS EQUAL TO APPROXIMATELY
134
MILLION CARS



Wärtsilä collaborates with customers, suppliers and research institutions

Wärtsilä has continuous discussions with customers to utilise sustainable fuels in greenfield projects - or to evaluate fuel blends or fuel conversions for existing assets. Wärtsilä is committed to support its customers to move forward on their path to decarbonisation.

As part of the strong green hydrogen boom Wärtsilä is planning several hydrogen projects with partners and customers ranging from utilising hydrogen blends in existing assets at customers to a P2X2P plant in collaboration with partners.

For the maritime sector, Wärtsilä is currently installing and commissioning the first ammonia pilot dual-fuel engine in Norway. Wärtsilä's methanol-fuelled engines have powered the Stena Germanica ferry since 2015 and in 2021 the methanol engine solution including fuel storage and supply system (MethanolPac) has been launched.

Wärtsilä has invested heavily in its development and production facilities during the last years. Later in 2022 there will be the grand opening of the Wärtsilä Smart Technology Hub in Vaasa, Finland. Together with both internal and external partners, the Wärtsilä Smart Technology Hub is a collaboration ecosystem both on local and global level. It connects companies, start-ups, organisations and academia in developing future sustainable societies.

Fuel testing and engine development will continue throughout the coming years. Wärtsilä is there to enable the transition to a decarbonised future with innovations in fuel flexible technology and decarbonisation services.

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WÄRTSILÄ ENERGY IN BRIEF

Wärtsilä Energy leads the transition towards a 100% renewable energy future. We help our customers in decarbonisation by developing market-leading technologies. These cover future-fuel enabled balancing power plants, hybrid solutions, energy storage and optimisation technology, including the GEMS energy management platform.

Wärtsilä Energy's lifecycle services are designed to increase efficiency, promote reliability and guarantee operational performance. Our track record comprises 74 GW of power plant capacity and more than 80 energy storage systems delivered to 180 countries around the world.

www.wartsila.com/energy