Future Fuel Conversion:

Engine Retrofit Report summary

Presented by:

VICTOR SOLANO

NEW CONSTRUCTION CLIENT MANAGER FOR SPAIN & PROTUGAL,
Lloyd's Register

Tracking the progress, opportunity and challenges in alternative fuel conversion

The Engine Retrofit Report is an annual publication helping you to stay informed with the latest thinking, and make the right decisions for your fleet today, tomorrow and throughout the alternative fuel transition.

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Demand for retrofitting vessels for alternative fuels is rising

Fleets are under increasing pressure to meet tightening decarbonisation targets, creating more demand for alternative fuels.

20%

of ships originally designed and arranged to be powered by fossil fuels are likely to remain in service by 2050

9 to 12.9k

large merchant vessels could consider engine retrofits to decarbonise by 2050

Customer sustainability

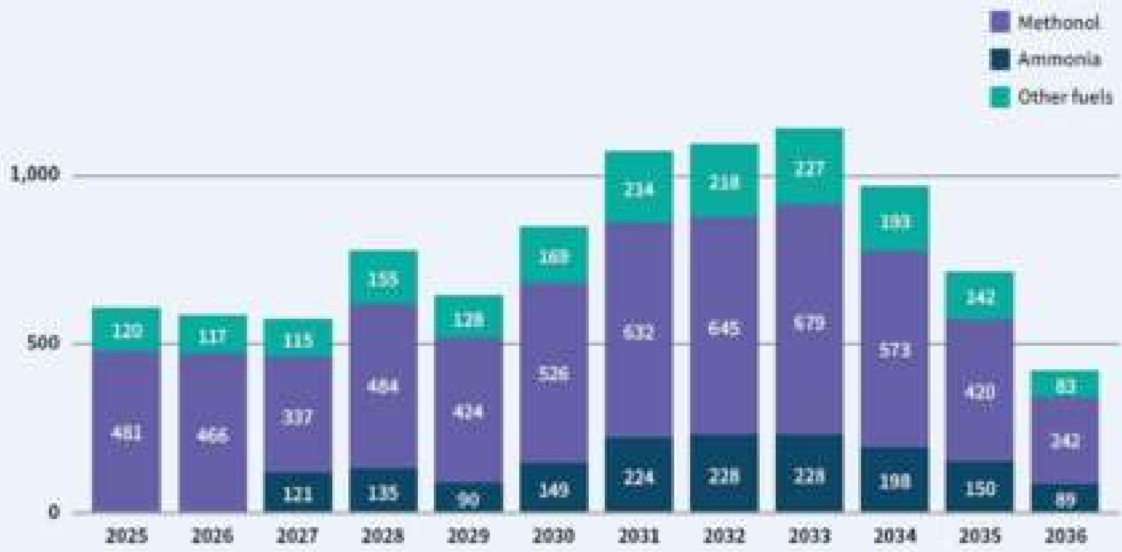
goals are driving retrofit demand

Clarksons

Container sector

is an early driver of demand

Retrofit demand model (Scenario 1)*– Number of vessels by year



The retrofitting period based on conversion age limits, if the transition to zero-emission only construction begins in 2027.

* Early adoption of zero-emission newbuilds, maximum retrofit age of 10 years, no delay in uptake on smaller vessels

How many vessels are alternative fuel ready?

A vessel is "ready" when they are recognised as having no barriers that prevent them adopting the alternative fuel in the future. The number of "fuel-ready" vessels in service/on order indicates potential uptake of engine retrofits.

477

Fuel ready and capable vessels in service and on order

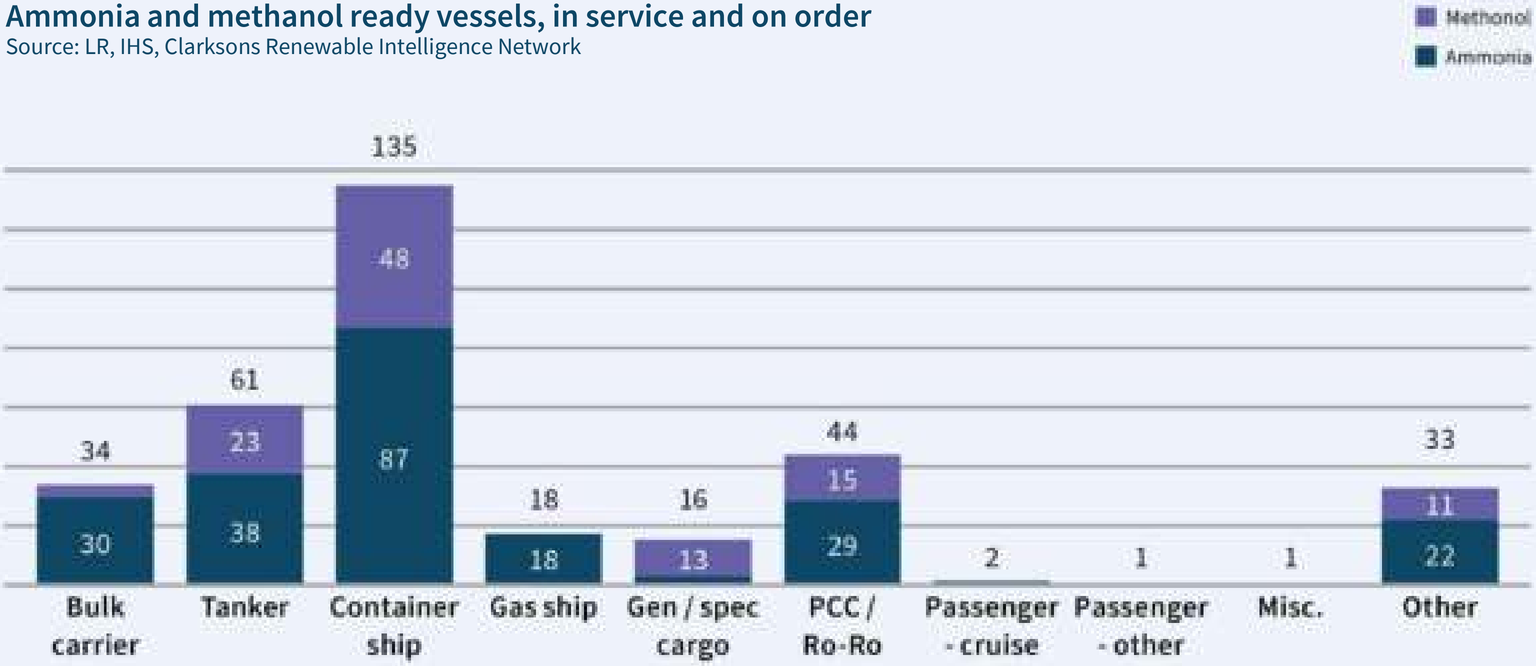
3 May 2023

Approx. 13,000

Vessels (across ship segments) are potential candidates for alternative fuel retrofits by 2036

Ammonia and methanol ready vessels, in service and on order

Source: LR, IHS, Clarksons Renewable Intelligence Network



Understanding real readiness: Our Zero Ready Framework

The Zero Ready Framework gives a better understanding of vessel readiness and the costs involved in zero-emissions vessels. Helping you to:

- Support strategic planning and investment
- Better manage risk
- Demonstrate climate commitments

Access the Zero Ready Framework at
www.lr.org/ZRF

Zero Ready Framework by the LR Maritime Decarbonisation Hub

	Readiness standard		Criteria		
	Name	Description	Capabilities	Additional requirements	Comments
1	Near net zero GHG vessel	Capable of bunkering and operating for all onboard energy usage in all operating modes.	All required equipment installed and commissioned.	Capabilities apply to all energy sources onboard. Cannot be powered by fossil fuels.	-
2	Low GHG vessel	Capable of bunkering and operating for primary propulsion in the majority of operating modes.	All required equipment installed and commissioned.	Capabilities apply to primary propulsion.	Fossil pilot fuels acceptable. Dual/multi fuels acceptable.
3	Conversion under preparation	Primary propulsion capable of using fuels in scope. Some key components already installed but not yet commissioned.	Minimum requirements: • Engine retrofitted for fuel in scope • Fuel storage system in place	Capabilities apply to primary propulsion.	
4	Designed for conversion	Fossil fuel vessel with high level of detailed design for conversion.		Capabilities apply to primary propulsion.	Detailed design is preferred to high level. Ideally drawings for conversion provided.
5	Potential for conversion	Fossil fuel vessel with main engine that could fuel in scope, if retrofitted.	-	Retrofit pack available for main engine.	Will become the norm as dual or multi-fuel engines become the default.
	Fossil fuel only	Has no possibility of retrofit.	None	None	-

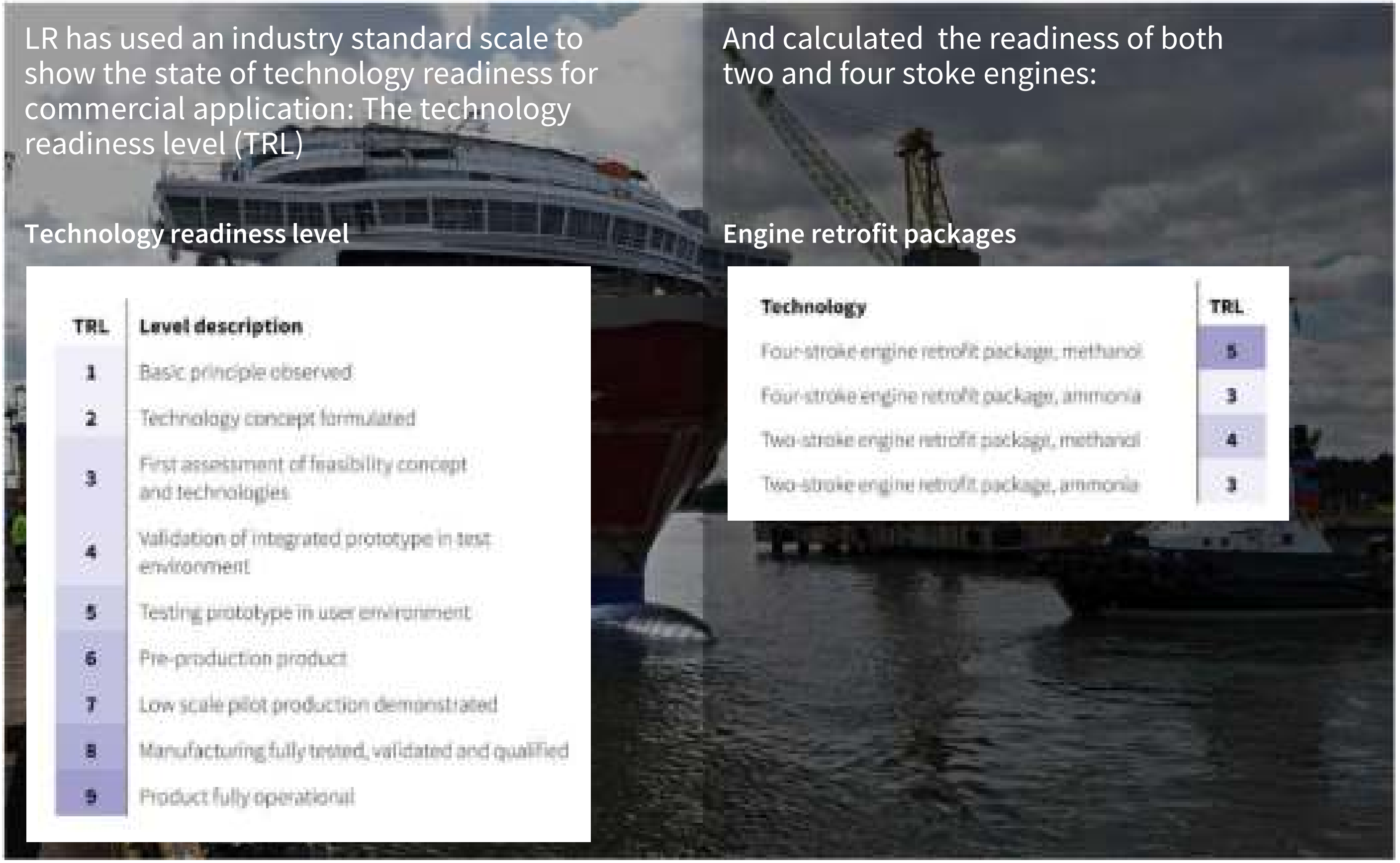
Vessel technology remains under development

Methanol technology is moving ahead

- Widely deployed in newbuild
- One retrofit case – Stena Germanica – and several on order

Ammonia technology has more obstacles

- Not deployed in newbuild
- Significant challenges to retrofitting – emissions parameters and abatement technologies are under investigation



LR has used an industry standard scale to show the state of technology readiness for commercial application: The technology readiness level (TRL)

Technology readiness level

TRL	Level description
1	Basic principle observed
2	Technology concept formulated
3	First assessment of feasibility concept and technologies
4	Validation of integrated prototype in test environment
5	Testing prototype in user environment
6	Pre-production product
7	Low scale pilot production demonstrated
8	Manufacturing fully tested, validated and qualified
9	Product fully operational

And calculated the readiness of both two and four stoke engines:

Engine retrofit packages

Technology	TRL
Four-stroke engine retrofit package, methanol	5
Four-stroke engine retrofit package, ammonia	3
Two-stroke engine retrofit package, methanol	4
Two-stroke engine retrofit package, ammonia	3

Regulation is adding pressure to adopt alternative fuels

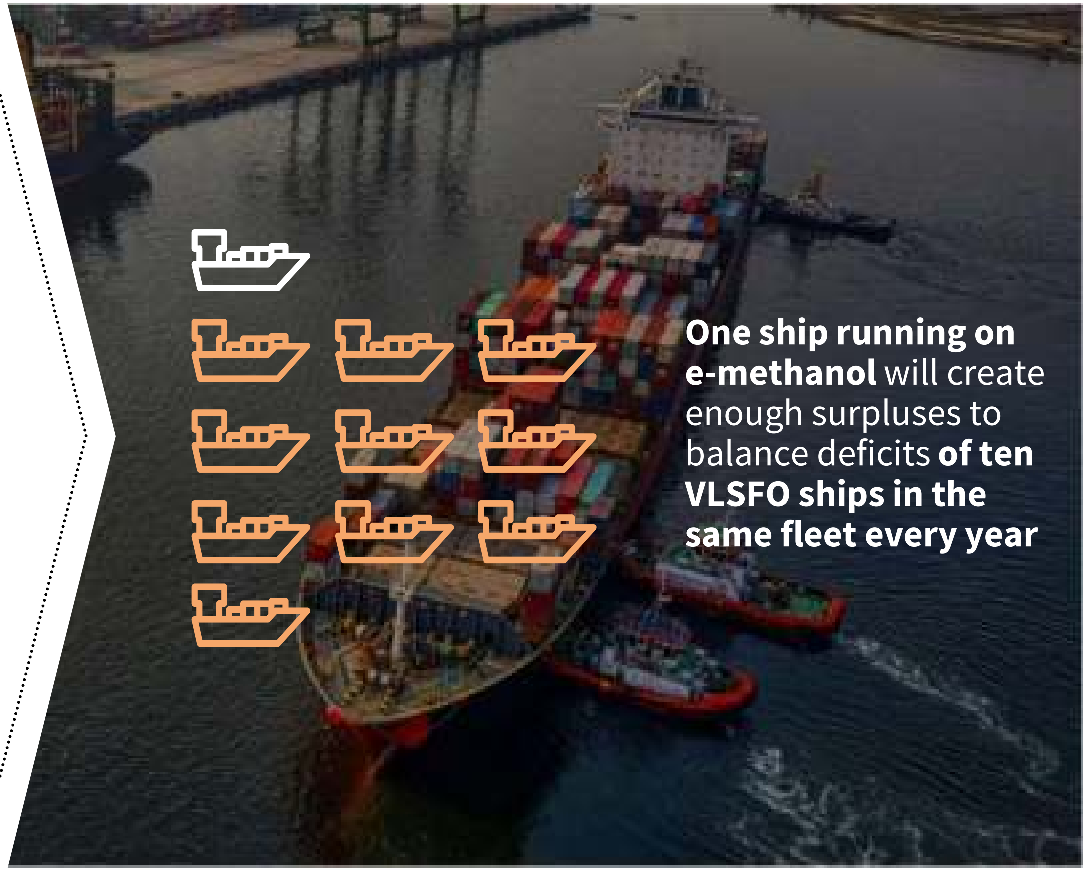
5-10%
target for alternative fuel use by 2030

IMO's GHG strategy

Rising
cost of carbon

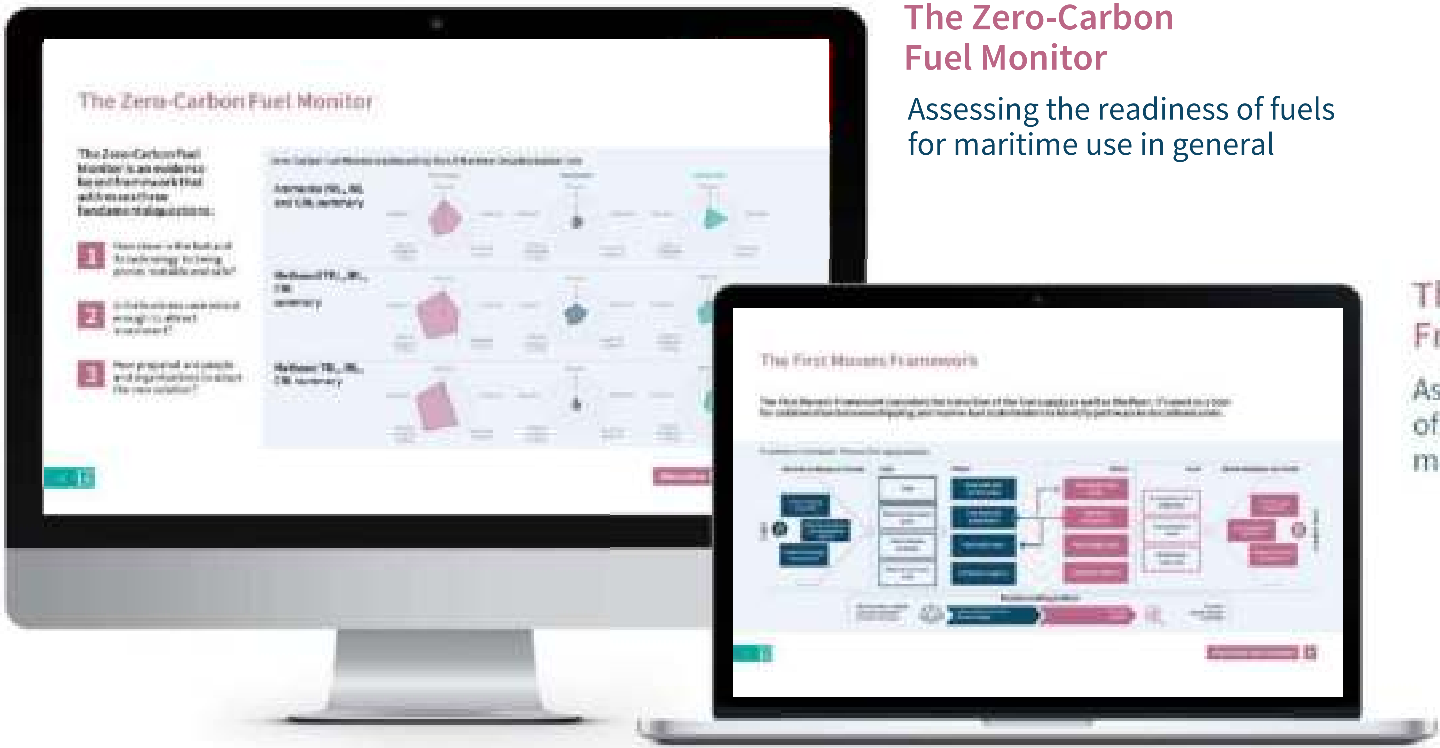
EU's ETS and Fuel EU Maritime

Retrofitting for zero or near-zero carbon fuels can help meet regulation and offset costs:



The availability and price of alternative fuels remains uncertain

**This impacts ship owners' decisions on how and when to convert.
So, LR has established two useful tools for addressing these uncertainties:**



The Zero-Carbon Fuel Monitor

Assessing the readiness of fuels for maritime use in general

The First Movers Framework

Assessing the readiness of fuels for particular maritime trades

The Zero-Carbon Fuel Monitor

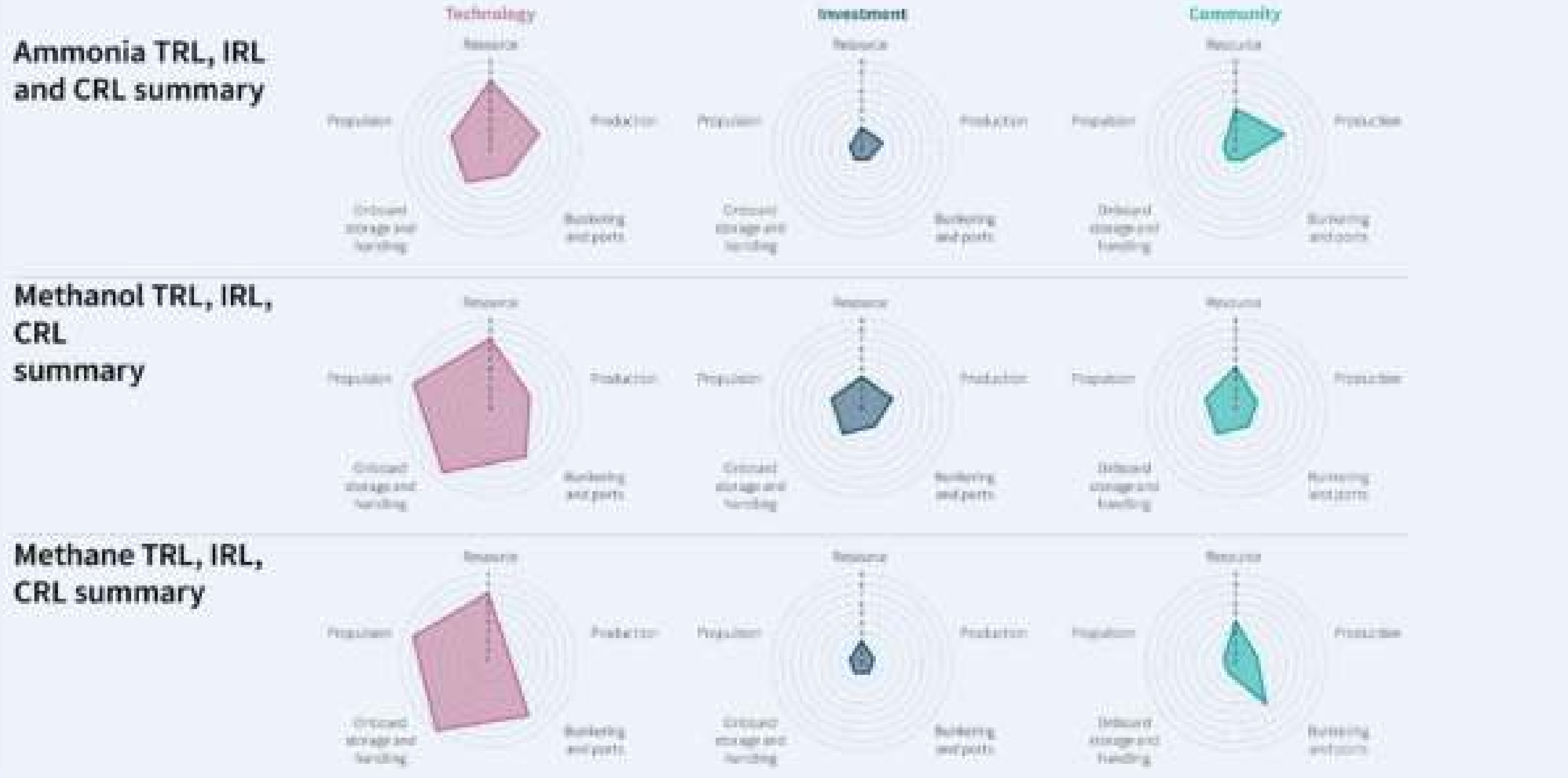
The Zero-Carbon Fuel Monitor is an evidence-based framework that addresses three fundamental questions:

1. How close is the fuel and its technology to being proven scalable and safe?

2. Is the business case robust enough to attract investment?

3. How prepared are people and organisations to adopt the new solution?

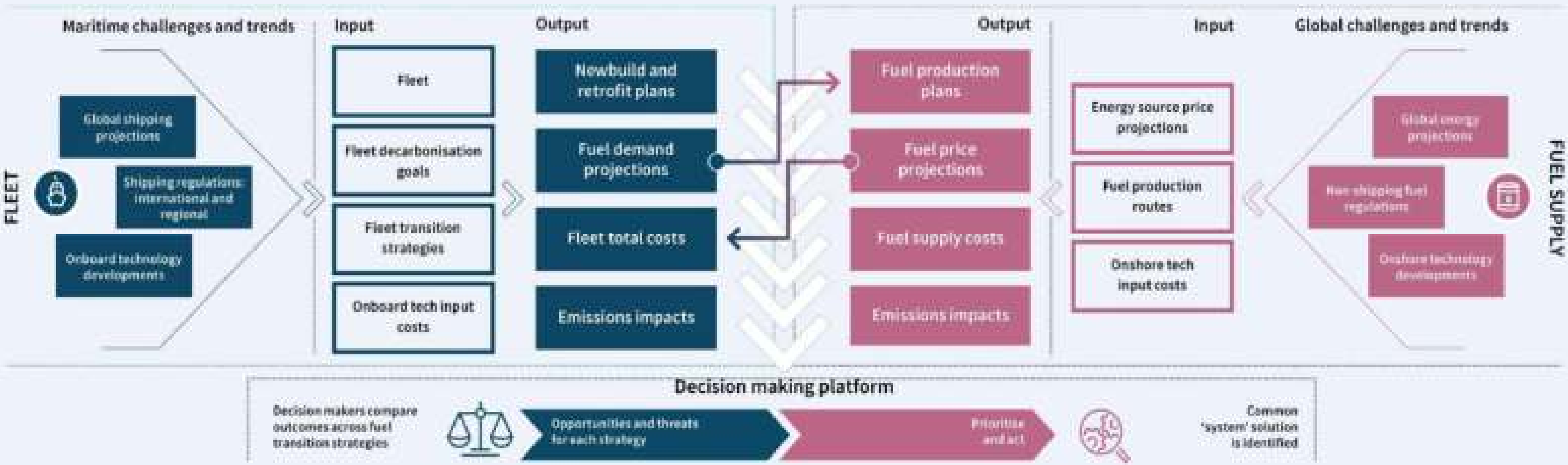
Zero-Carbon Fuel Monitor dashboard by the LR Maritime Decarbonisation Hub



The First Movers Framework

The First Movers Framework considers the transition of the fuel supply as well as the fleet. It's used as a tool for collaboration between shipping and marine fuel stakeholders to identify pathways to decarbonisation.

First Movers Framework – fleet and fuel supply analysis



Rules governing alternative fuels are in various stages of development

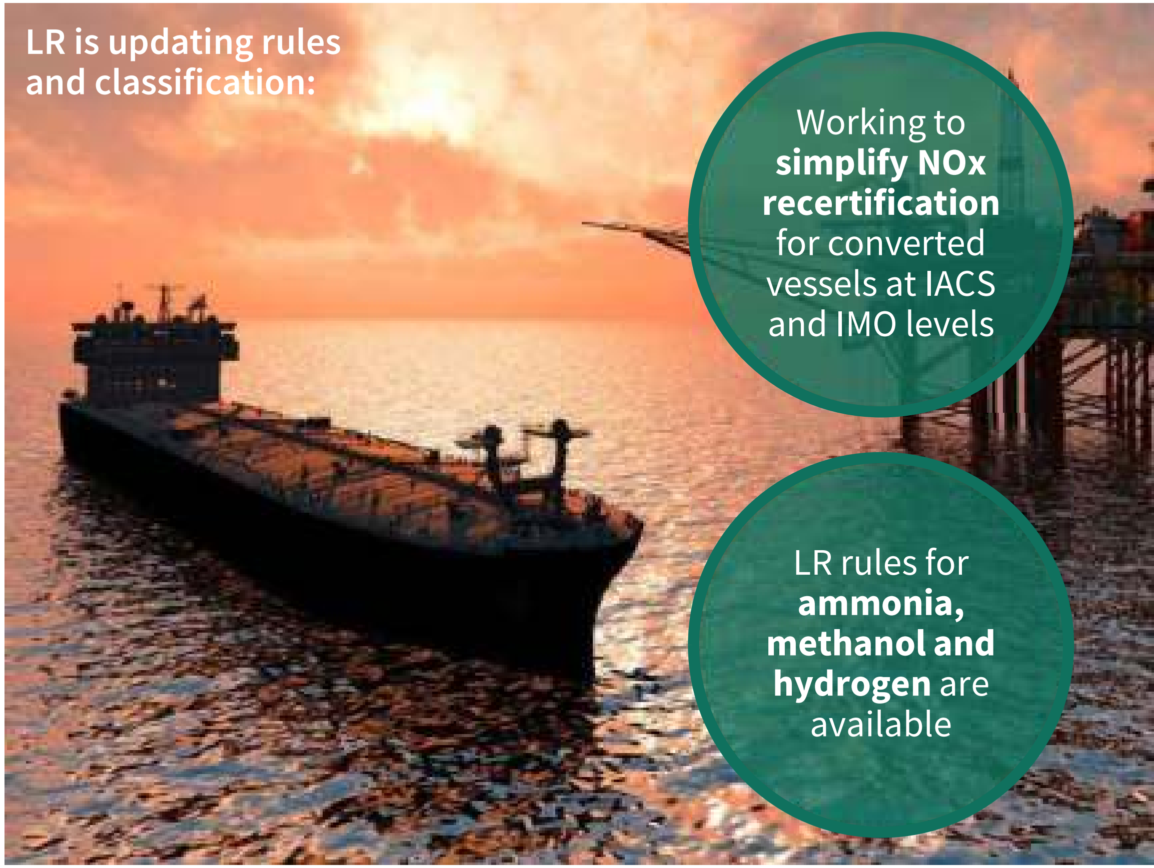
IMO SOLAS requirements –
IGF Code

Detailed requirements for the use of natural gas.
Interim guidelines for methanol, ammonia or ethanol.

IMO MARPOL requirements –
NOx recertification

A retrofitted engine likely has NOx critical components changed, so need to be recertified.

Until prescriptive rules for methanol and ammonia designs are introduced, risk-based design is needed. LR uses the ShipRight Risk Based Certification process to demonstrate compliance with SOLAS.



The availability of retrofits corresponds to engine development

Retrofit package availability

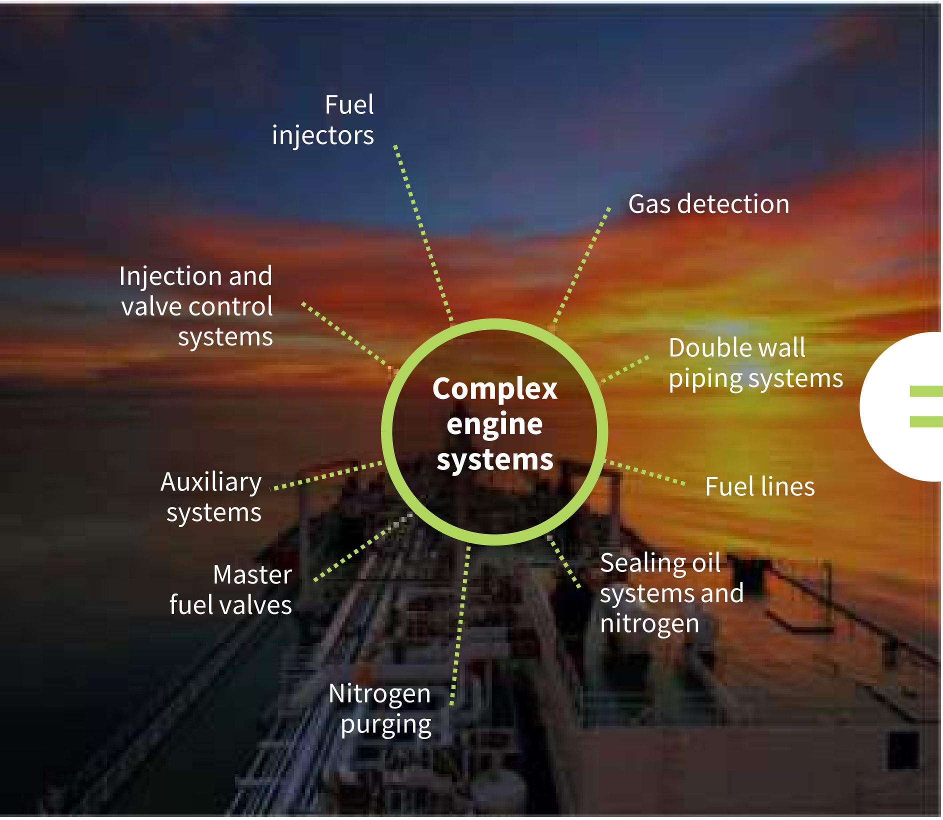
Two-stroke engines

- **Not a linear process**
- The first engine deliveries prove the concept
- The roll out of alternative fuel retrofit capability **follows newbuild engine orders**
- Retrofit packages can be developed once engine concepts established
- Design can take up to six months or more:
  - Ammonia: **longer lag time** due to additional safety needs
  - Methanol: **faster development** as newbuild engines already in service

Four-stroke engines

- Retrofit technology can be installed **ahead of newbuild production**
- MAN and Wartsila: developing methanol capability first **via retrofits**
- Hyundai Himsen: type approval of methanol-fuelled engines **as newbuilds**
- Retrofits can be **one after the other** while vessel is in operation, if generating power can be maintained
- **Shorter dry-docking** still needed for the wider fuel storage, fuel supply system, auxiliary equipment and safety systems

Key design challenges and complexities of engine design



Key considerations

Adapting engine control system hardware and software

Enhancing alarm, monitoring and safety systems

Selecting materials that are compatible for the fuel type being used

The two main combustion concepts applied are the **Diesel** and **Otto** cycle

In two-stroke engines, both main designers are opting for **Diesel cycle combustion** for methanol and ammonia, to maximise fuel efficiency and offer lower emissions

Ammonia is more restrictive and requires typical construction materials to be reselected

Engine retrofit technologies are starting to progress

Methanol retrofit packages are ready to go on some engine sizes. Ammonia conversion will start early 2027.

Key themes:

Methanol is moving ahead:

Limited technology obstacles, some engines have been operating for years

Ammonia research and options emerging:

There are gaps in safety regulation and operational aspects

Pre-operational conversions:

Increasing due to maturing business models and limited yard capacity and capability

New structures and systems:

Integrating e.g. fuel preparation rooms, tanks and emissions abatement into existing vessel structures are a big obstacle

NOx emissions certification:

NOx certification increases cost, so will reduce uptake

There are key challenges for fuel system retrofitting

Tanks:
Finding safe, compliant locations for larger fuel tanks that reduce impact on structural integrity and cargo capacity

Fuel preparation:
Finding a contained space for the fuel pumps and valve train that is close to the engine room

Piping:
Fuel piping adds cost and needs more space, so should be routed to minimise impact on ship structures

Safety arrangements:
Venting, purging, ventilation and fire/gas leak detection and prevention add complexity

Designers must focus on safety and minimising crew exposure to toxic and flammable fuels

For methanol, existing storage tanks can be converted, and fuel supply systems are commercially available

Ammonia fuel needs greater storage adjustments, more development of fuel supply systems, and more ventilation

Retrofitting requires new capabilities and increased yard capacity

Capabilities needed:

Naval architecture

Experience of complex projects e.g., offshore structures

Electrical engineering

Integrating advanced control, monitoring and abatement into vessel IT infrastructure

Fuel handling

Safe commissioning using non-conventional fuels

A rise in yard capacity:

~16 yards

capable of meeting requirements for skills and experience

~300 fuel retrofits

can currently happen every year, based on capacity and a 60-day conversion period (across all ship segments)

Access to a skilled workforce and increase in yard capacity will be a key challenge

Training crew and mitigating human risks is a key challenge

Mitigating human risks

There is need for:

Engineering principles like ergonomics in vessel design *

Enhancements to safety and environmental management systems and approach *

Training crew

Significant gaps in training frameworks to prepare crew:

LR Maritime Technology Forum project:
"Operational Management to Accelerate Safe Maritime Decarbonisation"

Gaps identified and recommendations made across STCW, MLC and ISM frameworks

*Based on research commissioned by LR's Decarbonisation Hub and Maersk McKinney Moller Centre for Zero Carbon Shipping

What is the current investment readiness?

To assess the business attractiveness of fuel conversions across cruise, container, bulk, carrier and tanker vessels, LR analysed market structure and orderbook developments to create the Investment Readiness Level (IRL).

IRL	Level description
1	Hypothetical commercial proposition
2	Commercial trial, small scale
3	Commercial scale up
4	Multiple commercial applications
5	Market competition; Driving widespread development
6	Bankable asset class

IRL by vessel type

Vessel type	Methanol	Ammonia
Container	2	1
Cruise	2	1
Tanker	1	1
Bulk carrier	1	1

Costs of retrofitting for alternative fuels

Techno-economic analysis of fuel cost and carbon price LR calculated how retrofitting for alternative fuels could affect costs for owners and operators. It's based on two scenarios:

High-cost: Fuel price to the end of the decade

Low-cost: Fuel costs around 2050, where fuel is 50% cheaper and carbon price is higher

	High-cost scenario	Low-cost scenario
VLSFO (USD/mt)	620	620
Methanol (USD/mt)	1222	757
Ammonia (USD/mt)	1200	655
Carbon Tax (USD/mt/CO_2)	200	350

This example is based on an Ultra Large Container Ship (ULCS). Other vessel types are covered within the report

The high-cost scenario (today) more than doubles fuel costs for all vessels

The low-cost scenario is just beyond the tipping point where alternative fuels become cheaper

Plus, retrofitting costs are uncertain and will impact the business case for owner and operator

What to do next for ship owners

14-month minimum timeframe from feasibility study to converted vessel in service.

Four major milestones

Feasibility (6-12 months)

- Conversion identified
- Initial design and safety statement
- Approvals in principle

Design & Engineering (5 months)

- Risk assessments
- Consultation with flag state
- Approvals in principle
- Detailed designs
- Equipment component certification begins
- Time for delivery

Conversion (2 months)

- Conversion begins on completion of approvals
- Equipment surveyed and certified
- Site survey
- Assessment for the Development of In-Service Documentation (RBC-5b) to be completed

Adoption (1 week)

- Commissioning
- Sea trial
- Class and flag certification completed

What to do next for ship designers and OEMS

Two month lead time for a retrofit project, depending on:

Size of vessel	**Scope of changes**	**Level of preparation**

Six stage project plan

1	2	3	4	5	6
Removal of existing components	Modification of retained elements	Assembly and install of new components	Electrical wiring	Commissioning and testing	Sea trial

Ready to start now?

Let us guide you in making informed decisions for your fleet today.

Reach out for an assessment of your fleet's status and compliance options, including a feasibility study for your engine retrofit project.

Find out more and and get in touch at www.lr.org/ETA

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Read the full report at www.lr.org/ERR to find out more
Sign up to our series of reports on alternative fuels "Fuel for thought" www.lr.org/FFT

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Thank You