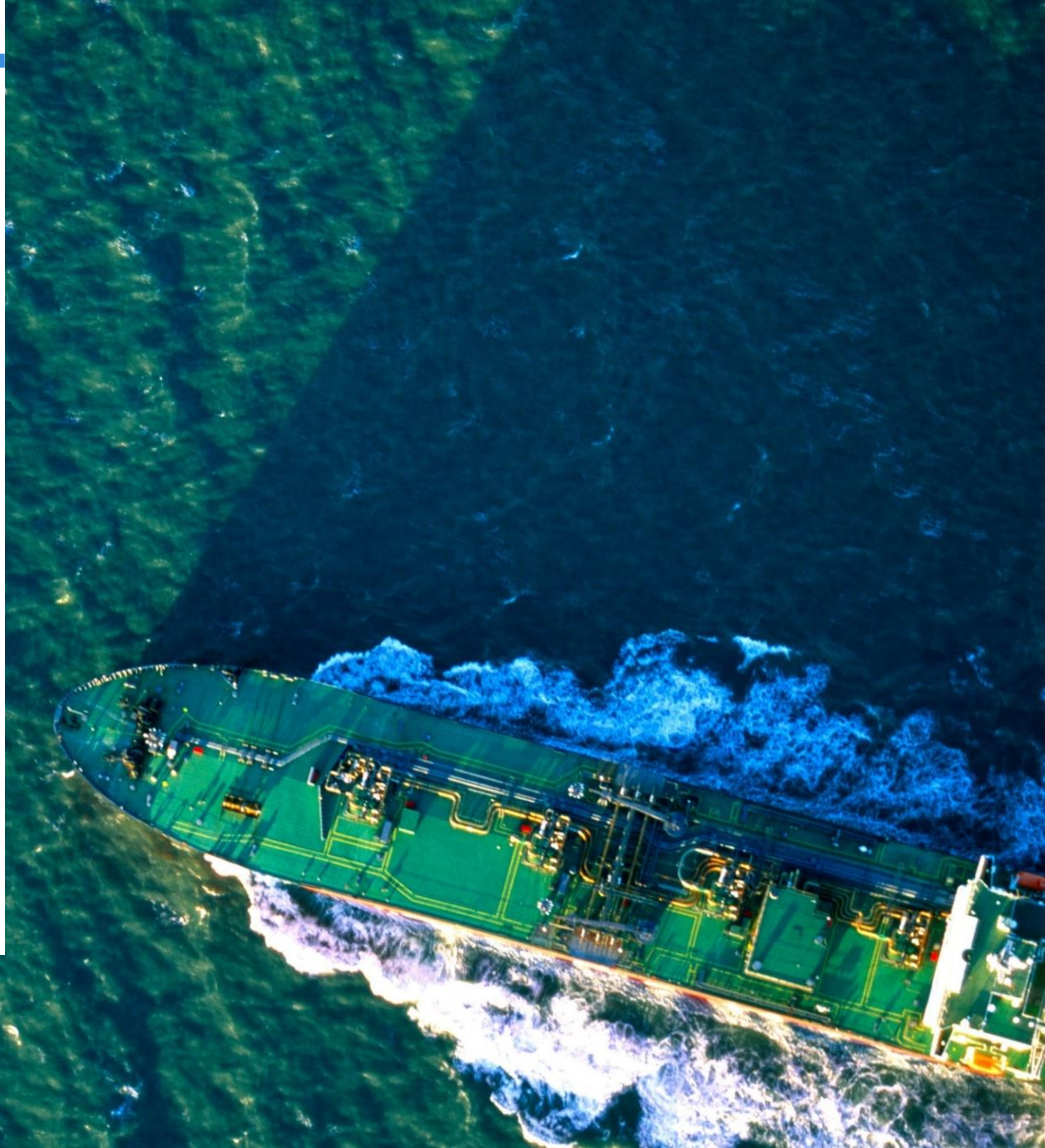
Decarbonisation Transition Pathways.

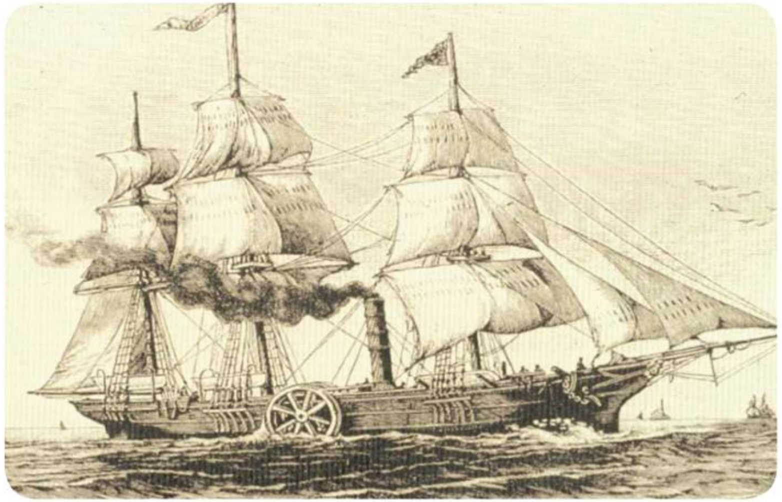
SMTF 18th September 2019

Lloyd's Register



Our heritage - It started with a cup of coffee…

Lloyd's Register was set up in 1760 by customers of Edward Lloyd's coffee house in London and it maintains a happy relationship between tradition and foresight.



Our heritage - It started with a cup of coffee…

Who we are - Safety, Quality & Performance

The Lloyd's Register group is a global organisation with a mission to protect life and property and advance transportation and engineering education and research.
We offer services to the marine, energy and management systems services across a wide range of sectors – focused on improving safety, quality and performance.

Our vision
Year by year we will continuously improve in helping our clients ensure supply chains are safe, responsible and sustainable.

Our Values
- Trustworthy
- Accountable
- Courageous
- Open minded
- Spirited

Objective.

To identify the potential future fuels, indicate their relevance to decarbonisation, and highlight the potential pathways to their integration in the shipping industry.

Key Messages.

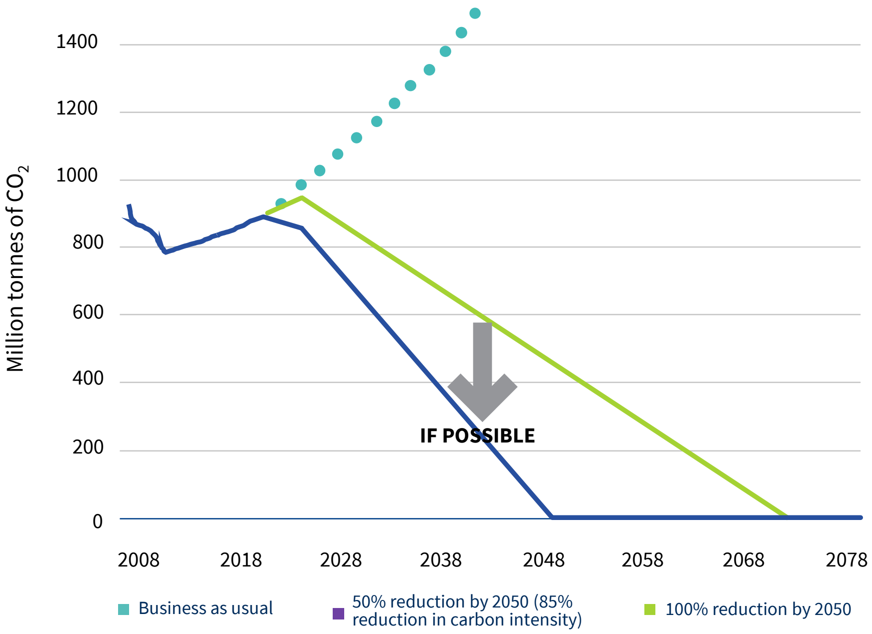
- Decarbonisation requires transition away from fossil-based fuels
- Efficiency gains and renewables energy use onboard are available now
- Research and development, pilots and prototypes are critical
- Compound knowledge by achieving small goals
- Novelty and complexity in fuels and technology

Why are zero-carbon fuels needed for full decarbonisation?

To achieve an absolute reduction in GHG of at least 50% by 2050.

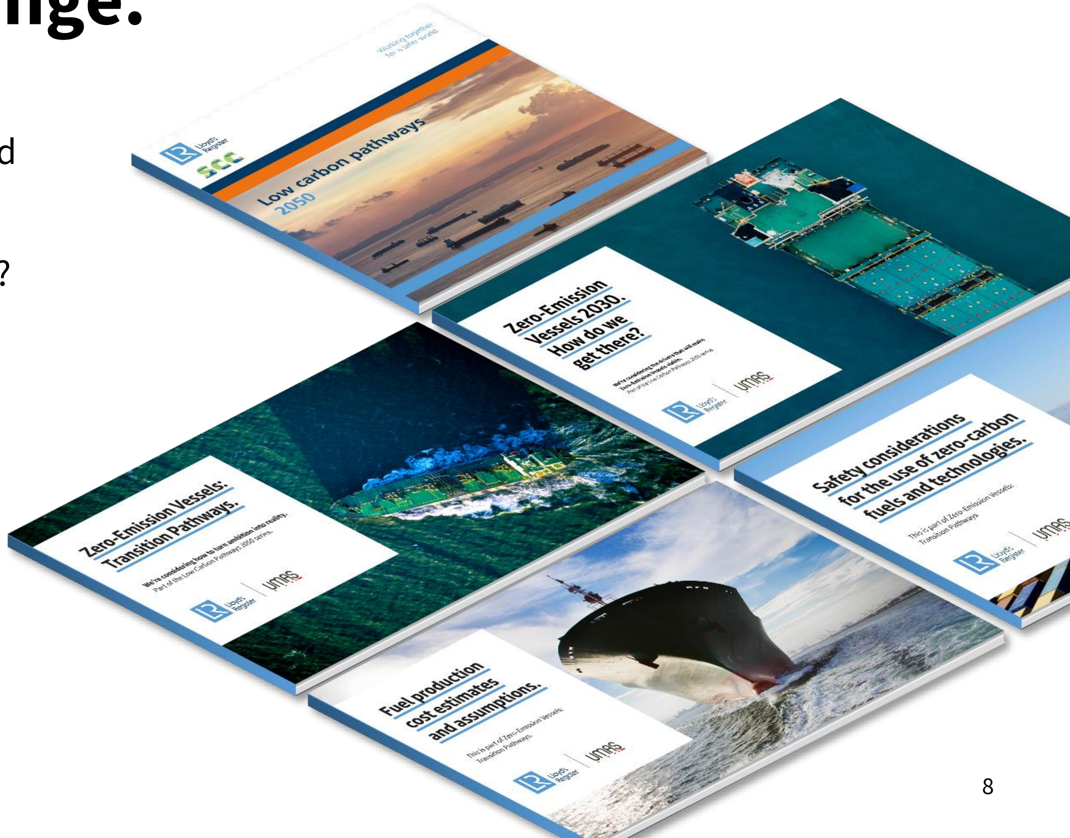
- This equates to around **85%** reduction in carbon intensity
- Efficiency and renewables are not enough to reach the goal
- Zero-emission vessels need to be entering the fleet from 2030

Pathways for international shipping's CO_2 emissions



Developing new knowledge and tools to help the industry understand the complexities of the challenge.

- Low carbon pathways 2050: how might shipping be required to change?
- Zero-Emission Vessels 2030: what is the economic viability?
- Zero-Emission Vessels: Transition Pathways: What conditions are required to achieve the goal?
- Safety considerations: How do we safely use zero-carbon fuels?
- Fuel Production cost estimates & assumptions: What are the relative production costs?



COLLABORATION.

How we play our part?

Maritime Industry Decarbonisation Council

GLOBAL MARITIME FORUM

GLOBAL INDUSTRY ALLIANCE TO SUPPORT LOW CARBON SHIPPING

CP LC CARBON PRICING LEADERSHIP COALITION

sustainable shipping initiative

What do we mean by zero-carbon fuels?

Transition to zero emission vessels means phasing out fossil based fuels.

	Zero-carbon fuels				
Energy source	**Methanol**	**Gas oil**	**Hydrogen**	**Ammonia**	**Electricity**
Natural gas with CCS			NG-H_2	NG-NH_3	
Biomass	bio-methanol	bio-gas oil			
Renewable electricity	e-methanol	e-gas oil	e-H_2	e-NH_3	batteries

Fuel pathways for transitioning to zero-carbon fuels.

Fuel	Relative cost	Enabler	Limitations
Hydrogen & Ammonia produced from natural gas	Their price may vary between: **50 to 105 $/MWh**	Availability of cheap natural gas	Projected limitation of fossil-fuel and CCS energy capacity under the 1.5°C pathway
Biofuels	Their price may vary between: **25 to 95 $/MWh**	Technology known (non-complex, non-novel) Can be used as blends	Sustainability Production volume
Electro fuels	Their price may vary between: **20 to 130 $/MWh**	Flexible and distributed infrastructure Supply	Electro-fuel producers need to enter the marine market

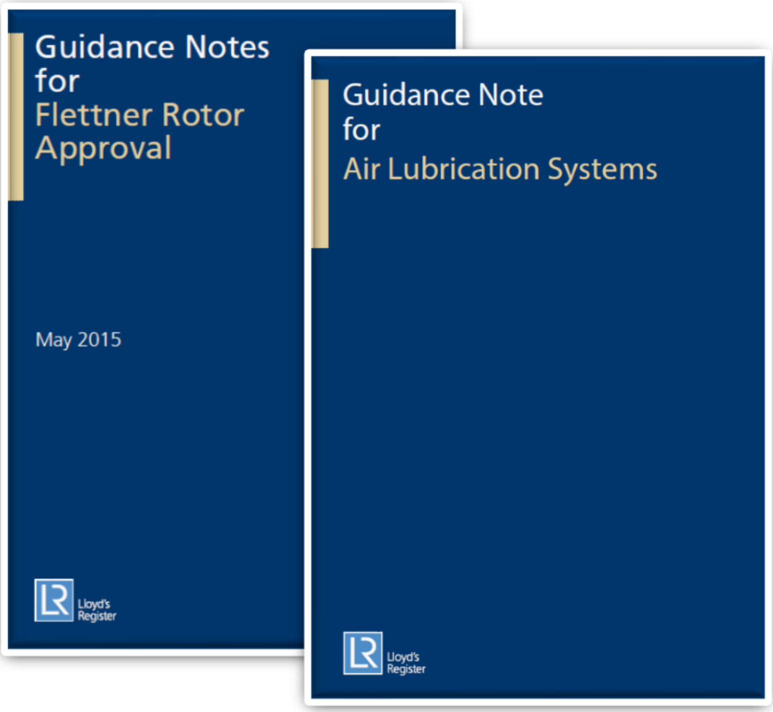
Common elements of the three pathways.

- Supply & bunkering infrastructure
- Price
- Environmental consumer groups
- Policy-makers
- Ports
- Civil society
- Financiers
- Fuel production
- Safety
- Propulsion
- Design / operation

Key:
- Actors
- Policies & Institutions
- Market factors
- Non-market & environmental factors
- Propulsion
- Landscape & external factors

How to integrate alternative energy generators?
How to reduce the energy demand on board?

- Wind Propulsion Systems
- Propulsion efficiency
- Hull optimisation
- Air lubrication



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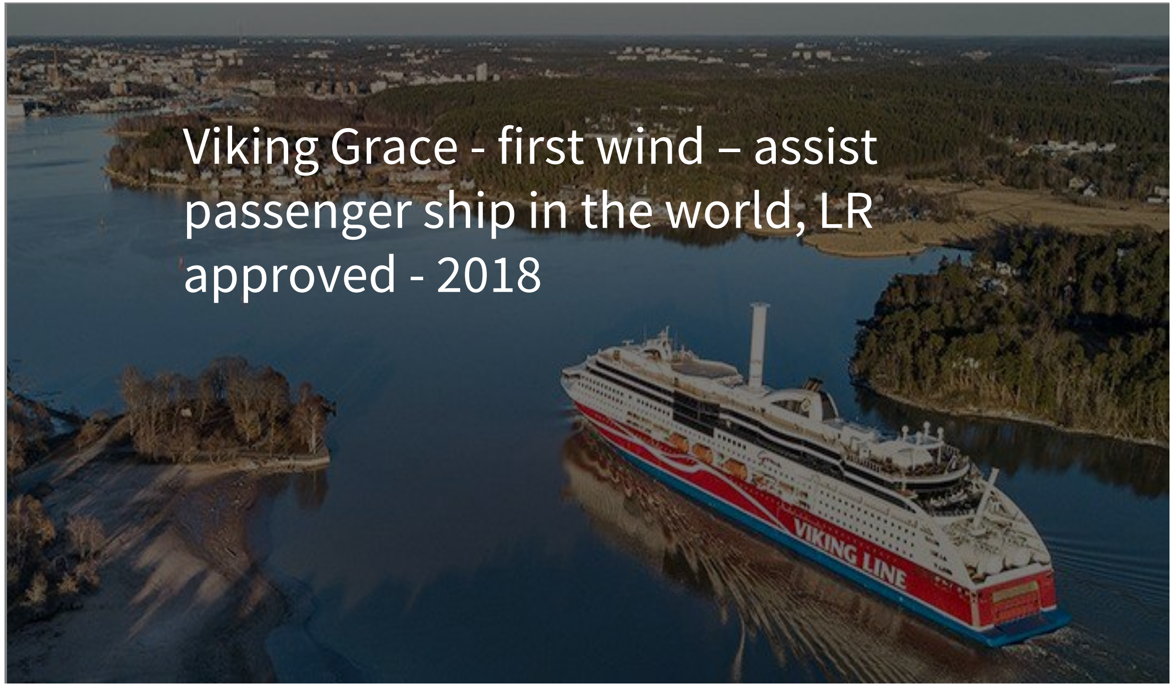
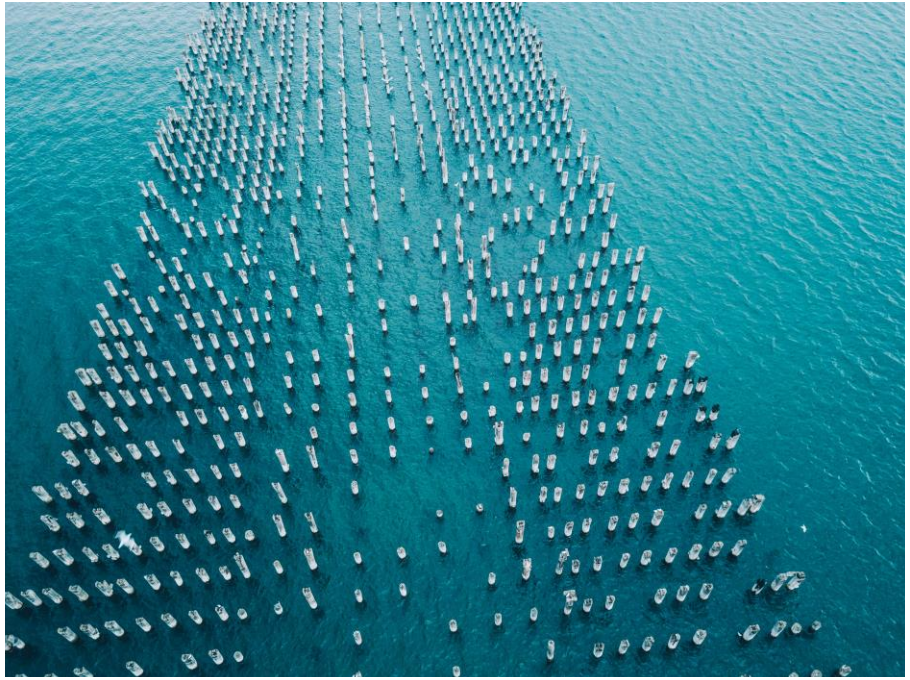


Delivered efficiency gains and onboard renewable energy.

Ammonia (NH_3): fuel characteristics.

- Ammonia is a colourless, flammable, highly toxic and corrosive gas
- Flame speed is low (0.07 m/s)
- Formation of NOx during consumption
- Highly soluble in water
- Ammonia has a low flammability (15-28%)
- Latent heat of evaporation is high meaning no reliquification would be required



Functionally they are equivalent to petroleum-derived fuels and compatible with existing machinery and infrastructure.

Biodiesels have a lower energy density typically 38 MJ/kg compare d to 48 MJ/kg

Can be used as blends with conventional fuels

Compatibility and on-board fuel management is essential to manage any risks

Delivered biofuel project.

Project deliverables:

- Establish FAME and blend interaction with marine environment over time.
- Establish impact on Fuel delivery system and engine when used in an unmodified Engine
- Establish emission impact of FAME and blends when used in an unmodified Engine

FAME (Fatty Ester Methyl Ester) Trial

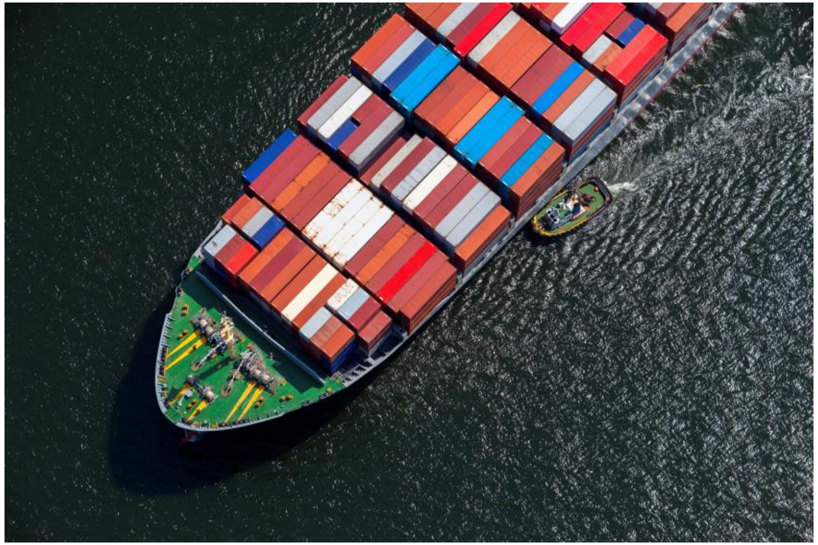
Project partners: Maersk, Shell and Lloyd’s Register

3.5 MW Auxiliary engine to provide electric power 4000 l lubrication oil 0.4 m^3/h fuel consumption

Maersk Kalmar

Methanol (Me-OH): Fuel characteristics.

- Not a zero-carbon fuel
- Boiling point 64.7 °C at atmospheric pressure
- It is a neutrally buoyant fuel
- Burns outside in the visible range
- Requires specialized fire detection and fire extinguishing equipment



Delivered Vessel: Methanol.

Lloyd's Register's Deliverables:

- Classification of the ship with methanol propulsion system
- Facilitation of the risk studies, controlling the risk register, and verifying recommendation closures
- Providing advice on fire fighting, witnessing sea trails, supporting client with regulators and developing the bunkering procedures.

First ship methanol powered vessel!

Project Partners:

Stena
Wartsila
Methanex
Lloyd's Register

Convert a 1,500 passenger,
240 m long ferry
to methanol
propulsion
by early 2015

Stena Germanica

Hydrogen (H_2) : fuel characteristics.

- Zero carbon fuel
- High pressure containment (900 bar) or low temperature at -253 °C
- Wide flammability limit (04 - 75%) and low ignition energy (0.0011 mJ)
- High flame speed
- Permeability combined with LEL and ignition energy requires careful consideration
- High positive buoyancy – ventilation arrangements
- Boiling point of oxygen is -183 °C and nitrogen −195.79 °C
- Ideal reliquification of hydrogen is ~x12 greater than that of LNG

Batteries have an important role in energy load/ demand management onboard.

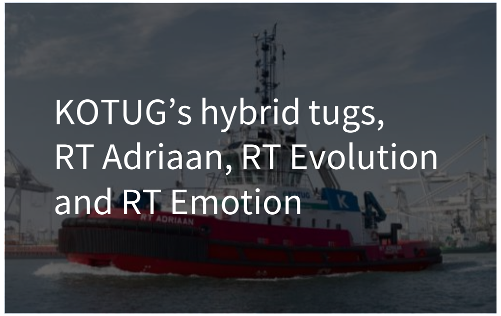
Variation in chemistry, design and construction

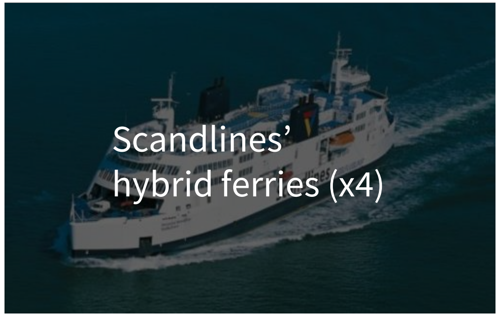
Performance degradation at adverse temperatures

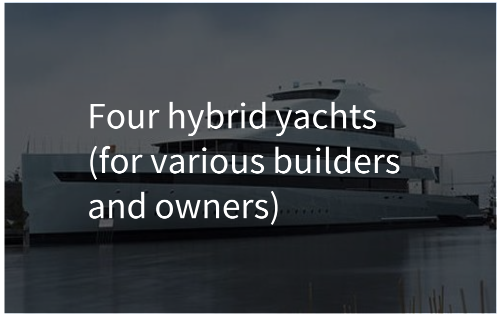
Thermal runway is a prominent failure mode

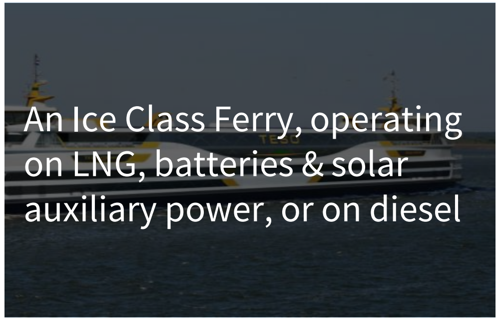
Venting of toxic flammable gas, fire and explosion risks

Delivered hybrid Li-ion battery systems.









Comparative energy equivalence.

LNG
Mass ~x0.8
Volume ~x2

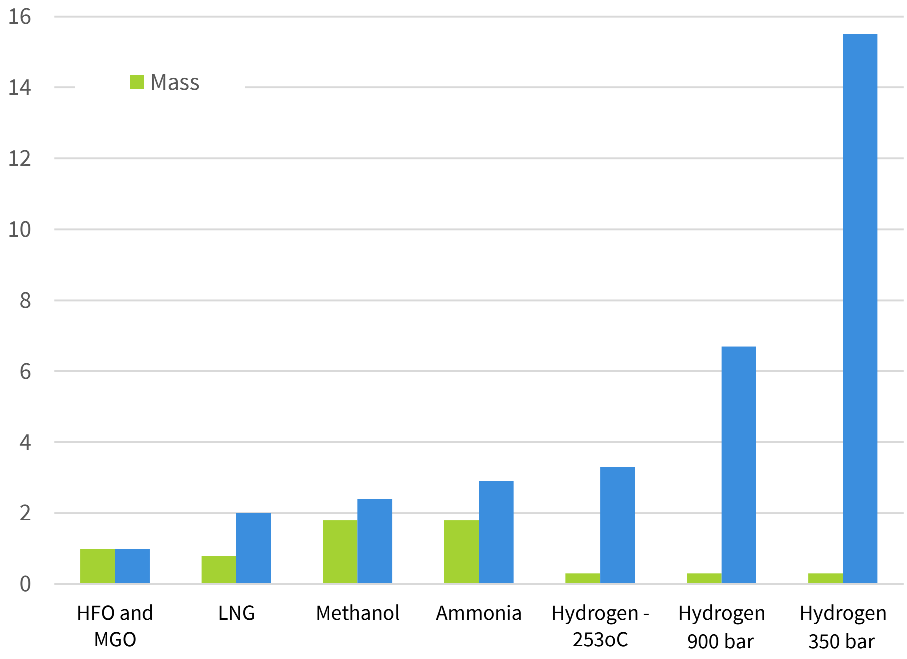
Methanol
Mass ~x1.8
Volume ~x2.4

Ammonia
Mass ~x1.8
Volume ~x2.9

Hydrogen 350 bar
Mass ~x0.3
Volume ~x15.5

Hydrogen 900 bar
Mass ~x0.3
Volume ~x6.7

Hydrogen -253 °C
Mass ~x0.3
Volume ~x3.3



IMO and Classification Policy.

Methanol

- LR Provisional Rules and Regulations
- IMO Initial Guidelines for Methanol
- Approved engines

Ammonia

- IMO not currently an agenda item
- IGC Code prohibits toxic *cargo*
- IGF Code: Goals, Functional Reqs.
- LR Cargo as Fuel rules (soon)

Hydrogen

- LR Guidance Notes for CH_2
- IMO not currently an agenda item
- MSC.420(97)
- IGF Code: Goals, Functional Reqs.

Li-Battery Systems

- LR Rules and Regulations, July 2019
- Li-Battery Type Approval Test Spec.

Fuel Cells

- Provisional Fuel Cell Test Spec.
- Draft Rules for Fuel Cell Systems

Hybrid Systems

- Currently under development

What next?

Compound knowledge.

- Local and global fuelling infrastructure
- Joint-Investment-Projects
- On board energy demand: eliminate and reduce
- Methanol, ammonia, compressed hydrogen
- Smaller goals compound to achieve the 2050 level of ambition

Pathfinder Projects.

	Project Purpose	Deliverable	LR Contribution
Stena Germanica	Reduction in exhaust emissions	Methanol powered vessel	Classification services and risk studies
CMB Hydroville	Zero on board emissions	Compressed hydrogen fuelled vessel	Classification services and risk studies
Viareggio Super Yachts	Commercialise fuel cell and LOHC	Hydrogen fuelled vessel	Approval in Principle and risk studies
HySEAS IIII	Zero emission vessel	Fuel Cell/Battery propulsion	Classification services and risk studies
MethaShip	Achieve Methanol integration	Normalising methanol as fuel	Allocation of SME
HyMethShip	Create a Methanol fuel life cycle	Demonstrable land based system	Facilitation of project and SME
proFLASH	Develop understanding	Methanol as fuel guidelines	Guiding the investigations
EMSA Ethyl/Methyl Alcohol	Life cycle analysis of methanol	Study on benefits and challenges	Co-authored the publication
PRESLEY	Closing hydrogen knowledge gaps	Theoretical and practical research	Guiding the investigations
LEANShips	Minimise emissions	Seven demonstration projects	De-risking by using the RBD process
ISHY	Integrate hybrid and fuel cell tech.	Develop a working business model	Facilitation of project and SME
HYDIME	Create a fuel life cycle infrastructure	Hydrogen fuelled vessel	Facilitation of project and SME
ASKO Hydrogen	Zero emission transportation	Hydrogen refuelling infrastructure	Quantitative Risk Assessment
Uno-X Hydrogen	Zero emission transportation	Hydrogen refuelling infrastructure	Quantitative Risk Assessment

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