MAN Energy Solutions
Future in the making

# Pathways to zero carbon shipping

*an engine designers perspective*

IMO-Singapore Future of Shipping Conference 2021

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23rd April 2021

# MAN ES in the aspect of Decarbonization

**~ 80%** of global freight is transported by sea.

Shipping is responsible for **~ 3 %** of the global CO2 emissions.

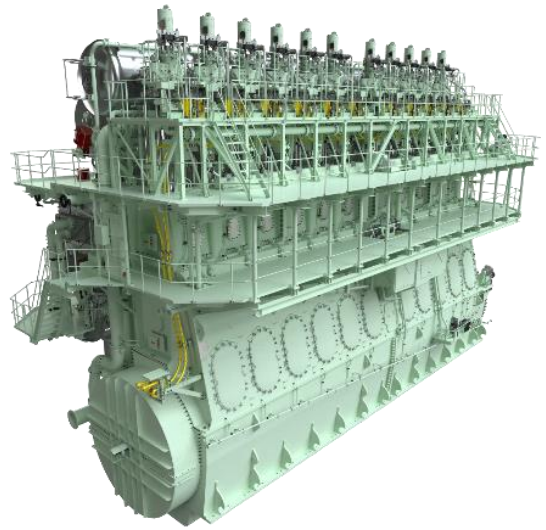
**~ 50 %** of global freight is transported by a MAN ES engine.

**We make an impact and are committed to drive the transition towards a carbon-neutral world together with our partners**

**Our corporate strategy revolves around Decarbonization and Digitalization**

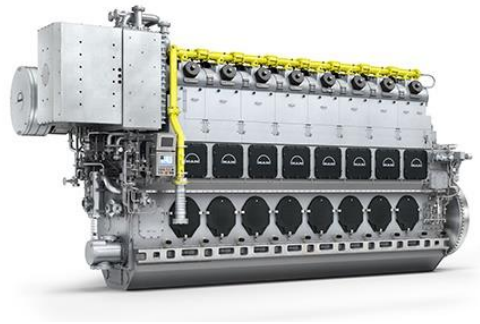
# Decarbonization – Threat or Opportunity?

Future Requirements for Propulsion Systems



## Key Market Requirements

- Life cycle cost efficiency (invest, fuel consumption, maintenance, …)
- Robustness / longevity under harsh operating conditions
  (incl. local variations in fuel spec.)
- Operational flexibility
  e.g. load dynamics, dual-/multi-fuel operation, blend-in fuels
- Retrofit possibility
  address existing fleet; future proof current investments
- Near-zero pollutant and greenhouse gas emissions
  Positive Life Cycle Assessment (LCA) from well to wake is a key enabler



⇒ **The piston engine is well prepared to meet future requirements**

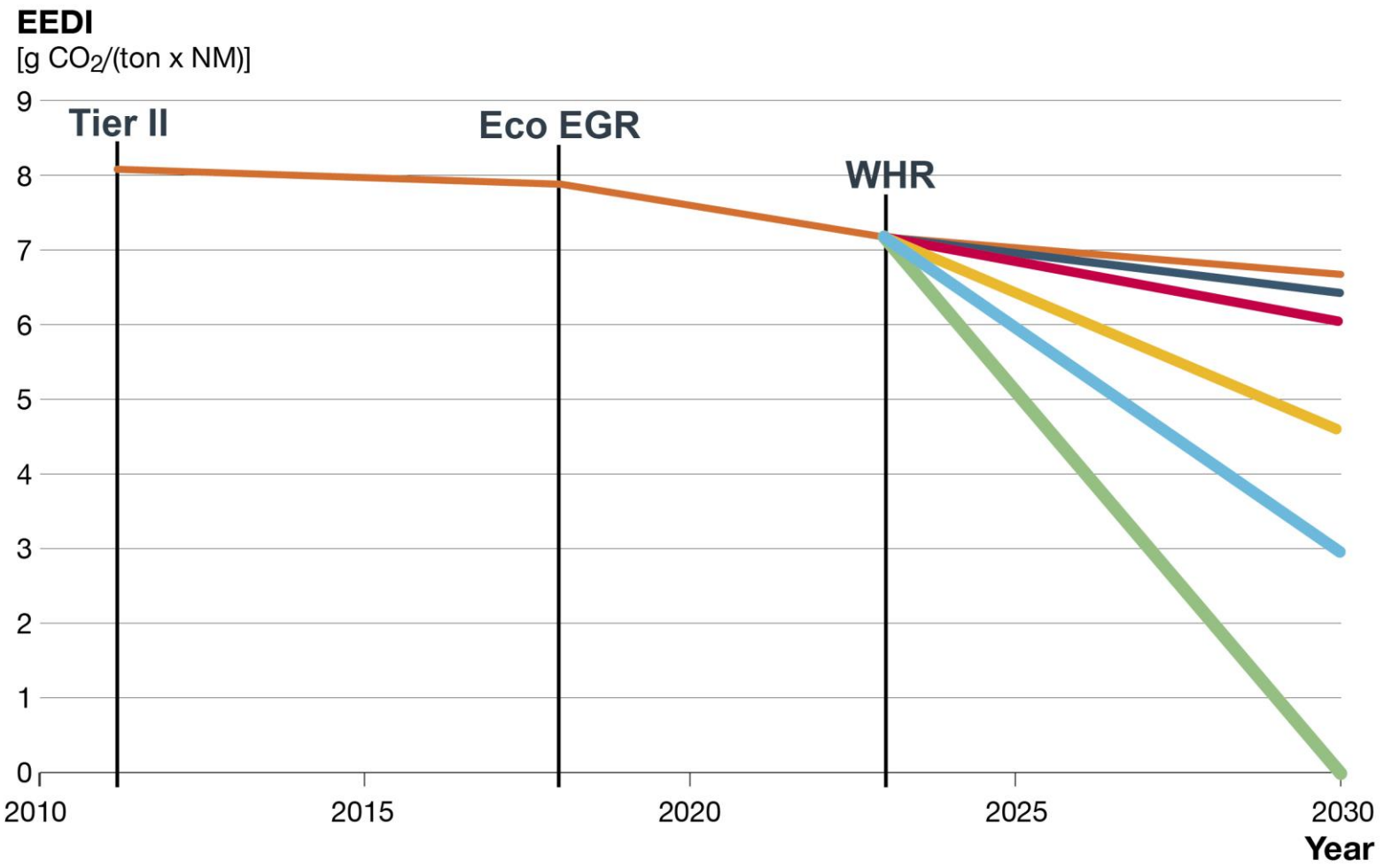
⇒ **Large amounts of renewable energy import needed for Europe & Northeast Asia**

⇒ **Should the most efficient way of transport be concerned about higher energy costs?**

**Mastering Fuel Complexity will be Key for Success**

# A pathway to low carbon emissions

EEDI for a 20,000 teu container vessel (example)




## Considerations

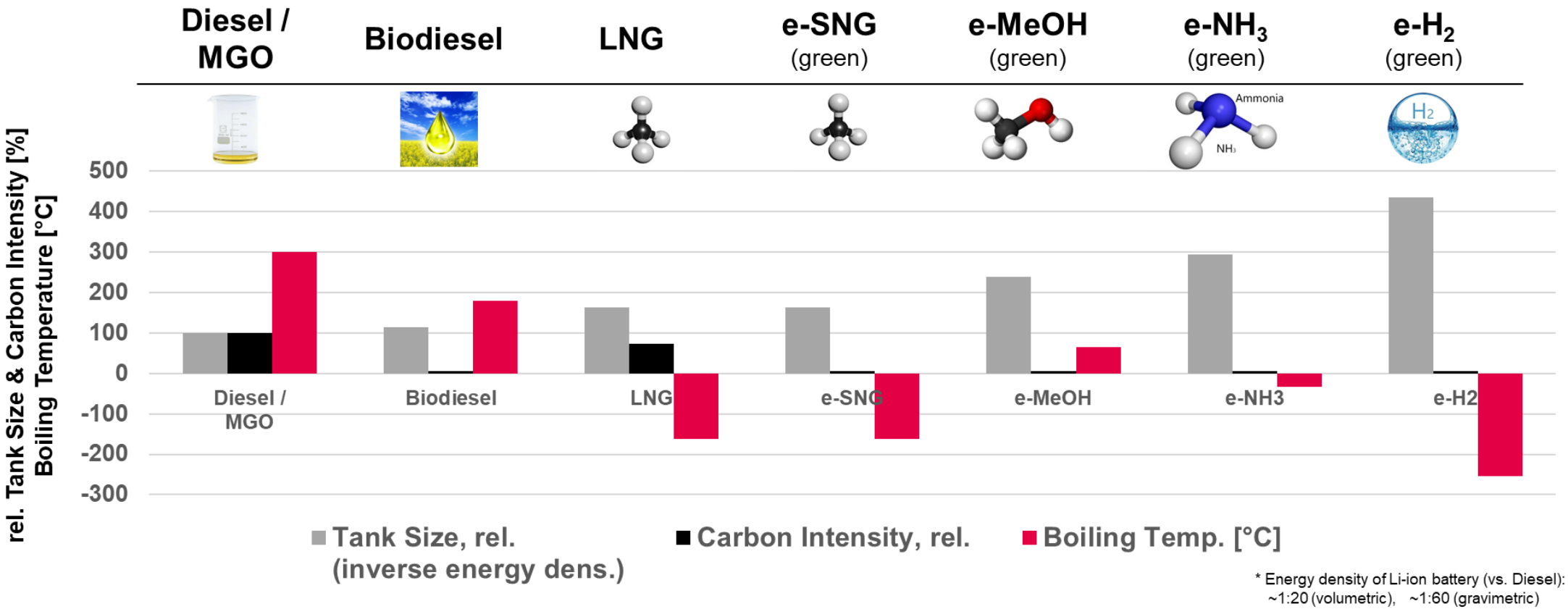
- Combination of technologies and operational measures needed to achieve low carbon emission
- New low carbon fuel types needed to close the gap

Machinery efficiency
+ PTO
+ Twin-screw
+ LNG
+ 20% speed reduction
Carbon free fuel ($H_2$, $NH_3$)

**Fuel choice important to reach near zero emissions.**

# Fuels Towards Carbon Neutrality

Alternative Future Fuel Options




* Energy density of Li-ion battery (vs. Diesel):
~1:20 (volumetric), ~1:60 (gravimetric)

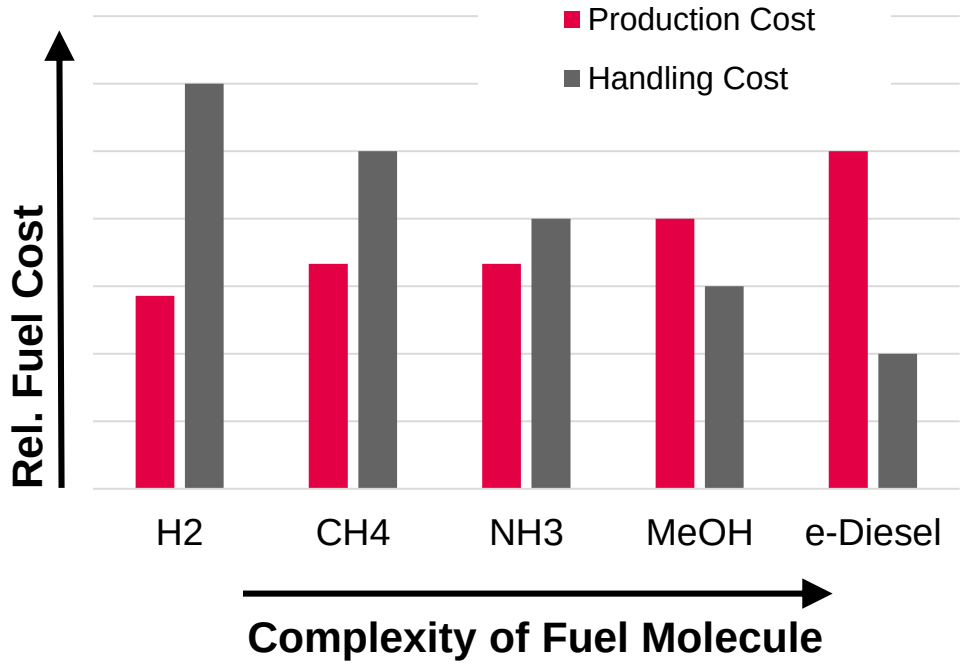
**The engine can burn it => Production cost, infrastructure and storage / handling are decisive.**

# Cost of Alternative Fuels (indicative figures)

E-Fuels: Production & Handling – Engine & Plant Cost

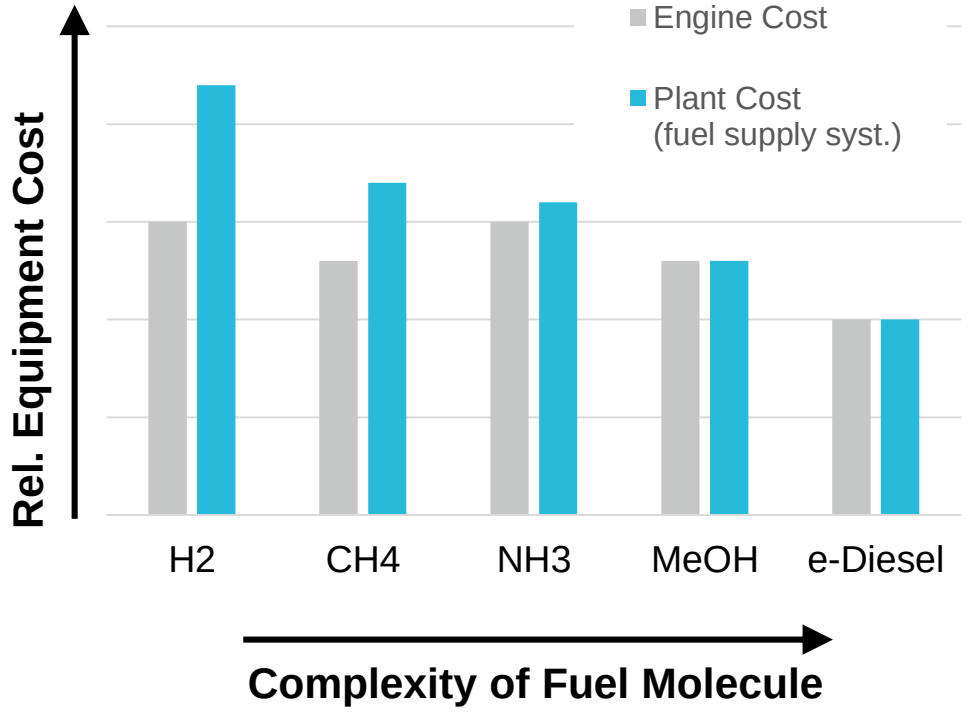
## e-Fuels: Fuel Production & Handling Costs

(indicative)



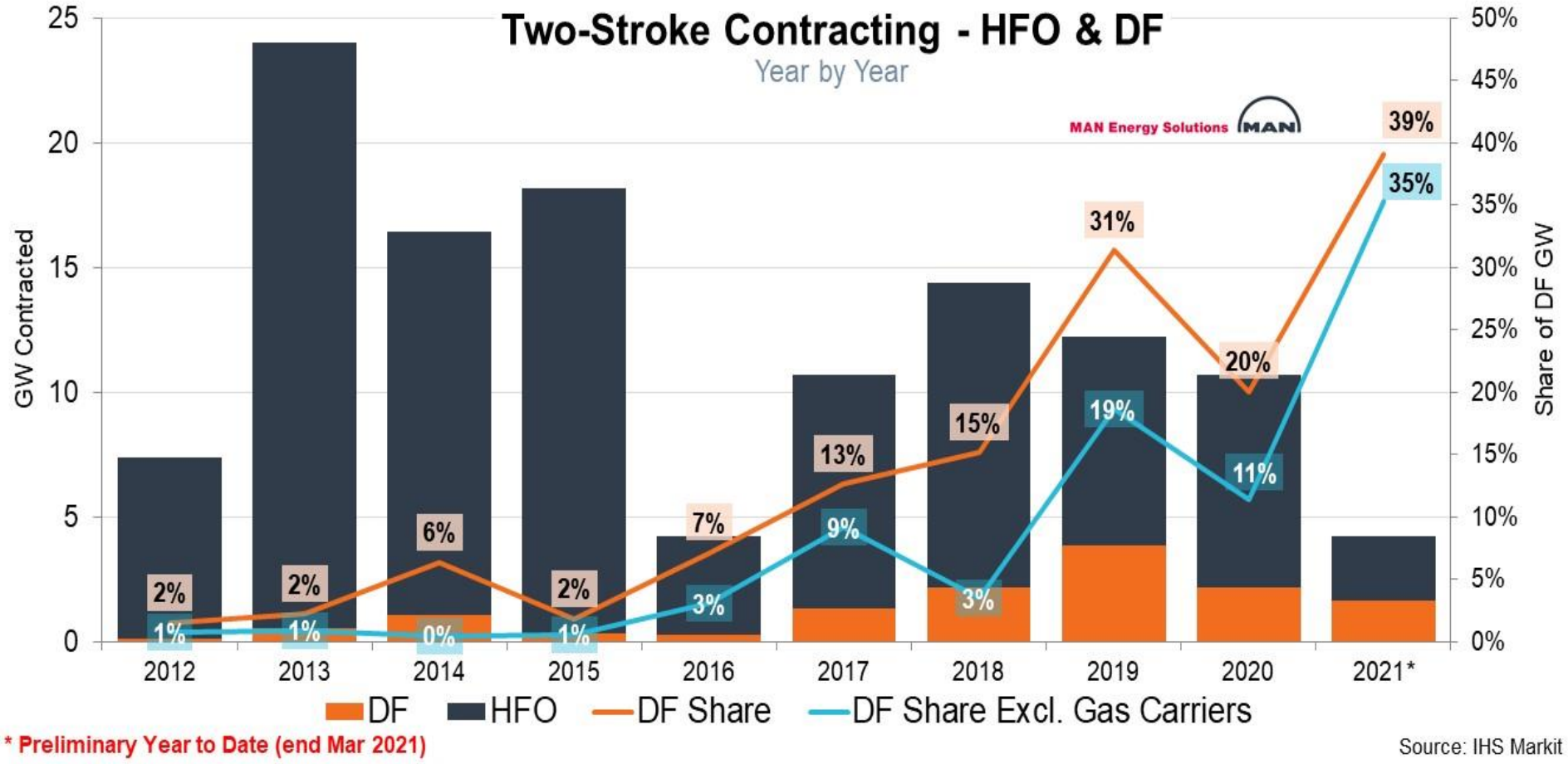

## Engine & Plant First Cost (Fuel Supply Syst.)

(indicative)




**The optimum e-Fuel will likely depend on vessel type, trade scheme and region – We have to expect a variety of fuels !**

# The Dual Fuel Transition has Started




- COVID19 might have accelerated the transition
- ~35% Dual Fuel share in new order intake, mainly driven by LNG
- Fossil LNG with 5…20% greenhouse gas benefit compared to diesel fuel (incl. $CH_4$-slip)
- Important as first step and bridging technology
- Subsequent drop-in of green synthetic Methane or retrofit to e.g. MeOH or $NH_3$

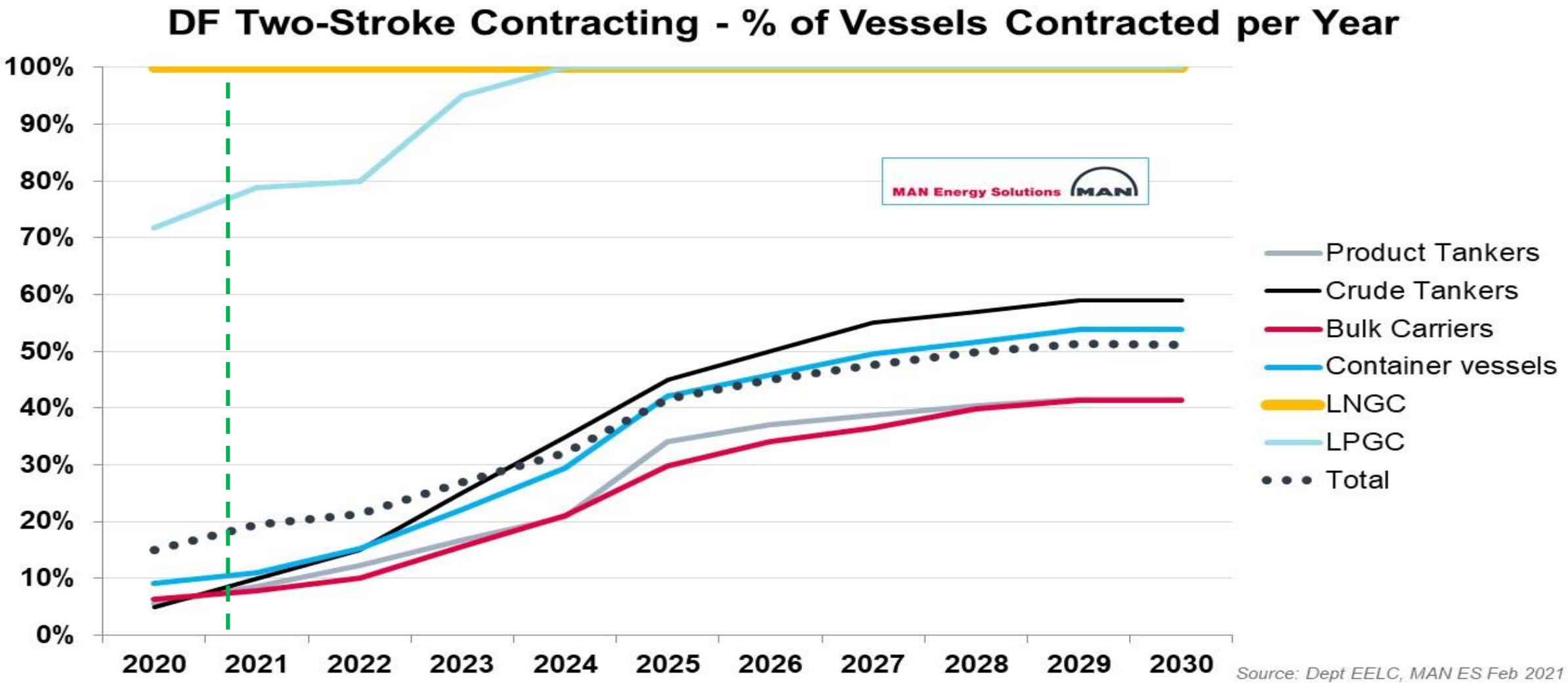
**The Maritime Energy Transition is gaining momentum.**

# Dual-fuel engine reference

April 2021 – MAN ES perspective

| Fuel | Engine type | Number of engines | | Stroke | Bore | Total engines ordered | Engines in service |
|---|---|---|---|---|---|---|---|
| LNG | ME-GI | 249 | 22 | G | 95 | 374 | 158 |
| | | | 3 | S | 90 | | |
| | | | 25 | G | 90 | | |
| | | | 17 | G | 80 | | |
| | | | 2 | S | 80 | | |
| | | | 4 | S | 70 | | |
| | | | 151 | G | 70 | | |
| | | | 2 | L | 70 | | |
| | | | 8 | G | 60 | | |
| | | | 3 | S | 60 | | |
| | | | 9 | S | 50 | | |
| | | | 1 | G | 50 | | |
| | | | 2 | G | 45 | | |
| Methanol | ME-LGIM | 23 | 20 | G | 50 | | |
| | | | 3 | S | 50 | | |
| Ethane | ME-GIE | 23 | 16 | G | 60 | | |
| | | | 3 | G | 50 | | |
| | | | 4 | S | 50 | | |
| LPG | ME-LGIP | 79 | 57 | G | 60 | | |
| | | | 7 | S | 60 | | |
| | | | 9 | G | 50 | | |
| | | | 6 | S | 35 | | |

# Dual Fuel uptake forecast




**The Maritime Energy Transition is segment dependent**

# 2S Modular & Future Proof Design

## Built-in Fuel Flexibility - A Necessity

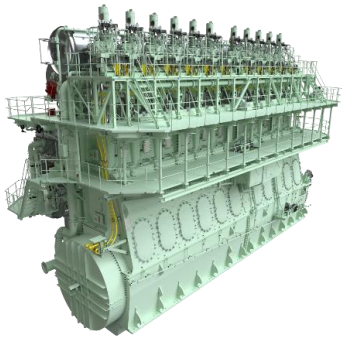
| Fuel types | MC | ME-B | ME-C | ME-GI | ME-GA | ME-GIE | ME-LGIM | ME-LGIP |
|---|---|---|---|---|---|---|---|---|
| 0-0.50% S VLSFO | Design | Design | Design | Design | Design | Design | Design | Design |
| High-S HSHFO | Design | Design | Design | Design | Design | Design | Design | Design |
| LNG | - | - | Retrofit*** | Design | Design | Retrofit*** | Retrofit*** | Retrofit*** |
| LEG (Ethane) | - | - | Retrofit*** | Retrofit*** | - | Design | Retrofit*** | Retrofit*** |
| Methanol / Ethanol | - | - | Retrofit** | Retrofit** | - | Retrofit** | Design | Retrofit** |
| LPG | - | - | Retrofit** | Retrofit** | - | Retrofit** | Retrofit** | Design |
| Biofuels | Design | Design | Design | Design | Design | Design | Design | Design |
| Ammonia**** | - | - | (Retrofit**) | (Retrofit**) | - | (Retrofit**) | (Retrofit**) | (Retrofit**) |

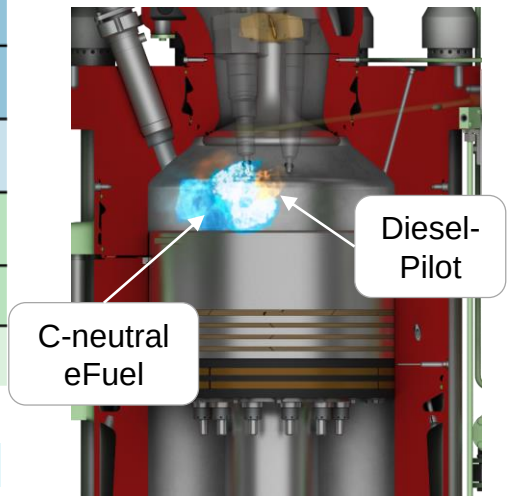
Fuel by original design of type

** One second fuel per retrofit

*** Both LNG and LEG

**** development started







World's 1st **LNG** driven container vessel

World's 1st **MeOH** driven vessel

World's 1st **Ethane** driven vessel

World's 1st **LPG** driven vessel

# Two-Stroke Ammonia Engine Development

## Development Schedule

### 2019

**Pre-study**

- ✓ NH3 combustibility investigation

### 2020

**Project kick-off**

- ✓ 4T50ME-X test engine received as platform for the Ammonia engine development
- ✓ HAZID workshop on engine concept
- ✓ Combustion chamber 1st evaluation

### 2021

**Engine concept R&D**

- ✓ Engine basic concept defined based on R&D and simulations
- Ammonia fuel supply & Auxiliary systems specified and established in Research Centre Copenhagen (RCC)

### 2022

**Engine combustion and emission**

- 1st engine confirmation at Research Centre Copenhagen (RCC)
- Specification of emission after-treatment done

### 2023

**Full scale engine test**

- Full scale engine test at Research Centre Copenhagen (RCC) evaluated for 1st commercial design

### 2024

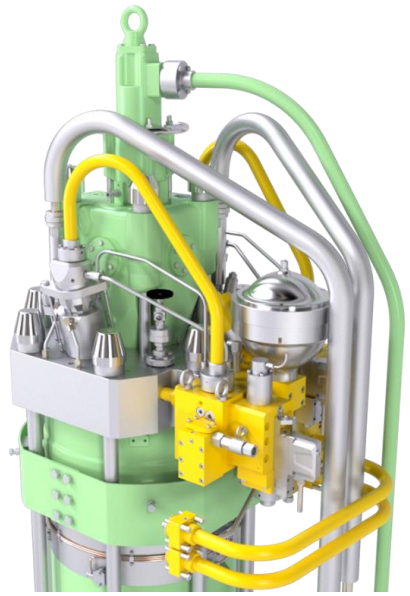
**1st engine delivery to yard**

- Ammonia engine in engine programme
- 1st ammonia fueled engine delivered to shipyard

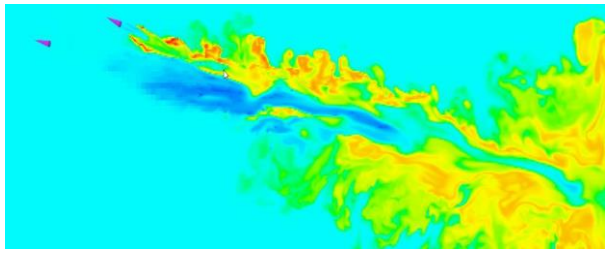
# Two-Stroke Ammonia Engine Development

## Status – April 2021

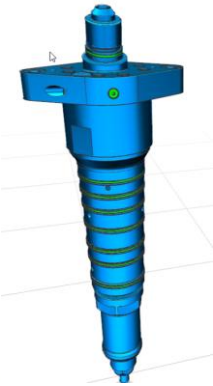
- Detailed feasibility investigation on ammonia combustion completed. Small scale test with Technical University of Denmark is in progress.
- Emission abatement investigation is in progress together with Danish- and foreign universities and SCR manufactures.
- Concept for ammonia injection system is complete and material is clarified.
- Ammonia supply-, purge- and venting system concept is complete and design is in progress by external partner based on MAN ES specification.
- Preparation for the first test running with ammonia combustion in a 2-stroke marine engine is under preparation at MAN ES Research Center Copenhagen
- Safety concept is developed in cooperation with marine classification societies



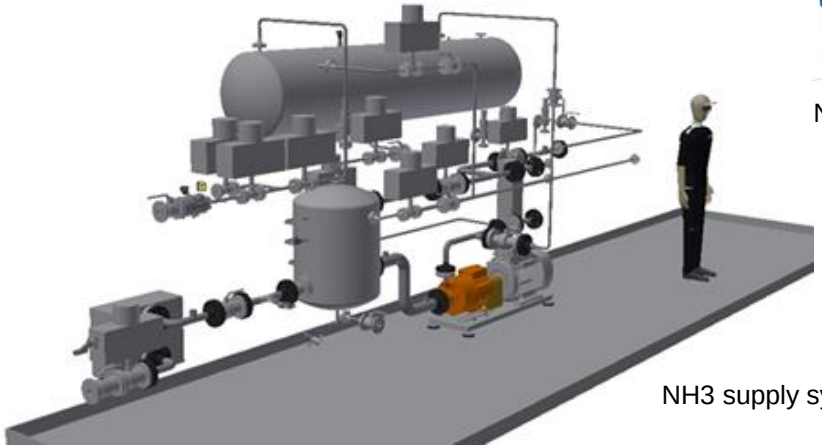
NH3 injection system



Combustion simulation



NH3 booster injector



NH3 supply system

# Summary

Decarbonizing Large Bore Engines

- The **low carbon vessels** of tomorrow must be **commercial viable**
- Alternative **fuel selection not obvious –** optimum depends on application
- **Fuel flexibility** and **retrofit options** are decisive!
- **Natural gas (LNG) is available now** – both engine technology and infrastructure
  - ⇒ Low pollutant emissions ($NO_x$, $SO_x$, BC / particulates)
  - ⇒ Positive GHG impact already with fossil NG, C-neutral with SNG
  - ⇒ $CH_4$-slip substantially cut-down, further reductions in the pipeline
  - ⇒ Smooth, incremental transition by renewable drop-in fuels (PtX)
- **Methanol, ammonia, hydrogen** as future fuels with zero carbon potential
- **$CO_2$ -pricing** to drive decarbonization – must be **Globally Harmonized**
- It is an **industry challenge** and requires global collaboration

# Disclaimer

All data provided in this document is non-binding.
This data serves informational purposes only and is especially not guaranteed in any way.
Depending on the subsequent specific individual projects, the relevant data may be subject to changes and will be assessed and determined individually for each project. This will depend on the particular characteristics of each individual project, especially specific site and operational conditions.

# Whatever your vessel – we have a fuel solution that fits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