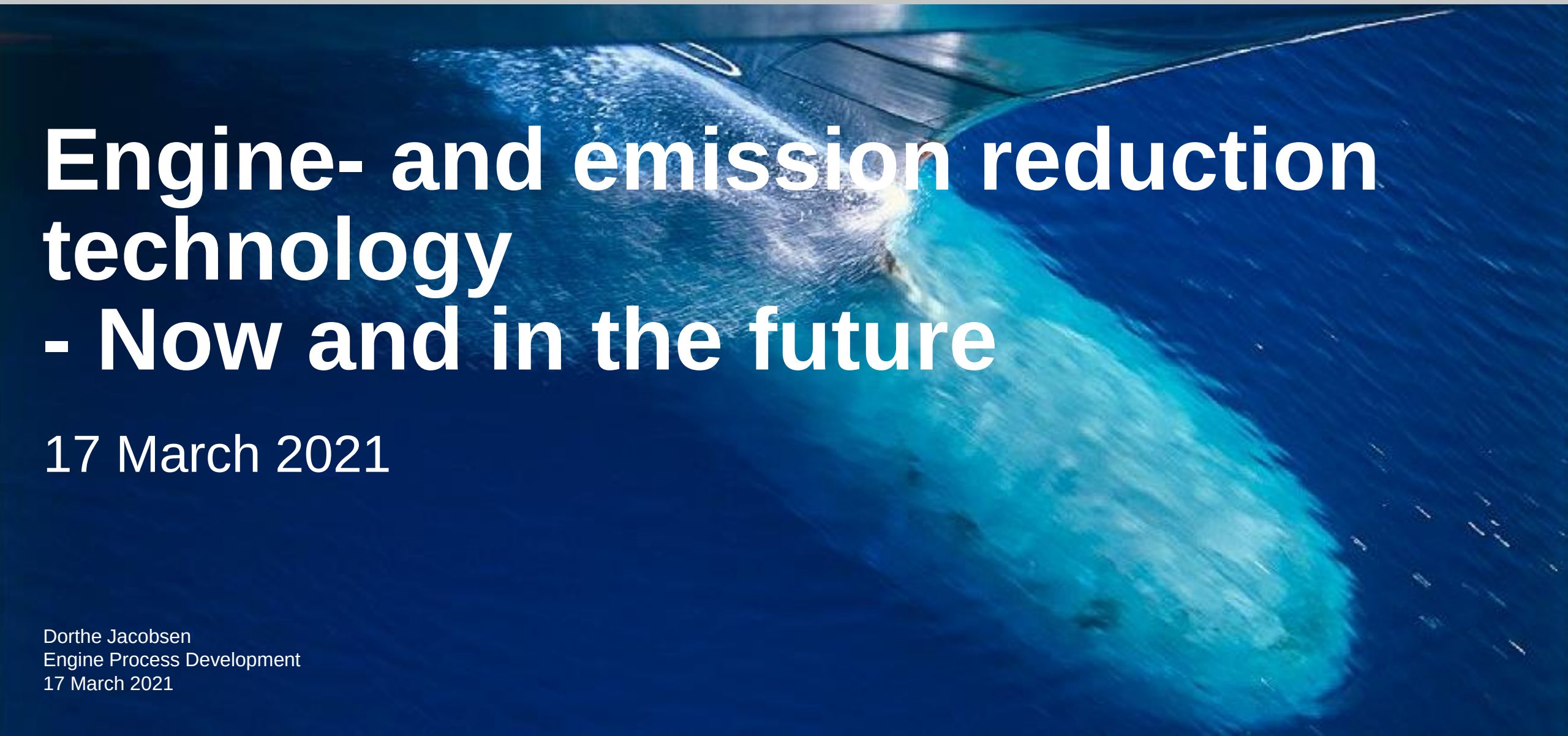
MAN Energy Solutions
Future in the making



Engine- and emission reduction technology - Now and in the future

17 March 2021

Dorthe Jacobsen
Engine Process Development
17 March 2021

Agenda

1 **Our business in a global context**

2 **Future fuels**

– MAN B&W Two-stroke – Multi fuel engines

3 **Drivers for change**

4 **Future emission regulation in marine**

1 Our business in a global context

Our Business in a Global Context

United Nations Climate Change

13 CLIMATE ACTION

Paris Agreement

UN Sustainable Development Goals

INTERNATIONAL MARITIME ORGANIZATION

IMO Initial GHG Strategy (13 April 2018):

Goals for International Shipping:

- Reduction of CO_2 **per transport work**: min. **40% by 2020** towards min. **70% in 2050***
- GHG emissions to **peak as soon as possible**
- Reduction the **total annual GHG** emissions by **min. 50% by 2050***

*) Compared to 2008

MAN Energy Solutions

Our marine engines for large ships

≈ 1.5 % of world's CO_2

We take responsiblity to reduce climate impact!

Focus Areas – 2030 / 2050

Focus -> 2030

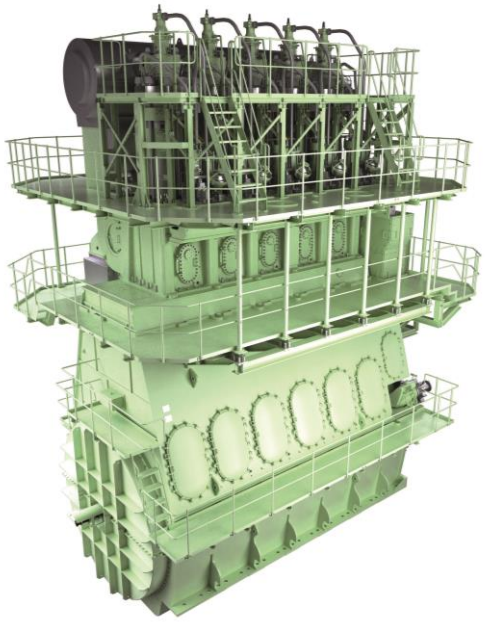
- Implemention of energy efficient technologies
- Further develop fuel flexible engines

Focus -> 2050

- Implementation of net-zero carbon fuels

Need for drivers!

Fuel Type	MAN ES 2-Stroke	MAN ES 4-Stroke
Diesel/ Heavy fuel	X	X
LNG	X	X
LEG (Ethane)	X	
Methanol	X	(*)
LPG	X	(*)
Biofuels	X	X
Ammonia (NH_3)	(X)	(*)
Hydrogen		(*)



(X): Under development. Product: 2024

(*): R&D testing

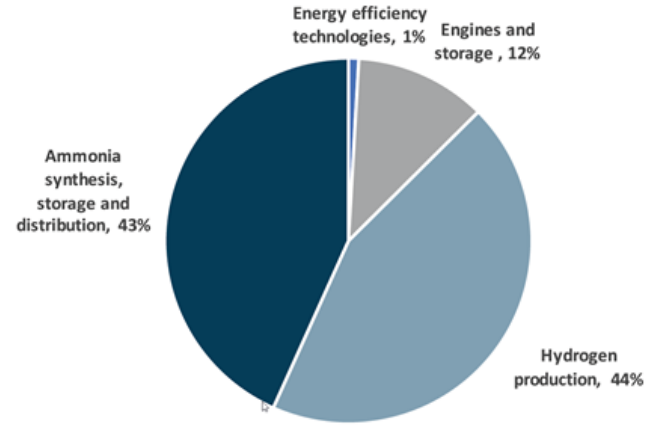
The way to zero carbon shipping

At least 50% GHG reduction in 2050 requires:

- Drivers (regulatory and/or economical)
- Major investments in energy/fuel production (upstream)
- Funding: Research, development and demonstration
- Cross-sectoral cooperation projects
- LCA approach to ensure net-GHG reduction
- **Implementation of new fuels to start by 2030 - preferably sooner**

Work should start now - and we all have our roles

Investment breakdown across vessels and land-based infrastructure*



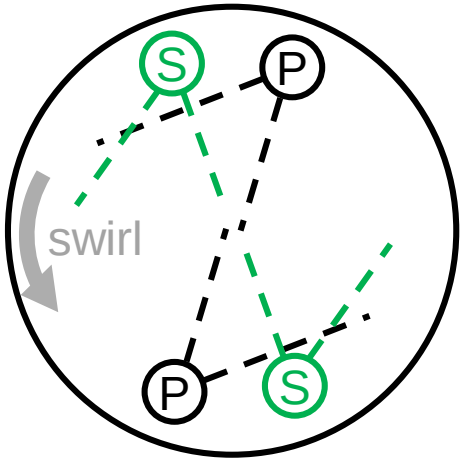
Life Cycle Analysis

*) Getting to Zero Coalition: https://www.globalmaritimeforum.org/news/the-scale-of-investment-needed-to-decarbonize-international-shipping/

2 MAN B&W two-stroke – multi fuel engines

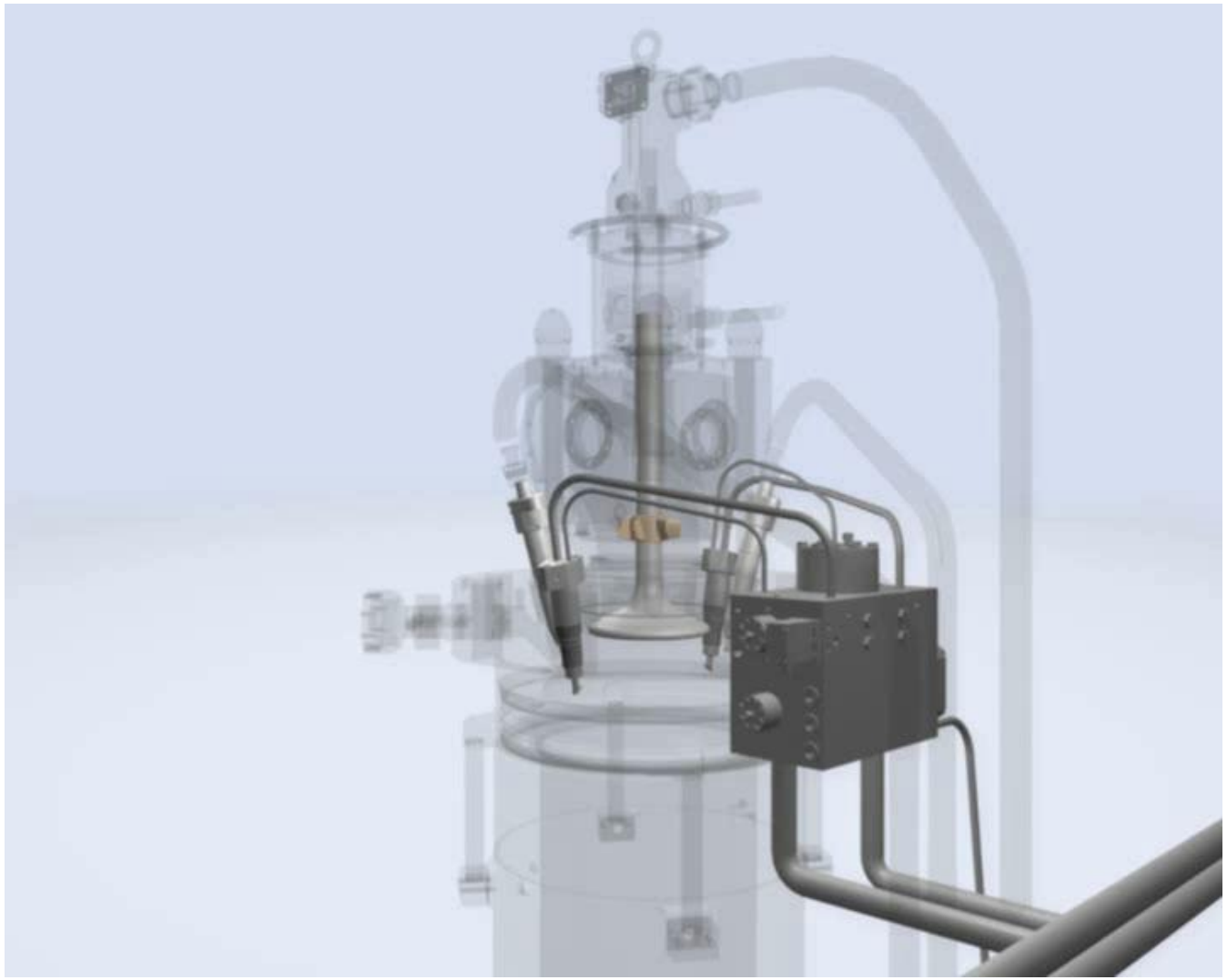
Dual fuel engines

Engines capable of operating on conventional HFO / Diesel and an additional fuel through a separate fuel injection system.



P Diesel injector for pilot injection

S Second fuel injector



MAN B&W Two-Stroke – Multi fuel Engines

Historical timeline

2011 – Engine delivery for TOTE Maritime

2012 – Engine delivery for TEEKAY LNG

2013 – ME-GI retrofit for Nakilat

2015 – 1st sea trial on methanol

2016 – 1st sea trial on ethane

2017 – First order of MAN B&W 6G60ME-LGIP engines by Exmar

2018 – 4 x MAN B&W ME-LGIP Retrofit orders for BW LPG. Dry dock 2020

2019 – Hapaq Lloyd 9S90ME-C ME-GI retrofit. Dry dock 2020

2011 – ME-GI test at RCC

2012 – ME-GI demonstration test at HHI

2013 – ME-GI demonstration test at MES

2015 – Development of ME-LGI

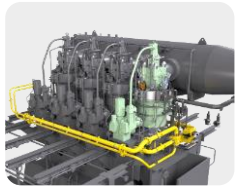
2016 – Ethane development

2017 – ME-GI/E PVU at RRC

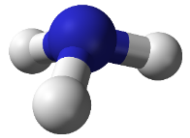
2018 – LPG tightness- & function test at RCC

2019 – LGIP cylinder installed on research engine at RCC

2020 – ME-GA test at RCC



2023/24 – Ammonia burning engine



MAN B&W engines for different fuels

Modular design enables extensive retrofit options, and MAN Energy Solutions future proof your investment

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	Design	Retrofit**	Retrofit**
LEG (Ethan)	-	-	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**)

*Otto-cycle gas engine.
**Only one second fuel per retrofit.
*** Ammonia burning engine development started.

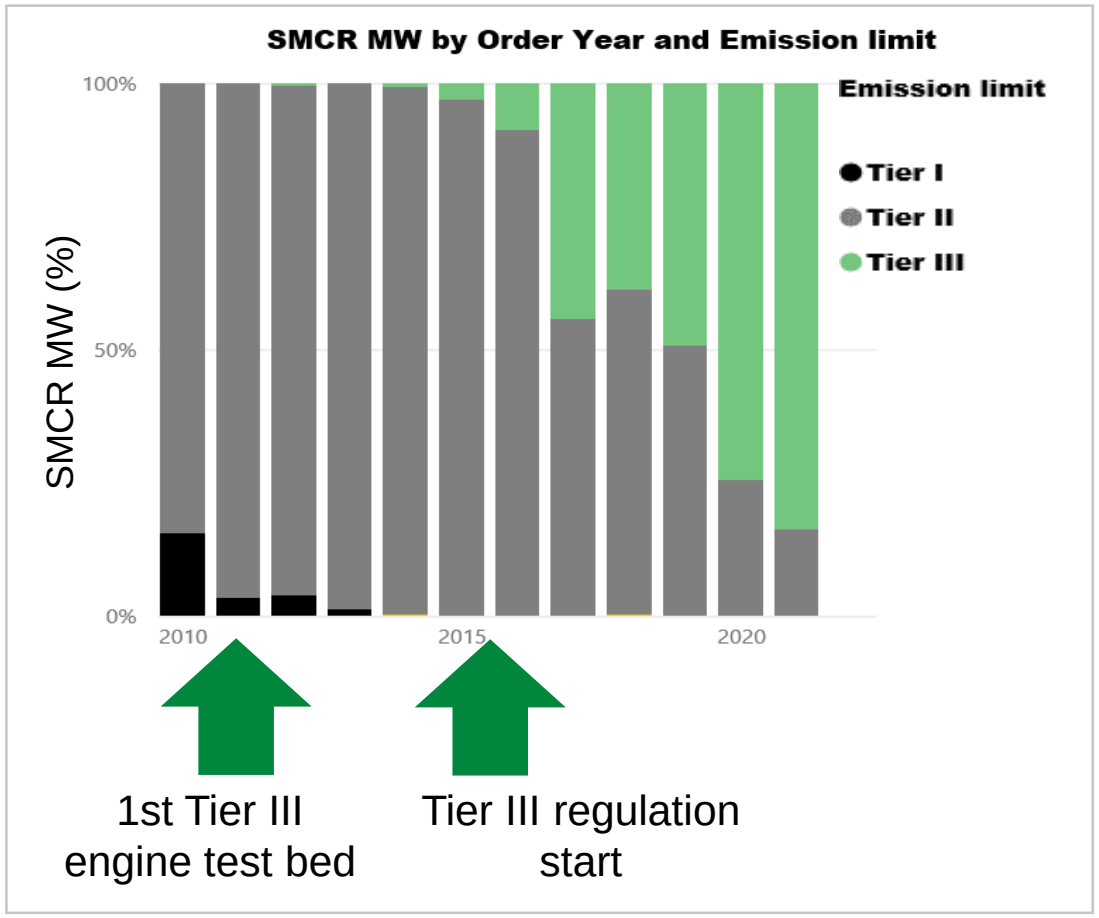
For description of MAN ES 2-stroke engine types:
https://marine.man-es.com/two-stroke/2-stroke-engines/overview

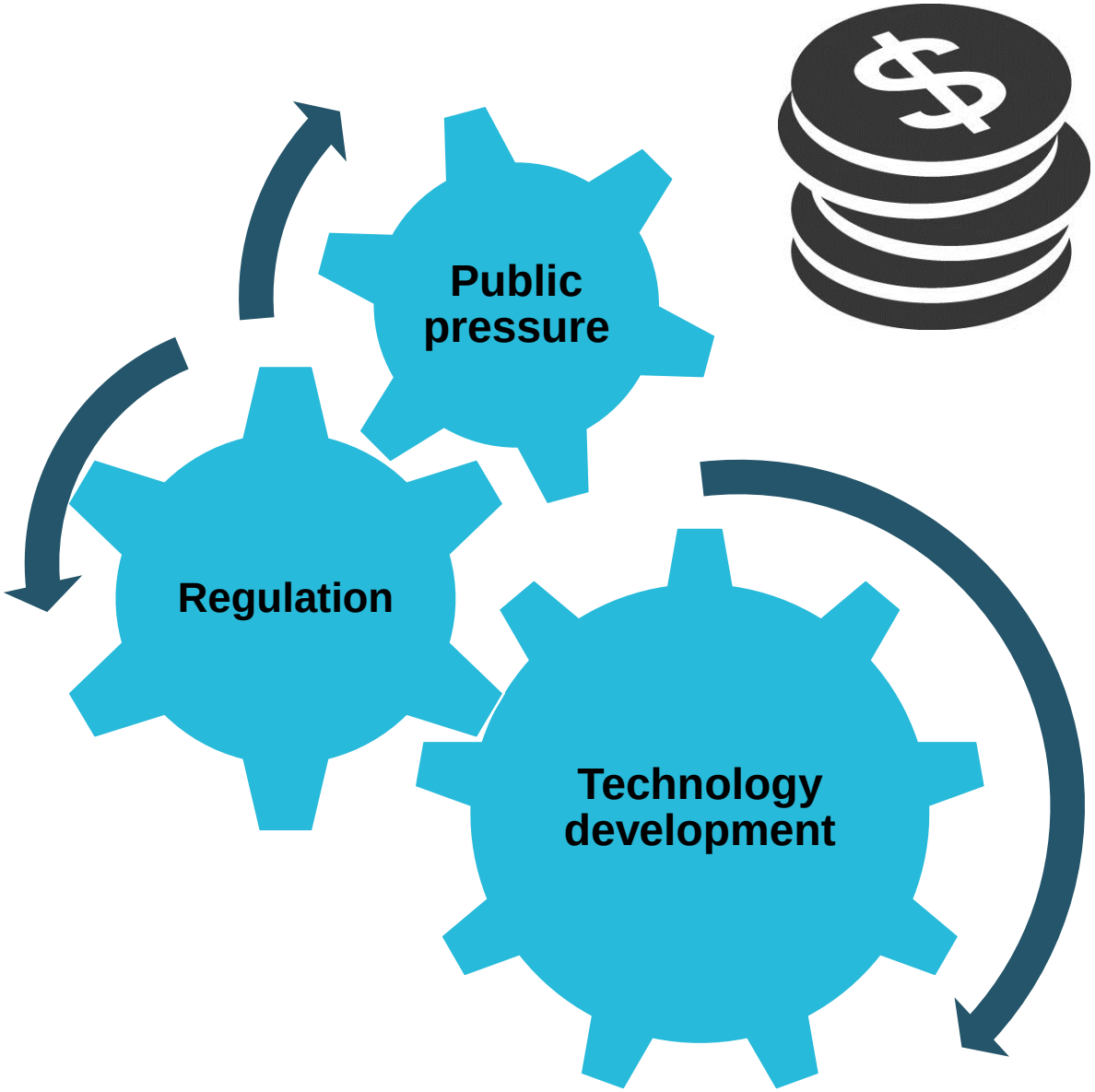
3 Drivers for change

Drivers for change

Public pressure + Regulation + Technology development

Market introduction: NOx reduction technology





Marine fuels: 2021 -> 2030 -> 2050

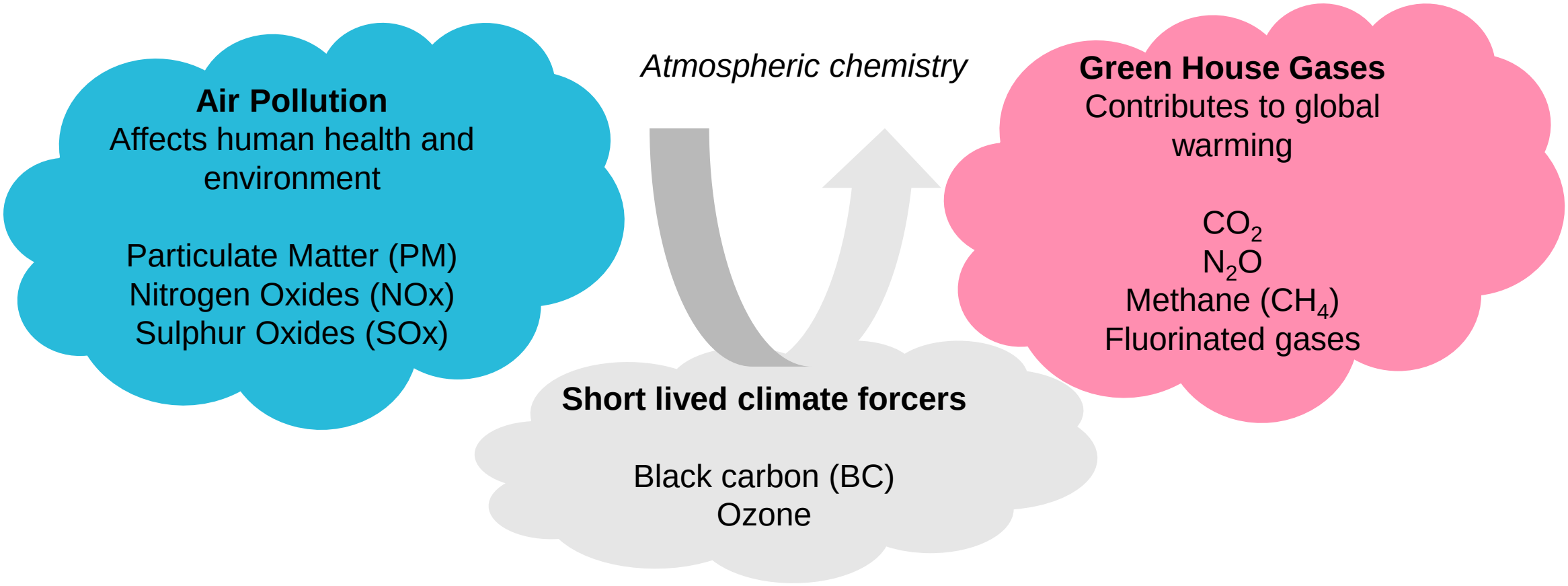
Green: Good
Red: Major challenge

Current status for different fuel types

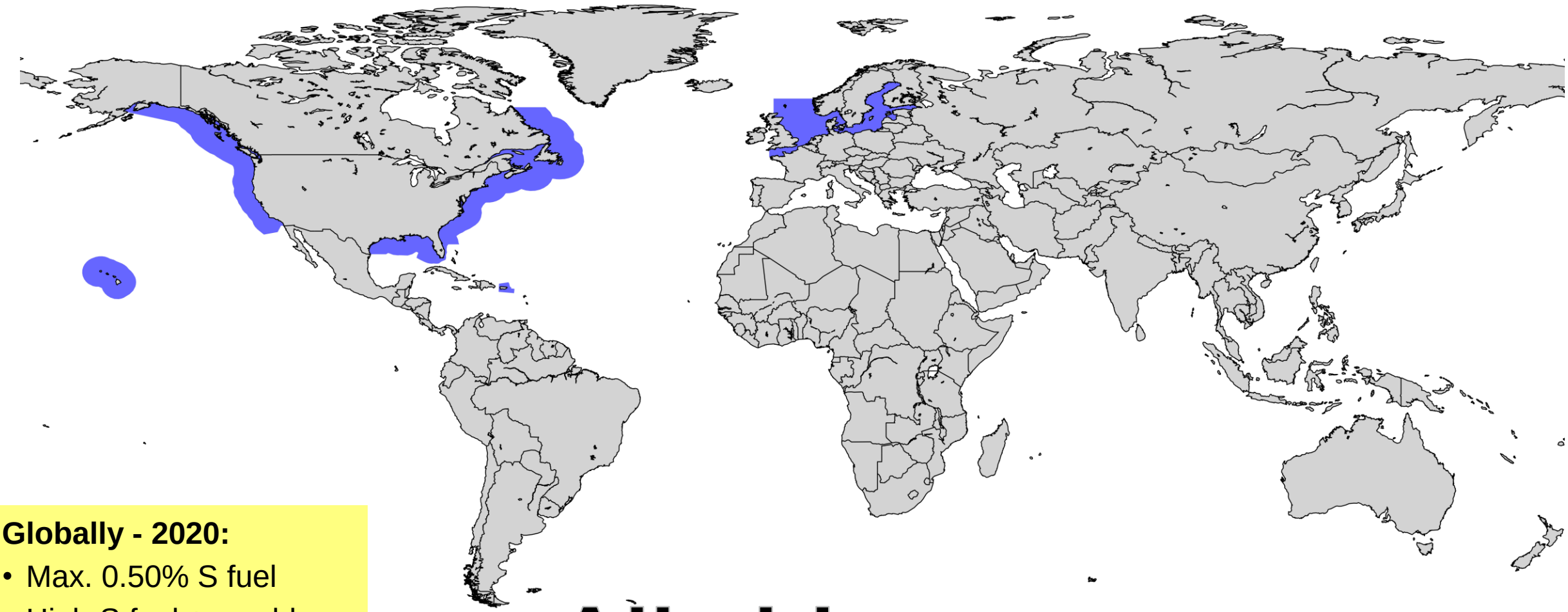
Fuel Type	Fuel production	Price	Availability	Competences in the marine industry	Regulation	Safety		Environment		
						Toxicity	Flamability	GHG		NOx, PM, SOx, BC
								Fuel production	On the ship	
0.10%S ULSFO	Fossil									
	Bio									
	PtX									
0.50 %S VLSFO	Fossil									
	Bio									
	PtX									
High-S Heavy fuel	Fossil									
LNG	Fossil									
	Bio									
	PtX									
Methanol	Fossil									
	Bio									
	PtX									
LEG (Ethane)	Fossil									
LPG	Fossil									
Ammonia (NH_3)	Fossil									
	Bio									
	PtX									
Hydrogen	Fossil									
	Bio									
	PtX									

4 Future regulation in marine

What is Air Pollution?



SOx Emission Controlled Areas (SECA)



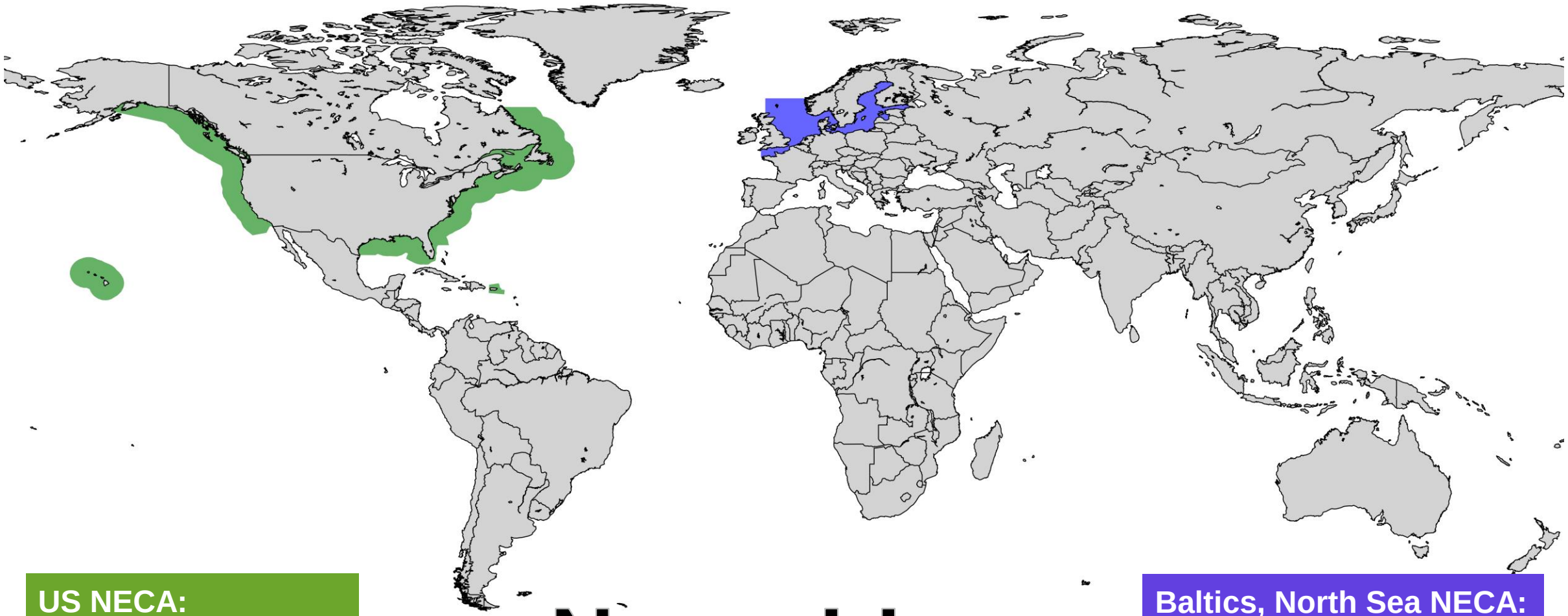
Globally - 2020:
- Max. 0.50% S fuel
- High-S fuel + scrubber

SECA: max. 0.10% S fuel

All ships

China: Max. 0.10% S fuel in parts of inland waterways

NOx Emission Controlled Areas (NECA)

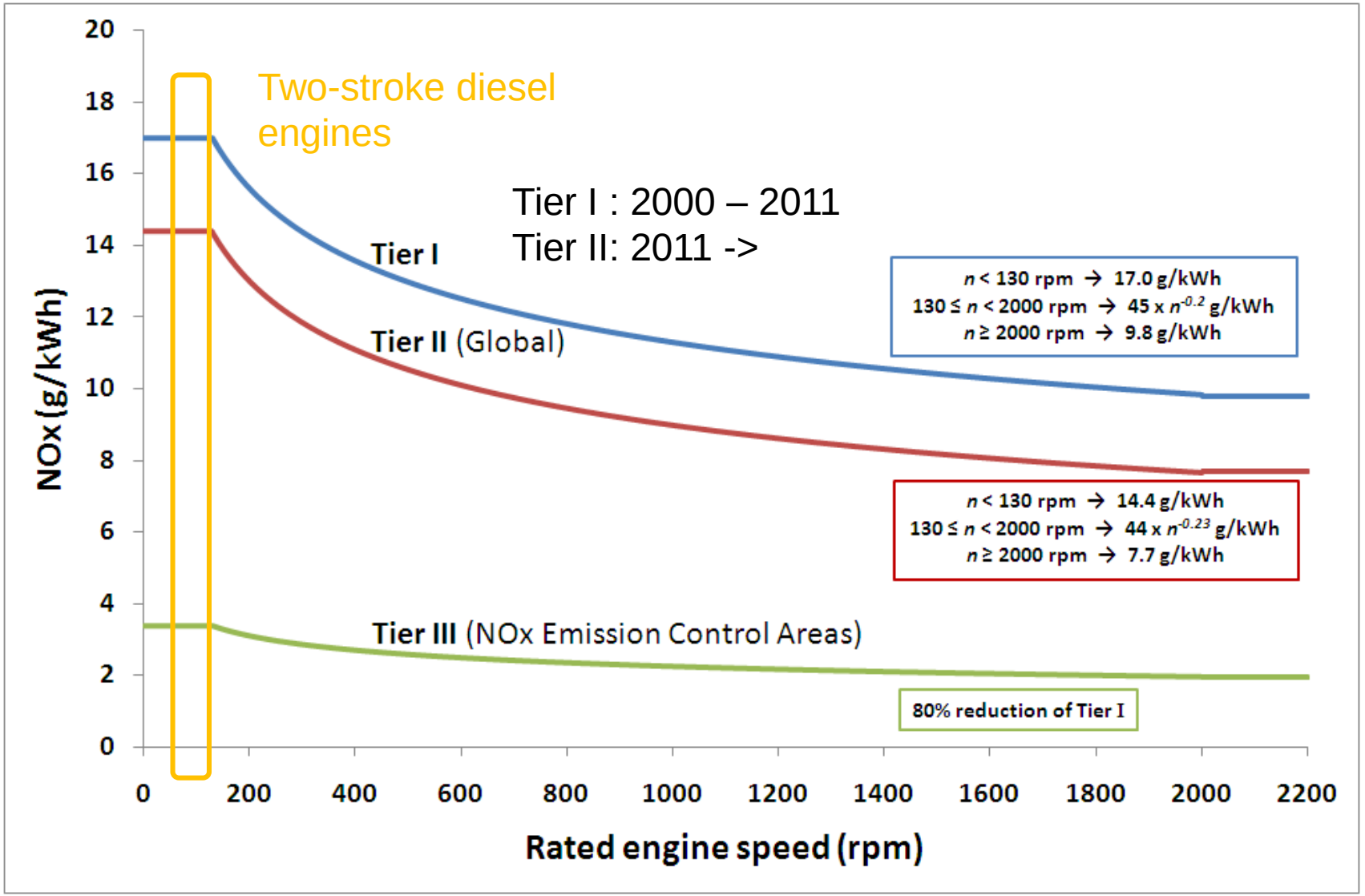


US NECA:
Vessels with keel laid as of 1st January **2016**

New ships

Baltics, North Sea NECA:
Vessels with keel laid as of 1st January **2021**

IMO NO_X regulation



NOx limits

For two stroke engines

Tier II

- 14.4 g/kWh (cycle)

Tier III

- 3.4 g/kWh (cycle)
- 5.1 g/kWh (Not to Exceed)

NOx Tier III technology overview

Fuel types

	Technology				
Fuel type	**EGR**	**HP-SCR**	**LP-SCR**	**LGIM-W**	***PIWIF****
ULSFO-DM					
ULSFO-RM					
VLSFO					
HS-HFO					
LNG (ME-GI)					
LNG (ME-GA)					
MeOH					
Ethane					
LPG					
NH_3					

** Under development*

Possible Future Regulation of Air Emissions

Trends pointing towards stricter regulation

Concern about poor air quality

– Poor air quality impacts human health and the environment

– Shipping contributes to air pollution in ports/coastal areas

Technological possibilities for further reduction

– New technology / fuels offers possibilities for further reduction of emissions

Focus “real life emissions”

– Automotive sector is facing regulation of “real driving emissions” of NOx

– Continuous emission monitoring applied in other sectors

Possible Future Regulation of Air Emissions

A look in the crystal ball...

Currently, IMO is focusing on GHG discussions

New IMO regulation of SOx, NOx, PM/BC not likely in a ≈ 5 year time frame

Issues that IMO may address in a ≈ 5 year time frame

– Methane slip

– (?N_2O?)

– Ammonia slip

– Continuous monitoring of NOx

EU is considering local regulation

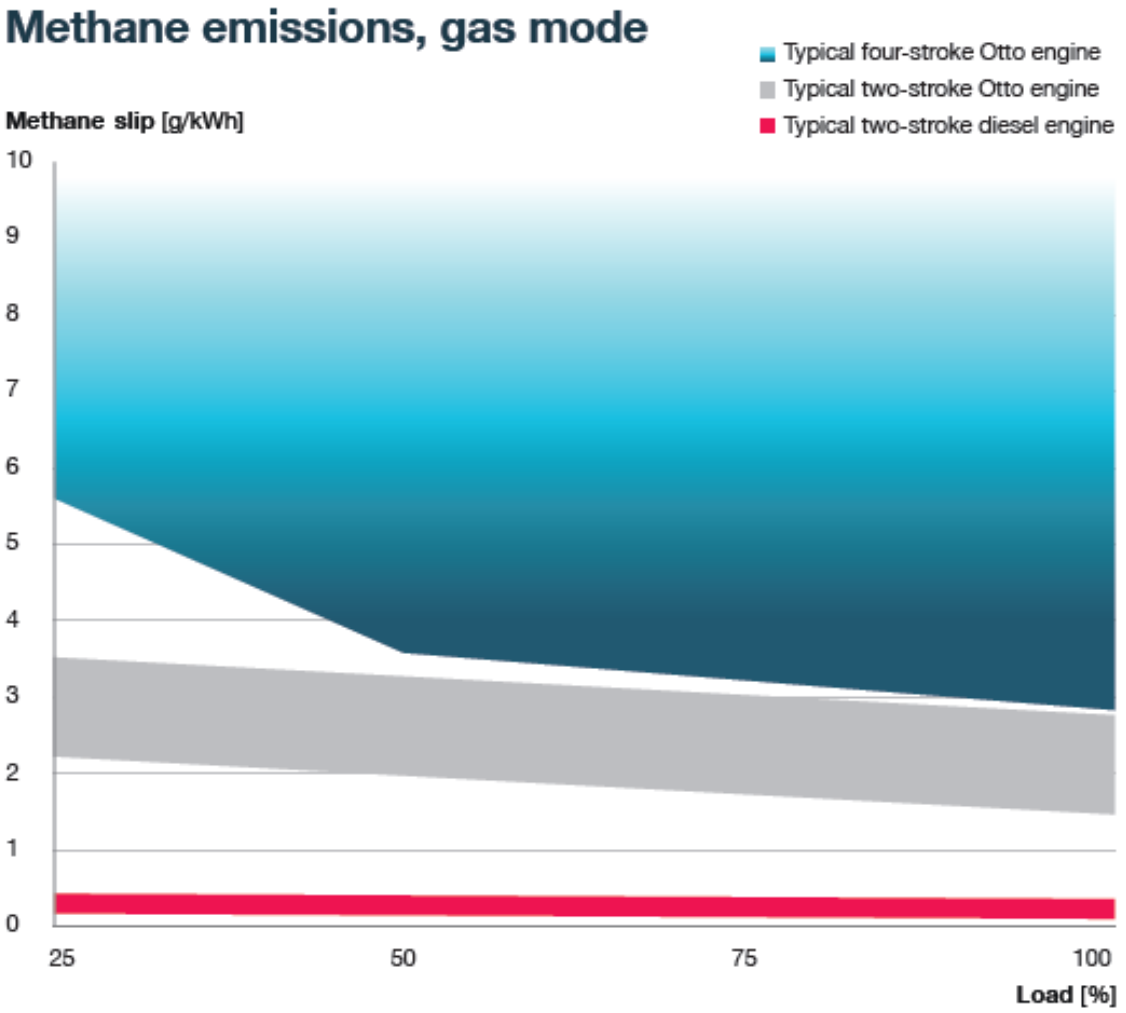
– New SOx (NOx) ECA's in the Mediterranean

– Local restriction of most polluting ships (in ports)

– Promotion of shore-side electricity

Methane (CH_4) slip

https://www.man-es.com/marine/campaigns/methane-slip

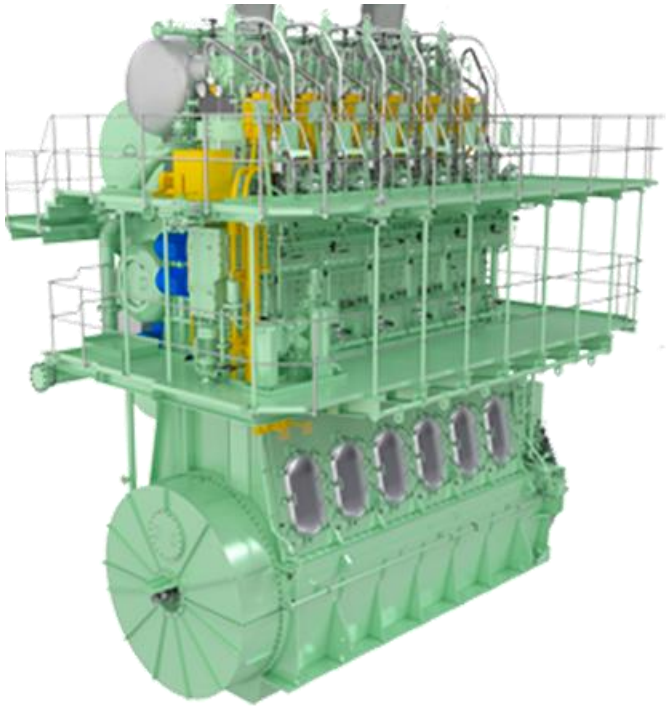


CH_4 slip strategy for MAN ES two-stroke gas engines

Operators choice

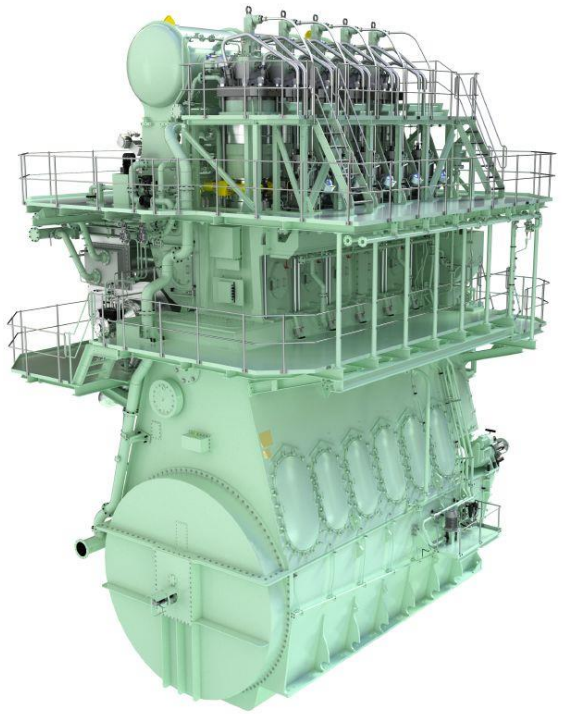
ME-GI engine

- CH_4 slip: 0.25 g/kWh



ME-GA engine

- CH_4 slip: 2.5 g/kWh



Expected methane slip for ME-GI and ME-GA engines

	Methane slip [g/kWh]	
Load [%]	**ME-GI**	**ME-GA**
100	0.20	2.00
75	0.23	2.25
50	0.25	2.50
25	0.28	2.75
0	0.30	3.00

These figures are guaranteed with a tolerance:

- ME-GI: +/-0.1 g/kWh
- ME-GA: +/-1.5 g/kWh

Challenges for operation on NH_3

Engine designer perspective

Combustion chamber:

- Combustion:
  - Dual fuel
  - Pilot fuel type, amount?
- Cylinder condition
- Lube oil

Emissions:

- NH_3 slip
- NOx
- N_2O?

Fuel system:

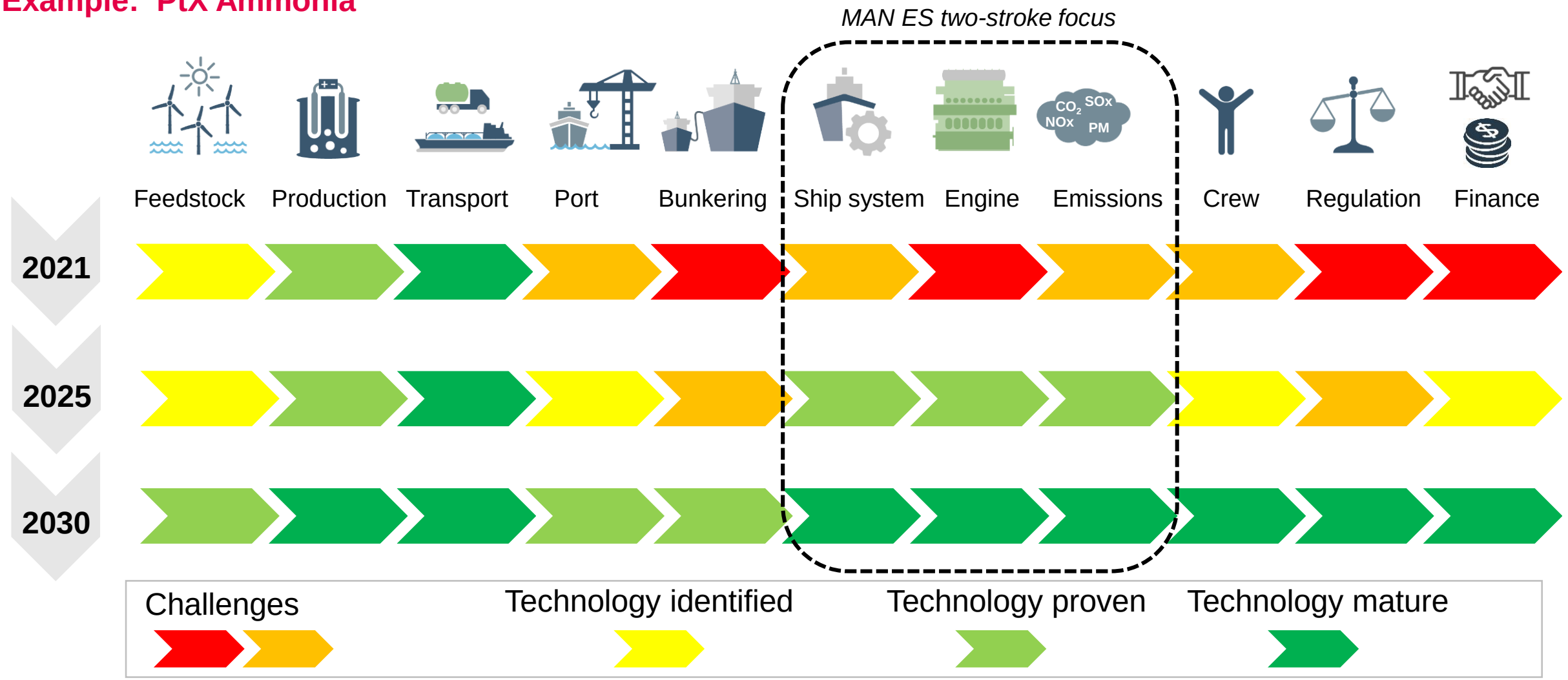
- No leak
- Seal
- Lubricate
- Suitable materials
- Bigger

NH_3 characterisics

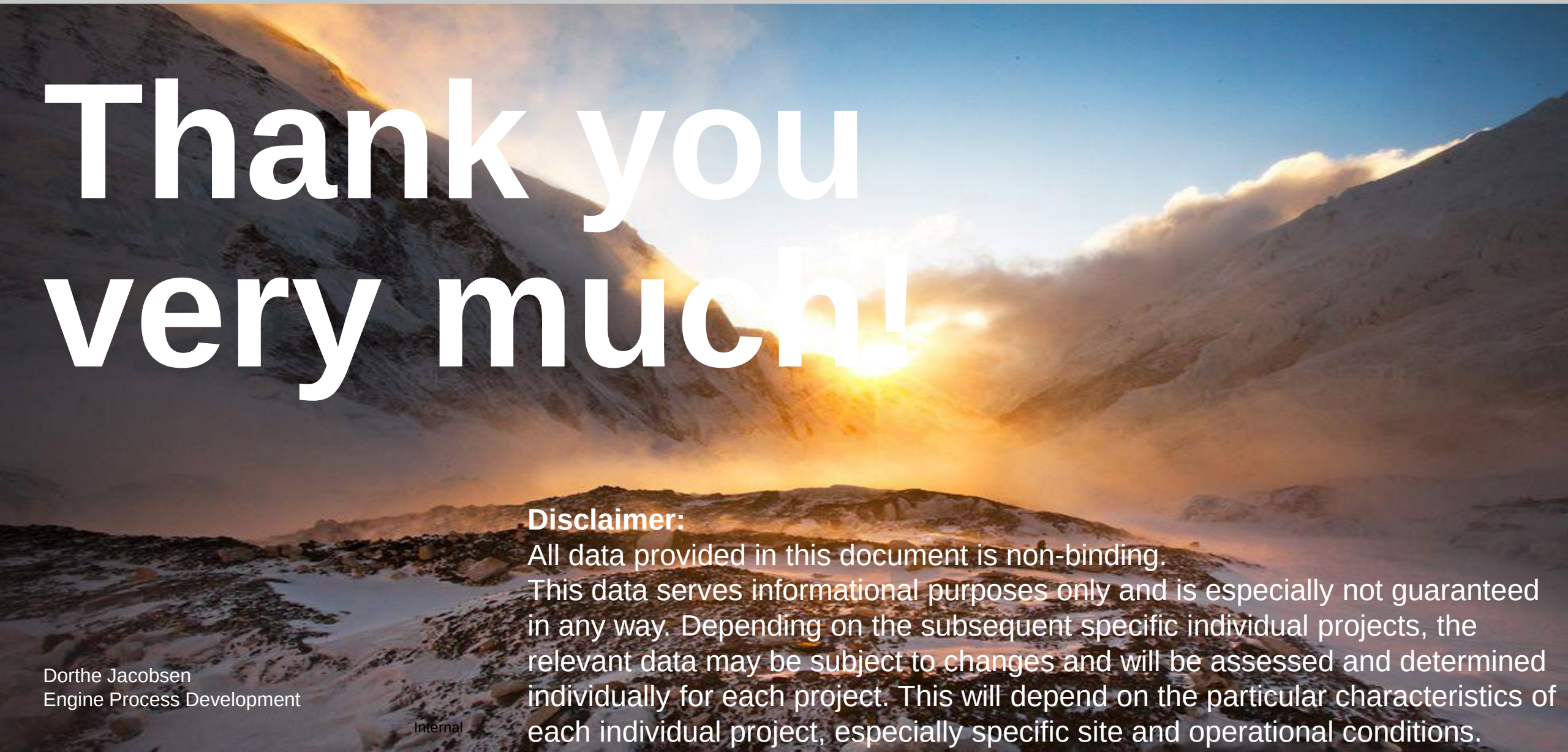
- Safety: Toxic
- Smelly
- Volatile
- Degreaser
- Very low viscosity
- Low energy density
- Difficult to ignite
- Aggresive to materials:
  - Elastomers
  - Metals:
    - SCC
    - General corrosion

Possible implementation pathway for a new marine fuel

Example: PtX Ammonia



Based on framework developed by Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping



Thank you very much!

Dorthe Jacobsen
Engine Process Development

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