MAN Energy Solutions

Future in the making





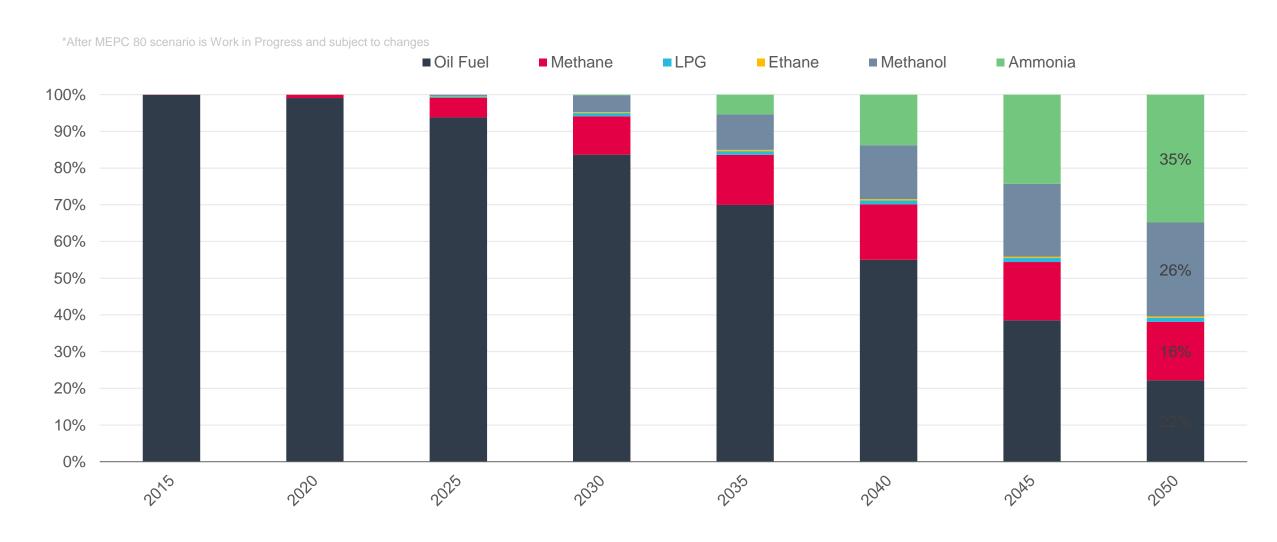
Agenda

- 1 Dual fuel engines
- 2 Drivers for change
- 3 Emissions
- 4 NH3 engine
- 5 Conclusion

1 Dual fuel engines

Demand for e-Fuels from shipping will be high

MAN ES evaluation



Powering sustainable shipping

MethaneME-GI & ME-GA

>687 - 278

Methanol ME-LGIM >177 LPG ME-LGIP 183

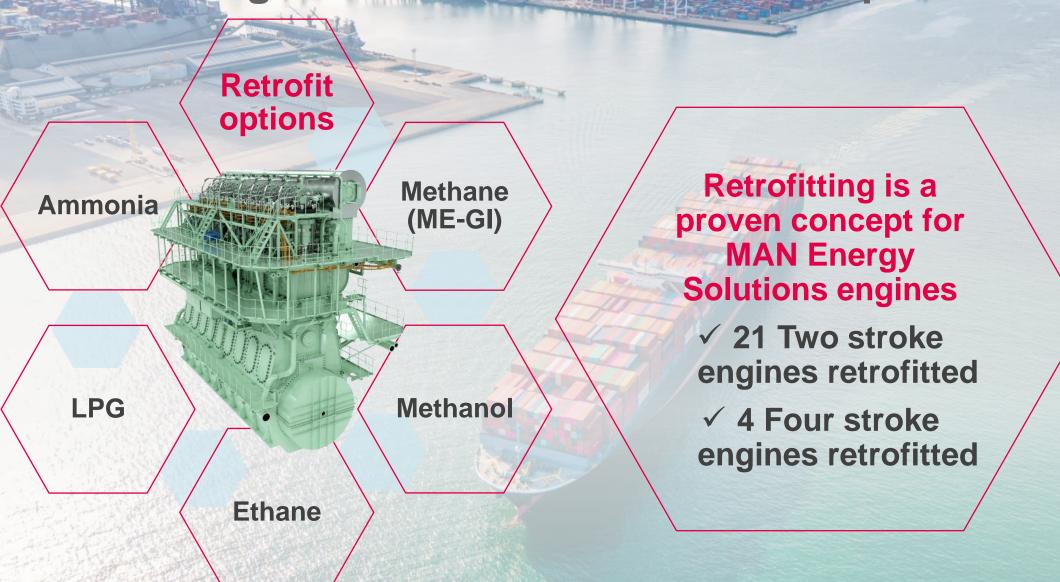
> Ethane ME-GIE 54

13804

Ammonia →

> 2021 2022 2023 dual-fuel engine orders

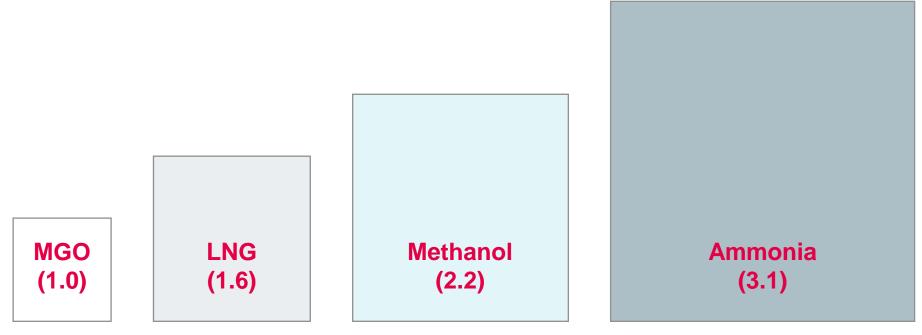
Modular design enables extensive retrofit options



Tank considerations for alternative fuels

Storage tanks

Based on the specific energy density alone, the below tank sizes apply.



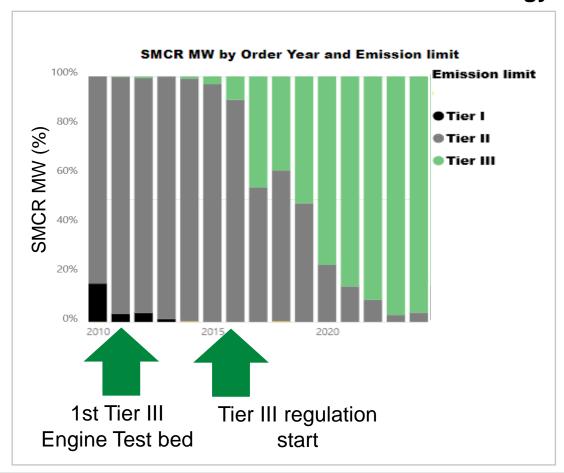
Above tank sizes are based on the specific energy density alone. Additional space for insulation etc. must be considered as well

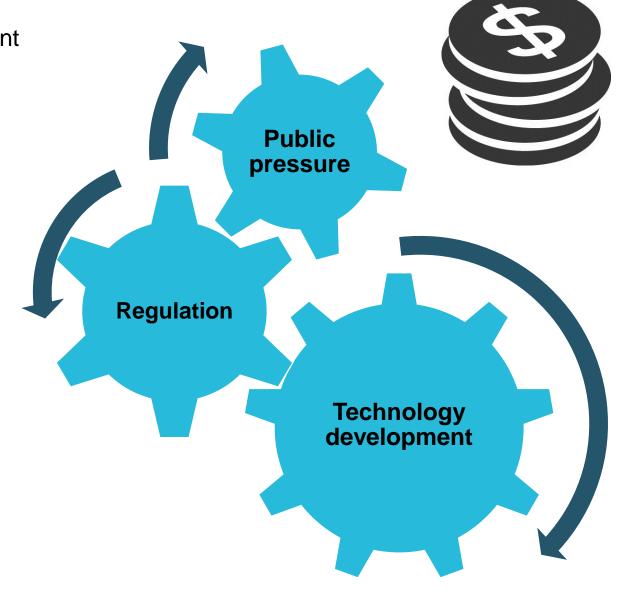
2 Drivers for change

Drivers for change

Public pressure + Regulation + Technology development

Market introduction: NOx reduction technology





International Maritime Organization

IMO



IMO Headquater in London

- International Maritime Organization (IMO)
- United Nations specialized agency for shipping
- Regulates environmental issues and safety for international shipping
- 174 member states and 63 intergovernmental organizations represented
- Regulation enforced by flag States and port States
- Classification Societies act on behalf of flag States
- MAN ES participate in:
 - MSC (1 person)
 - MEPC (5 persons)
 - ISWG (2 persons)
 - PPR (5 persons)





The way to zero carbon shipping

What are the challenges in using new fuels on international, short-sea and inland shipping? How can these challenges be addressed?



1. Upscale production of green fuels



- 2. Reduce (eliminate) price differential on fossil and green fuels
 - Increase price on traditional fuels (CO₂ pricing)



2. Develop cheap green fuels





- 3. Make regulation to support/enable use of new, green fuels
 - 1. Requirement





2. Ports

4. Ships



3. Bunkering





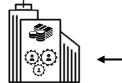




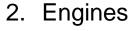


Develop ship technology to handle new, green fuels











- 5. Enablers for use of new fuels
 - International fuel specifications



Training







Actors











Emissions

What is Air Pollution?

Impacts on human health and environment

Air Pollution

Affects human health and environment

Particulate Matter (PM) Nitrogen Oxides (NOx) Sulphur Oxides (SOx)

> NH_3 **HCHO** CO HC Other...

Atmospheric chemistry

Short lived climate forcers

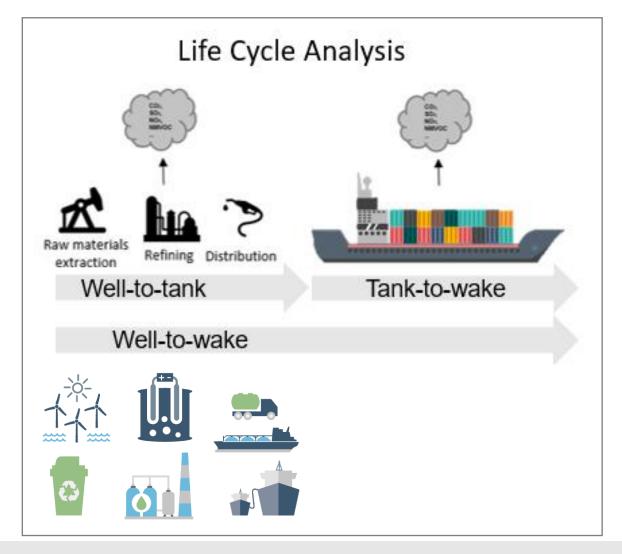
Black carbon (BC) Ozone

Green House Gases Contributes to global warming

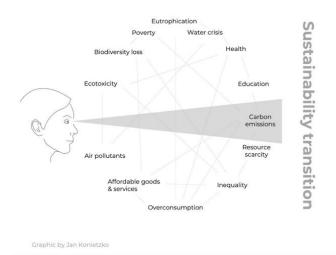
 CO_2 N_2O Methane (CH₄) Fluorinated gases

LCA – Life Cycle Assessment

Introducing new fuels



Carbon Tunnel Vision



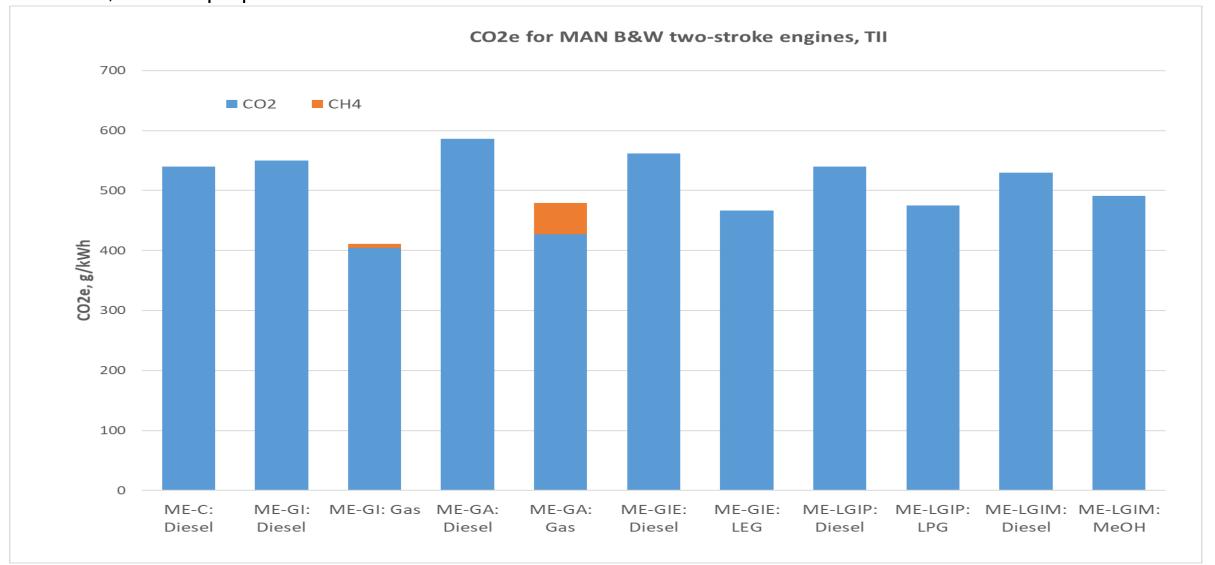
Life Cycle Impact Assessment (LCIA)

	CA 9.00	Drivation	to water	Inventory results Mi	idpoint	Endnoint	Area of protection
Substance	CARLE .		2000	inventory results in	uponit	Enapoint	Area of protectio
accuration .		_	_				
2-hydroxy-ethenacrylete	010-01-0	0.0346					
4-methylenebia cyclohesylamine	1701-71-2				W		
	7004-01-7		4.25-05	, C	limate change		
	7440-36-2	2.05-00	4200	/ -	minate enange	1	
	71-43-2 (cu	5.05-02		/		1	Human health
and (Pb)	7439-92-1	8.55.06		/ 0	tratacabaria azana	1	i i uman neami
	111-70-2	0.05-01		/ 5	tratospheric ozone	1	
Carbondovide	12456-9	2.05+02		/ .			
Carbonmonoxide (CC)	630-06-0	1.95-01		/ / de	epletion	\\///	
admirr (Cd)	7440-40-0	2.25-07		// 4	opiciion	\ V //	
Chlorine (CD)	7702-50-5	4.05-04		//		V//	
	7440-47-3	5.35-06		//		1 V /	
Scyciobevane methane	00-73-0	5.15-02	-	// . H	luman toxicity	- VI	
Marous colder N2O)	10024-97-2			///		^ Y	
	121-14-2	9.55-02		///_		/ V	
	5124-30-1	7.55-00		// / P	articulate matter	/ //	
Vdro carbona (electricity, stationary combusti	1120-00-1	1,75400			articulate matter	/ / / \	
ydrogen ions (I+)			1.05-00	Elementary flows	- man atlan	/ //	
	70-03-1	3.55-02	CAPAD	3 /// / 10	ormation	/ //	
	67-63-0	9.25-01		5 ///		/ //	
copper(Ou)	7740-50-0	1.05-05		¥ ///	Markette and a second	/ //	
	7439-97-0	2.75-06		+ /// P	Photochemical ozone	/	
	74-82-8	5.05-00		> //		_	202000000000000000000000000000000000000
	100-10-1	5,75-02		10	ormation		Natural
	75-04-7	-	7.95-00	m le	Jillation		radulai
	7440-02-0	1.15-05	1,000	= 1			environment
	10102-44-0	1.15400		- 111	and and alder	///	environment
MVDC, diesel engine (exhaust)		3.95-02		@ E	cotoxicity	- ///	
MVOC power plants (stationary combustion)		3.95-03		E 11/1 -		///	
Ottone (OO)	10028-15-6	1,05-00		# 1111 m	-1-1141 41	////	
	litte specific	2,45-00		<u> </u>	cidification	- ///	
Penol	100-95-2		1,35-05	111 1/1		///	
Phospene	75-44-5	1,45-01		m ///		/ //	
Sheter polici	ion specific	1.05-01		11 1 1 =	ustra minima til nam	/ //	
	75-50-9	0.25-02		11 / - E	utrophication	//	
	7702-77-0.0	0.55-02			and the state of t	//	
	7640-01-00	1.95-02		111		//	
	7702-49-2	2,05-05		11 11	and use	//	
Sulphur dicalde (902)	7440-09-5	1,35400		// · L	and use	1	
okene	100-55-5	4,55-00		11 -			
Tokuene-2,4-dantne	95-80-7	7,95-02				/	Natural
Okene discoveret (TDI)	26471-62-5	1.05-01		11		/	reacoron
Total-N			2.66-05	/ • W	Vater use		rocouroco
	121-66-0	1,05-01		/ "	ator doc		resources
hapedfied aidehydes		7,55-04					
Assectfied organic compounds	- 2	1.55,00					
	7440-62-2	1.05-04		` Δ	Abiotic resource use		
VOC. desel engine (exhaust)		0.45-00			biolic resource use		
CC, atefonary combustion (coal fired)	-	4.05-05					
VOC. stationary combustion (natural gas fired)	-	2.25-00					
VOC. stationary combustion (oil fired)		1.45-04					
	1330-20-7	1.45-01					
Cylene							

(2010)

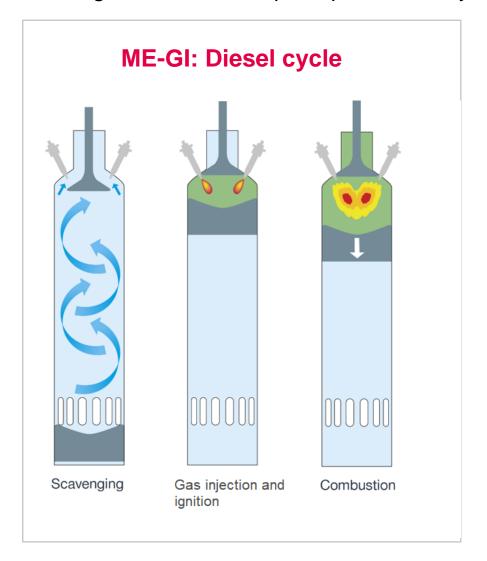
2S: CO2e emissions, Tier II

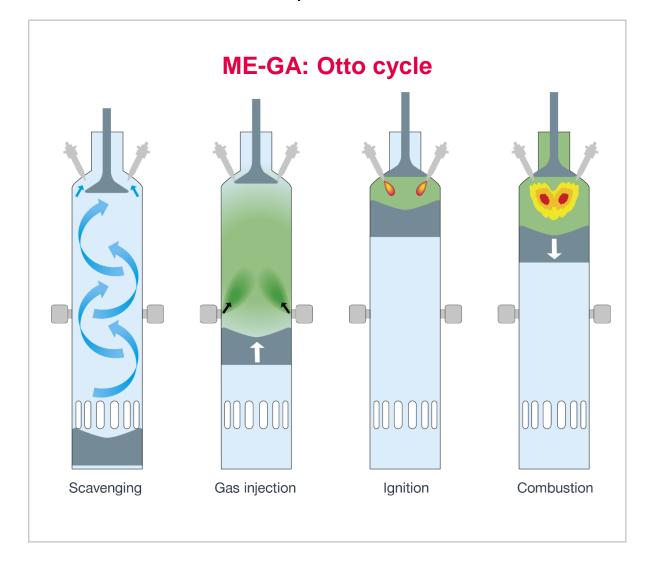
GWP100, Tank-to-propeller



Otto vs. Diesel cycle

Gas engine combustion principles and why there is a difference in Methane slip





NH3 engine

Foundation for design - Risk Assessment – HAZID & HAZOP

Risk assessment

- Failure Modes and Effects Analysis (FMEA) made in order to evaluate where and how components may fail and to assess the impact of different failures.
- Hazard identification (HAZID) and Hazard and Operability (HAZOP) assessments were made in order to live up to our own safety requirements.
- Experience from previous dual-fuel engine development projects.
- More than 4,000 hours spent on FMEA, HAZID and HAZOP



Engine emissions

How do we handle potential Nitrous Oxide (N₂O) emissions?

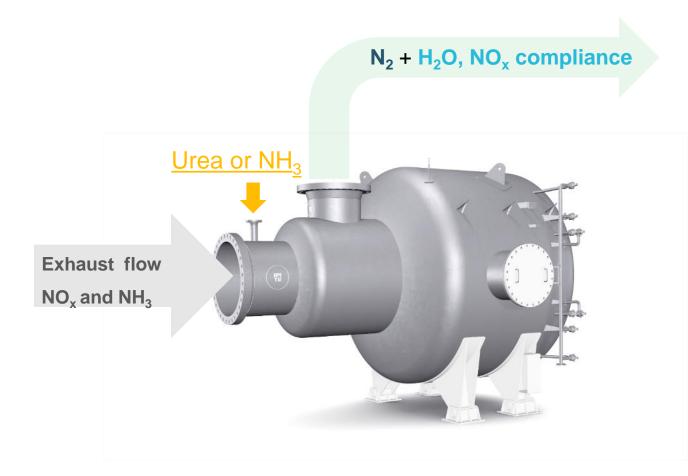
N₂O is a very potent GHG with GWP of 298.

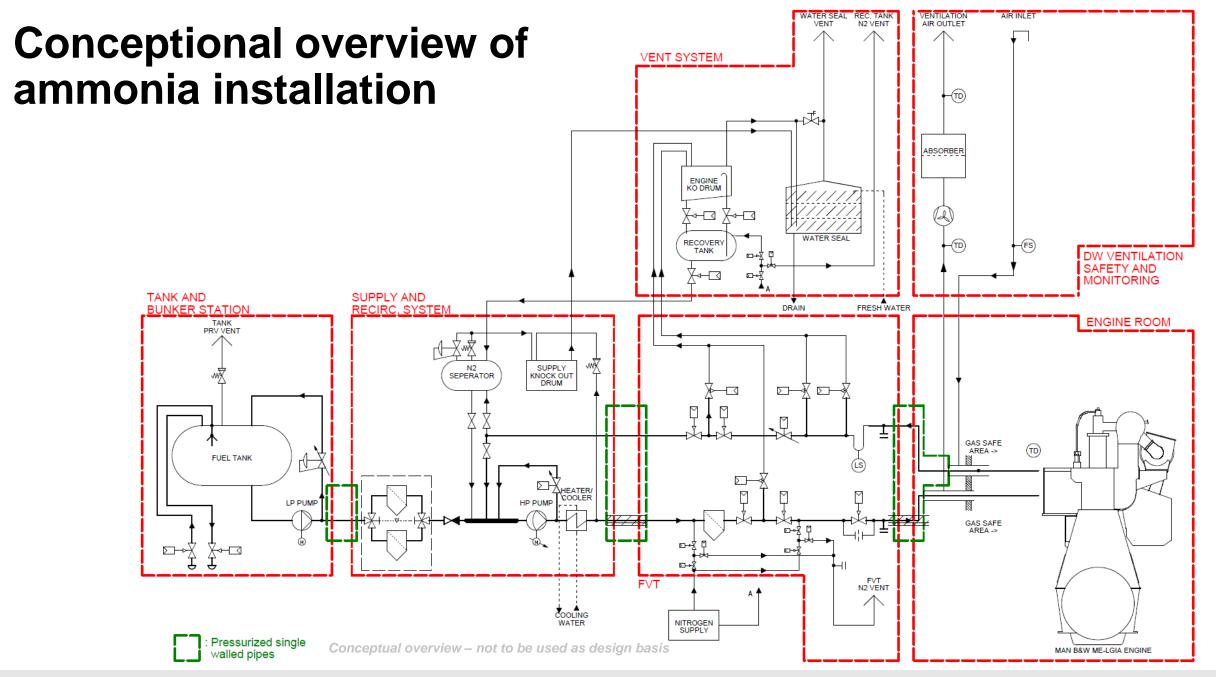
It will also be accounted in on-going adopted regulations

 Nitrous oxide (N₂O) will be removed by engine tuning.

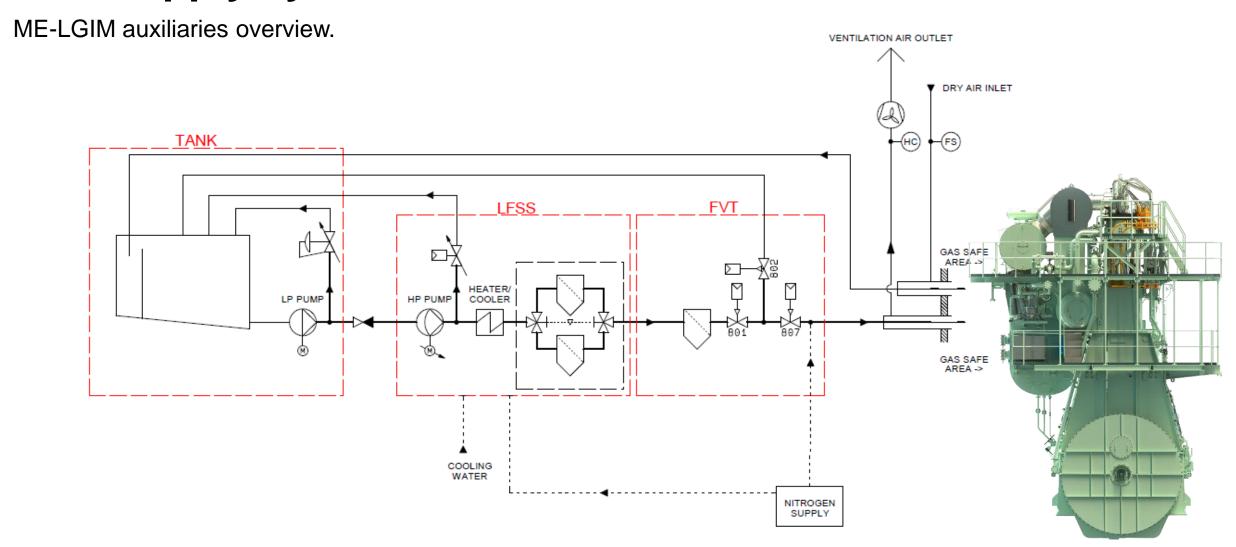
Ammonia slip and NOx emissions

- Unburned NH₃ and NO_x is removed in the SCR reactor.
- Dosing of additional ammonia to SCR reaction if needed.
- Known SCR technology is suitable and MAN HP-SCR reactor can be applied.





Fuel supply system



Two-stroke ammonia engine main development timeline











Full sales release

5 Conclusion

A quick summary

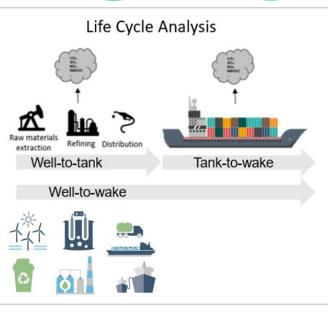








- Focus emissions at present: GHG, NOx, SOx (PM)
- Decarbonization of shipping may well be based on:
 - Bio-oils
 - Renewable methanol
 - E-ammonia
 - Renewable gas
- Life cycle analysis (LCA) of well to wake (WTW) value chain is critical for GHG reduction assessment
- MAN Energy Solutions offers ship engine technology for methanol, gas and a wide range of bio-oils
- Development of an ammonia engine is underway orders accepted from 2024
- It is not the engine technology, that is the barrier for decarbonization of shipping it is and will be the production capacity for renewable fuels! and enabling regulation!





Dorthe Jacobsen, Engine Process Development Low Speed