MARINE NH3

Ammonia as a Marine Fuel: Safety

Ammonia Energy Conference - Niels de Vries

13 November 2019

C-JOB

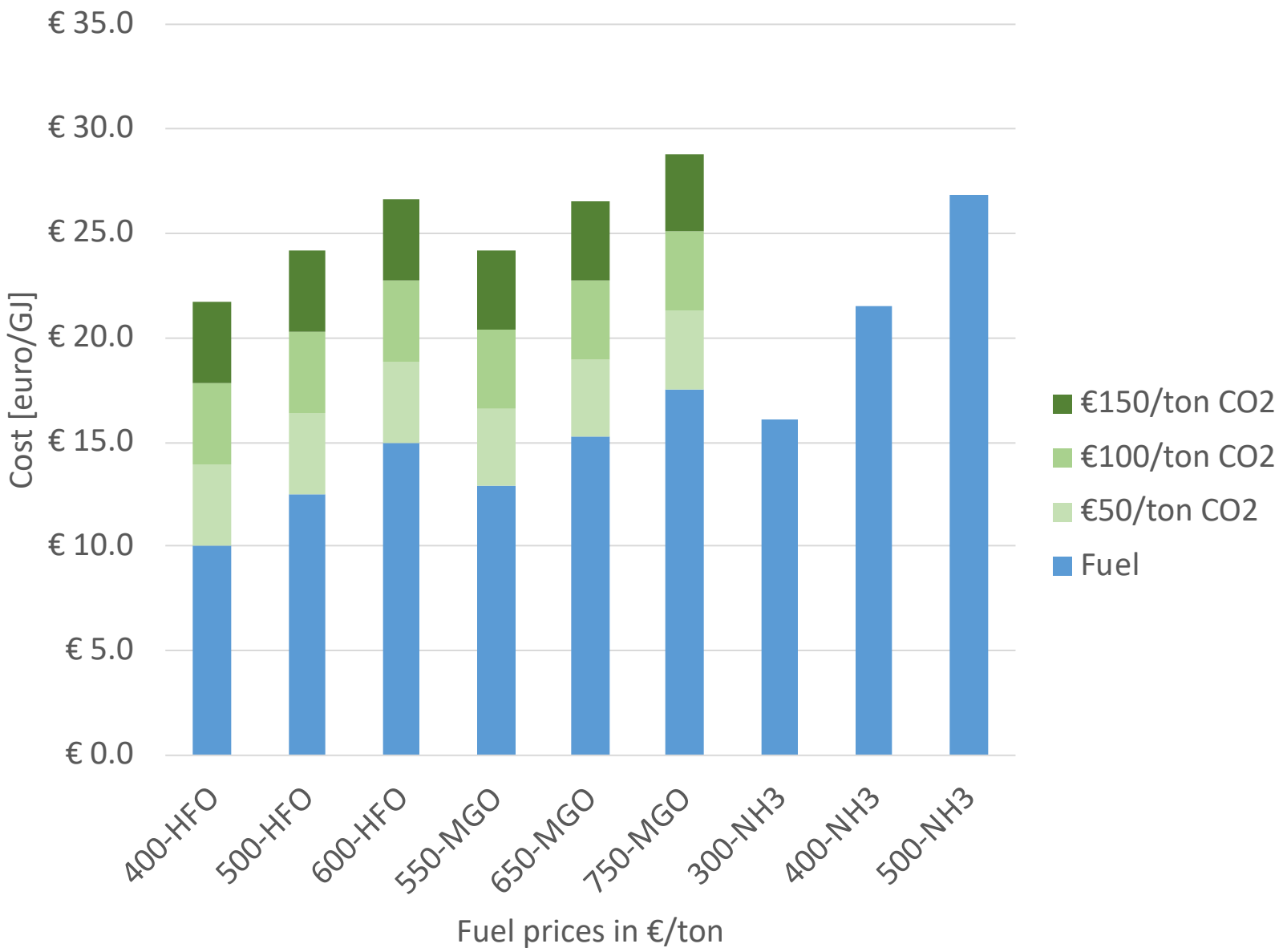
DEDICATED NAVAL ARCHITECTS

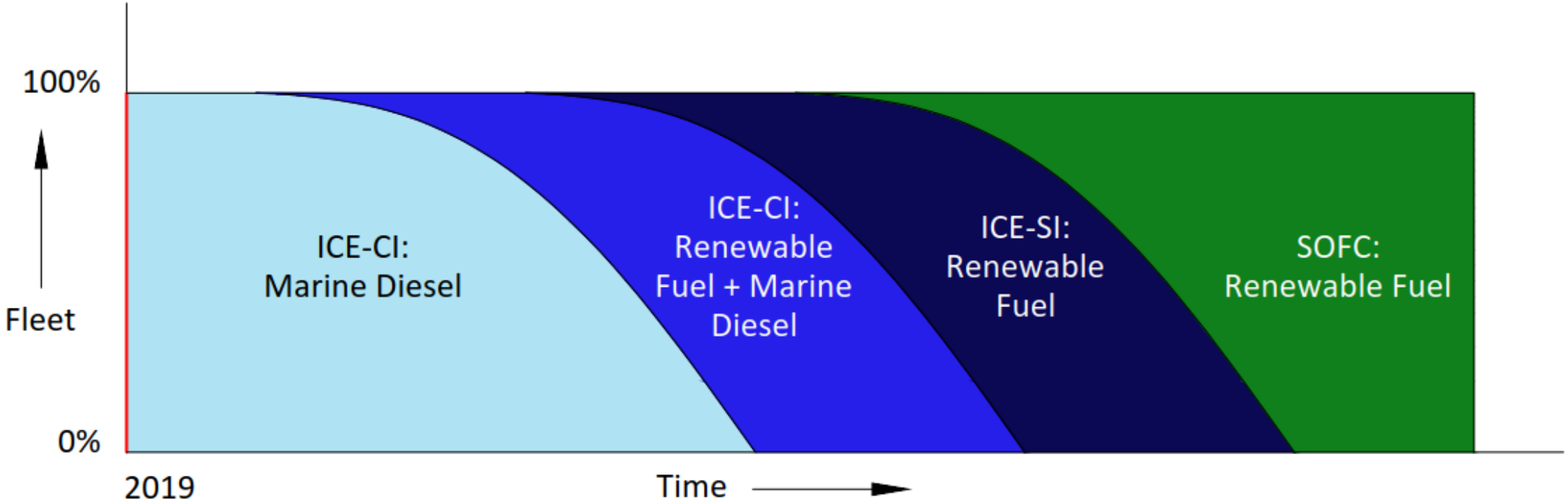
Renewable Fuel Options: Potential of Ammonia

Fuel type:	Energy density LHV [MJ/kg]	Volumetric energy density LHV [GJ/m3] ↓	Renewable synthetic production cost [MJ/MJ]	Storage pressure [bar]	Storage temperature [°C]
Marine Gas Oil (reference)	42.7	36.6	Not applicable	1	20
Liquid Methane	50.0	23.4	2.3	1	-162
Ethanol	26.7	21.1	3.6	1	20
Methanol	19.9	15.8	2.6	1	20
Liquid Ammonia	**18.6**	**12.7**	**1.8**	**1 or 10**	**-34 or 20**
Liquid Hydrogen	120.0	8.5	1.8	1	-253
Compressed Hydrogen	120.0	4.7	1.7	700	20

- Ammonia balanced solution
  - Volumetric energy density
  - Renewable synthetic production cost

Fuel Pricing





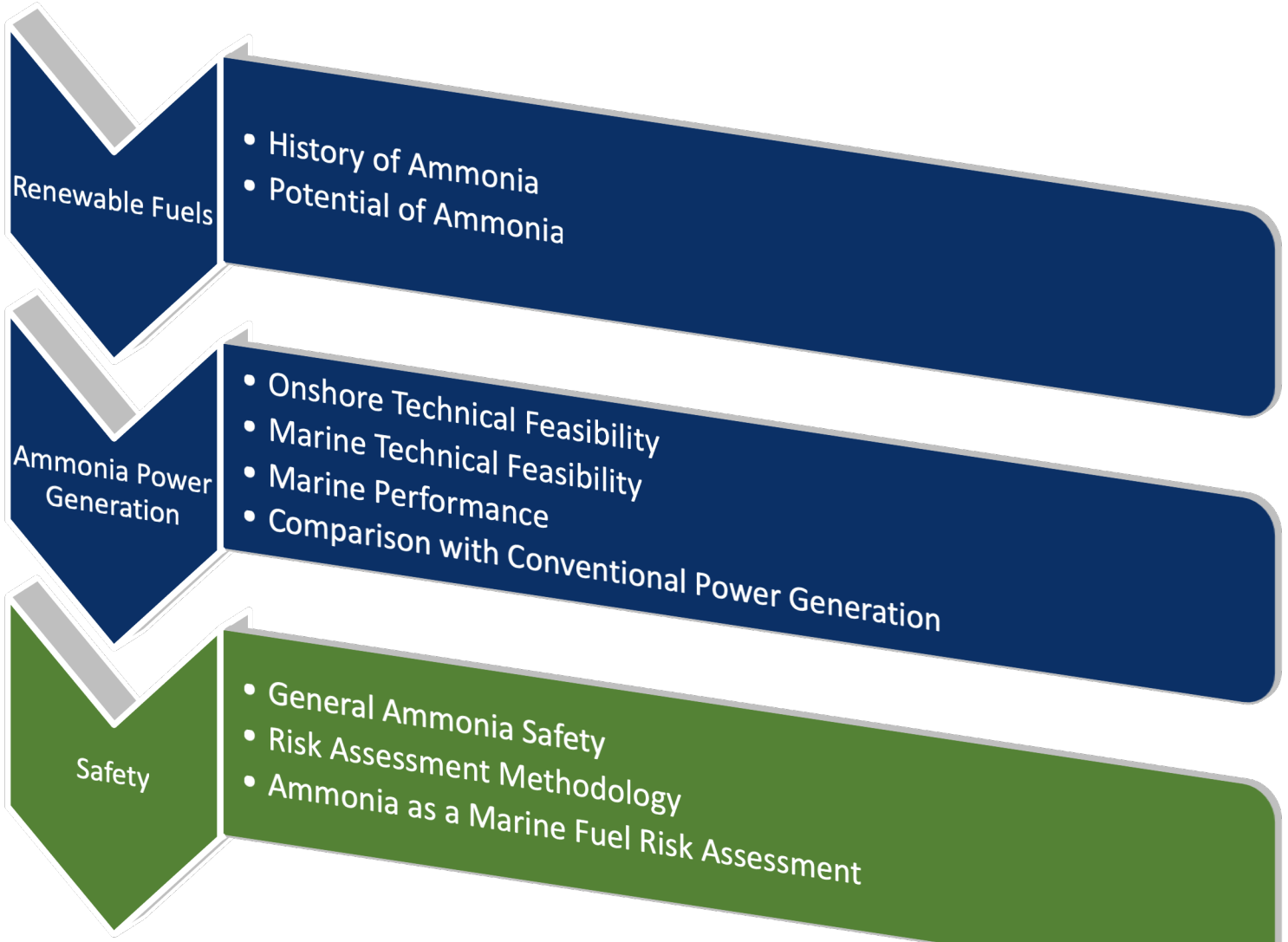
Reduction of Harmful Emissions			
CO2	>80%	100%	100%
NOx	0% (Apply SCR)	0% (Apply SCR)	100%
SOx	>80%	100%	100%
PM	>80%	100%	100%

Renewable Fuel options:
Hydrogen, Ammonia, Methanol and Others

ICE: Internal Combustion Engine
CI: Compression Ignition
SI: Spark Ignition
SOFC: Soild Oxide Fuel Cell

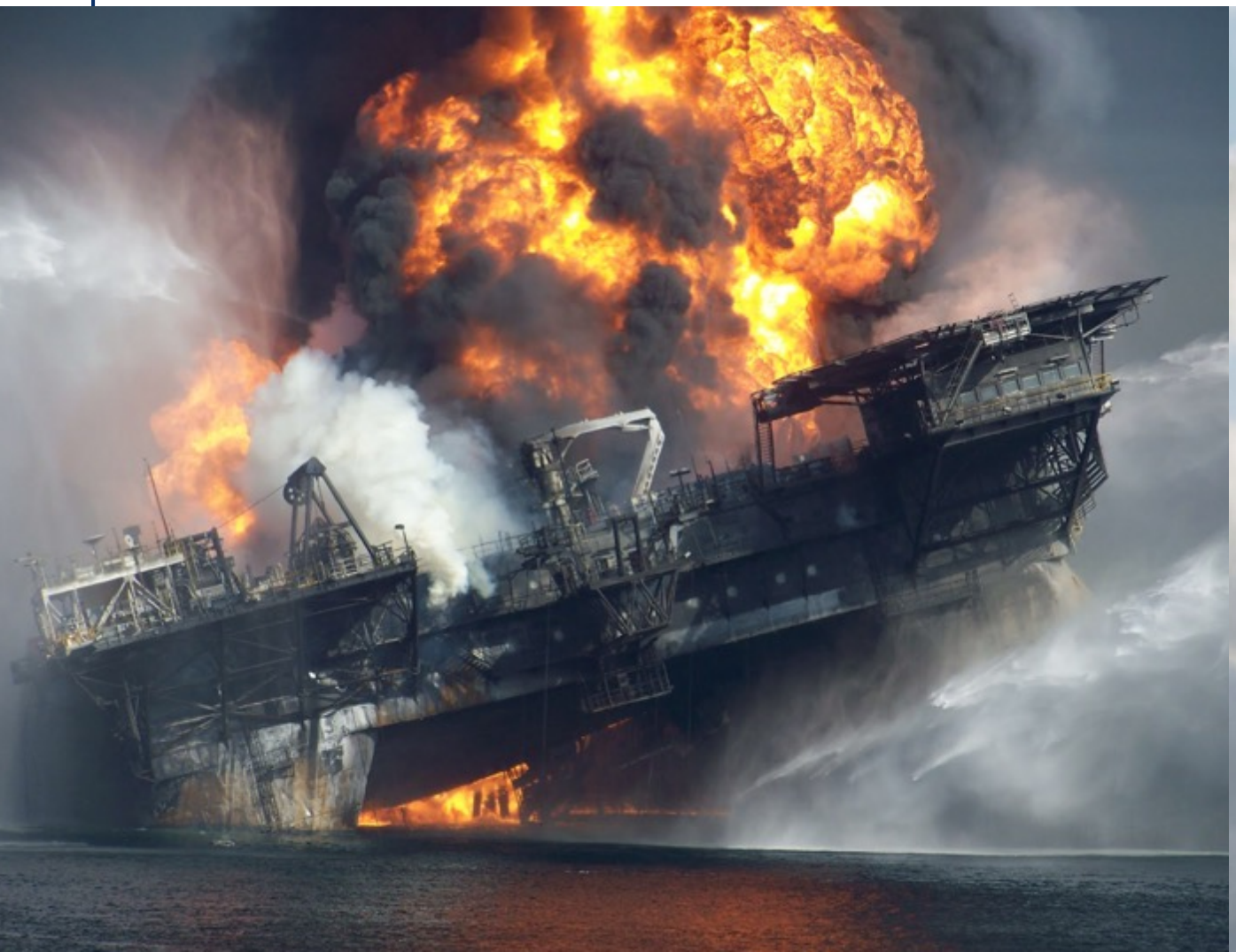
SCR: Selective Catalytic Reduction
Exhaust gas after treatment, capable of reducing NOx more than 95%

Agenda


Renewable Fuels
• History of Ammonia
• Potential of Ammonia
Ammonia Power Generation
• Onshore Technical Feasibility
• Marine Technical Feasibility
• Marine Performance
• Comparison with Conventional Power Generation
Safety
• General Ammonia Safety
• Risk Assessment Methodology
• Ammonia as a Marine Fuel Risk Assessment

What is Safety?

What is Safety?



Safety (Rules and Regulations)

Natural Gas

- Bulk transport
  - IBC Code - International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk, Amended by Resolution MEPC.225(64)
  - 1983/2014 IGC Code - International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
- Fuel
- 2005:
  - IGF Code - International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels First draft initiated
- 2017:
  - IGF Code Adopted

  Fully developed for natural gas only

Ammonia

- Bulk transport
  - IBC Code - International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk, Amended by Resolution MEPC.225(64)
  - 1983/2014 IGC Code - International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
- Fuel
- Future:
  - ?

General Ammonia Safety

- CNG: Compressed Natural Gas
- LNG: Liquefied Natural Gas
- ULSFO: Ultra Low Sulphur Fuel Oil (0.1%)

- Globally Harmonized System of Classification and Labelling of Chemicals (GHS)

Hazard statements	Hazard category	Ammonia [79]	CNG [80]	LNG [81]	Diesel [82]	ULSFO [83]
H220 Extremely flammable gas	1A		X	X		
H221 Flammable gas	2	X				
H226 Flammable liquid and vapour	3				X	
H227 Combustible liquid	4					X
H280 Contains gas under pressure; may explode if heated	Compressed gas		X			
	Liquefied gas (b)	X*				
H281 Contains refrigerated gas; may cause cryogenic burn or injury	Refrigerated liquefied gas			X		
H304 May be fatal if swallowed and enters airways	1				X	
H313 May be harmful in contact with skin	5				X	
H314 Causes severe skin burns and eye damage	1B	X				
H315 Causes skin irritation	2				X	
H331 Toxic if inhaled	3	X				
H332 Harmful if inhaled	4				X	X
H350 May cause cancer	1B					X
H351 Suspected of causing cancer	2				X	
H361 Suspected of damaging fertility or the unborn child	2					X
H373 May cause damage to organs through prolonged or repeated exposure	2				X	X
H410 Very toxic to aquatic life with long lasting effects	1	X				X
H411 Toxic to aquatic life with long lasting effects	2				X	

Table 7-1: Hazard statements comparison of ammonia with other fuels

General Ammonia Safety

- Risk levels:
  - Flammability
    - Flammable gas
    - A narrow flammability limit: 15-28%, with a high lower limit compared to other fuels
    - A high absolute minimum ignition energy compared to other fuels
    - A high auto ignition temperature: 651 °C
  - Toxicity
    - AEGL 3: Life-threatening health effects or death
  - Environmental impact
    - Very toxic to aquatic life with long lasting effects

(ppm)	10 min	30 min	60 min	4 hr	8 hr
AEGL 1	30	30	30	30	30
AEGL 2	220	220	160	110	110
AEGL 3	2,700	1,600	1,100	550	390

Table 7-4: Acute Exposure Guideline Levels (AEGL): Ammonia

Risk Assessment Methodology

- Identification, where the risk is identified
- Analysis, where the risk is quantified
- Assessment, where the risk is prioritized/ranked
- Mitigation, where the risk is eliminated, reduced or prevented

Risk Assessment Methodology

- Assessment based on IGF Code No. 146

Multiple fatalities	Catastrophic damage	**E**					
*Single fatality	Major damage	**D**					
Major injury	Localised damage	**C**					
Minor injury	Minor damage	**B**					
Zero injury	Zero damage	**A**					
People	Assets/ Environment		**1**	**2**	**3**	**4**	**5**
Severity ↑		Chance	Remote	Extremely Unlikely	Very Unlikely	Unlikely	Likely
		Chance per year	$<10^{-6}$/y	$\geq10^{-6}$/y $<10^{-5}$/y	$\geq10^{-5}$/y $<10^{-4}$/y	$\geq10^{-4}$/y $<10^{-3}$/y	$\geq10^{-3}$/y
Likelihood →		Chance in Vessel Lifetime	<1 in 40,000	≥1 in 40,000 <1 in 4,000	≥1 in 4,000 <1 in 400	≥1 in 400 <1 in 40	≥1 in 40

Table 9-1: Risk matrix, People, Assets and Environment combined

Risk Assessment Methodology

- Work flow example

Reference	Failure Mode	Cause	Effect	Detection	Original Risk Ranking
1-3-01	Ammonia leakage	Various	Engine room exposed with gaseous ammonia	None	E5

Table 9-2: Part I: Risk assessment work flow methodology example: Identification, Analysis and Assessment

Reference	Mitigation	Overall Assessment	Final Risk Ranking
1-3-01	1. Reduce exposed length ammonia piping length in engine room 2. Apply double walled vented piping in engine room 3. Add ammonia detectors in engine room and within double walled vented piping 4. Add main isolation valves	Chances reduced by exposed length reduction. Impact reduced by application of double walled piping in engine room. Impact further reduced by adding ammonia detectors and main isolation valves which close when an ammonia leakage occurs. Ammonia piping outside of engine room to be reviewed separately.	C2

Table 9-3: Part II: Risk assessment work flow methodology example: Mitigation

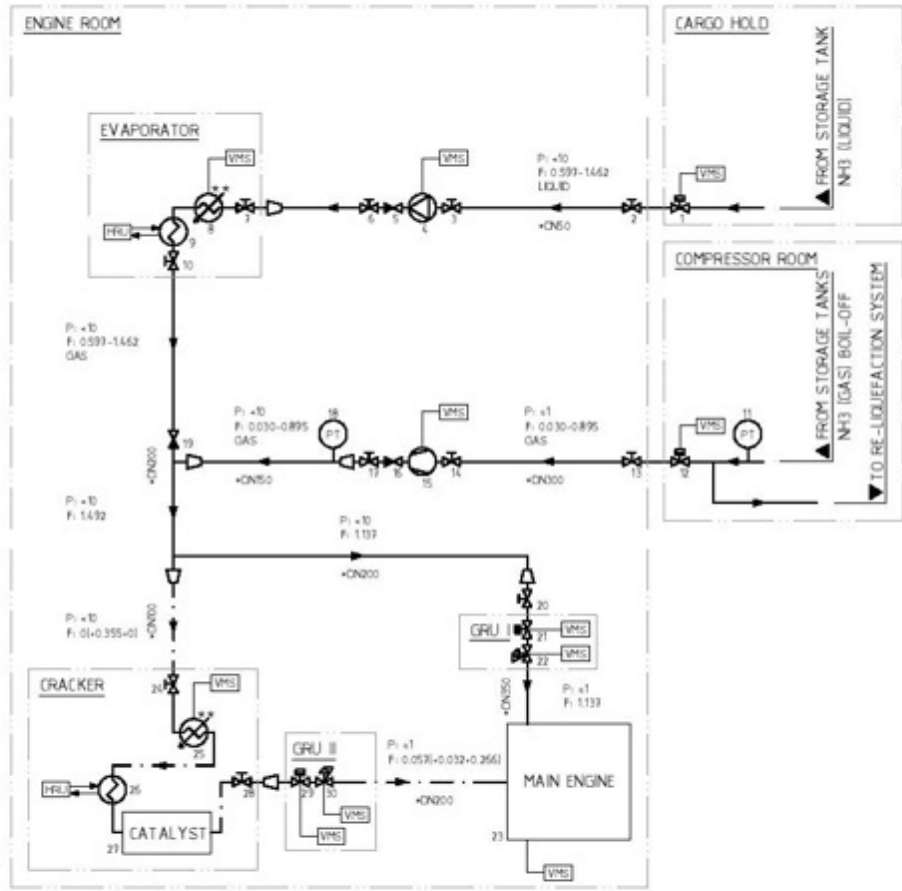
Ammonia as Marine Fuel Risk Assessment

- Risk assessment 1 (based on technical basis NH3 fuel system diagram, zero safety measures, functional only)
- Reflection risk assessment 1
- Risk assessment 2

Ammonia as Marine Fuel Risk Assessment

Main scope and assumptions:

- Zero leakage in normal operational conditions
- Main engine assumed to be inherently safe considering fuel injection
- Fuel label: Ammonia & hydrogen



SYMBOLS

	HAND OPERATED VALVE		REMOTE OPERATED VALVE
	NON RETURN VALVE		PRESSURE REGULATING VALVE
	REDUCER	PT	PRESSURE TRANSMITTER
	COMPRESSOR		CENTRIFUGAL PUMP
	HEAT EXCHANGER		HEATER

LEGEND

NH3 FUEL

H2+NH3+N2 FUEL

NOTES

PIPE INDICATION
P: PRESSURE bar
F: FLOW kg/s
STATE OF MATTER (GAS, UNLESS NOTED OTHERWISE)

HRU: EXHAUST GAS HEAT RECOVERY UNIT
GRU: GAS REGULATING UNIT
VMS: VESSEL MANAGEMENT SYSTEM (POWER SUPPLY AND CONTROL)

•) PROVISIONAL DIMENSIONS

••) START-UP POWER ONLY

INERT GAS SYSTEM TO EMPTY FUEL LINES FOR MAINTENANCE TO BE ADDED

REV.	DESCRIPTION	DRAWN	CHECK	APPR	DATE
A	GENERAL UPDATE	NDV	PL	WZ	20190503
0	FIRST ISSUE	NDV	PL	WZ	20190412

CLIENT PROJECT NO.:

CLIENT DRAWING NO.:

CJOB

CLIENT: -

YARD NO.: -

CLASS NO.: -

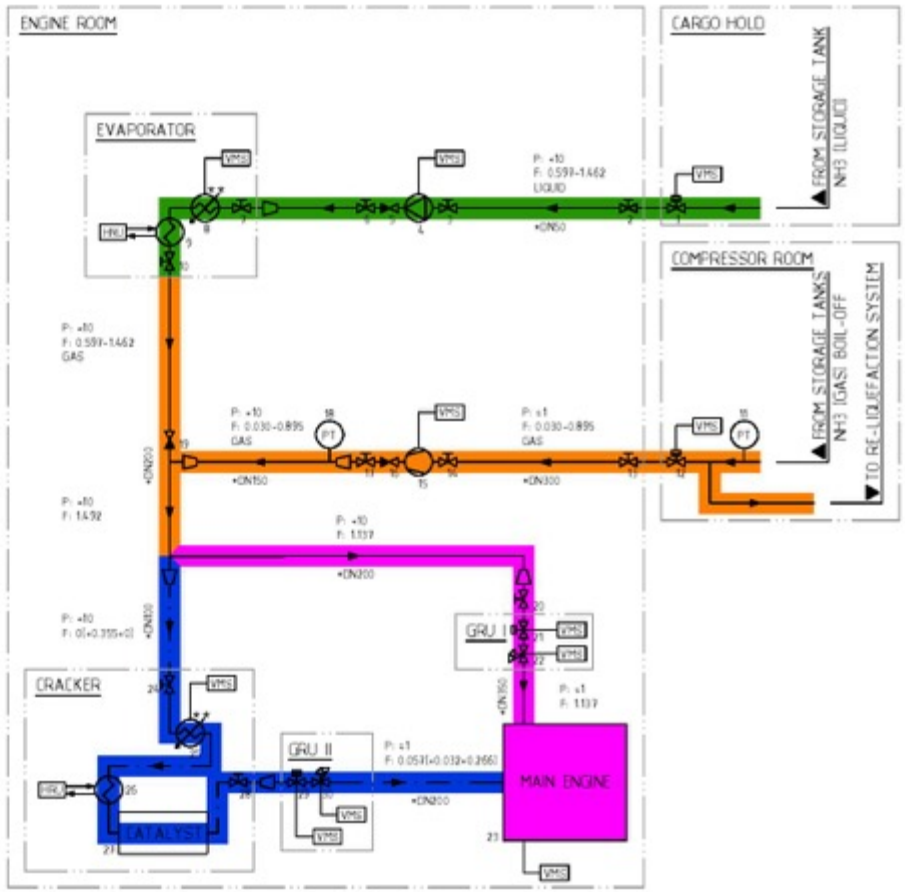
PROJECT NUMBER: 16.104

DRAWING NUMBER: 999-301

STATUS: PRELIMINARY

TITLE: DIAGRAM NH3 FUEL SYSTEM (TECHNICAL BASIS)

PROJECTION	DIM. UNIT	REV.	SHEET	SCALE	FORMAT
	mm	A	1-1	N.A.	A2



COLOUR CODING

- NODE 1: MAIN LIQUID AMMONIA SUPPLY
- NODE 2: MAIN GASEOUS AMMONIA SUPPLY
- NODE 3: AMMONIA ENGINE SUPPLY
- NODE 4: HYDROGEN ENGINE SUPPLY

SYMBOLS

	HAND OPERATED VALVE		REMOTE OPERATED VALVE
	NON RETURN VALVE		PRESSURE REGULATING VALVE
	REDUCER	PT	PRESSURE TRANSMITTER
	COMPRESSOR		CENTRIFUGAL PUMP
	HEAT EXCHANGER		HEATER

LEGEND

NH3 FUEL

H2+NH3+N2 FUEL

NOTES

PIPE INDICATION
P: PRESSURE bar
F: FLOW kg/s
STATE OF MATTER (GAS, UNLESS NOTED OTHERWISE)

HRU: EXHAUST GAS HEAT RECOVERY UNIT
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REV.	DESCRIPTION	DRAWN	CHECK.	APPR.	DATE
A	GENERAL UPDATE	NDV	PL	WZ	20190503
0	FIRST ISSUE	NDV	PL	WZ	20190412

CLIENT PROJECT NO.:

CLIENT DRAWING NO.:

C-JOB
DEDICATED MARINE ARCHITECTS

CLIENT: -
YARD NO.: -
CLASS NO.: -

PROJECT NUMBER: 16.104
DRAWING NUMBER: 999-301
STATUS: PRELIMINARY

TITLE:
DIAGRAM NH3 FUEL SYSTEM
[TECHNICAL BASIS]

PROJECTION | DIM. UNIT: mm | REV.: A | SHEET: 1-1 | SCALE: N.A. | FORMAT: A2

Ammonia as Marine Fuel Risk Assessment

Highlighting most important risks:

- Space (and environment) exposure with liquid and/or gaseous ammonia
- Space (and environment) exposure with gaseous hydrogen
- Increase in temperature and pressure within system
- Unable to supply fuel

E	2	4	9	10	
D		3	4	9	
C				1	
B			4	5	
A			2	8	
	1	2	3	4	5

Table 10-2: Original risk rating results risk assessment 1

Ammonia as Marine Fuel Risk Assessment

Mitigations and consequences similar as natural gas fuel system:

Highlights:

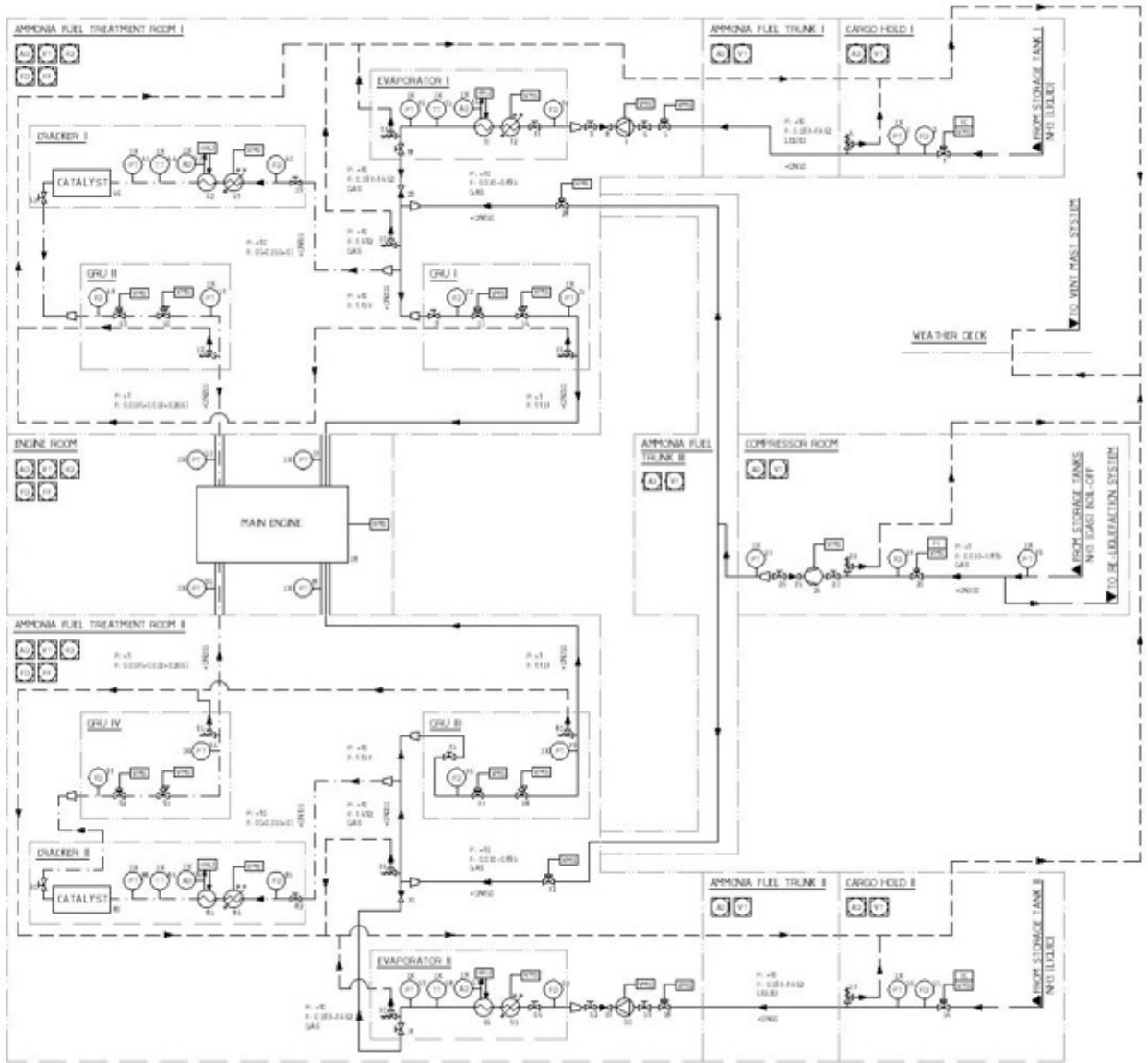
- Redundancy
- Ammonia and hydrogen detection
- Ventilation
- Pressure relieve system
- Remote operated isolation valves
- Route piping with sufficient distance from shell
- Locate piping in separate unmanned space
- Double-walled piping

E	2	4	9	10	
D		3	4	9	
C				1	
B			4	5	
A			2	8	
	1	2	3	4	5

Table 10-2: Original risk rating results risk assessment 1

E		1			
D	9	1			
C		12		2	
B				2	
A		3	10	21	
	1	2	3	4	5

Table 10-3: Final risk rating results risk assessment 1



SYMBOLS

	HAND OPERATED VALVE		REMOTE OPERATED VALVE
	NON RETURN VALVE		PRESSURE REGULATING VALVE
	NOZZLE		PRESSURE RELIEVE VALVE
	COMPRESSOR		PUMP
	HEAT EXCHANGER		HEATER
FD	FLOW DETECTION	PT	PRESSURE TRANSMITTER
AD	AMMONIA DETECTION	TT	TEMPERATURE TRANSMITTER
AD	SPACE AMMONIA DETECTION	HD	SPACE HYDROGEN DETECTION
FD	SPACE FIRE DETECTION	SV	SPACE VENTILATION
FF	SPACE FIRE FIGHTING SYSTEM		

LEGEND

- NH3 FUEL
- HYDROGEN FUEL
- BOIL-OFF GAS VENT
- NH3 FUEL DOUBLE WALLED
- HYDROGEN FUEL DOUBLE WALLED

NOTES

PIPE INDICATION
P: PRESSURE bar
F: FLOW kg/s
STATE OF MATTER (GAS, UNLESS NOTED OTHERWISE)

GRU EXHAUST GAS HEAT RECOVERY UNIT
GRU GAS REGULATING UNIT
VMS VESSEL MANAGEMENT SYSTEM (POWER SUPPLY AND CONTROL)
FG FUEL GLOSE, CLOSED VALVE IN CASE OF BLACK OUT

+) PROVISIONAL DIMENSIONS

++) START-UP POWER ONLY

1) SYSTEM DESIGN BASED ON ZERO LEAKAGE IN NORMAL OPERATIONAL CONDITIONS, FURTHER ANALYSIS REQUIRED TO CONTINUE DEVELOPMENT OF SYSTEM, FOR EXAMPLE BY MEANS OF QUANTITATIVE ANALYSIS

2) ALL SPACE SYSTEMS, TRANSMITTERS AND DETECTORS CONNECTED WITH VMS
3) REDUNDANCY OF SPACE SYSTEMS TO BE REVIEWED AND AGENT DISABILITIES OF SPACE SYSTEMS IN CASE OF FAILURE TO BE INCLUDED

4) PURGE GAS SYSTEM TO EMPTY FUEL LINES FOR MAINTENANCE TO BE ADDED
5) ALL FUEL PIPING TO BE ROUTED B/S FROM OUTER SHELL

6) VENTILATION INTAKES TO BE LOCATED OUTSIDE HAZARDOUS AREAS
7) HAZARDOUS AREAS OF VENTILATION EXHAUSTS TO BE DESCRIBED
8) HAZARDOUS AREA AND RELIABLE TO MONITOR FLOW/ELECTRICITY OF VENT MAST TO BE REFERENCED
9) ADDITIONAL MEASURES FOR MITIGATION OF AMMONIA VENTILATION EITHER BY WATER SPRAY OR FLARING TO BE REVIEWED

REV	DESCRIPTION	DRAWN	CHECK	APPR.	DATE
A	GENERAL UPDATE	NDR	PS	MZ	2019-02-21
0	FIRST ISSUE	NDR	PS	MZ	2019-01-18

CLIENT PROJECT NO.: CLIENT DRAWING NO.:

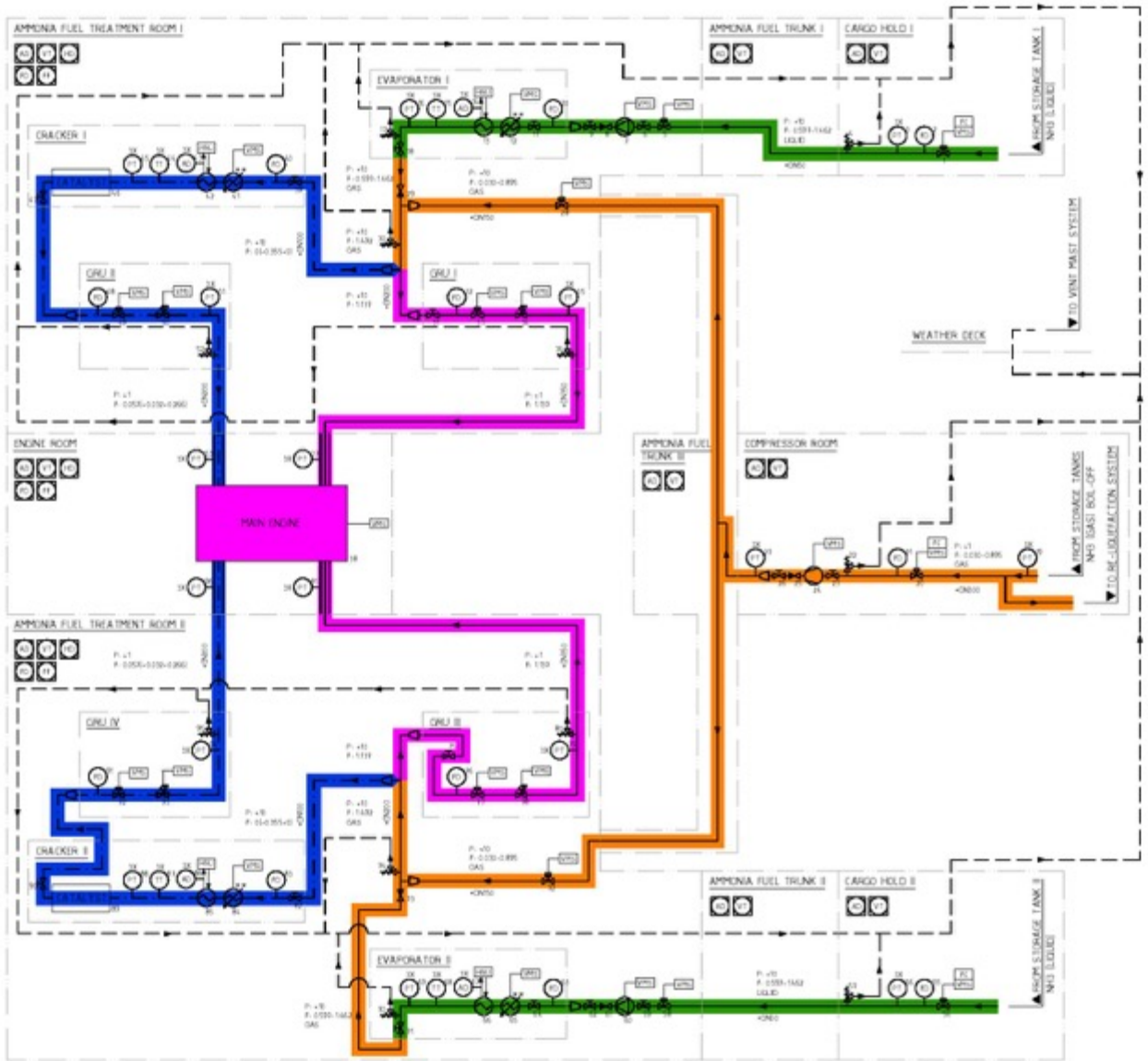
C-JOB

CLIENT: - YARD NO.: - CLASS NO.: -

PROJECT NUMBER: 16.104 | DRAWING NUMBER: 999-301 | STATUS: PRELIMINARY

TITLE: DIAGRAM NH3 FUEL SYSTEM (2X 100%)

PROJECTION: | SCALE: N.A. | SHEET: 1-1 | REV: A | FORMAT: A1



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SYMBOLS

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	NON RETURN VALVE		PRESSURE REGULATING VALVE
	REDUCER		PRESSURE RELIEVE VALVE
	COMPRESSOR		PUMP
	HEAT EXCHANGER		HEATER
FD	FLOW DETECTOR	PT	PRESSURE TRANSMITTER
AD	AMMONIA DETECTOR	TT	TEMPERATURE TRANSMITTER
AD	SPACE AMMONIA DETEITION	HD	SPACE HYDROGEN DETECTION
FD	SPACE FIRE DETEITION	VT	SPACE VENTILATION
FF	SPACE FIRE FIGHTING SYSTEM		

LEGEND

- NH3 FUEL
- HEL/MGO FUEL
- AIR/GAS VENT
- NH3 FUEL DOUBLE WALLED
- HEL/MGO FUEL DOUBLE WALLED

NOTES

TYPE INDICATION
P - PRESSURE bar
F - FLOW kg/s
STATE OF MATTER (GAS), UNLESS NOTED OTHERWISE

HRU EXHAUST GAS HEAT RECOVERY UNIT
GRU GAS REGULATING UNIT
VMS - VESSELS MANAGEMENT SYSTEM (POWER SUPPLY AND CONTROL)
FC FAIL CLOSE, CLOSES VALVE IN CASE OF BLACK OUT

+/- PROVISIONAL DIMENSIONS

++) START-UP POWER ONLY

1) SYSTEM DESIGN BASED ON ZERO LEAKAGE IN NORMAL OPERATIONAL CONDITIONS, FURTHER ANALYSIS REQUIRED TO CONTINUE DEVELOPMENT OF SYSTEM, FOR EXAMPLE BY MEANS OF QUANTITATIVE ANALYSIS

2) ALL SPACE SYSTEMS, TRANSMITTORS AND DETECTORS CONNECTED WITH VMS

3) REDUNDANCY OF SPACE SYSTEMS TO BE REVIEWED AND ALERT CAPABILITIES OF SPACE SYSTEMS IN CASE OF FAILURE TO BE INCLUDED

4) INERT GAS SYSTEM TO EMPTY FUEL LINES FOR MAINTENANCE TO BE ADDED

5) ALL FUEL PIPING TO BE ISOLATED BY/S FROM OUTER SHELL

6) VENTILATION INTAKES TO BE LOCATED OUTSIDE HAZARDOUS AREAS

7) HAZARDOUS AREAS OF VENTILATION EXHAUSTS TO BE DETERMINED

8) HAZARDOUS AREA AND PRESSURES TO MONITOR FLOW/ACTIVITY OF VENT MAST TO BE REVIEWED

9) ADDITIONAL MEASURES FOR MITIGATION OF AMMONIA VENTILATION, EITHER BY WATER SPRAY OR FLARING TO BE REVIEWED

REV	DESCRIPTION	DRAWN	CHECK	APPR.	DATE
A	GENERAL UPDATE	NDH	PS	MZ	20190503
0	FIRST ISSUE	NDH	PS	MZ	20190412

CLIENT PROJECT NO.: | CLIENT DRAWING NO.:

C-JOB NAVIGATION

CLIENT: - | YARD NO.: - | CLASS NO.: -

PROJECT NUMBER	DRAWING NUMBER	STATUS
16104	999-301	PRELIMINARY

TITLE: DIAGRAM NH3 FUEL SYSTEM (ZOK 10.050)

PROJECTION	DIM. UNIT	REV.	SHEET	SCALE	FORMAT
	mm	A	1-1	N.A.	A1

Ammonia as Marine Fuel Risk Assessment

Redundancy -> 2x 100%

Requirement: maintain adequate ship speed and manoeuvrability

Convert -> 2x 50%

50% power results in roughly 80% maximum ship speed

Ammonia as Marine Fuel Risk Assessment

Risk assessment 2

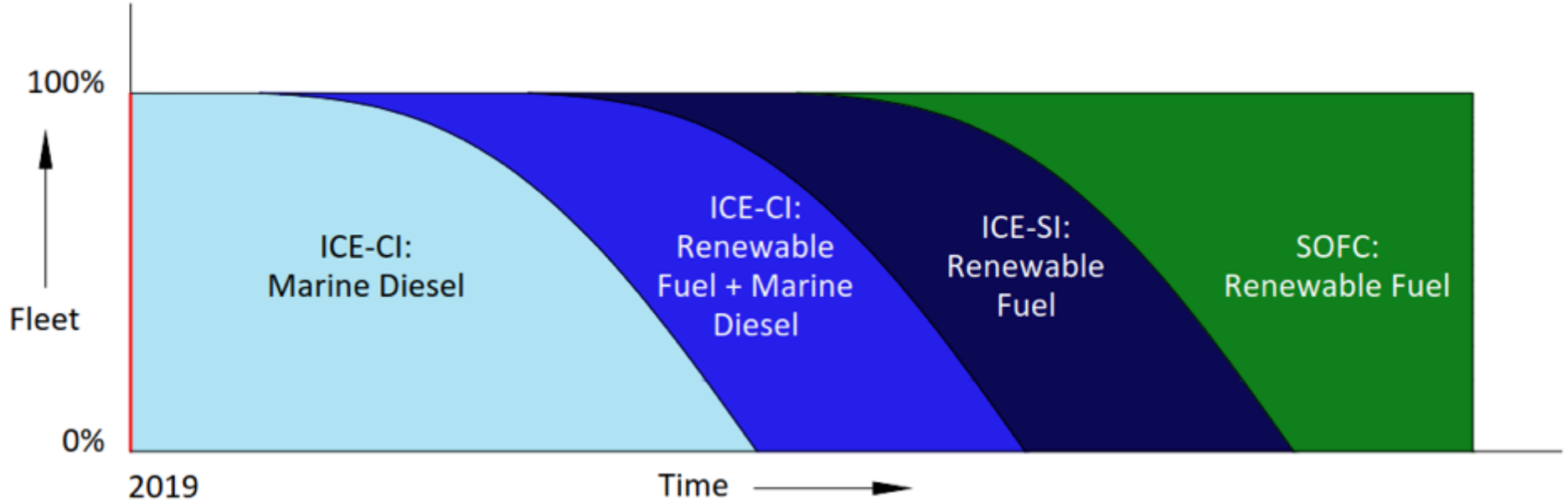
E		1			
D	9	1			
C		12		2	
B				2	
A		3	10	21	
	1	2	3	4	5

Table 10-3: Final risk rating results risk assessment 1

E		1			
D	11	1			
C		16		2	
B		6		2	
A		3	12	33	
	1	2	3	4	5

Table 10-4: Risk rating results risk assessment 2

Outlook



Further research:

- ICE Ammonia + Hydrogen
- ICE Ammonia + Diesel
- Fuel cell application, especially the SOFC and vessels which already have fuel-electric configurations
- Other vessel types, besides ammonia carrier, to address fuel storage
- Further study safety, class involvement HAZID

Ammonia + Diesel

- Storage Space
- Fuel Treatment Room
- Gas Regulating Unit Room
- Engine Room

More information

- https://cjob.nl/the-next-step-in-c-jobs-ammonia-research/

- https://repository.tudelft.nl/islandora/object/uuid:be8cbe0a-28ec-4bd9-8ad0-648de04649b8?collection=education

C-JOB

DEDICATED NAVAL ARCHITECTS

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Back-up Slides

General Ammonia Safety

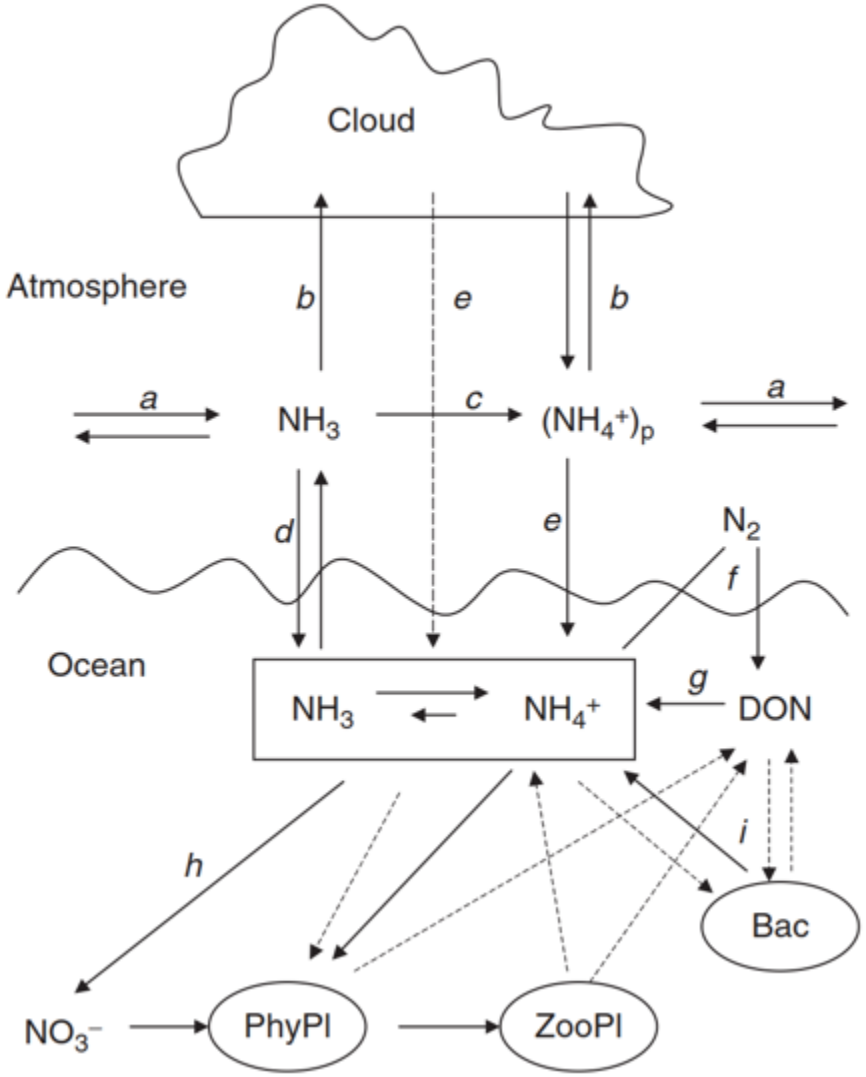
- Existing safety measures
  - Leakages in enclosed spaces (Ventilation)
  - Leakages in open spaces (Water spray)
  - Overpressure in storage tanks (Flaring)

General Ammonia Safety

- Ammonia in the Nitrogen Cycle

pH Water	mol Ammonia NH_3	mol Ammonium NH_4^+	mol NH_3/NH_4^+
7.25	1%	99%	1:100
8.25	9%	91%	1:10
9.25	50%	50%	1:1

Table 7-3: Fraction of chemical species of ammonia present with change in pH (at 25°C)



D. G. Capone, D.A. Bronk, M. R. Mulholland and E. J. Carpenter, "Chapter 2: Gaseous Nitrogen Compounds (NO, N2O, N2, NH3) in the Ocean - Ammonia & Outlook," in *Nitrogen in the Marine Environment (2nd edition)*, Burlington, Elsevier, 2008, pp. 75 - 84.