MARINE NH3

Safe and Effective Application of Ammonia as a Marine Fuel

NCE: Ammonia in the Maritime Sector - Niels de Vries

12 November 2019

C-JOB
DEDICATED NAVAL ARCHITECTS

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

Renewable Fuels Motivation

- Reduction of greenhouse gas (GHG) emissions
- Circular economy

IMO Goals

- IMO: reducing overall carbon intensity of the cargo transported per kilometer by at least:
  - 40% by 2030
  - 70% by 2050

  (compared to 2008)

- IMO: reduce total annual GHG emissions by at least 50% by 2050 (compared to 2008)
  - Pursuing efforts towards phasing them out entirely

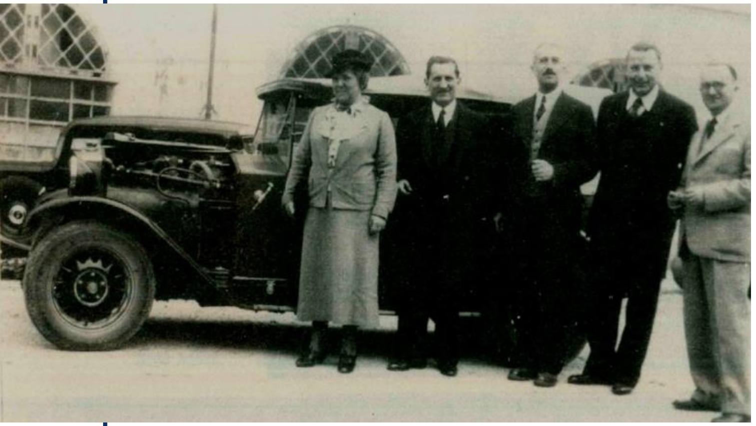
INTERNATIONAL MARITIME ORGANIZATION

History of Ammonia

- 100 years of experience transporting & handling
  - Fertilizer industry
    - Global production > 180 million tonnes
    - Bulk transport (ships/tankers up to 60,000 tonnes DWT)
  - Cooling systems
  - DeNOx (Ammonia in form of Urea)

History of Ammonia as Fuel

- Transportation methods



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

Agenda

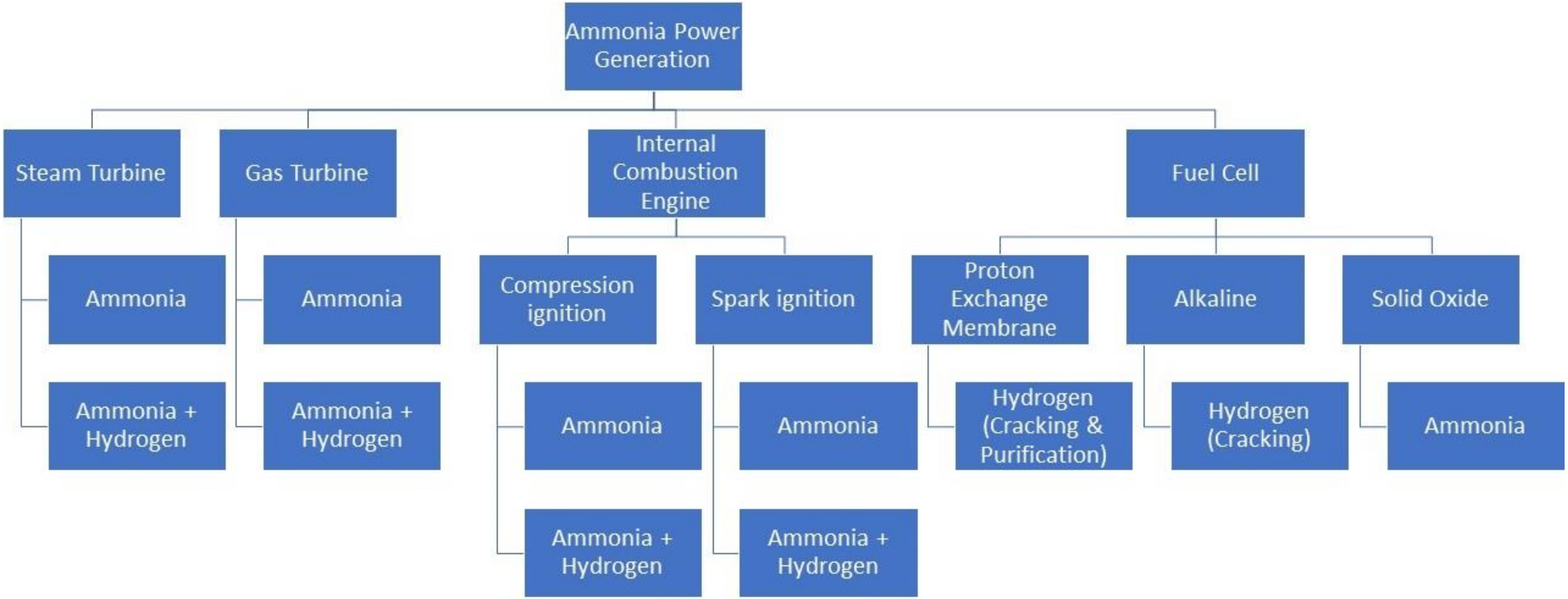
- Renewable Fuels
  - Motivation
  - History of Ammonia
  - Potential of Ammonia
- Ammonia Power Generation
  - Onshore Technical Feasibility
  - Marine Technical Feasibility
  - Marine Performance
  - Comparison with Conventional Power Generation
- Safety
  - General Ammonia Safety
  - Risk Assessment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

Ammonia Properties

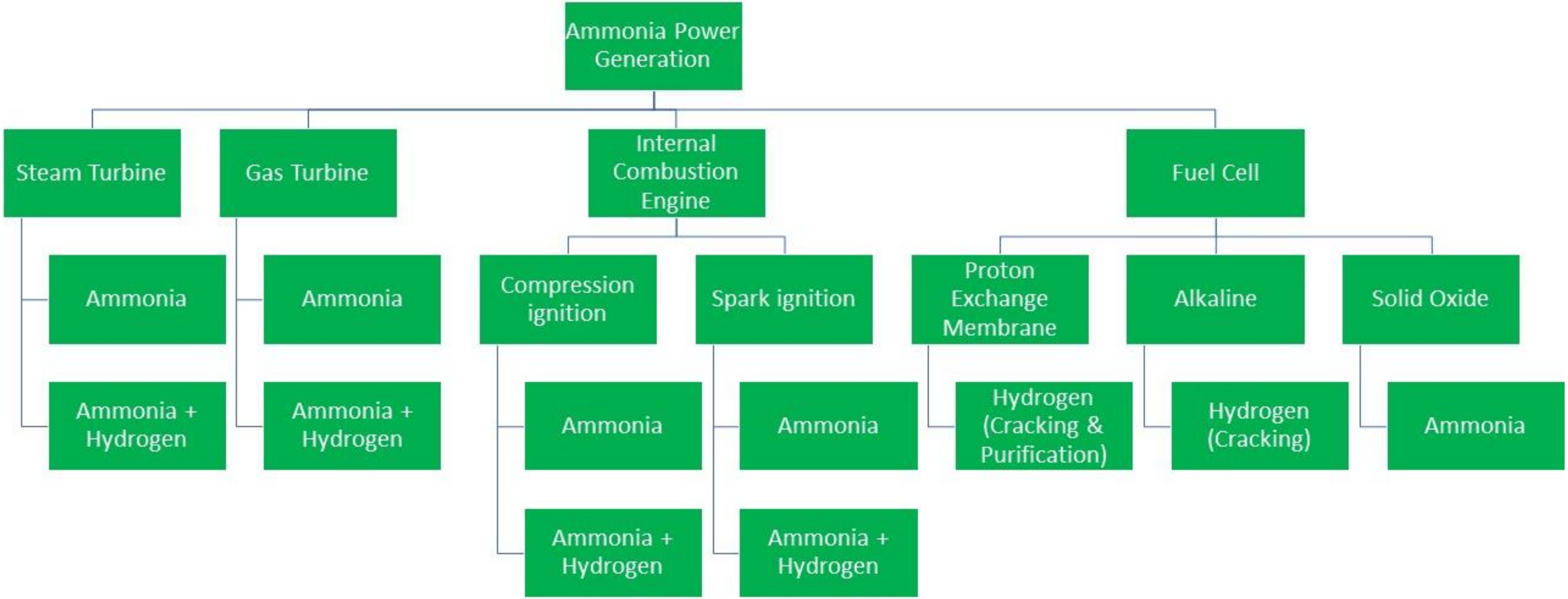
- Ammonia
  - Flammable and highly toxic gas
  - Auto-ignition temperature: 651 °C
  - Flammability limits: 15-28% (vol)
  - Low flame speed
  - High heat of vaporization

- Ammonia Hydrogen Mixtures
  - Improve combustion properties

Ammonia Power Generation Options



Ammonia Power Generation: Selection Onshore Technically Feasible Options

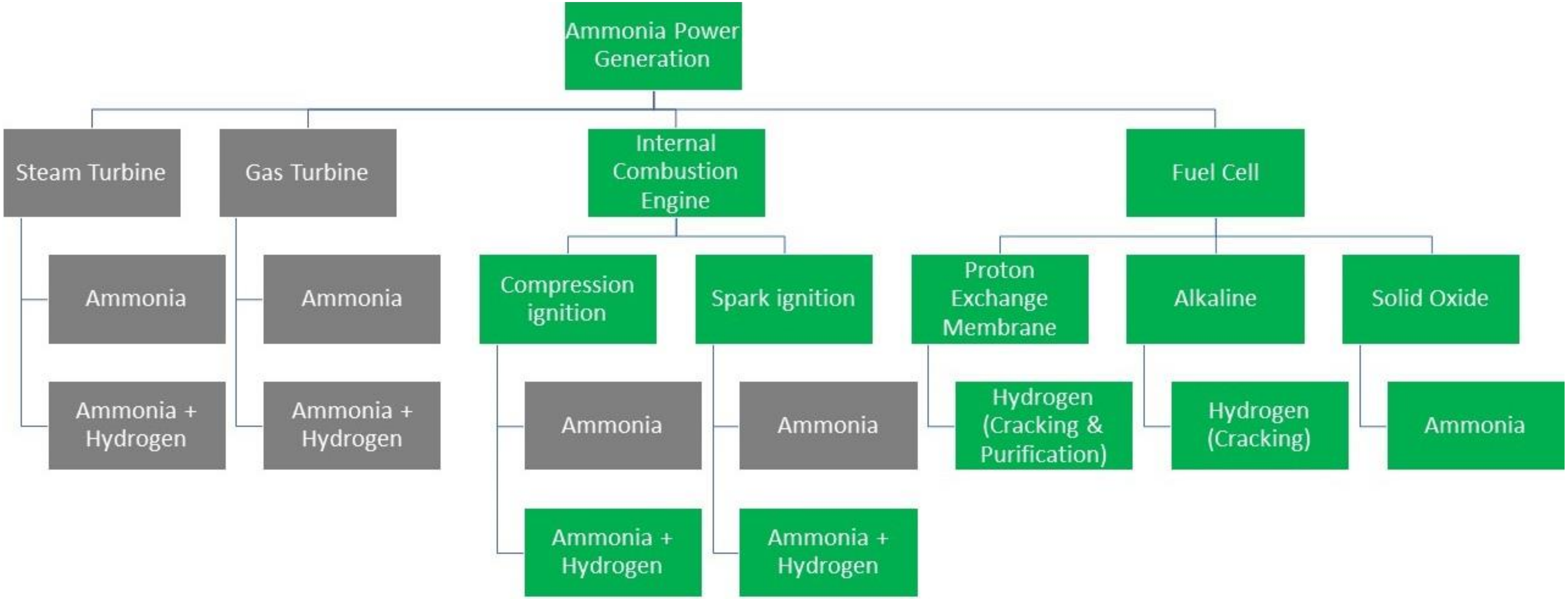


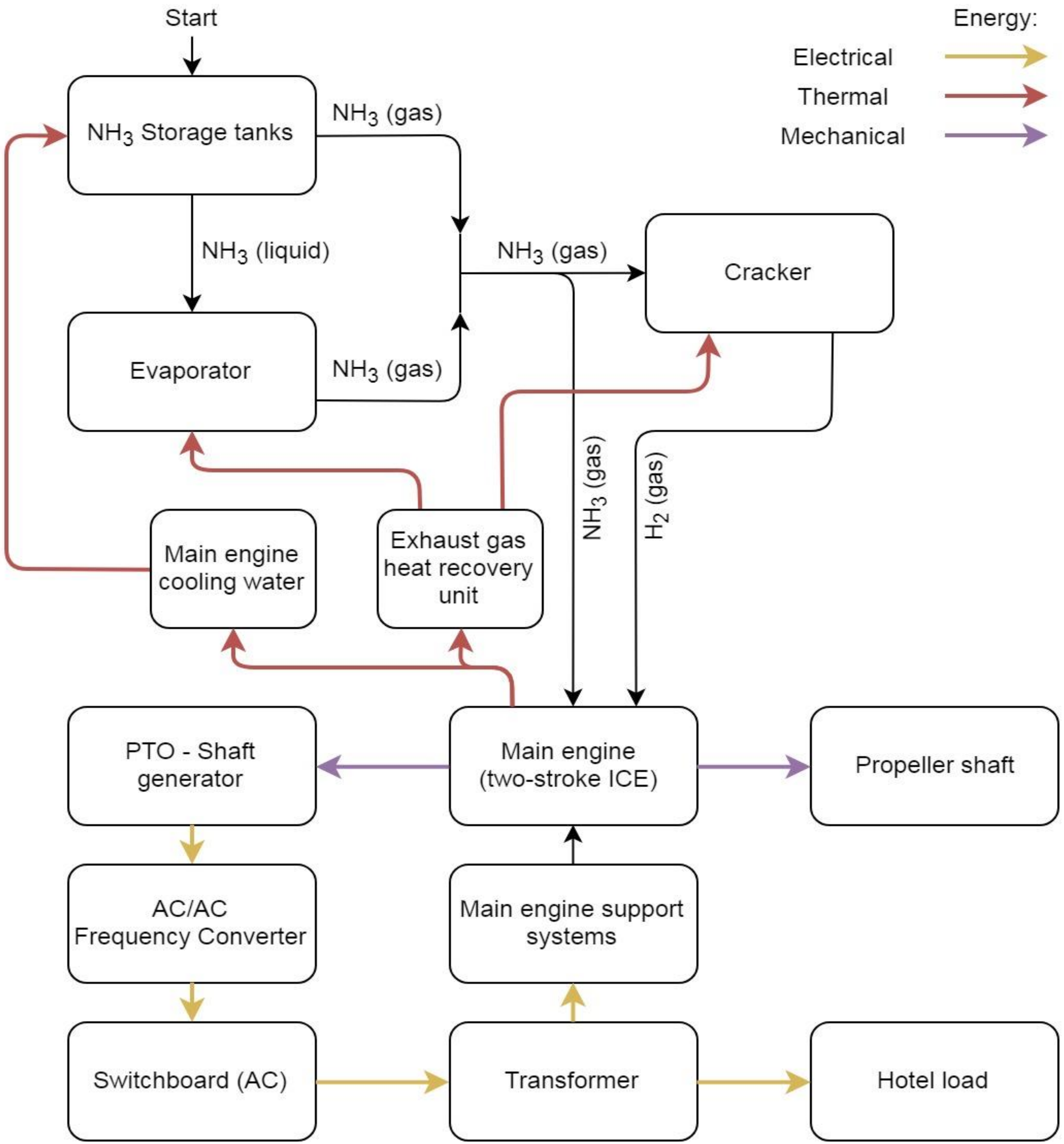
Ammonia Power Generation: Marine Technically Feasible

- Ship type: Ammonia carrier

  Efficiency dominant performance indicator

Ammonia Power Generation: Selection Marine Technically Feasible Options




Start
Energy:
Electrical
Thermal
Mechanical
NH3 Storage tanks
NH3 (gas)
NH3 (liquid)
NH3 (gas)
Cracker
Evaporator
NH3 (gas)
NH3 (gas)
H2 (gas)
Main engine cooling water
Exhaust gas heat recovery unit
PTO - Shaft generator
Main engine (two-stroke ICE)
Propeller shaft
AC/AC Frequency Converter
Main engine support systems
Switchboard (AC)
Transformer
Hotel load

Ammonia Power Generation: Marine Performance

- Internal Combustion Engine: Harmful emissions
  - NOx (Guideline)

Ammonia			Diesel (IMO Tier II)		
Large engine	Low speed	?	Large engine	Low speed	14 g/kWh
				High speed	8 g/kWh
Small engine	High speed	+/-8 g/kWh	Small engine	High speed	8 g/kWh

Ammonia Power Generation: Marine Performance

- Internal Combustion Engine: Harmful emissions (NOx)

Reasons for higher NOx:

-More Nitrogen in fuel (NH3)

Reasons for lower NOx:

-Lower exhaust gas temperature compared to diesel

-More homogenous air fuel mixture compared to diesel

-No 'diesel dilemma' reducing peak temperatures*

-Selective Non-Catalytic Reduction due to fuel slip could aid NOx reduction (unconfirmed)

Reference:

Selective Catalytic Reduction (NOx reduction) applied for diesel engines:

Ammonia in form of Urea: $$(NH_2)_2CO + H_2O \longrightarrow 2\,NH_3 + CO_2$$

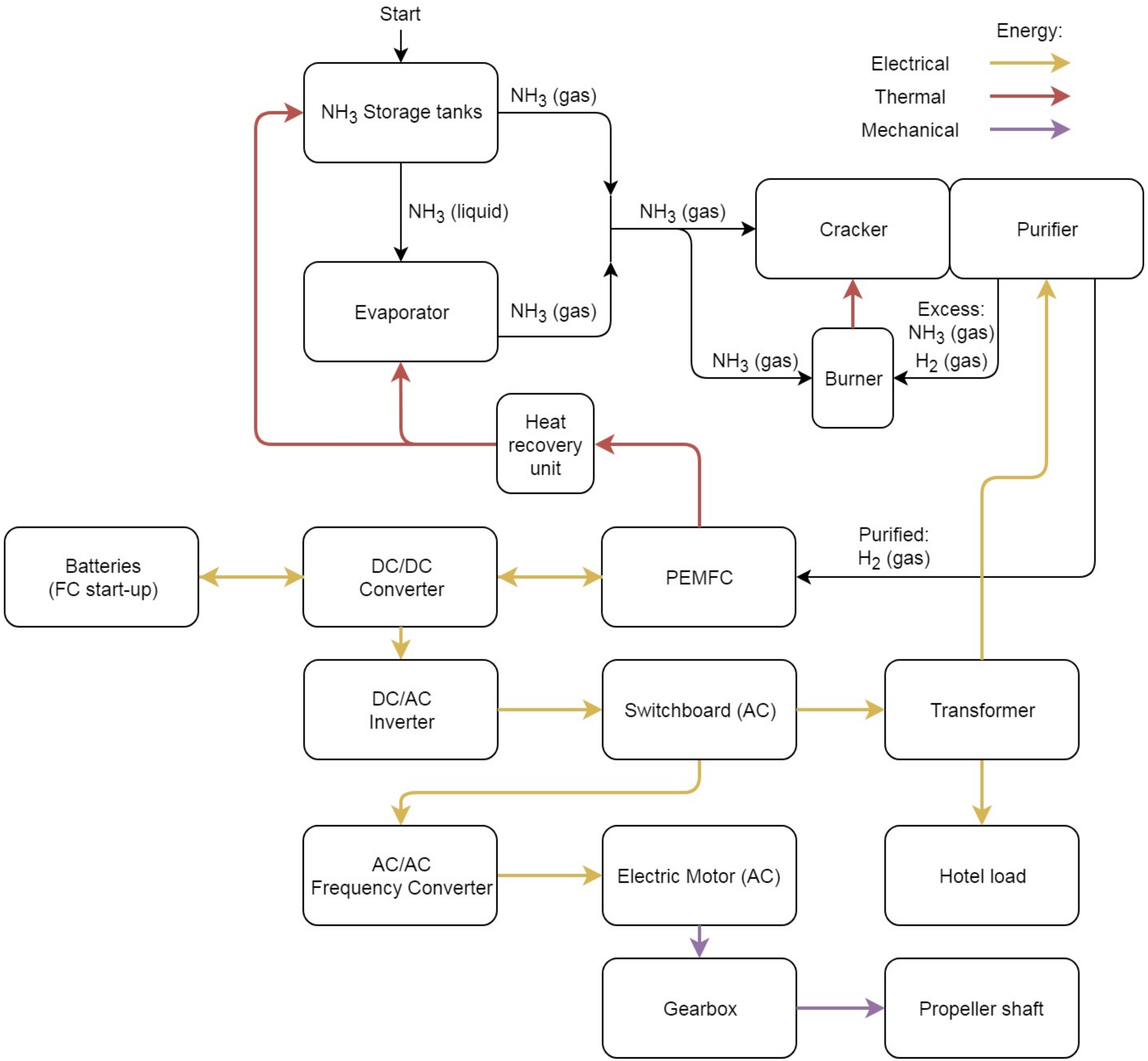
Actual process: $$4\,NO + 4\,NH_3 + O_2 \longrightarrow 4\,N_2 + 6\,H_2O$$

Ammonia Power Generation: Marine Performance

- Internal Combustion Engine: Harmful emissions
  - NOx (Guideline)

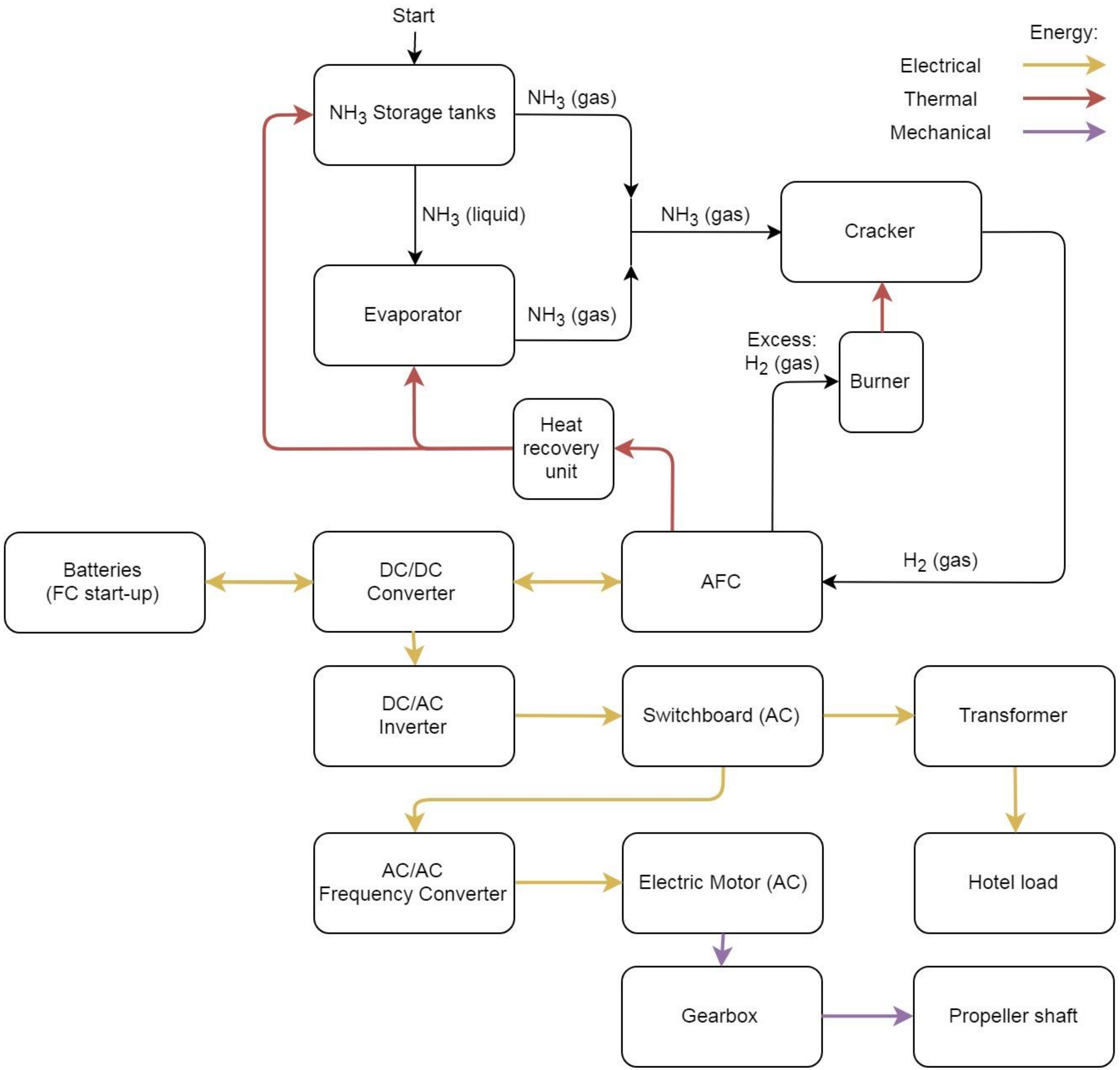
Ammonia			Diesel (IMO Tier II)		
Large engine	Low speed	+/-14 g/kWh	Large engine	Low speed	14 g/kWh
				High speed	8 g/kWh
Small engine	High speed	+/-8 g/kWh	Small engine	High speed	8 g/kWh

- **To be further investigated**
- **Results will show to what extend SCR (NOx reduction) is required**


Start
NH3 Storage tanks
NH3 (gas)
NH3 (liquid)
Evaporator
NH3 (gas)
NH3 (gas)
Cracker
Purifier
Energy:
Electrical
Thermal
Mechanical
Excess:
NH3 (gas)
H2 (gas)
NH3 (gas)
Burner
Heat
recovery
unit
Batteries
(FC start-up)
DC/DC
Converter
PEMFC
Purified:
H2 (gas)
DC/AC
Inverter
Switchboard (AC)
Transformer
AC/AC
Frequency Converter
Electric Motor (AC)
Hotel load
Gearbox
Propeller shaft

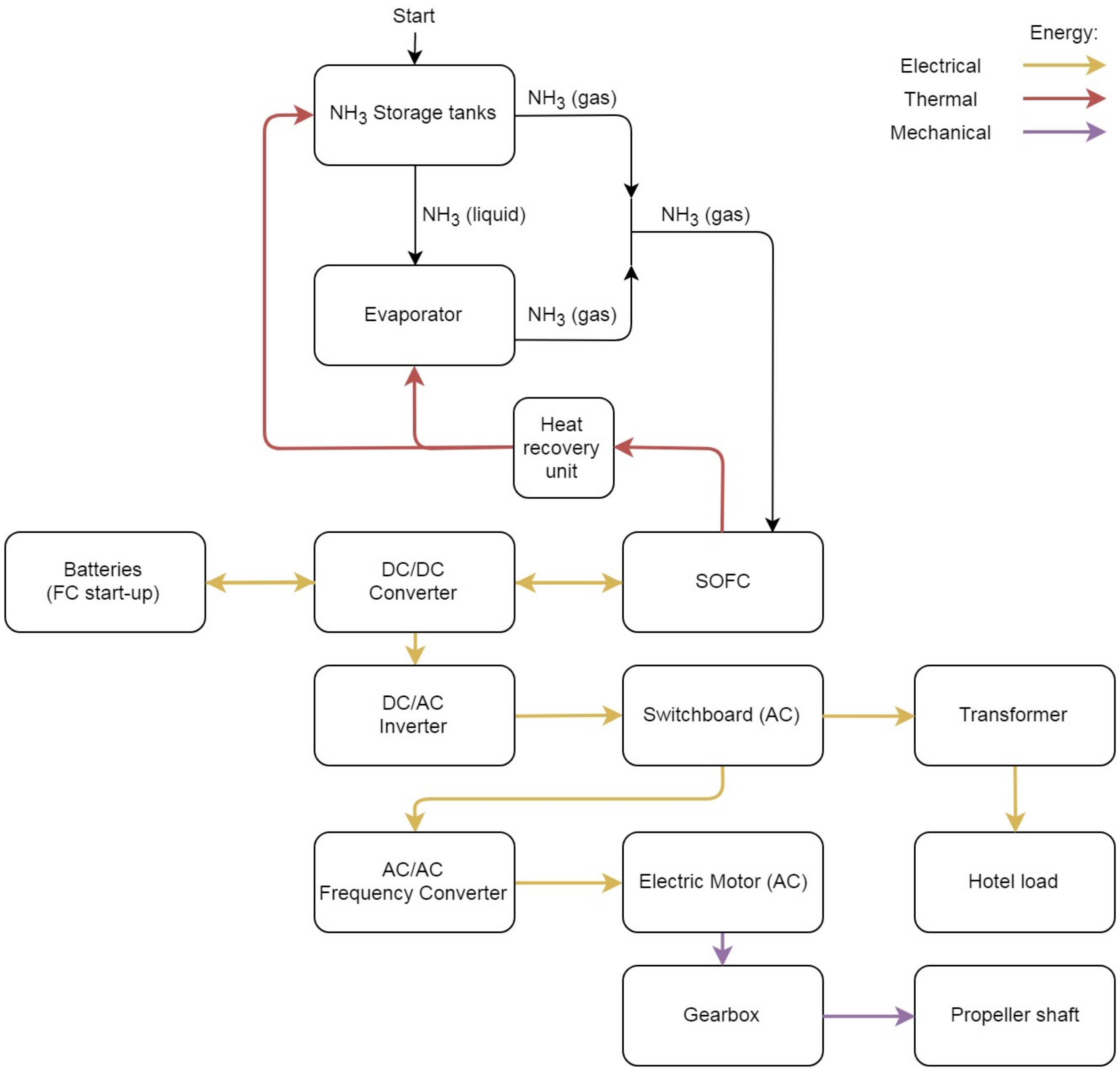
- AFC:

System definition



- SOFC:

System definition



Ammonia Power Generation: Marine Performance

Option	*Power density		Harmful emissions	***Load response		
	[kW/ton]	[kW/m3]		Heavy weather	Port	[%Pmax/s]
ICE	+/-38	+/-29	**+/-14 g/kWh NOx & 100ppm ammonia slip	V	V	+/-0.800
PEMFC	+/-256	+/-99	None	V	V	>16.000
AFC	+/-8	+/-6	None	V	V	>16.000
SOFC	+/-17	+/-8	None	X	X	+/-0.003

Table 5-18: Comparison of options, Part 1

*Power density is a guideline based on simplified measurements of the engine or fuel cell only. Other equipment such as support systems and electrical systems are excluded.
**Emissions of main engine, apply SCR to reduce NOx as much as possible.
***Load response:
V: System has sufficient capability to cope with conditions
X: System insufficiently capable, additional measures to be taken, part of problem could be solved with batteries, which are already installed for start-up power
%Pmax/s is a guideline only.

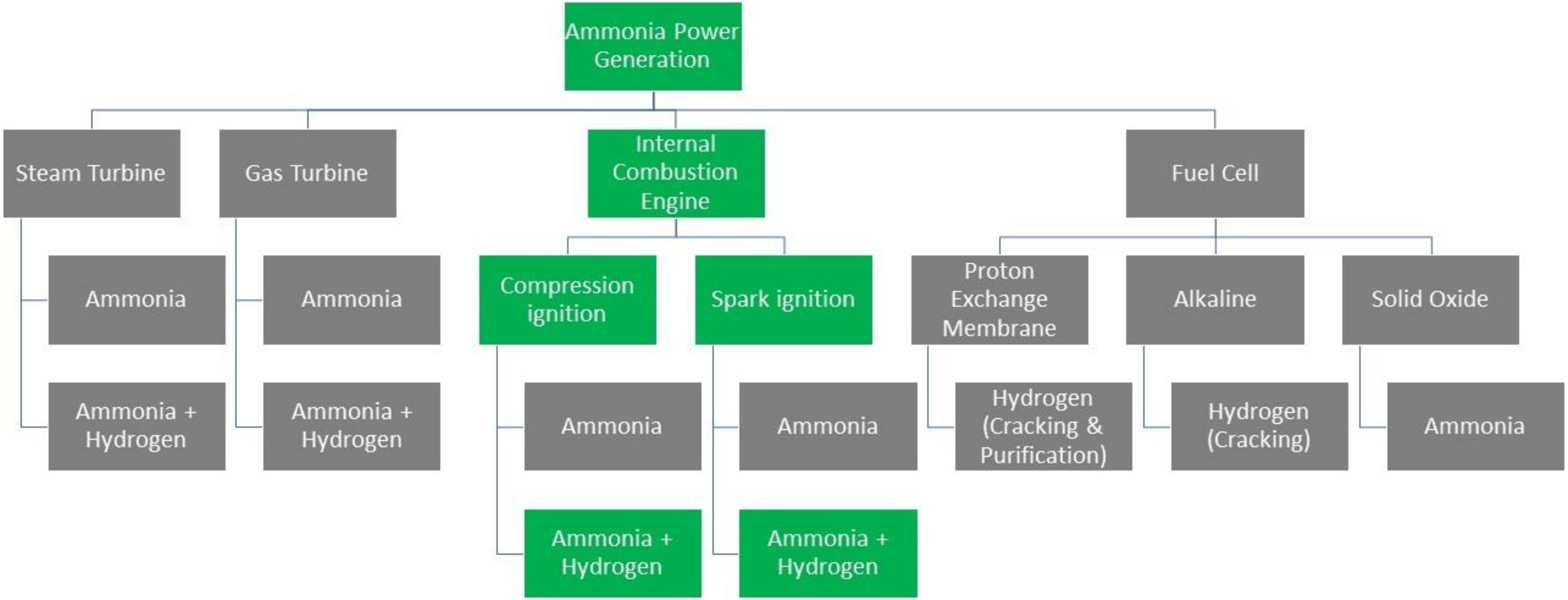
Ammonia Power Generation: Marine Performance

Option	*Part load	Marine environment	System efficiency	Total cost of ownership (ΔTCO)
ICE	V	No issues	49.4%	€689,496,925
PEMFC	V	Air treatment required: filtration	44.5%	€795,923,500
AFC	V	Air treatment required: CO_2 scrubbing	44.8%	€807,876,500
SOFC	V	No issues	53.9%	€744,443,475

Table 5-19: Comparison of options, Part 2

*Part load
V: System has sufficient capability to supply minimum power in port conditions

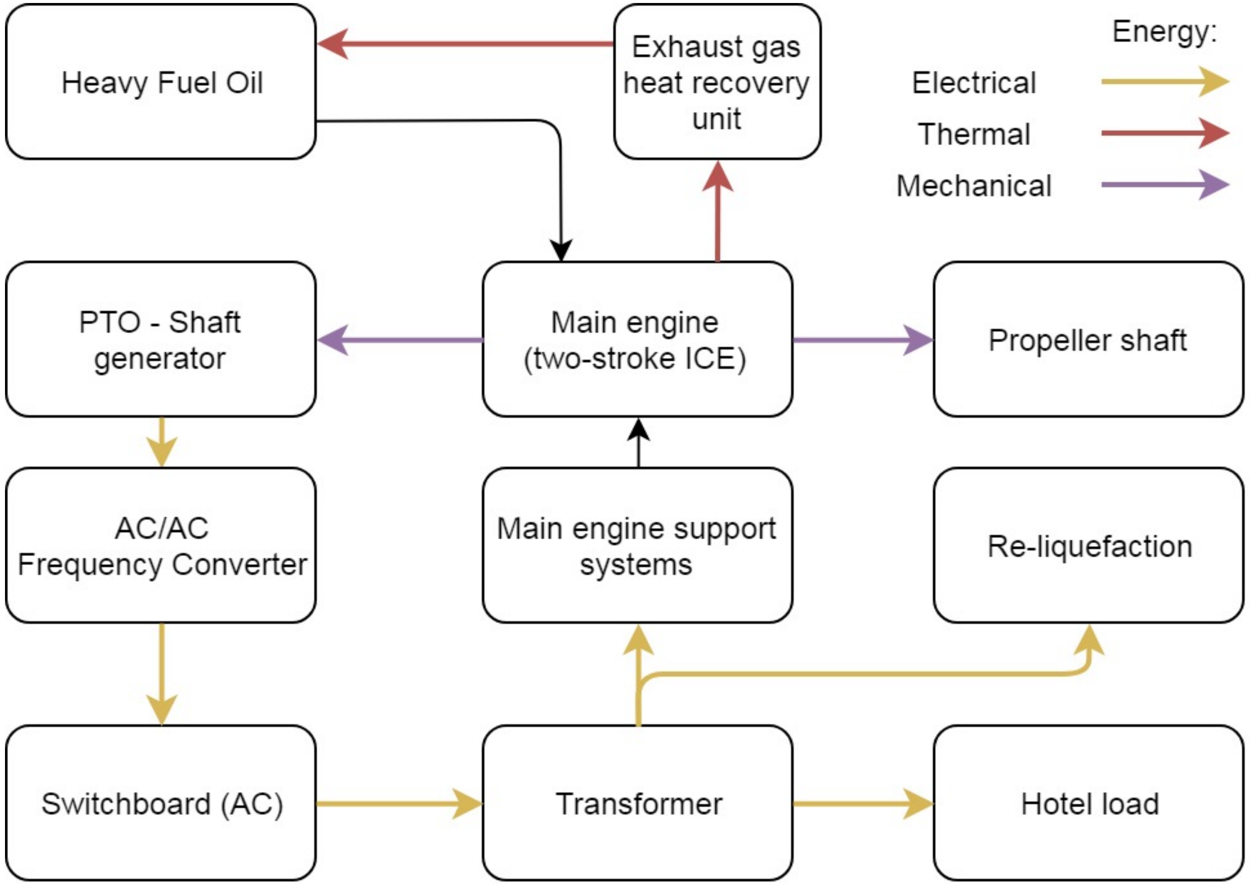
Ammonia Power Generation: Selection Marine Performance Option



Ammonia Performance Comparison with Conventional Power Generation

- Internal Combustion Engine (conventional):

System definition



Ammonia Performance Comparison with Conventional Power Generation

Option	*Power density		Harmful emissions	***Load response	
	[kW/ton]	[kW/m3]		Heavy weather	Port
ICE (NH_3)	+/-38	+/-29	**+/-14 g/kWh NOx 100ppm ammonia slip	V	V
Conventional	+/-35	+/-32	561 g/kWh CO_2 1 g/kWh SOx & PM **14 g/kWh NOx	V	V

Table 6-5: Comparison with Conventional option, Part 1

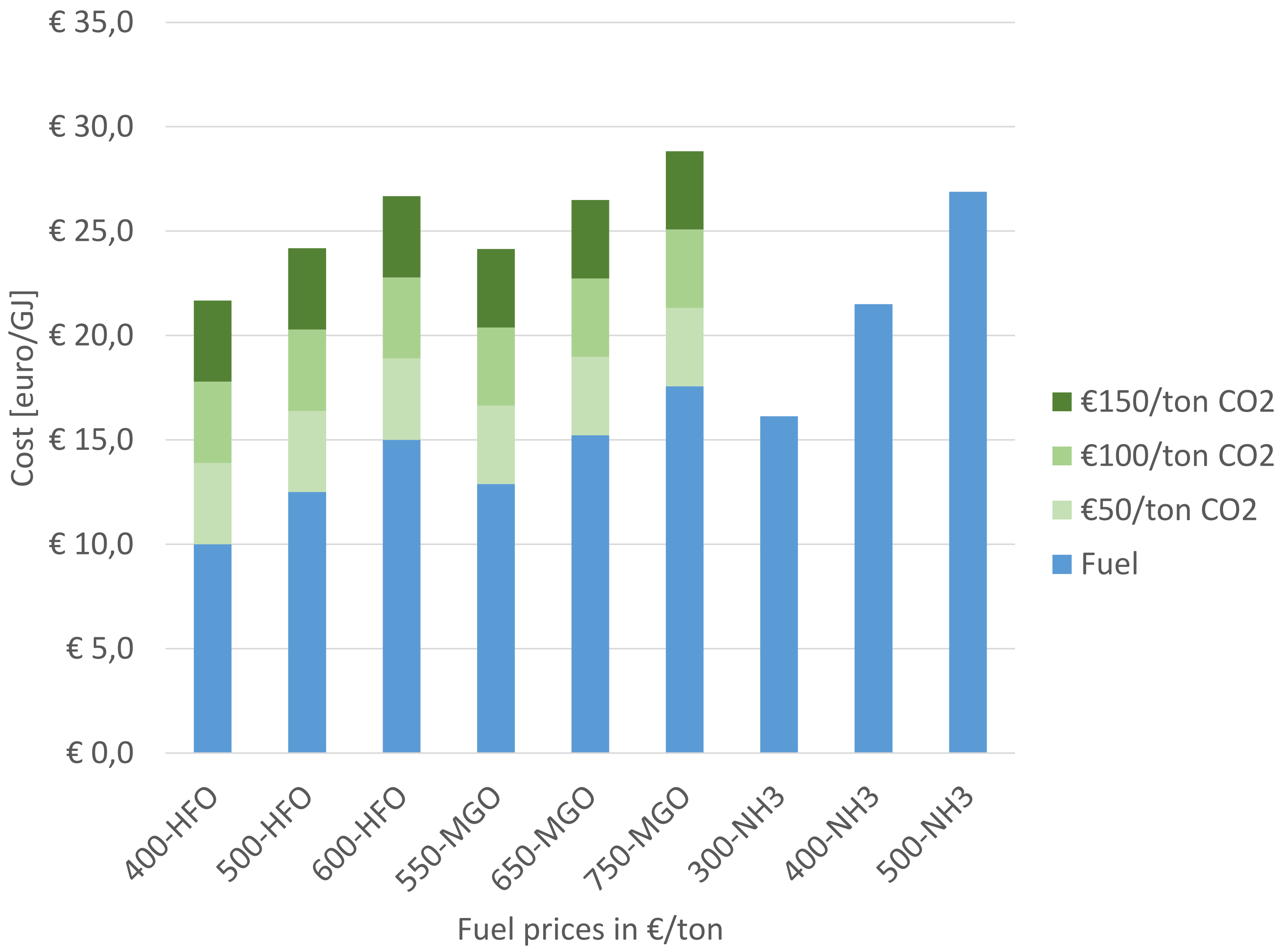
*Power density is a guideline based on simplified measurements of the engine. Other equipment such as support systems and electrical systems are excluded.
**Emissions of main engine, apply SCR to reduce NOx as much as possible.
***Load response:
V: System has sufficient capability to cope with conditions

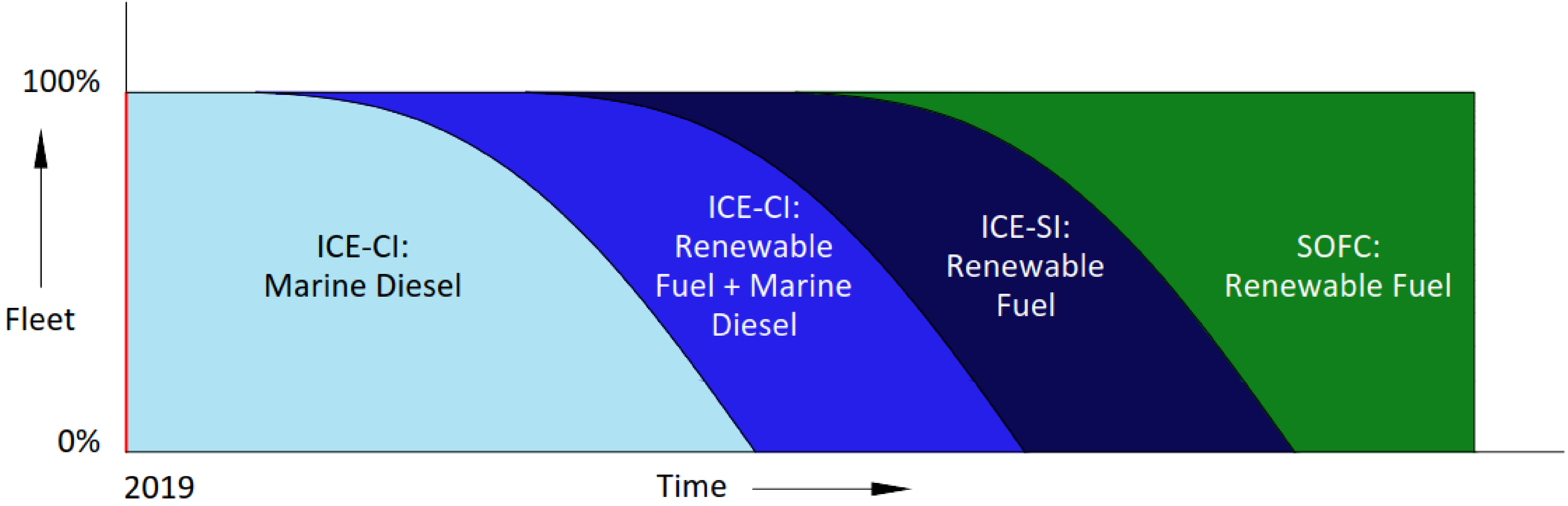
Option	*Part load	Marine environment	System efficiency	Total cost of ownership (ΔTCO)
ICE (NH_3)	V	No issues	49.4%	€689,496,925
Conventional	V	No issues	47.3%	€212,988,650

Table 6-6: Comparison with Conventional option, Part 2

*Part load
V: System has sufficient capability to supply minimum power in port conditions

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

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- Potential of Ammonia

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- Onshore Technical Feasibility
- Marine Technical Feasibility
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Safety
- General Ammonia Safety
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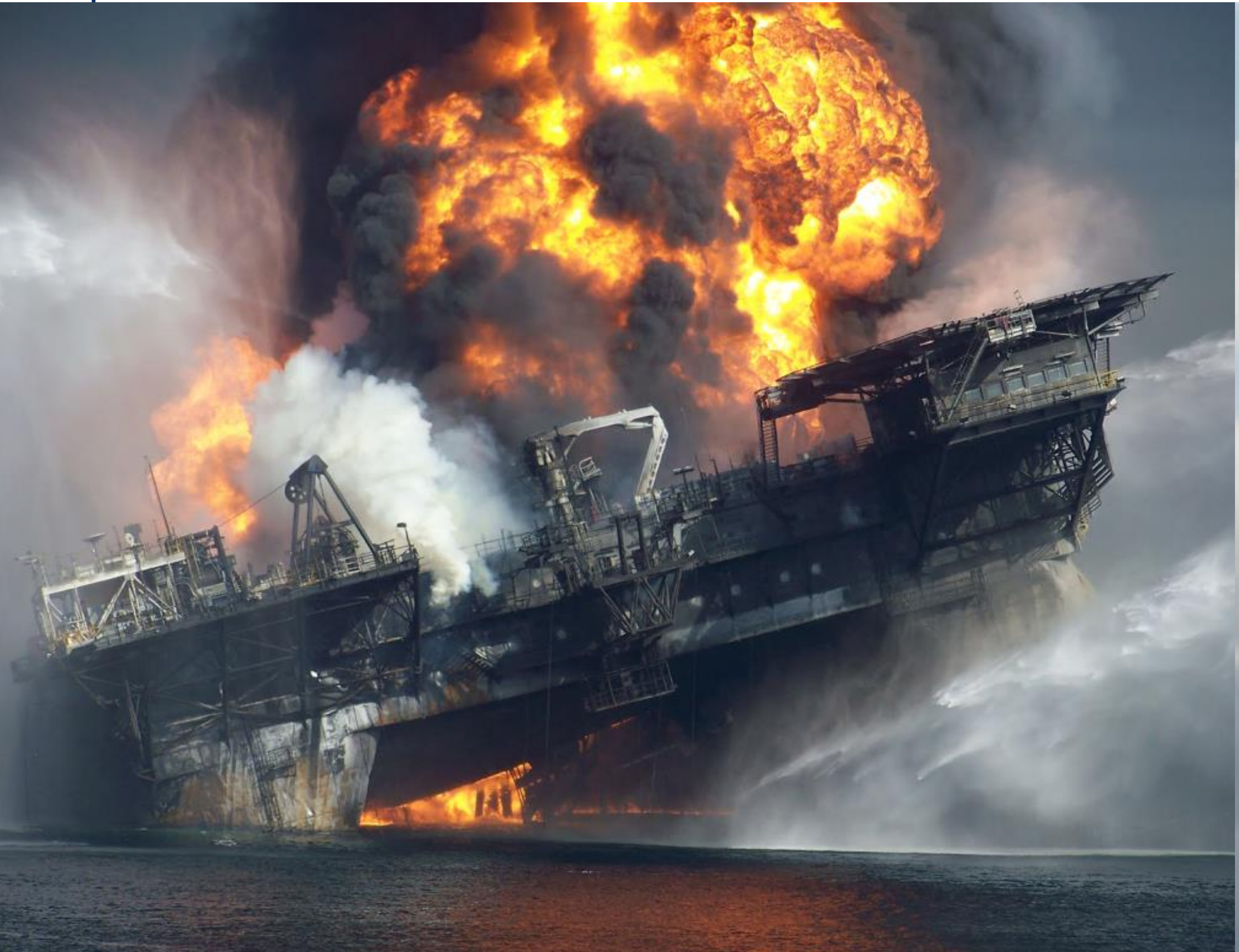
What is Safety?

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

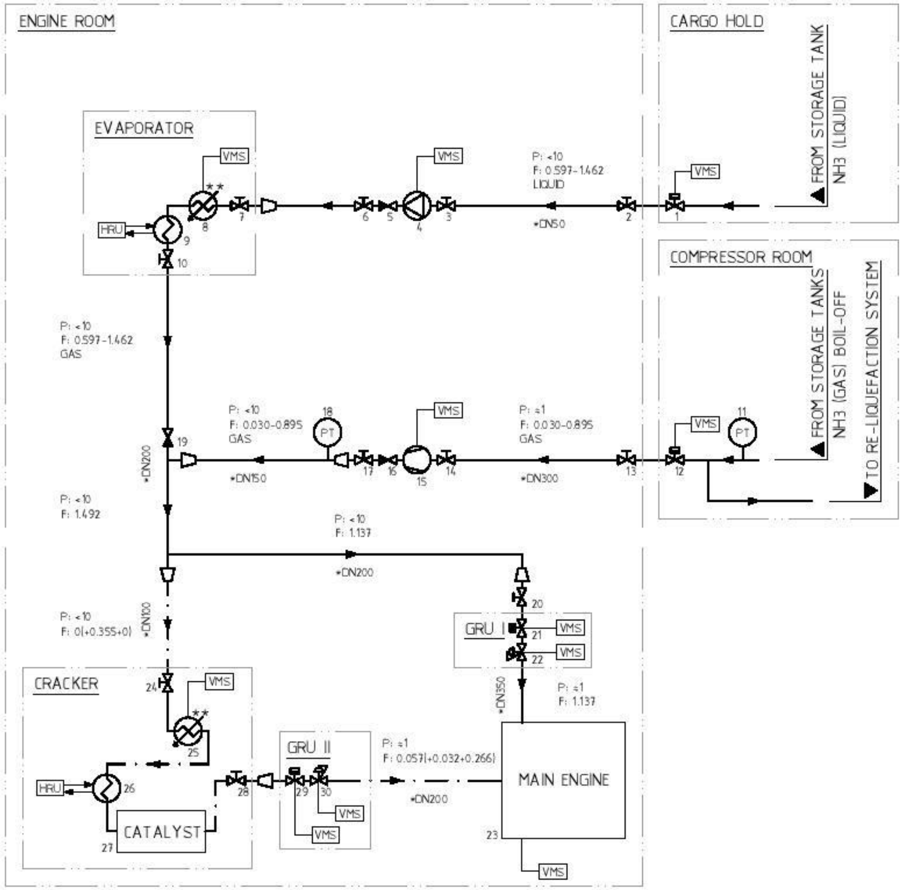
Ammonia as Marine Fuel Risk Assessment

- 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.:

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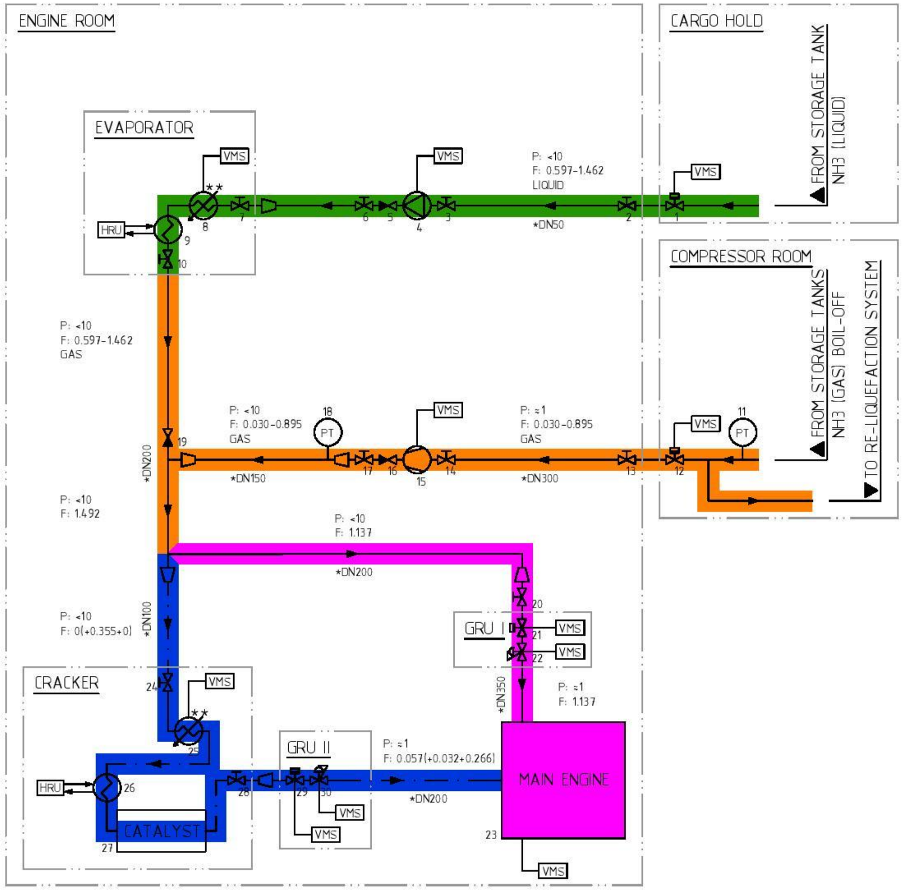
E: info@c-job.com

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	COPYRIGHT OF C-JOB, WHOSE PROPERTY, THIS DOCUMENT REMAINS. NO PART THEREOF MAY BE DISCLOSED, COPIED, DUPLICATED OR IN ANY OTHER WAY MADE USE OF EXCEPT WITH THE APPROVAL OF C-JOB	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	PRESSURE TRANSMITTER
COMPRESSOR	CENTRIFUGAL PUMP
HEAT EXCHANGER	HEATER

LEGEND

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- H2(+NH3+N2) FUEL

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A	GENERAL UPDATE	NDV	PL	WZ	20190503
0	FIRST ISSUE	NDV	PL	WZ	20190412

CLIENT PROJECT NO.: | CLIENT DRAWING NO.:

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E: info@c-job.com

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:

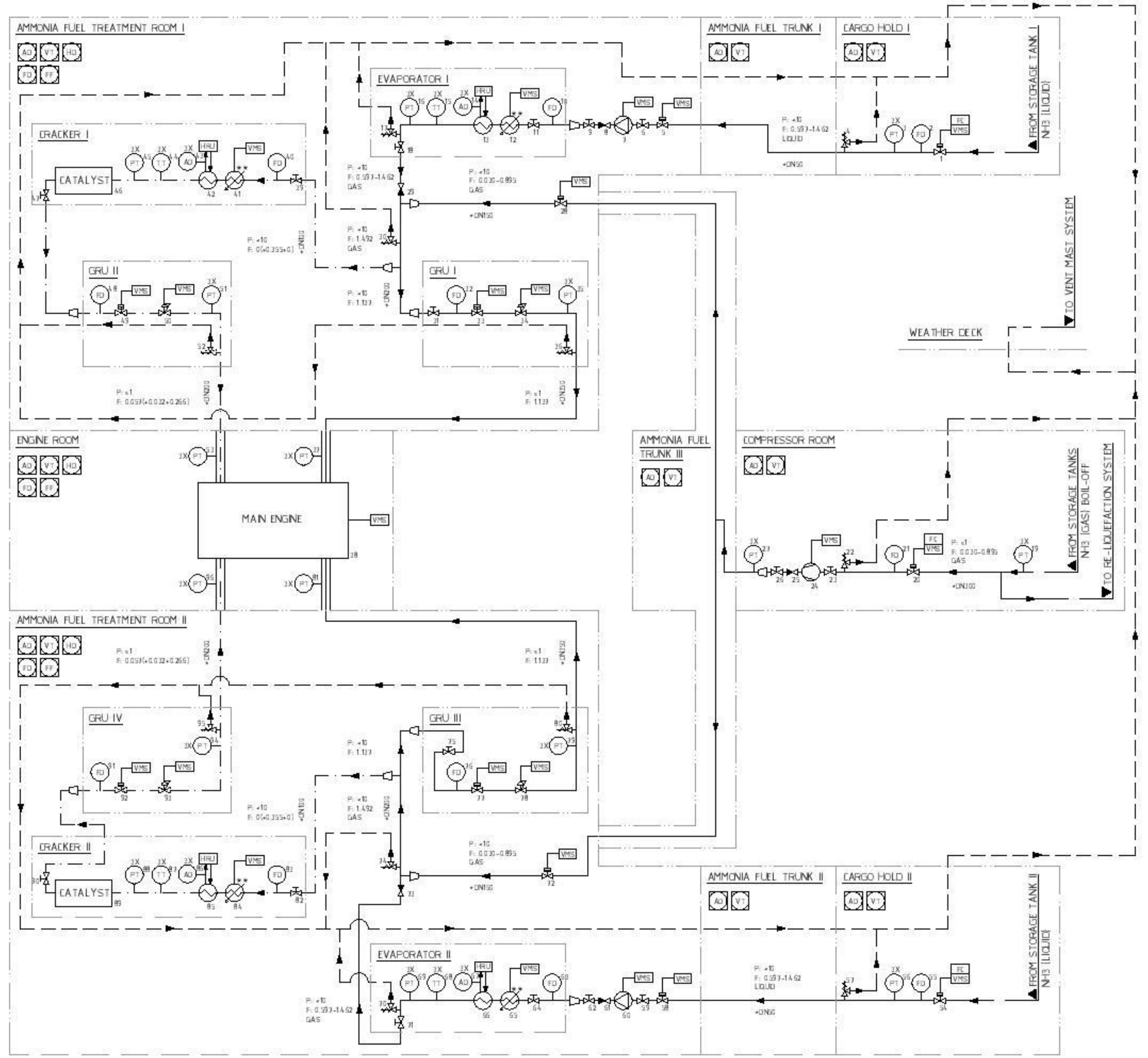
- Redundancy
- Ammonia and hydrogen detection
- Ventilation
- Pressure relieve system
- Remote operated isolation valves
- Route piping with sufficient distance from shell
- Locate piping in separate unmanned space
- Double-walled piping

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
REDUCER	PRESSURE RELIEVE VALVE
COMPRESSOR	PUMP
HEAT EXCHANGER	HEATER
FLOW DETECTOR	PRESSURE TRANSMITTER
AMMONIA DETECTOR	TEMPERATURE TRANSMITTER
SPACE: AMMONIA DETECTION	SPACE: HYDROGEN DETECTION
SPACE: FIRE DETECTION	SPACE: VENTILATION
SPACE: FIRE FIGHTING SYSTEM	

LEGEND

- NH3 FUEL
- H2(+NH3+N2) FUEL
- AIR/GAS VENT
- NH3 FUEL DOUBLE WALLED
- H2(+NH3+N2) FUEL DOUBLE WALLED

NOTES

PIPE INDICATION:
P: PRESSURE bar
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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)
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, TRANSMITTERS 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 ROUTED B/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 MEASURES 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	NOV	PL	WZ	20190503
0	FIRST ISSUE	NOV	PL	WZ	20190412

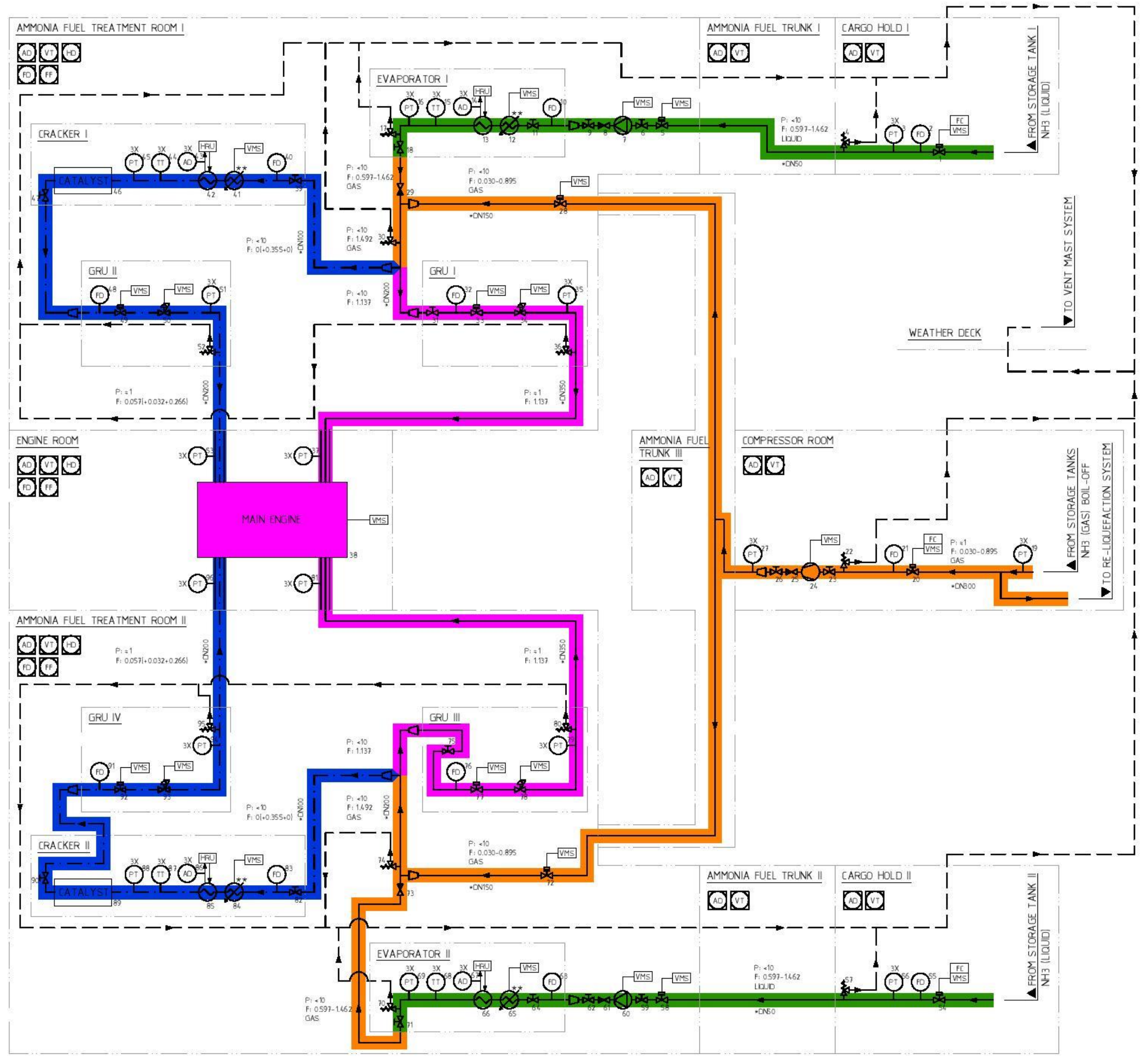
CLIENT PROJECT NO.:
CLIENT DRAWING NO.:

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



COLOUR CODING

- NODE 1: MAIN LIQUID AMMONIA SUPPLY (green)
- NODE 2: MAIN GASEOUS AMMONIA SUPPLY (orange)
- NODE 3: AMMONIA ENGINE SUPPLY (magenta)
- NODE 4: HYDROGEN ENGINE SUPPLY (blue)

SYMBOLS

HAND OPERATED VALVE	REMOTE OPERATED VALVE
NON RETURN VALVE	PRESSURE REGULATING VALVE
REDUCER	PRESSURE RELIEVE VALVE
COMPRESSOR	PUMP
HEAT EXCHANGER	HEATER
FLOW DETECTOR	PRESSURE TRANSMITTER
AMMONIA DETECTOR	TEMPERATURE TRANSMITTER
SPACE: AMMONIA DETECTION	SPACE: HYDROGEN DETECTION
SPACE: FIRE DETECTION	SPACE: VENTIALTION
SPACE: FIRE FIGHTING SYSTEM	

LEGEND

- NH3 FUEL
- H2(+NH3+N2) FUEL
- AIR/GAS VENT
- NH3 FUEL DOUBLE WALLED
- H2(+NH3+N2) FUEL DOUBLE WALLED

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)
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, TRANSMITTERS 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 ROUTED B/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 MEASURES 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	NDV	PL	WZ	20190503
0	FIRST ISSUE	NDV	PL	WZ	20190412

CLIENT PROJECT NO.: | CLIENT DRAWING NO.:

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CLIENT: -		YARD NO.: -	CLASS NO.: -
PROJECT NUMBER: 16.104	DRAWING NUMBER: 999-301	STATUS: PRELIMINARY	

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

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

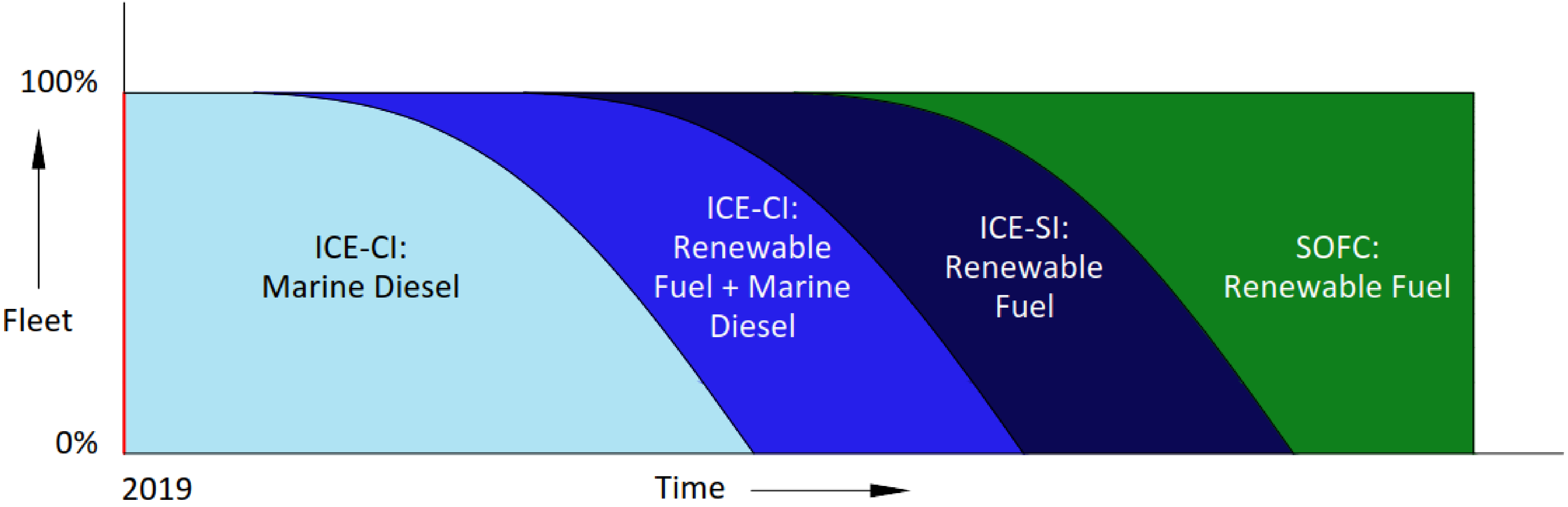
Conclusion

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

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

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

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