Ammonia as a Marine Fuel

Woudschoten Chemie Conferentie - Niels de Vries

November 4, 2022

C-JOB

DEDICATED NAVAL ARCHITECTS

Agenda

- C-Job & Niels
- Why Ammonia?
- Ammonia Storage
- Ammonia Power Generation
- Ammonia Fuel Knowledge Gaps
- Ammonia Marine Developments

Back Up Slides

Independent design and engineering company

- Serving ship owners and shipyards worldwide
- 7 offices:
  - Hoofddorp
  - Rotterdam
  - Heerenveen
  - Nikolayev
  - Houston
  - Athens
  - Gdansk
- > 180 in-house engineers employed

Renewable Energy Storage & Power Generation

Experience in (R&D) projects

- Batteries
- Hydrogen (H2)
- Ammonia (NH3)
- Methanol (CH3OH)
- Nuclear

View on developments

- Sodium borohydride (NaBH4)
- Iron powder (Fe)
- Other

Research Questions

- Main: How can ammonia be applied safely and effectively as a marine fuel?

- Sub-1: What is the potential of ammonia as a fuel in a sustainable future with respect to storage and production?
- Sub-2: What is the technical feasibility of ammonia power generation onshore?
- Sub-3: What is the technical feasibility of ammonia power generation for marine applications?
- Sub 4: What is the performance of ammonia power generation for marine applications?
- Sub-5: How does conventional power generation compare with ammonia power generation for marine applications?
- Sub-6: What are the general properties of ammonia in consideration of risk & safety, and how to cope with them?
- Sub-7: What risks are identified when using ammonia as a marine fuel?
- Sub-8: What means are required to reduce the risks found in Q7 to an acceptable level, and how do they affect the design?

Winner Maritime Designer Award 2019

https://c-job.com/c-job-lead-naval-architect-niels-de-vries-wins-maritime-designer-award/

https://repository.tudelft.nl/islandora/object/uuid%3Abe8cbe0a-28ec-4bd9-8ad0-648de04649b8

Why Ammonia?

Fuel type	Energy density LHV [MJ/kg]	Volumetric energy density fuel [GJ/m3]	Volumetric energy density fuel + tank** [GJ/m3]	Renewable synthetic production cost [MJ/MJ]	Storage conditions
Marine Gas Oil	42.7	36.7	36.0	N.A.	Ambient
Synthetic Diesel	42.0	35.8	33.2	>3.0	Ambient
Ethanol	26.7	21.1	20.7	>3.0	Ambient
Methanol	19.9	15.8	15.5	2.4	Ambient
Liquid Methane*	50.0	23.4	9.9	2.3	-162 °C
Liquid Ammonia*	18.6	12.7	6.6	1.8	-34 °C
Liquid Hydrogen*	120.0	8.5	3.4	1.8	-253 °C
Compressed Hydrogen	120.0	5.0	1.9	1.7	700 bar

*Volume based on cylindrical tanks (type-C), volumetric energy density can be improved with bi-lobe (type-C), prismatic (type-B), or membrane tanks.

**Concept guideline: all presented information provides a preliminary comparison and is based on a number of assumptions/inputs. A more detailed custom comparison will require more work and could deviate from this preliminary comparison.

Renewable Fuel Selection: Suitability per Ship Type and Autonomy

The main philosophy in the selection process of renewable energy storage types is to aim at a low OPEX. When the size of a certain energy storage system becomes un-proportional in terms of mass volume and/or CAPEX, more dense options should be considered, which will have a higher OPEX.

Autonomy	Ship Type		
	Cargo	Passenger	Other
Hours	Batteries		
Days	Hydrogen		
Weeks	Ammonia / Methanol	Methanol	

Suitability per Ship Type and Autonomy: Examples

Autonomy	Ship Type			
	Cargo		Passenger	Other
Hours	Batteries			
Days	Hydrogen			
Weeks	Ammonia	Methanol	Methanol	

Ferries – Local (Inland)

Ferries – Regional (Baltic Sea)

Cargo ships – Short Sea & Deep Sea

Dredgers – Global

Ammonia Storage

Ammonia as cargo:

- Fully pressurized — 10 bar at atmospheric temperature
- Semi pressurized/refrigerated — Intermediate P & T
- Fully refrigerated — Atmospheric pressure at -34°C

Ammonia as fuel:

- Cost & complexity
- Density
- Tank types
- Safety considerations

Ammonia Storage

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Ammonia as fuel:

- Cost & complexity
- Density
- Tank types
- Safety considerations

Type:	Cylindrical	Bi-lobe	Prismatic
Common design pressure:			
High pressure	X		
Medium pressure	X	X	
Low pressure	X	X	X

Ammonia Storage

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Ammonia as fuel:

- Cost & complexity
- Density
- Tank types
- Safety considerations

Ammonia Fuel System Principles

- Fully refrigerated ammonia storage

- Ammonia fuel treatment room:
  - Supply (compression & heating/cooling):
    - Liquid
    - Boil-off (gas)
  - Pumps:
    - Low pressure supply +/-10 bar
    - High pressure supply >70bar

- Engine room:
  - Double walled piping (ventilated or pressurized with nitrogen)

Ammonia Fuel System Principles

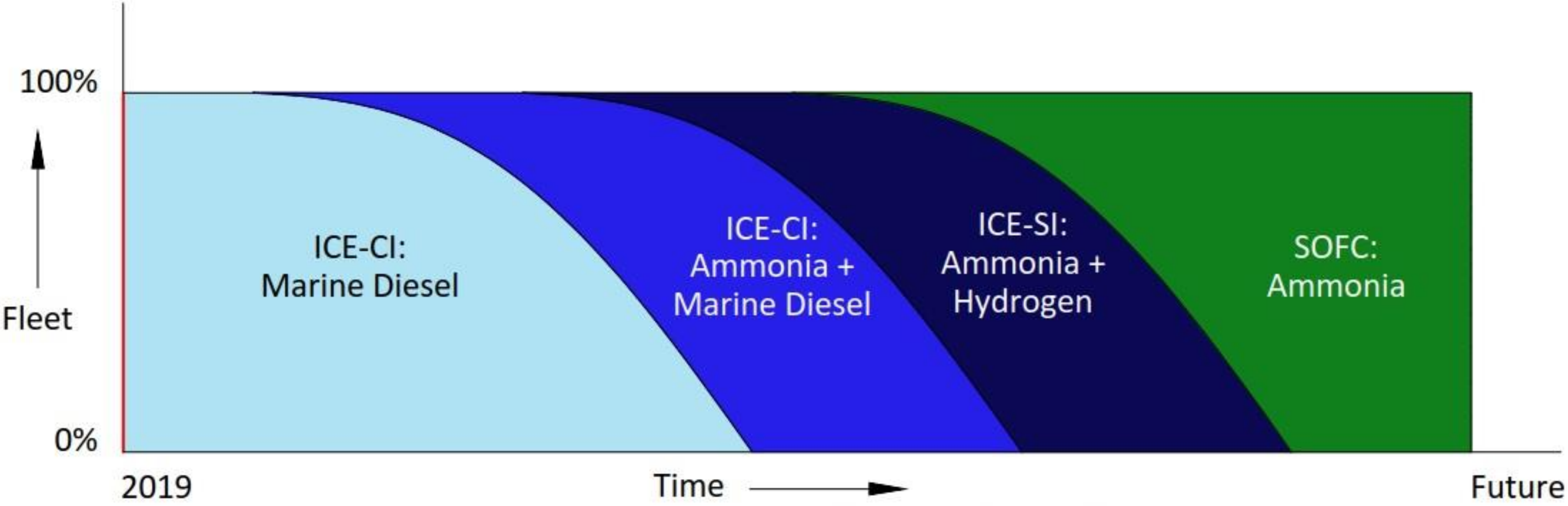
- Exhaust system:
  - Engine
  - Ventilated ammonia spaces
  - Vent system (pressure/thermal relief)

- Nitrogen system

Ammonia Power Generation

Internal Combustion Engines

Fuel Cells



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

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%

AmmoniaDrive

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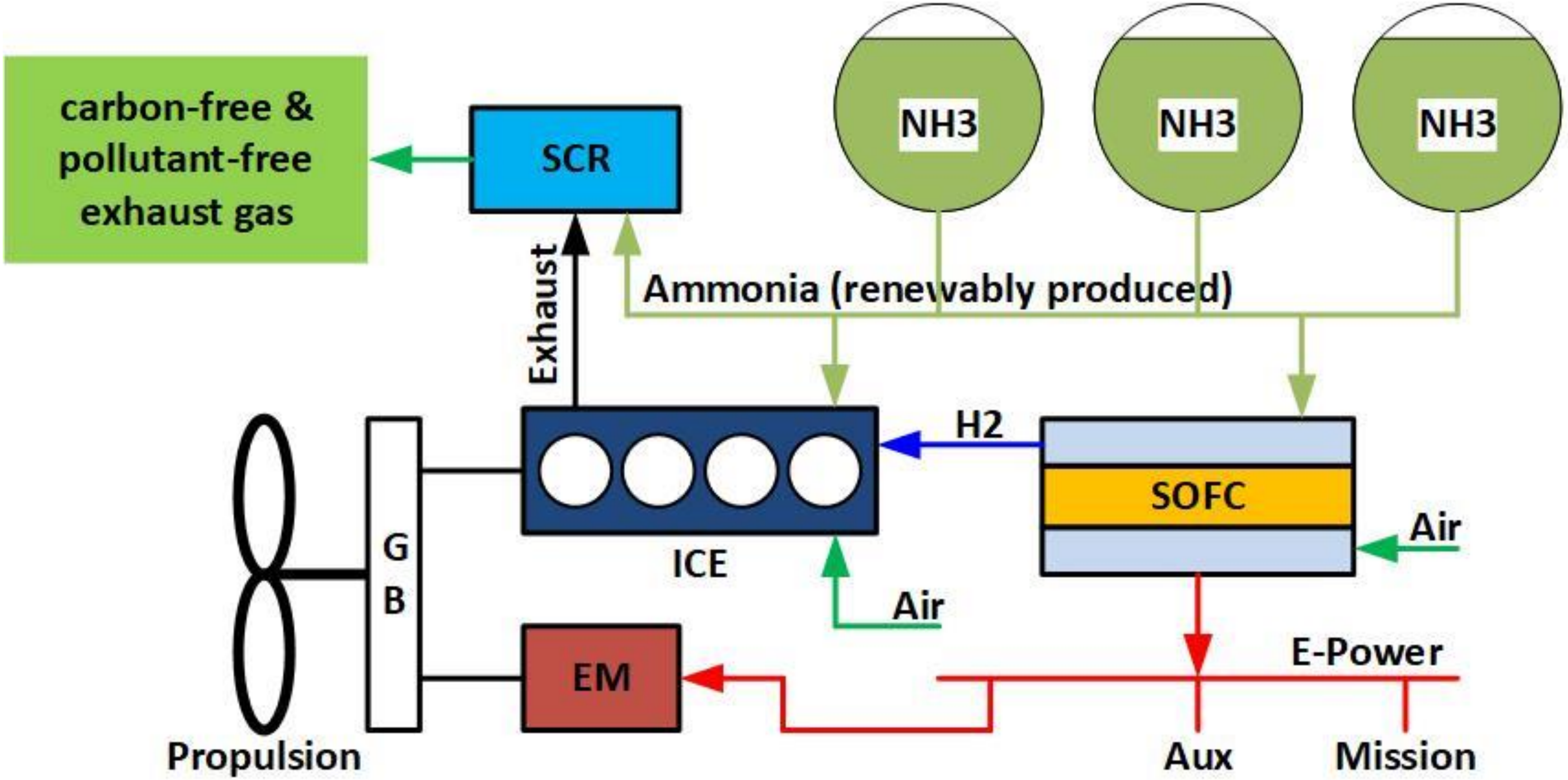
GasDrive
Ammonia



Ammonia Fuel Knowledge Gaps

Including, but not limited to:

- Engine performance, harmful emissions:
  - NOx
  - N2O
  - NH3
- Ventilated ammonia spaces (highly diluted NH3)
- Vent system (high NH3 concentration)

Considerations:

-> SCR

-> SCR, catalyst capabale of also reducing N2O

-> Ammonia slip guidelines SCR system

-> Ammonia scrubber or (harbour) restictions

-> Ammonia scrubber or (harbour) restictions

Maritime Ammonia Developments

Disclaimer

Maritime Ammonia Developments

180,000 ton DWT bulk carrier (Dec-2019)

- Shanghai Merchant Ship Design & Research Institute
- LR Approval in Principle (AiP)
- MAN ES (dual-fuel)

2,700 TEU container ship (Chittagongmax) (Dec-2019)

- Shanghai Merchant Ship Design & Research Institute
- ABS
- MAN ES (dual-fuel)

Maritime Ammonia Developments

23,000 TEU container ship (Dec-2019)

- Dalian Shipbuilding Industry Co
- LR Approval in Principle (AiP)
- MAN ES (dual-fuel)

23,000 TEU container ship (Oct-2020)

- Daewoo Shipbuilding & Marine Engineering
- LR Approval in Principle (AiP)
- MAN ES (dual-fuel)

Maritime Ammonia Developments

Viking Energy to be retrofit for ammonia fuel in 2024

- 2MW SOFC on green ammonia
- €10.0 million EU funding
- €21.5 million total budget

Goal:

- Installation 2023
- Operation 2024
- 3000 hours of operation annually

SHIPFC
GREEN AMMONIA ENERGY SYSTEM

The ShipFC project has received funding from the Fuel Cells and Hydrogen Joint Undertaking under grant agreement No 875156. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation program and from Hydrogen Europe.

Maritime Ammonia Developments

Joint Venture **Viridis Bulk Carriers** (Mar-2021)

- Navigare Logistics
- Amon Maritime
- Mosvolds Rederi

Maritime Ammonia Developments

Höegh Autoliners (Apr-2021)

The Aurora Class' multi-fuel engine can run on various biofuel and conventional fuels, including LNG. With minor modifications it can **transition** to use future zero carbon fuels, including Green **Ammonia**.

DNV's new ammonia ready notation

DNV

Maritime Ammonia Developments

Pt F, Ch 11, Sec 35

SECTION 35 AMMONIA-PREPARED SHIPS

1.1 Application

1.1.1 The additional class notation **AMMONIA-PREPARED** is granted to new ships that are designed with specific arrangements to accommodate future installation of an ammonia fuel system, in accordance with the requirements of this Section. The following cases are considered:

Examples:

AMMONIA-PREPARED

AMMONIA-PREPARED (T)

AMMONIA-PREPARED (S,T,H)

C-JOB

DEDICATED NAVAL ARCHITECTS

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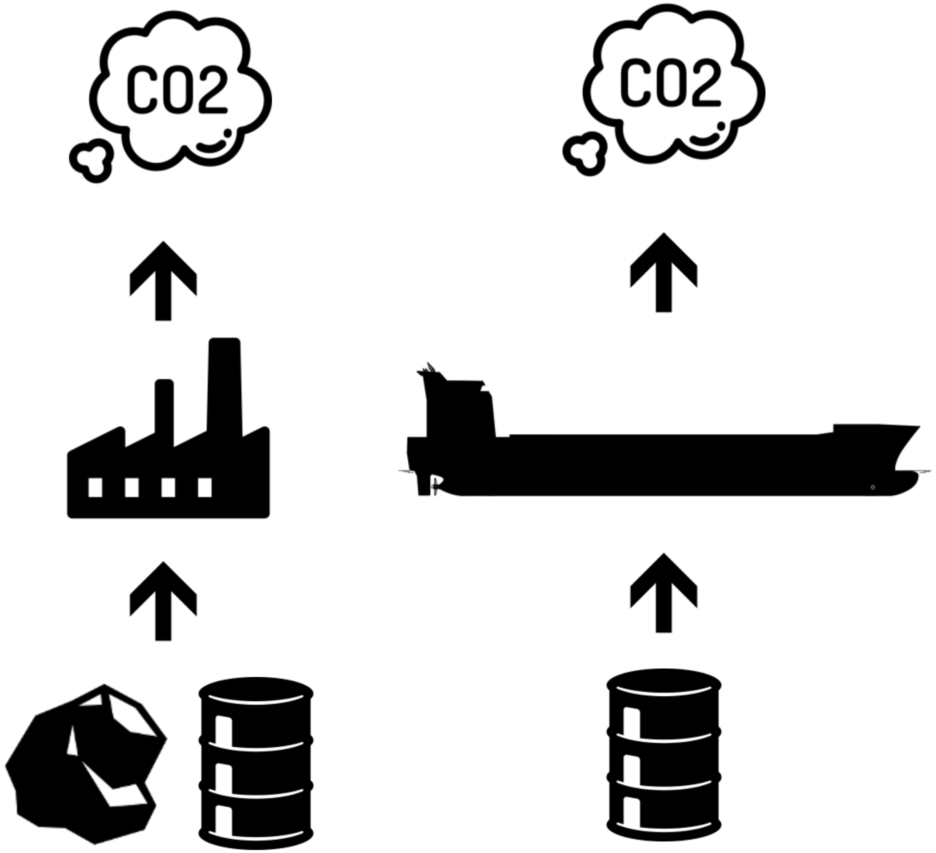
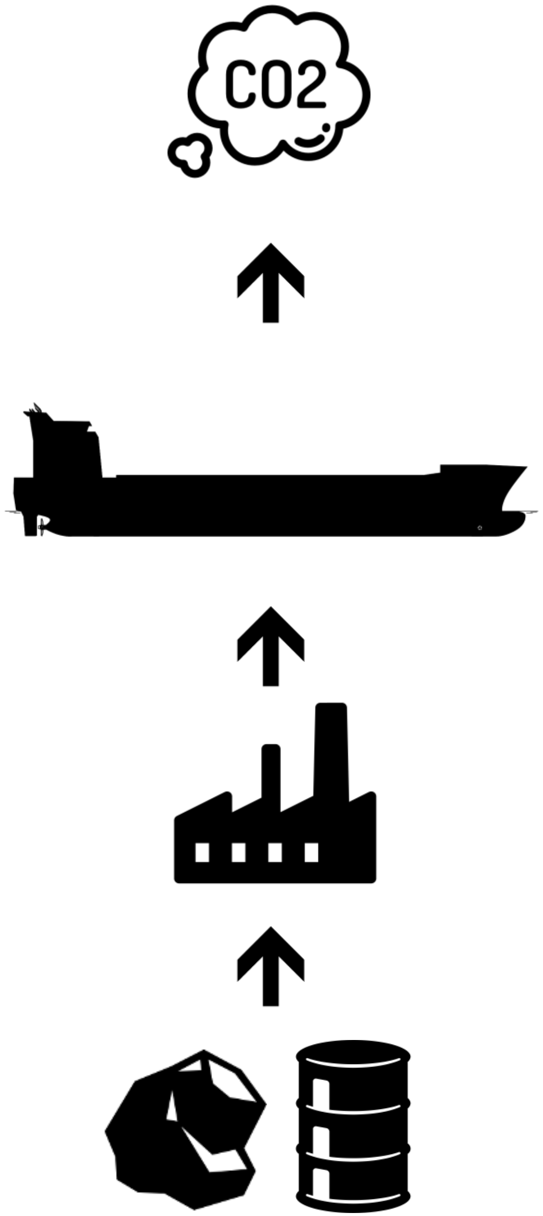
Back Up Slides

Renewable Fuel Principle





Production -> Consumption

Consumption -> Emission

Emission -> Production

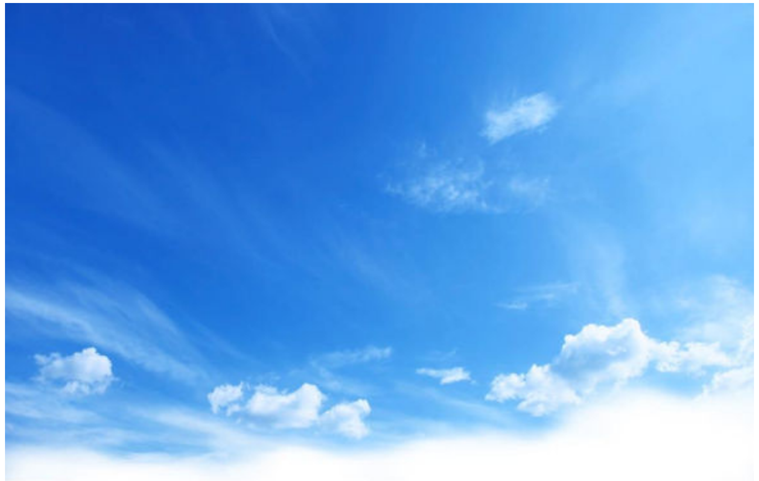
Renewable Fuel Options

Hydrogen usage:

• Methane	$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$	50%
• Methanol	$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$	67%
• Ammonia	$N_2 + 3H_2 \rightarrow 2NH_3$	100%

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

- 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

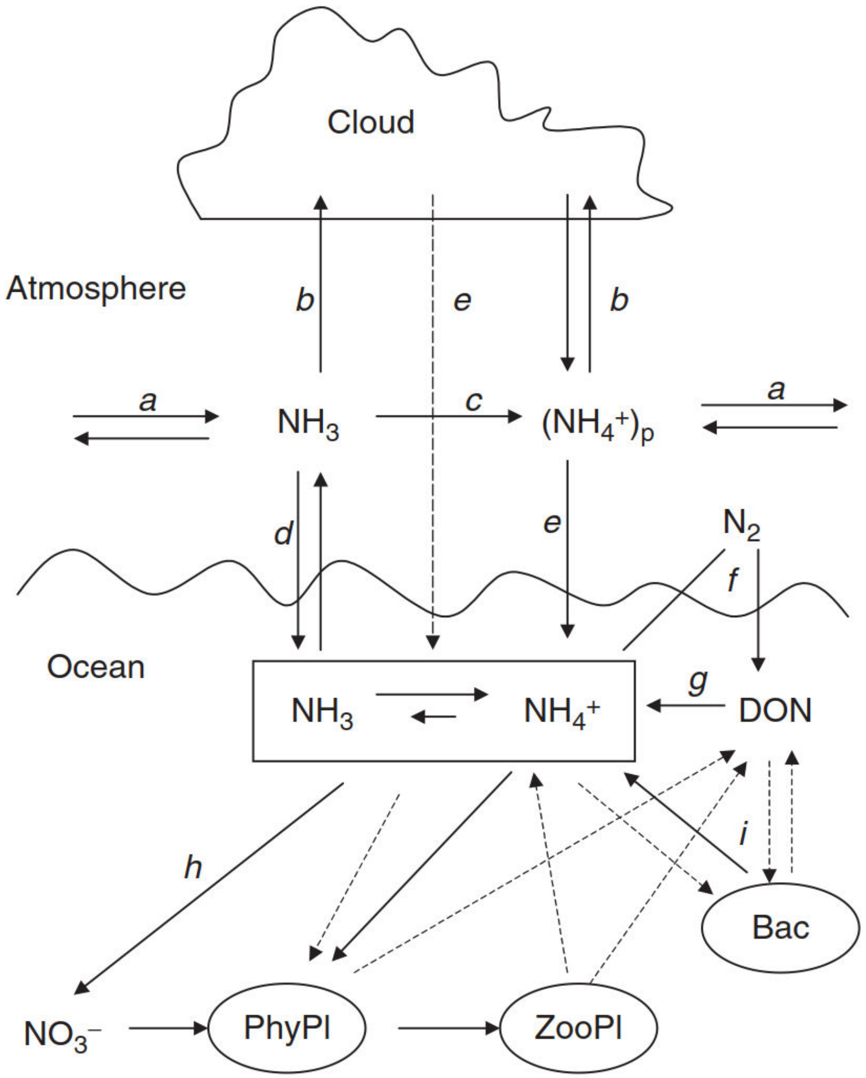
Table 7-4: Acute Exposure Guideline Levels (AEGL): Ammonia

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.

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

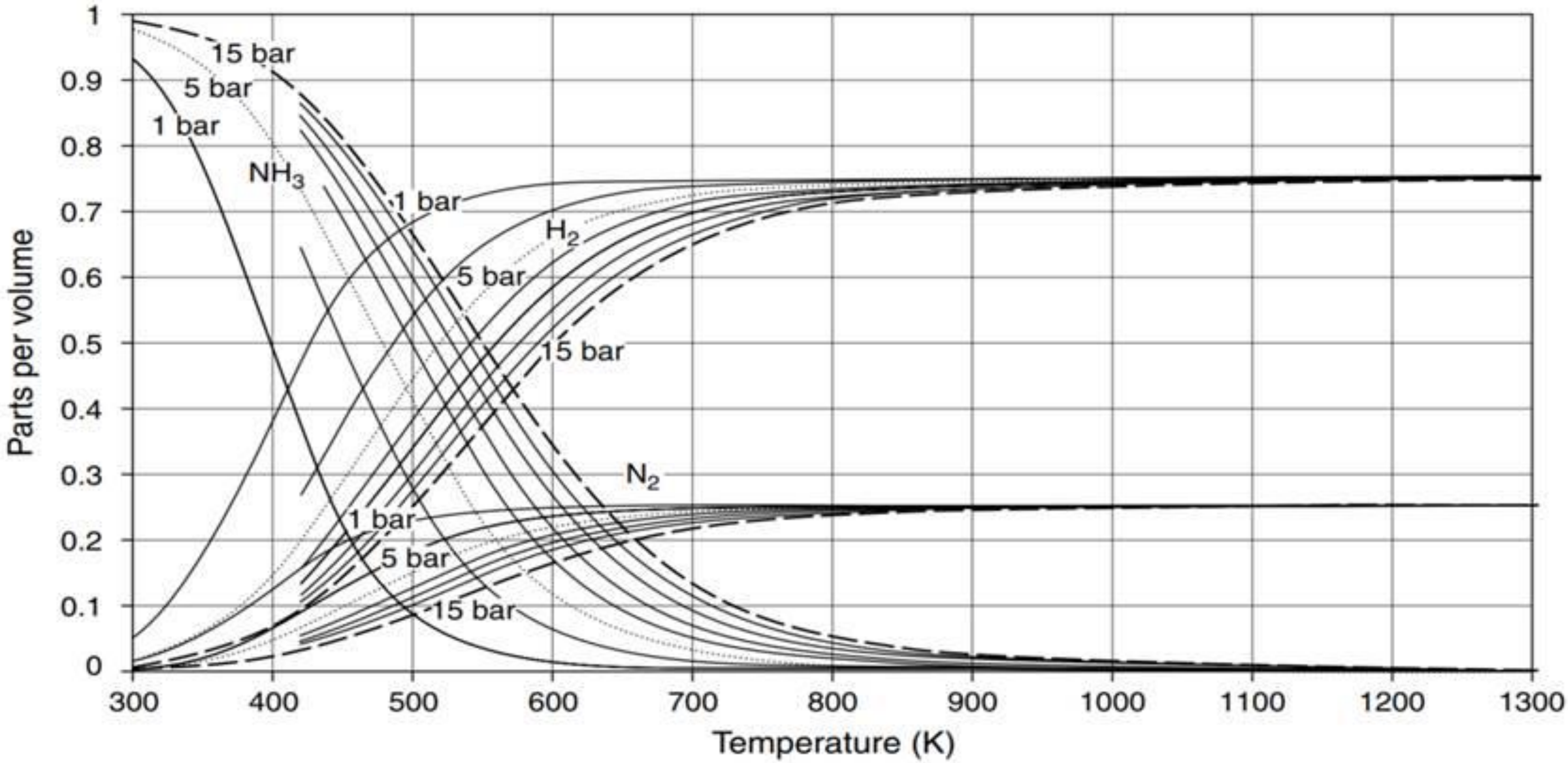
General Hydrogen Safety

- CNG: Compressed Natural Gas
- LNG: Liquefied Natural Gas
- ULSFO: Ultra Low Sulphur Fuel Oil (0.1%)
- H: Hazard statement
- 2: Physical hazard
- 3: Health hazard
- 4: Environmental hazard
- Hazard category: a hazard class for which the of a hazard statement is applicable

Hazard statements	Hazard category	Hydrogen [101]	CNG [80]	LNG [81]	Diesel [82]	ULSFO [83]
H220 Extremely flammable gas	1A	X	X	X		
H221 Flammable gas	2					
H226 Flammable liquid and vapour	3				X	
H227 Combustible liquid	4					X
H280 Contains gas under pressure; may explode if heated	Compressed gas	X	X			
	Liquefied gas (b)					
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	
H315 Causes skin irritation	2				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
H411 Toxic to aquatic life with long lasting effects	2				X	

Table 8-1: Hazard statements comparison of hydrogen with other fuels

Cracking ammonia



Renewable Energy Storage & Power Generation

Roles of C-Job

- Knowledge partner
- Technical and economical feasiblity studies
- System integration
- Design & engineering

Enabling shipyards and ship owners in the role of knowledge partner to assess and implement the latest technologies to realize the energy transition

Additional experience

- Energy saving
    - Wind-assisted propulsion
    - Weather routing
    - Other

Knowledge and Engineering Partner

- Aid shipowners in review, selection and implementation of renewable energy storage / future fuels
  - Insight in technical consequences
  - Evaluate total cost of ownership
  - Co-creation, implementing operational experience