Workshop on Ammonia FC System for Maritime Application

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Introduction
on Ammonia FC system

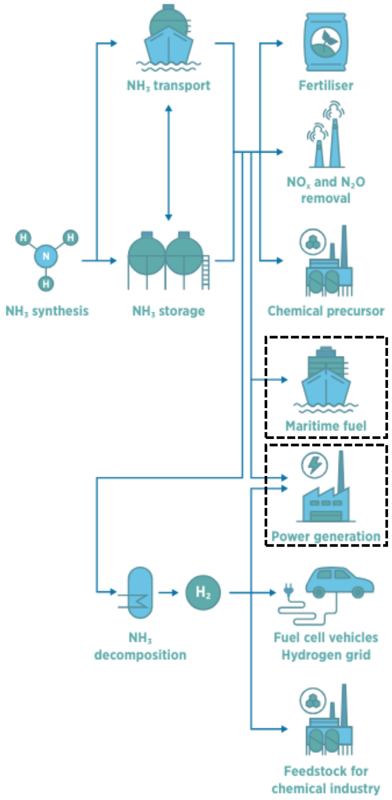
HYDROGEN CARRIERS

Liquid H2	Ammonia	Methyl Cyclohexane
Need additional construction for large scale LH2 supply	Opportunity to utilize available (LPG) infrastructure and expand existing ammonia plant.	Adaptation of existing gasoline infrastructure.
Hydrogen combustion.	Direct combustion. Hydrogen combustion after decomposition.	MCH must be dehydrogenation for burning hydrogen.
High purity. No dehydrogenation and purification.	Direct use without dehydrogenation. Well established trading and storage existing ammonia infrastructure.	No cooling for storage. Existing chemical infrastructure available for storage. Low cycle losses.
Indicative Value chain LCOH **6.09 €/kg**	Indicative Value chain LCOH **2.16 €/kg**	Indicative Value chain LCOH **5.41 €/kg**

Liquid H2	Ammonia	Methyl Cyclohexane
Very low temperature (-253°C)	Safety aspects related to toxicity	High temperature heat source required for dehydrogenation
Liquefaction can consume about 30% of energy	Dehydrogenation (~ 13% of hydrogen energy) and Purification are energy intensive process.	Heat required for dehydrogenation is elevate.
LH2 retention difficult for long-term storage		Large handling infrastructure.
Higher leak propensity		

SOURCE: CLEAR AIR TASK FORCE, LOW-CARBON AND RENEWABLE HYDROGEN ECONOMIC ASSESSMENT STUDY LANDED COST OF HYDROGEN CARRIERS, June 2022

AMMONIA as H2 carrier: MARKET



*Viking Energy

- Ammonia-fuelled two-stroke and four-stroke engines
- Solid oxide fuel cells
- Dual-fuel engines

* Mitsubishi Power’s H-25 Series

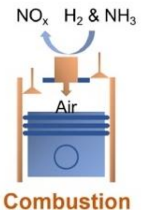
- Small-scale combustion engines, Solid oxide fuel cells and alkaline fuel cells for off-grid power
- Telecommunication towers or back-up aggregates
- Combined-cycle gas turbine systems

Source: IRENA and AEA (2022), Innovation Outlook: Renewable Ammonia, International Renewable Energy Agency, Abu Dhabi, Ammonia Energy Association, Brooklyn

AMMONIA as HYDROGEN CARRIER for POWER PRODUCTION

Power production

Direct Combustion



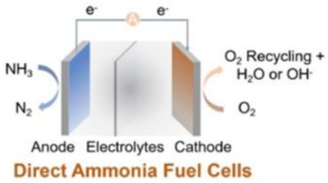
Indirect Fuel Cells

Direct Fuel Cells

Low temperature (25°C – 100°C)

High temperature (500°C - 1000°C)

SOFC



185 *Mt/year globally*

85% *in fertilisers*

45% *of H2 produced*

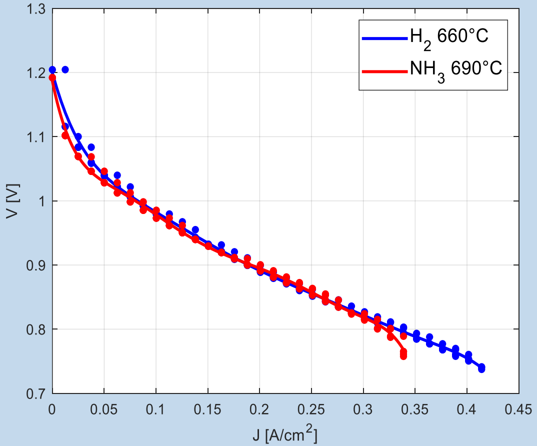
- Cogeneration applications
- High ammonia decomposition activity
- High efficiency and power density

→Ammonia have an **extra gear** especially in long-term energy storage and **long-distance energy transport** and could constitute a safer and less expensive alternative

→**Energy transition** is likely to involve a **combined solution of hydrogen and ammonia**, but also of other energy storage and transporting technologies.

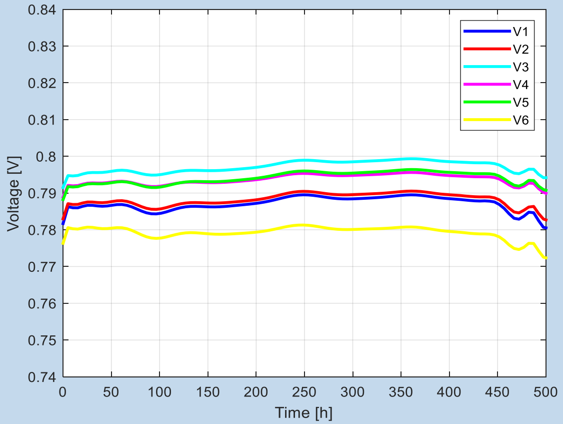
- Durability aspects
- Business case In progress
- **Balance of Plant complexity**

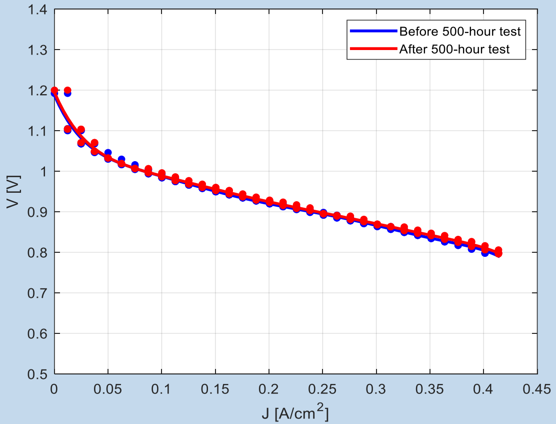
PERFORMANCE: Hydrogen and ammonia comparison



- Similar VI with respect to pure hydrogen
- Stability under investigation (demonstrated up to 6000 hrs)[1]

STABILITY: 500-hour continuative working test exploiting ammonia[2]





[1] Peter Vang Hendriksen *et al* 2023 *ECS Trans.* **111** 2085

[2] Test performed in FBK

Direct Ammonia SOFC

R&D for Direct Ammonia Solid Oxide Fuel Cell

Demonstrate an effective DA-SOFC system to achieve very high efficiency

- Material of SOFC (Anode/cathode/electrolyte)
- BoP (Heat Exchangers, Balance of Plant, Anode recirculatory)
- Strong coupling between the safety assessments and technical aspects,

Lowering system CAPEX for DA-SOFC system

- Exploit auto thermal cracking of ammonia in SOFC to reduce external thermal request
- Reduce the complexity of plants (HEXs)
- Optimize air consumption and ancillary power consumption

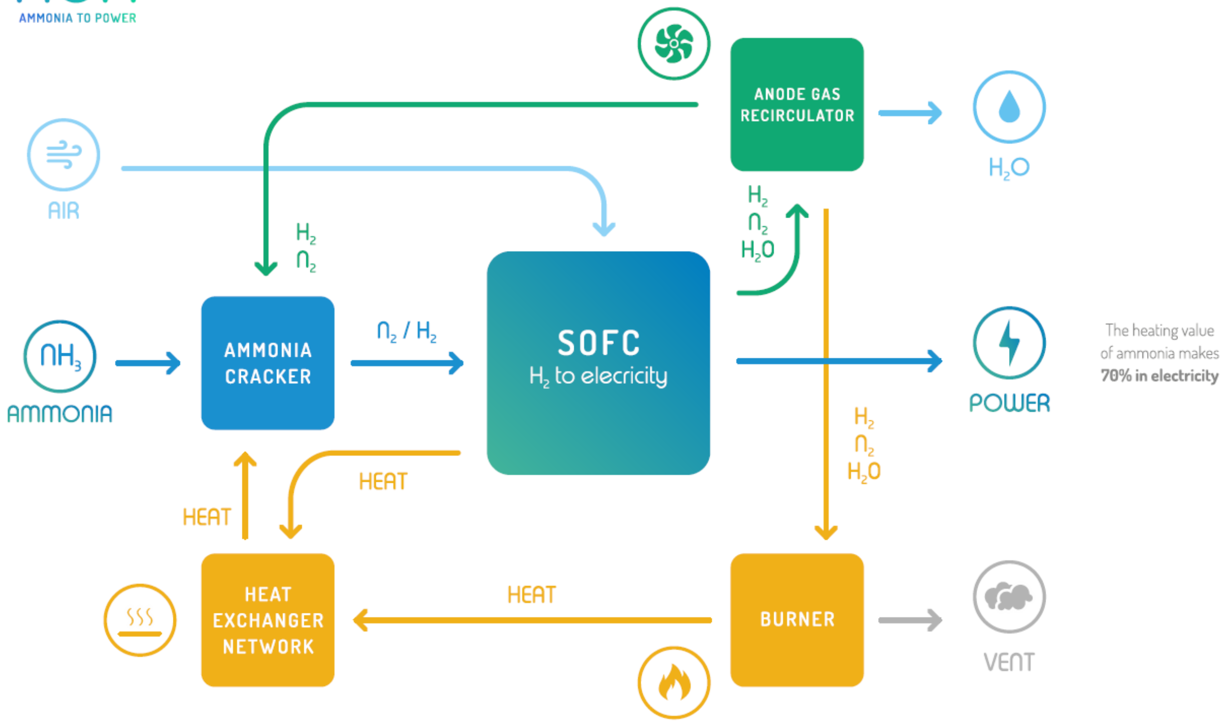
Lowering the impact from nitridation

- Partial decomposition of the ammonia in a heat exchanger or a dedicated cracker
- Coating to protect against the nitridation

AMMONIA TO POWER

Development of a next generation AMMONIA FC system

The project is supported by the Clean Hydrogen Partnership and its members Hydrogen Europe and Hydrogen Europe Research, under Grant Agreement No 101101521



- System prototype up to **8 kW**
- Electrical **efficiency** higher than **70%**
- **Demonstration** for at least **3000 hrs**
- **Availability** of system higher than **90 %** and **dynamic operation range** between **30-100%**

AMMONIA TO POWER

Development of a next generation AMMONIA FC system

FBK
Fondazione Bruno Kessler
(Italy)

SolydEra
(Italy)

Alfa Laval Technologies AB (Sweden),
Alfa Laval Aalborg AS (Denmark),
Alfa Laval SPA (Italy)

SAPIO
Produzione Idrogeno Ossigeno Srl
(Italy)

KIWA Nederland BV (The Netherlands)
e KIWA Cermet (Italy)

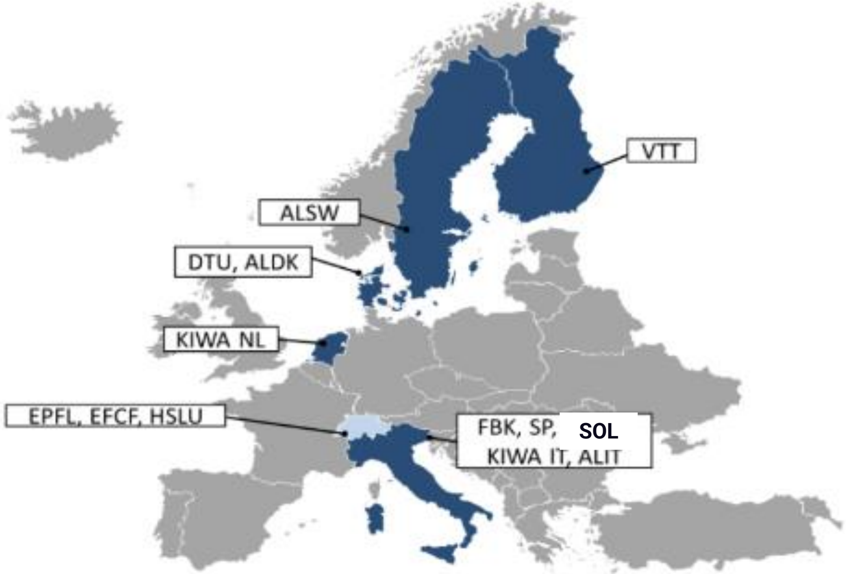
VTT Technical Research Centre of Finland
(Finland)

Technical University of Denmark
(Denmark)

Ecole Polytechnique Fédérale De Lausanne
(Switzerland)

Electrolyser & Fuel Cell Forum
(Switzerland)

Fachhochschule Zentralschweiz Hochschule Luzern
(Switzerland)



Clean Hydrogen Partnership

Co-funded by the European Union

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AMMONIA TO POWER

Development of a next generation AMMONIA FC system

Contribution on **AMMONIA FC system**

AMON: Engineering & Integration
Debasish Chakraborty
Alfa Laval Lund/SWE & Copenhagen/DEN

AMON: Safety aspects on ammonia power systems
Alvaro Fernandez
KIWA, Apeldoorn/NLD

AMMONIA TO POWER

Development of a next generation AMMONIA FC system

Panel with **End user**, **Marine** and **Ammonia Experts**

Manufacturing components, Integrator
Debasish Chakraborty
Alfa Laval Lund/SWE & Copenhagen/DEN

Ammonia producers, Ammonia plant
Elli Varkaraki
Yara Technology & Project, Geneva/CH

Maritime Use, Harbors
Víctor Collazos Rodríguez,
Fundación Valenciaport, Valencia/ESP

Ammonia producers, Ammonia plant
Marco Matrascia,
SOL Group, Monza/ITA

THANK YOU

more info www.amon.eu

Dr. Elli Varkaraki (YARA)
1.What are your expectations in global ammonia production especially in the light of use for green ammonia?
2. How can government policies and incentives stimulate investment in NH_3 production and infrastructure?
3.How does the cost of green NH_3 production, compared to traditional fuels like natural gas, impact its feasibility and upscaling?

Ing. Víctor Collazos (Naval Engineer and expert in decarbonization of the maritime sector, **Fundacion Valencia Port)**
1.What are the most promising applications of green ammonia in the context of power production, both on shore and on board in maritime application following your experience?
2.Considering the current energy landscape, what are your expectations for the widespread adoption of NH_3 for power generation, considering regulations like IMO 2020? (onboard and in port)? And what can the timeline be for the adoption?
1.Beyond safety, what is the reason why NH_3 is more attractive than H_2 for specific power generation applications in maritime application?

Debasish Chakraborty (Alfa Laval Technologies AB)

1.What technological advancements are necessary to enhance the efficiency and viability of ammonia as a fuel for power production or fossil fuel substitution
2.Can advanced ammonia cracking technologies make NH_3 a safer and more efficient way to utilize H_2 for power generation? 3.How do you ensure your products comply with international standards and regulations for ammonia use in power production?

Marco Matracia (SOL Spa)

1.What infrastructure developments are required to support the widespread adoption of green ammonia as a fuel source?
2.Given its toxicity and corrosiveness, how do you address the challenges of ammonia storage and transportation in the context of a relevant upscaling of use (in particular for green ammonia)?
3.What research and development efforts are needed to improve the safety profile and public perception of NH_3 as a fuel source?