MariNH$_3$

Clean, green ammonia
engines for maritime

Thermal and H_2 fuel storage

Marcus Adams - 28/06/2023

The partnership

University of Nottingham UK | CHINA | MALAYSIA

UKRI Science and Technology Facilities Council

UNIVERSITY OF BIRMINGHAM

University of Brighton

CARDIFF UNIVERSITY PRIFYSGOL CAERDYD

Funded by UKRI Engineering and Physical Sciences Research Council

Why thermal or H_2 storage?

MariNH$_3$
Clean, green ammonia engines for maritime

Latest brief:

- When engine is at **full load** (ocean),
  - Engine is hot
  - If NH_3 is only used, minimal NO_x.
- When engine is at **part load** (approaching port),
  - Engine is not hot
  - If only NH_3 is used, significant NO_x.

How can we keep NO_x emissions low when approaching port?

Thermal Energy Storage

Hydrogen

The partnership
University of Nottingham UK | CHINA | MALAYSIA
UKRI Science and Technology Facilities Council
University of Birmingham
University of Brighton
Cardiff University Prifysgol Caerdydd
Funded by UKRI Engineering and Physical Sciences Research Council

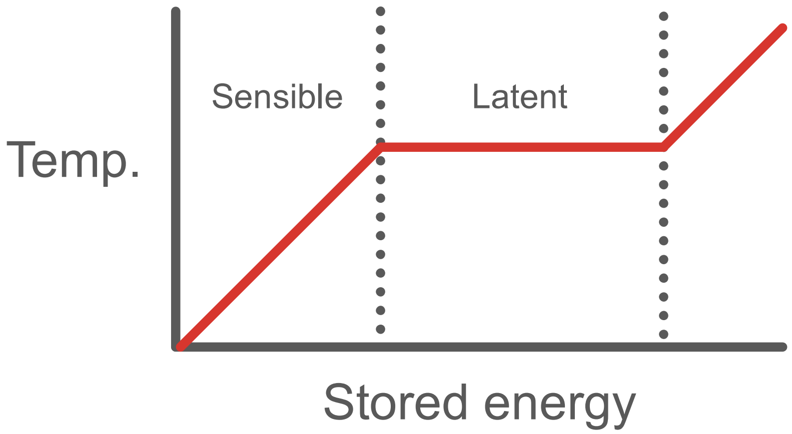
Thermal energy storage

MariNH3
Clean, green ammonia engines for maritime

Types of thermal energy storage

- Sensible
- Latent
- Thermo-chemical

- Require high energy density
- Minimise thermal exergy losses



The partnership
University of Nottingham UK | CHINA | MALAYSIA
UKRI Science and Technology Facilities Council
UNIVERSITY OF BIRMINGHAM
University of Brighton
CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD
Funded by UKRI Engineering and Physical Sciences Research Council

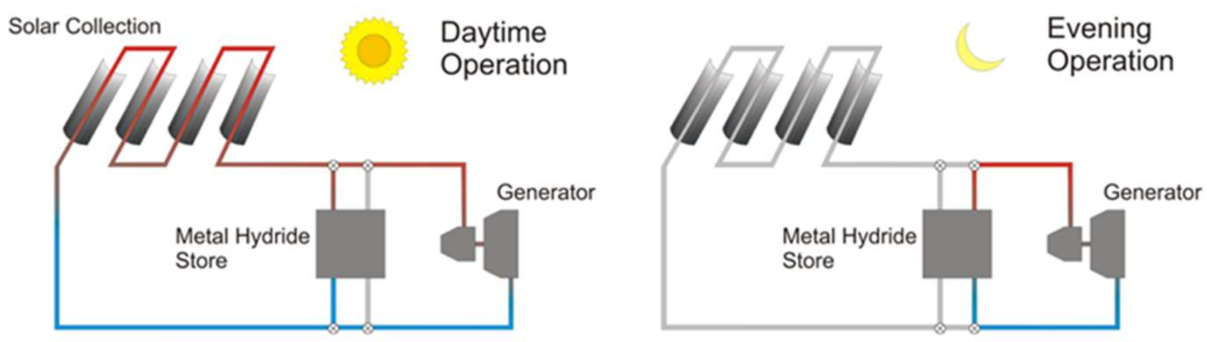
Thermo-chemical energy storage (TCES)

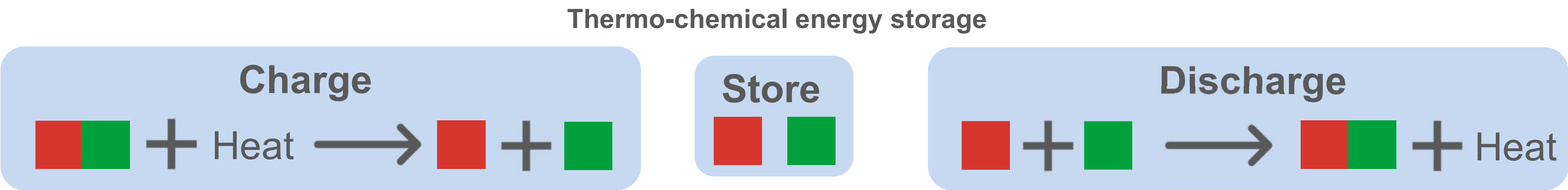
MariNH3
Clean, green ammonia engines for maritime

Examples

- Hydride based – hydrogen storage
- Oxide based – air as store
- Ammoniate based – use ammonia storage

- Choose system based on temperature range and gap.
- And with suitable pressure driving force.





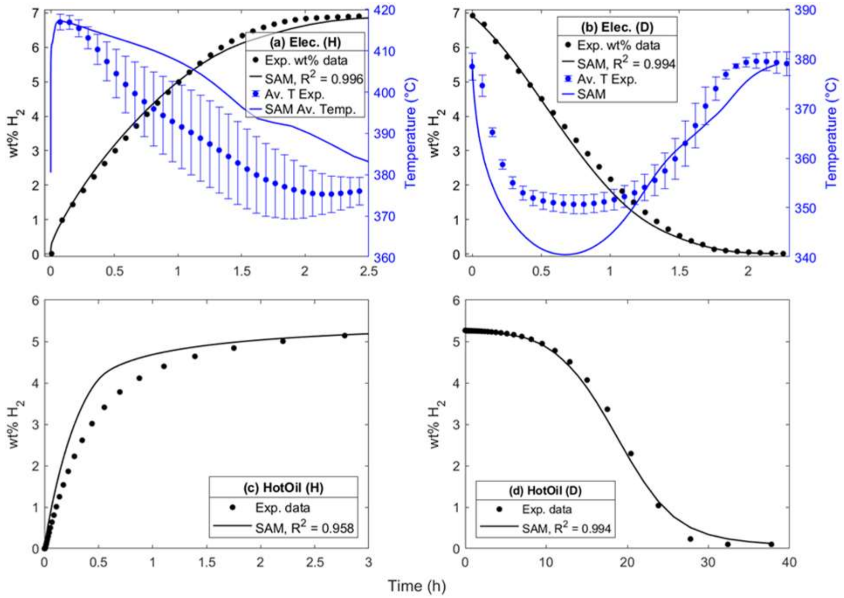
The partnership
University of Nottingham UK | CHINA | MALAYSIA
UKRI Science and Technology Facilities Council
UNIVERSITY OF BIRMINGHAM
University of Brighton
CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD
Funded by UKRI Engineering and Physical Sciences Research Council

Hydride based TCES

MariNH$_3$

Clean, green ammonia engines for maritime

- UoN has developed a hydride based thermo-chemical store
- Based on magnesium hydride
- Unsuitable for NH_3 shipping (need for compressed H_2 store)



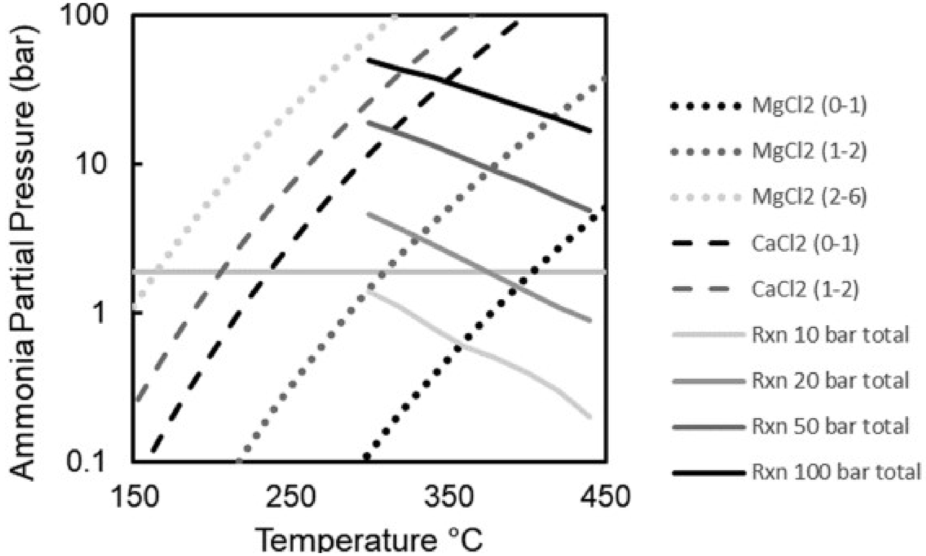
Demonstration of the Site Availability Model for MgH_2 system (150 g) with hot oil and electric heating and the hot oil system

The partnership
University of Nottingham UK | CHINA | MALAYSIA
UKRI Science and Technology Facilities Council
University of Birmingham
University of Brighton
Cardiff University Prifysgol Caerdydd
Funded by UKRI Engineering and Physical Sciences Research Council

Ammoniate based TCES

MariNH3
Clean, green ammonia engines for maritime

- New concept
- Use $MgCl_2$ or $CaCl_2$ ammoniate reaction to store thermal energy.
- Use with NH_3 storage.



Smith (2019) Optimizing the Conditions for Ammonia Production Using Absorption

Hydrogen

MariNH3
Clean, green ammonia engines for maritime

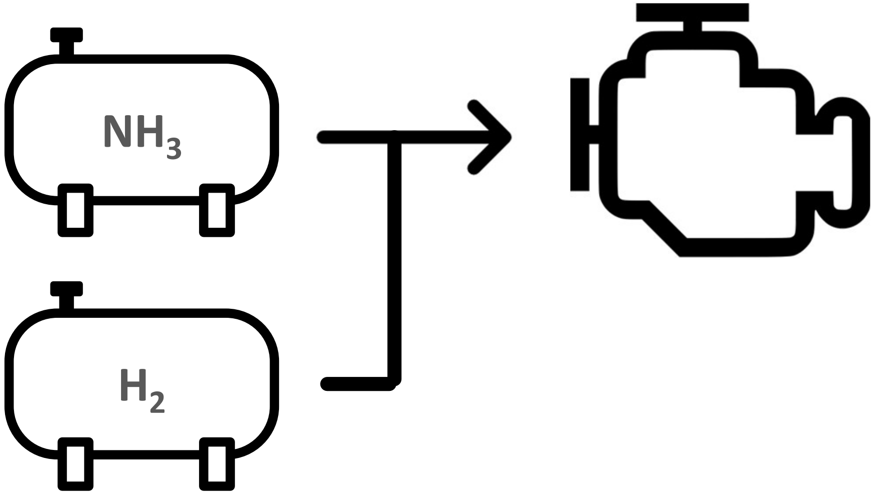
Crack ammonia

- Examples: Fe/Ru/Ni or multi-element
  - Oxide supports
  - Amide supports
  - Carbon nanotubes

- High temperature: ≈ 400 °C or greater

https://doi.org/10.1021/acs.iecr.1c00843
Ind. Eng. Chem. Res. 2021, 60, 18560−18611

Store hydrogen



Hydrogen storage methods

MariNH3
Clean, green ammonia engines for maritime

Some methods	Gravimetric capacity (wt %)	Pressure (bar)	Temperature (°C)	Energy density (kg (sys)/m³)	Issues
Compressed hydrogen	100	350 - 700	RT	12 - 25	High pressure
Liquid hydrogen	100	1	-253	35	Boil off
Metal hydrides (AB_2, AB_5, AB, MgH_2,etc.)	1.3 – 6.6	1 - 50	RT – 1000	< 60	Room temp. has low capacity
Chemical hydrides ($NaAlH_4$, $LiBH_4$, $LiNH_2$, etc.)	5 - 25	10 - 100	150 – 400	25 – 75	High temperature, Reversibility
Porous materials (MOF, CNT, etc.)	6 - 14	1 - 150	- 196	≈ 35	Low temperature, High pressure

The partnership
University of Nottingham UK | CHINA | MALAYSIA
UKRI Science and Technology Facilities Council
University of Birmingham
University of Brighton
Cardiff University Prifysgol Caerdydd
Funded by UKRI Engineering and Physical Sciences Research Council

Metal hydrides – room temp.

MariNH3
Clean, green ammonia engines for maritime

Small prototype based on UoN alloy

- 10 g H_2 store for integration with a small electrolyser system.

Required operational performance

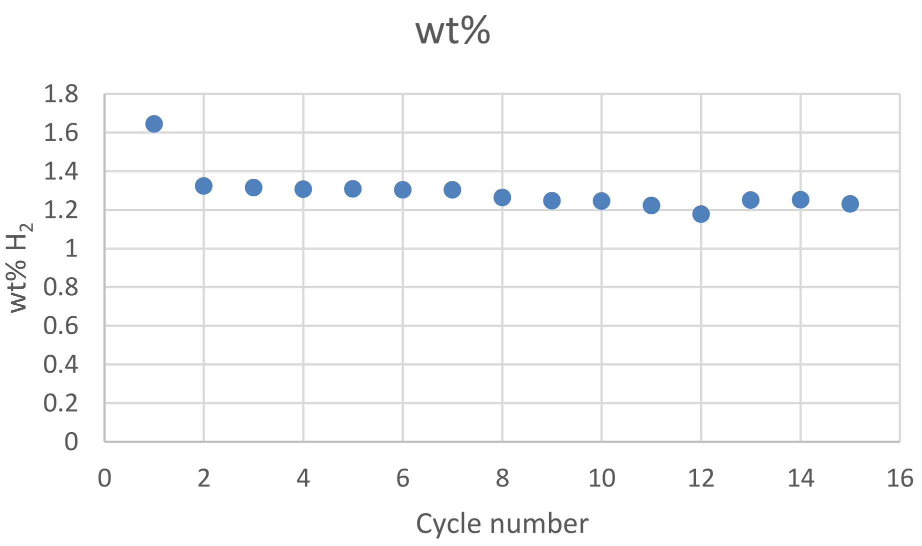
- Charge, 10 g H_2 refillable in 10 hours at ambient temperature and an input pressure of 0.3 – 0.7 MPa (3 – 7 bar)
- Discharge, H_2 discharge 1 – 4 hours at a pressure at 50 mbar above ambient.

The partnership
University of Nottingham UK | CHINA | MALAYSIA
UKRI Science and Technology Facilities Council
UNIVERSITY OF BIRMINGHAM
University of Brighton
CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD
Funded by UKRI Engineering and Physical Sciences Research Council

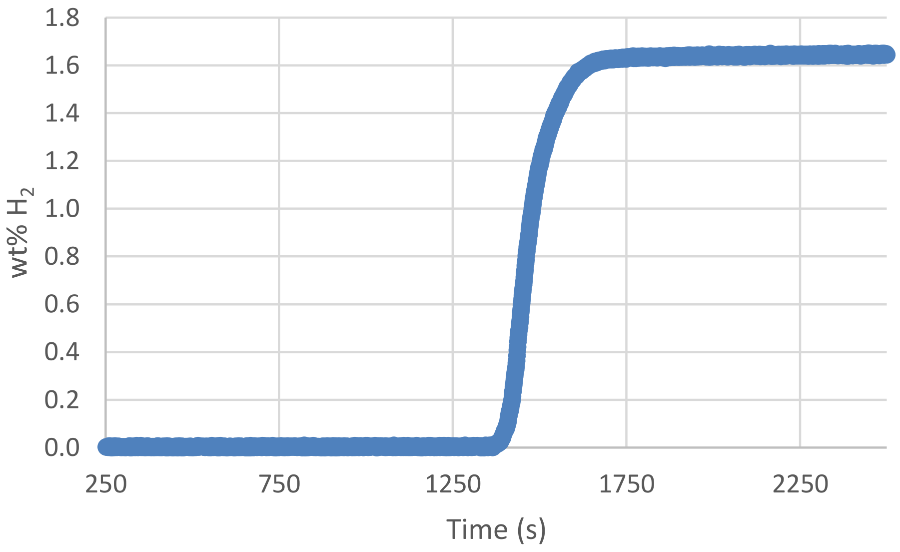
Metal hydrides – activation/cycle life

MariNH3
Clean, green ammonia engines for maritime

Cycle life data – maintains capacity after initial drop.



Activation – room temperature activation in-situ

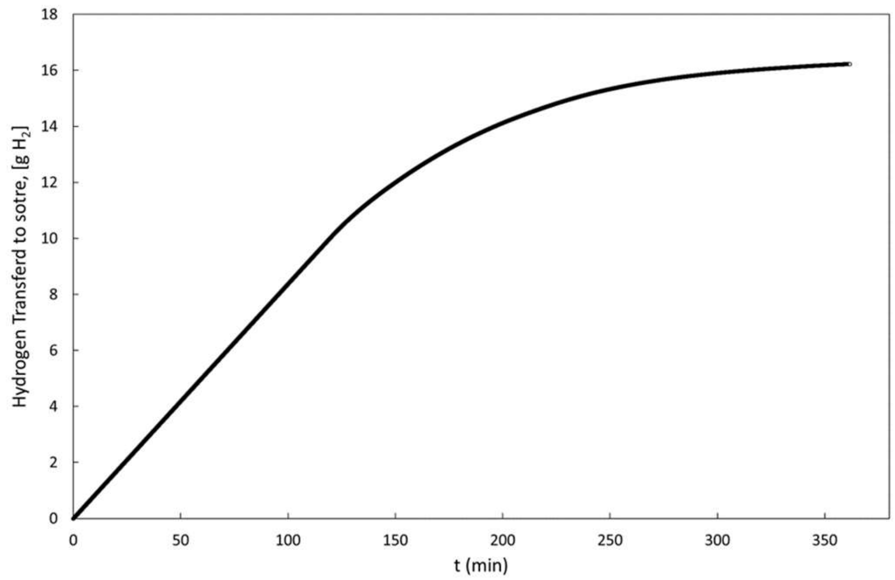


Metal hydrides – performance data

MariNH3
Clean, green ammonia engines for maritime

Performance data

- 1.6 kg of the Nottingham AB2 alloy were manually crushed for the store.
- Discharge, 10 g H_2 discharge in 2 hours.



The partnership
University of Nottingham UK | CHINA | MALAYSIA
UKRI Science and Technology Facilities Council
University of Birmingham
University of Brighton
Cardiff University Prifysgol Caerdydd
Funded by UKRI Engineering and Physical Sciences Research Council

Small scale test bench

MariNH$_3$
Clean, green ammonia engines for maritime

- Developed a rig that can test prototype reactors or varying sizes

- Performance tests
  - Flow rate
  - Start-up
  - Cycle life.

The partnership

University of Nottingham UK | CHINA | MALAYSIA

UKRI Science and Technology Facilities Council

UNIVERSITY OF BIRMINGHAM

University of Brighton

CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

Funded by UKRI Engineering and Physical Sciences Research Council

Amides as a hydrogen store

MariNH$_3$
Clean, green ammonia engines for maritime

On ship:

Metal hydride + Ammonia → Metal amide + hydrogen

$$\mathbf{MH + NH_3 \rightarrow MNH_2 + H_2}$$

- Exothermic
- Room temperature.
- Use onboard ammonia storage.
- Potential for high hydrogen weight percent.

Recharge at port:

Metal amide + hydrogen → Metal hydride + Ammonia

$$\mathbf{MNH_2 + H_2 \rightarrow MH + NH_3}$$

- Endothermic
- 50 – 300 °C.
- Heat to be provided.
- Hydrogen generation facilities at port.

The partnership
University of Nottingham UK | CHINA | MALAYSIA
UKRI Science and Technology Facilities Council
UNIVERSITY OF BIRMINGHAM
University of Brighton
CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD
Funded by UKRI Engineering and Physical Sciences Research Council

MariNH3

Clean, green ammonia
engines for maritime

Thank you

The partnership

University of Nottingham
UK | CHINA | MALAYSIA

UKRI Science and Technology Facilities Council

UNIVERSITY OF BIRMINGHAM

University of Brighton

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

Funded by

UKRI Engineering and Physical Sciences Research Council