Circular Zero-Emission Hydrogen Propulsion System
Short-Sea Application

Introduction

- Shipping is one of the most efficient way of transportation.
- However, 940 Million tonne CO_2 (using ~300 Million tonne Diesel) by maritime industry in 2019.
- And is responsible for 2.5% of global Green-House Gas (13% of Europe) emissions.

Maritime fuel and emissions, 2019	
Compound	**Million tonne**
Marine Diesel	300
CO_2	940
NO_x	20
SO_x	6
Particular Matter (PM)	1
Hydrocarbon (HC)	1

- PDEng project (TUDelft, H2SHIPS)

  Conceptual design of a sodium borohydride fueled hydrogen propulsion plant for a short sea cargo ship

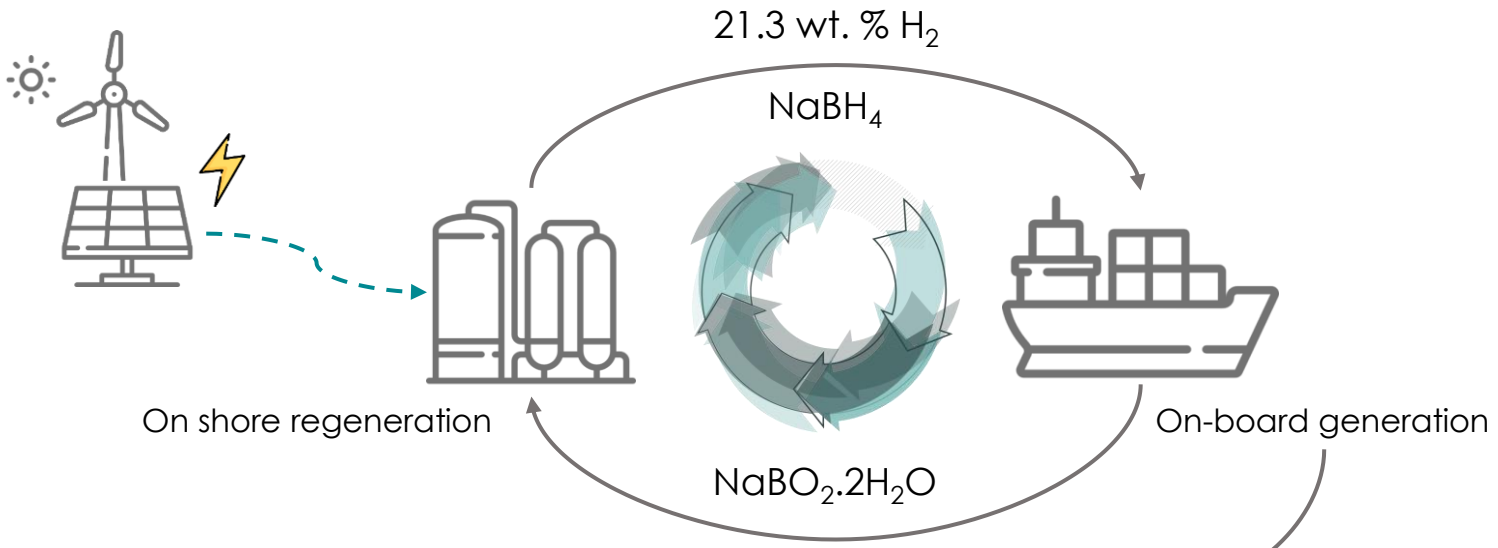
- The goal of Maritime Hydrogen B.V.

  Process and Equipment design of marine hydrogen fueled propulsion system using circular zero emission hydrogen carrier

Circular Hydrogen Solution

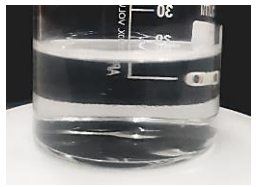
$NaBH_4$ Advantages:

- ✓ High energy density
- ✓ Less toxicity
- ✓ Non-explosive
- ✓ Less flammable
- ✓ Environmentally friendly
- ✓ Easy to store and handle

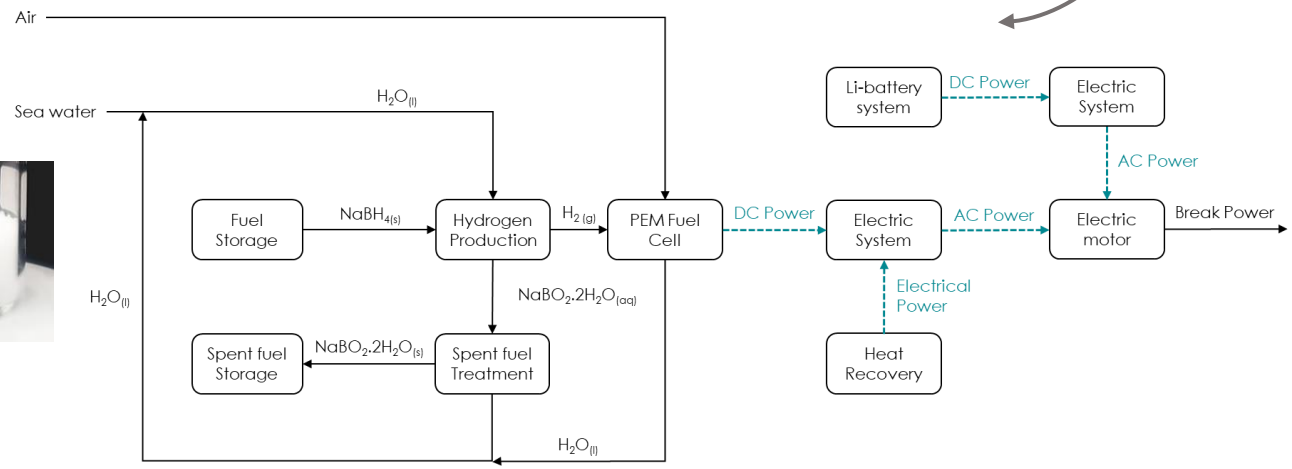



Dry fuel


H_2 Generation

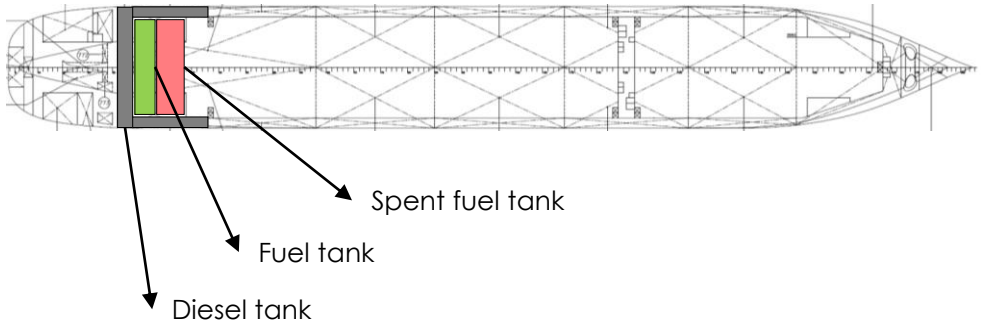

Reaction Effluent

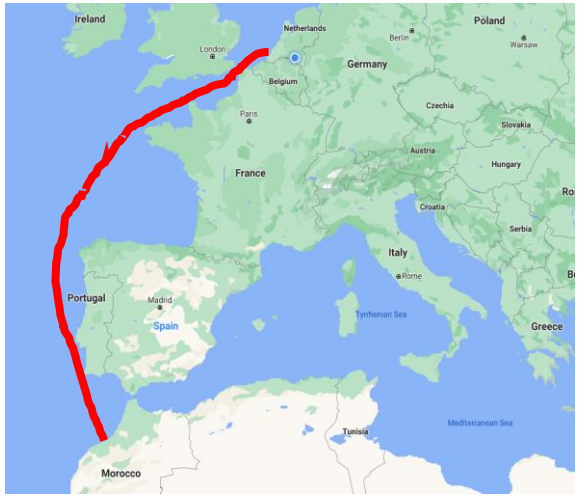

Dry spent fuel



Short-Sea Shipping Application (MS PIONEER)

Parameter	Unit	Value
Deadweight	tonne	11,000
Cargo capacity	m^3	13,000
Installed engine	MW	4
Maximum speed	kn	14
Average power	MW	2.5
Average speed	kn	11

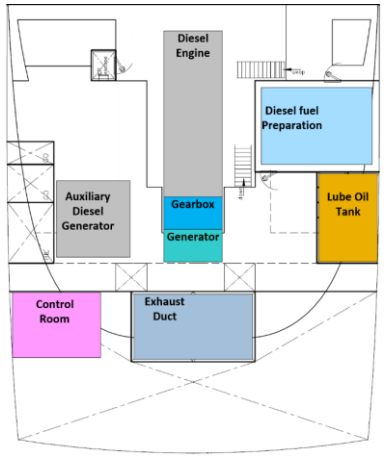




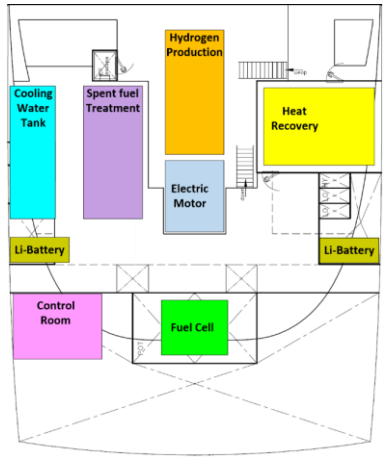
Port of Rotterdam ⇔ Port of Casablanca
3400 nm – 13 days

Parameter	Unit	Diesel [1]	$NaBH_4$
Power generator	-	ICE [2]	PEMFC [3]
Fuel	tonne (m^3)	190 (220)	240 (340)
Spent fuel	tonne (m^3)	-	640 (520)
Cargo capacity	tonne	10,810 (-2%)	10,300 (-7%)
	m^3	13,000 (-0%)	12,000 (-8%)
CO_2	**tonne**	**600** [4]	**0**
Noise level	dB	110 [5]	<60

Note 1: Marine Diesel Oil (MDO)
Note 2: Internal Combustion Engine
Note 3: Proton-Exchange Membrane Fuel Cells
Note 4: Also, 4 tonne SO_x , 12 tonne NO_x , 0.5 tonne HC, 0.3 tonne PM
Note 5: Maximum allowable dB for human is 85.

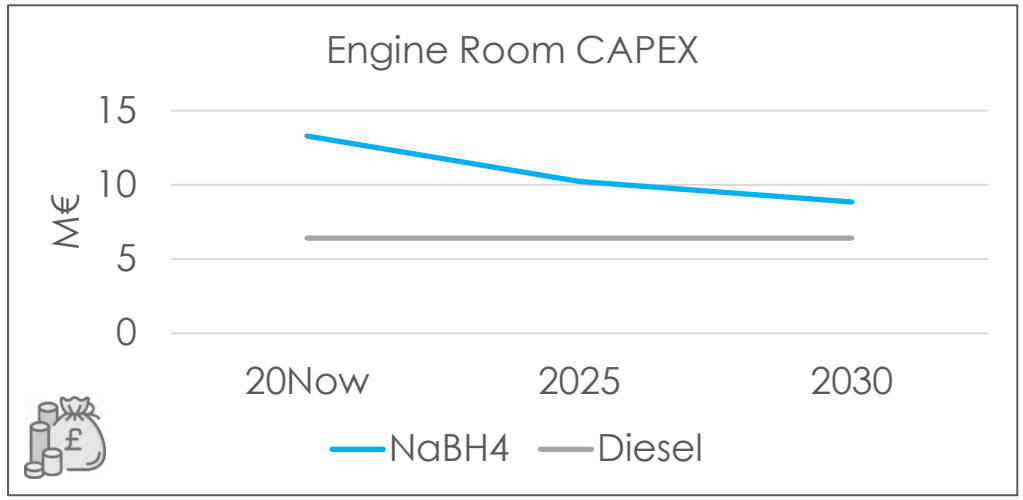


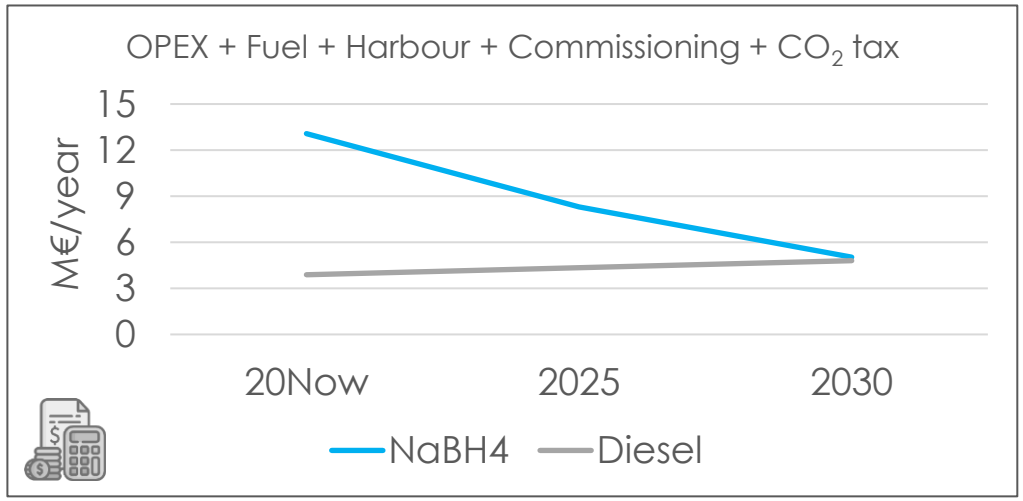
Before Retrofit

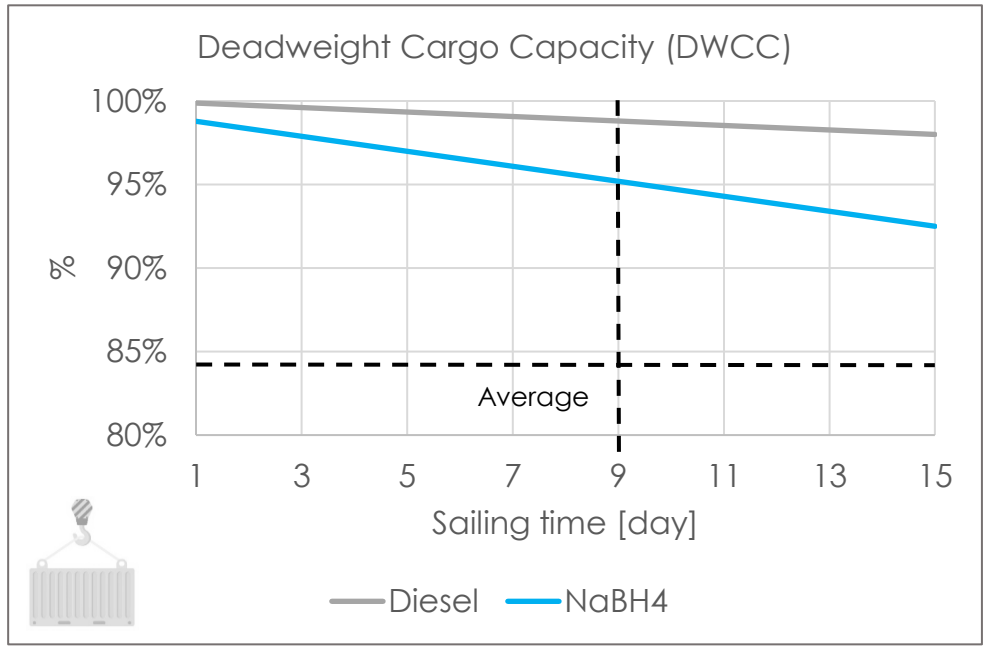


After Retrofit

CAPEX, OPEX, and Cargo Capacity







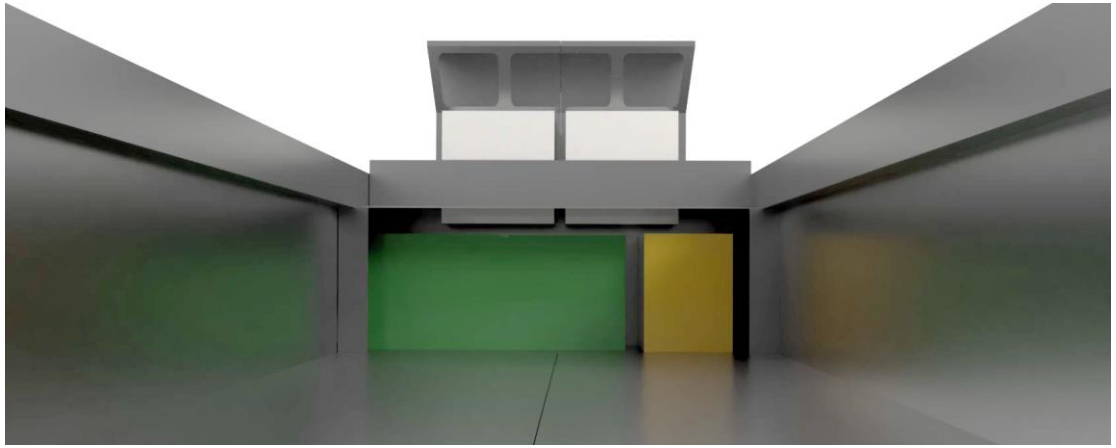
Fuel	Subsidy for (M€/year)	20Now	2025	2030
$NaBH_4$	Retrofitting	9.6	4.8	1.5
	New build	10	5.3	2

Subsidy can be paid from extra:

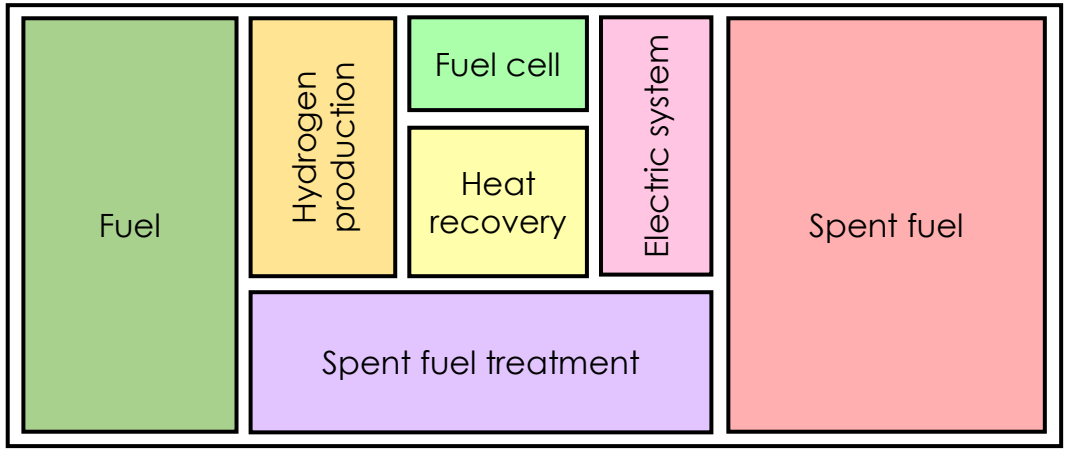
- CO_2 tax
- Harbour costs
- Commissioning costs
- Gross freight

Technology would also fit for an inland ship

Specification of the modular 300 kW Metal Borohydride PEM fuel cell system



300 kW power supply (green box) and 400 kWh Li-battery (yellow box)



Plant layout top view

Forklift storage underneath the "erf"

Dimensions		Unit	Value
Container	Length	m	6
	Width	m	2.4
	Height	m	2.3
Storage	Length	m	8
	Width	m	2.5
	Height	m	2.5

Specifications (Generation)	Unit	Value
AC output power	kW	316
Operating time	days	2
Initial weight	tonne	19.8
Final weight	tonne	27.4
$NaBH_4$ capacity	tonne (m^3)	4.5 (6.5)
Spent Fuel capacity	tonne (m^3)	12.1 (9.8)

Conclusion

- Borohydrides fuelled hydrogen fuel cell propulsion system are promising technologies for the maritime industry;
- However, challenges are:
    a. Spent fuel regeneration economics
    b. Fuel bunkering infrastructures and logistics
    c. Minimize loss of maximum cargo capacity
- Two ongoing projects are being done for on-board generation and spent fuel regeneration proof of concept at TUDelft, UvA, TUW.