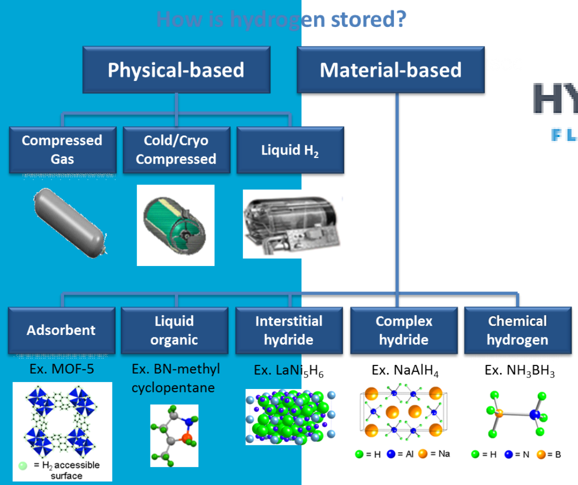


MARITIME HYDROGEN MARINE ENERGY
FLORØ, NORWAY 18-19 SEPTEMBER 2019

Interreg North-West Europe
EUROPEAN UNION
H2SHIPS
European Regional Development Fund

# Metal Hydrides in the H2SHIPS project

Maritime Hydrogen and Marine Energy Conference
Floro Norway September 18-19 2019

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# Why metal hydrides as ship hydrogen storage alternative?

- Drivers for Zero emission in the Netherlands
- Which strategy? The hydrogen case
- ***How to store hydrogen safe and with reasonable volumetric energy density?***
- A concept for maritime sodiumborohydride
- The EU Interreg NWE H2SHIPS project
- Other developments in the Netherlands
- The way ahead, future research

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# Drivers

- Governmental policy: EU and national
- Supply Chain Operators: clean transport
- Ship owners: compliance with (future) rules and regulations (both on greenhouse gas and air quality)
- Industry: innovation and competitive edge
- Society: towards a sustainable environment

*NL Government decided to implement a CO2-tax for CO2-emissions.*



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# Which strategy?

**Alternative (mixes of) fuels**

Synthetic, biological, carbon free or carbon neutral

**Alternative or modified energy converters**

Fuel cells, evolved Internal Combustion Engines

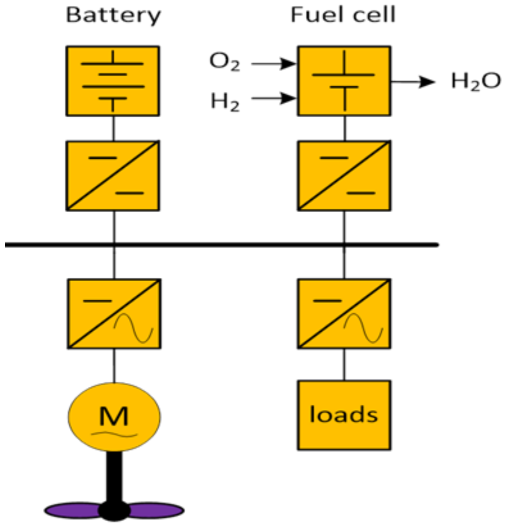
**Elimination at end of pipe**

Scrubber, selective catalytic reduction

# The Maritime Hydrogen case



No emissions, silent, no single point of failure, graceful degradation, solid state conversion: less maintenance req.



# Fuel cells characteristics

| | LT-PEMFC | HT-PEMFC | SOFC |
|---|---|---|---|
| *Operating temperature (˚C)* | 40 - 80 | 150 - 180 | 500-1000 |
| *Electrical efficiency (LHV)* | 50-60 | 40-45 | 50-65 |
| *Fuel purity required* | 99.999% H2 | CO<3% | Light hydrocarbons (S<20 ppm) |
| *Gravimetric power density (W/kg)* | 250-1000 | - | 8.0-80 |
| *Volumetric power density (W/l)* | 300-1550 | - | 4.0-32 |
| *Life time* | 5 to 20k hours | 10 to 60k hours | 10 to 40k hours |
| *Start-up time* | <10 seconds | 10 to 60 minutes | 30 minutes to hours |
| *Load transients (0 to 100%)* | <5 seconds | 2-5 minutes | <15 minutes |
| *Capital cost today ($/kW)* | >1000 | 4000-4500 | 3500-15000 |
| *Technology Readiness Level (TRL)* | 8 | 7-8 | 5-7 |
| *Cooling* | Water cooling | Water cooling | Air cooling |
| *Waste heat recovery* | - | -/+ | ++ |

van Biert, L., Godjevac, M., Visser, K., & Aravind, P. V. (2016). A review of fuel cell systems for maritime applications. *Journal of Power Sources*, *327*(X),
345–364. https://doi.org/10.1016/j.jpowsour.2016.07.007



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# Fuel cells

Courtesy Nedstack.nl

- PEMFC: low temperatures, available, high power density, quick start-up, good dynamic performance, pure H2 required, limited waste heat recovery, TRL: 7-9
- SOFC: high temperatures, high efficiency, high cost, low power density, higher tolerance to non H2-fuels, useful waste heat recovery, TRL: 5-7
- Additional maritime aspects: low noise, no CO2, no NOx, no SOx, no particulate matters. solid state tech: low maintenance (cost), high reliability and graceful degradation when in modules and stacks.

[1] Vora, S. D., Lundberg, W. L., & Pierre, J. F. (2017). Overview of U.S. Department of Energy Office of Fossil Energy's Solid Oxide Fuel Cell Program. *ECS Transactions*, *78*(1), 3–19. https://doi.org/10.1149/07801.0003ecst
[2] Mittermeier, T., Weiß, A., Hasché, F., Hübner, G., & Gasteiger, H. A. (2017). PEM Fuel Cell Start-up/Shut-down Losses vs Temperature for Non-Graphitized and Graphitized Cathode Carbon Supports. *Journal of The Electrochemical Society*, *164*(2), F127–F137. https://doi.org/10.1149/2.1061702jes
[3] van Biert, L., Godjevac, M., Visser, K., & Aravind, P. V. (2016). A review of fuel cell systems for maritime applications. *Journal of Power Sources*, *327*(X), 345–364. https://doi.org/10.1016/j.jpowsour.2016.07.007



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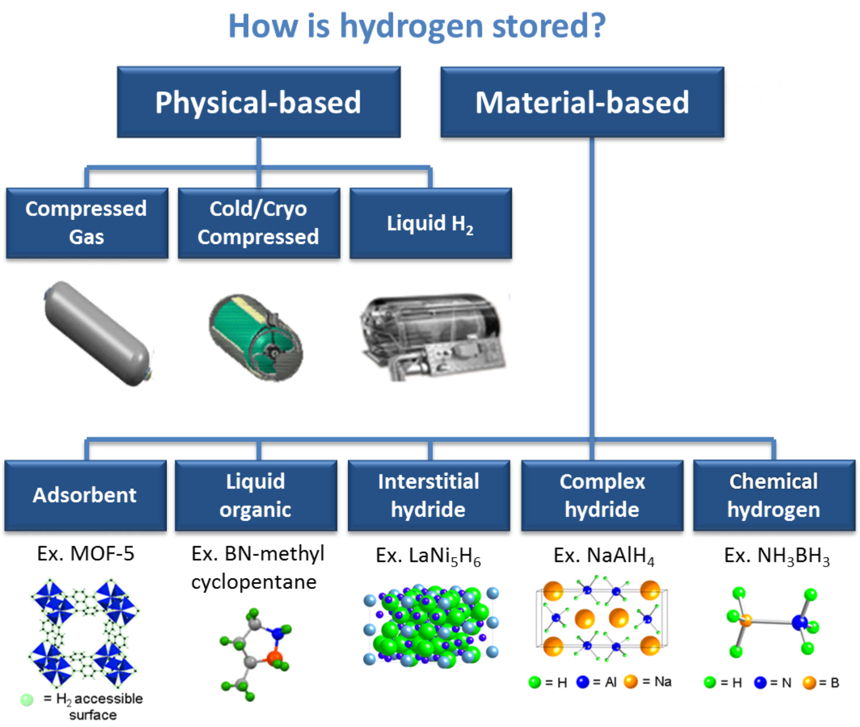
# The on board hydrogen storage challenge




Source: *hydrogenandfuelcells.energy.gov*

Drivers

Which strategy?

The Hydrogen case

Fuel cells

The on board hydrogen storage challenge

A concept for sodiumborohydride

Topical developments

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# Some concerns from our concept blue paper:

**Liquefied hydrogen**

Release of LH2 into enclosed spaces
- Pressure build-up due to rapid vaporization
- Low temperature effect on equipment
- Ignition of “oxygen snow” in LH2

Loss of vacuum in cryogenic storage tanks
- Excessive Boil-off discharge/pressure build-up in tank

Sloshing in tank
- Loss of tank pressure

Inerting issues
- Condensation and solidification of nitrogen

Condensation and solidification of oxygen

Safe arrangement of Tank connection space

**Compressed hydrogen**

- Release of CH2
- Pressure
- Ignition mechanisms
- The high pressure is a hazard on its own

**Common concerns for $LH_2$ and $CH_2$**

Develop relevant hazardous (EX) zones for hydrogen

Ignition source control

Material embrittlement

Risk of autoignition when burst discs are used

Capacity of safety relief valves

Ignition of hydrogen in case of release through the vent mast

Use of inerted spaces to reduce explosion risks
- Asphyxiation hazard
- Limits accessibility

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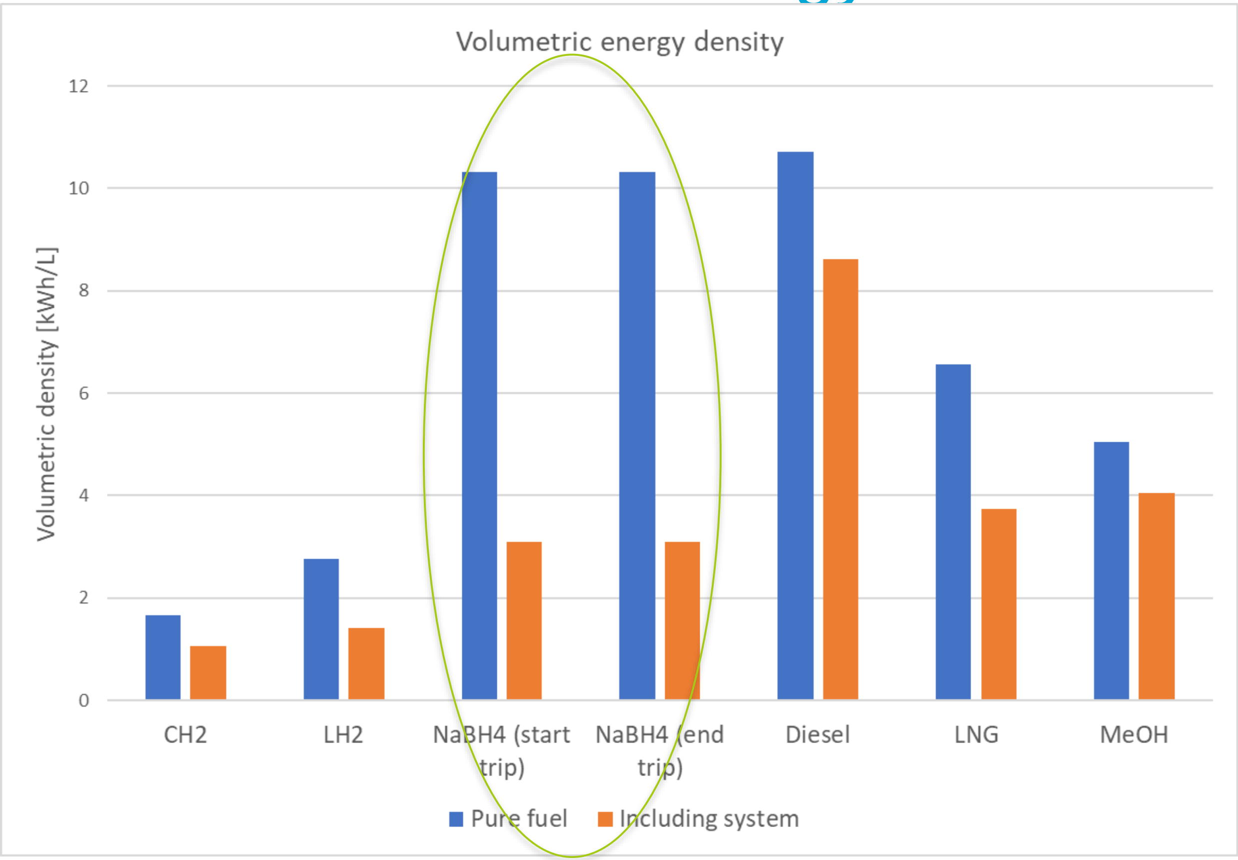
# Volumetric Energy densities



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# Principle of NaBH4 as a H2 carrier

$$\mathrm{NaBH_4} + 2\mathrm{H_2O} \xrightarrow{\text{catalyst}} NaBO_2 + 4H_2 + Heat$$

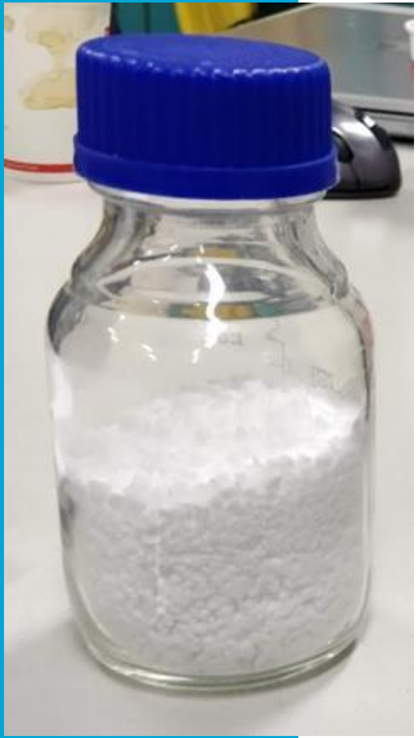
1 kg $H_2$ = 141,7 MJ or 39,4 kWh before the engine (Fuel Cell)

## Regeneration of the spent fuel

$$NaBO_2 \rightarrow \mathrm{NaBH_4}$$

Source: *H2Fuel*

# NaBH4 characteristics



- **characteristics:**

  - Metal hydride supplied in powder, granules or in a solution
  - Reacts with water
  - Flammable, but very slow
  - Energy density (38,5 MJ/kg)
  - Can be stored in a solution with a stabilizer (eg. $NaOH$)

| | | |
|---|---|---|
| Molecular Formula | $BH_4Na$ | |
| Description | White crystal powder | |
| Mol mass | 37.83 | g/mol |
| Melting point | 400 | °C |
| Boiling point | 500 | °C |
| Density | 1.035 | g/mL at 25 °C |
| Flashing point | 70 | °C |
| Water solubility | 550 | g/L at 25 °C |
| $\Delta H$ | -188.6 | KJ/mol |
| $\Delta G$ | -123.9 | KJ/mol |
| °S | 101.3 | J/mol/K |
| $C_p$ | 86.8 | J/mol/K |

Source: *H2Fuel-Systems B.V.*

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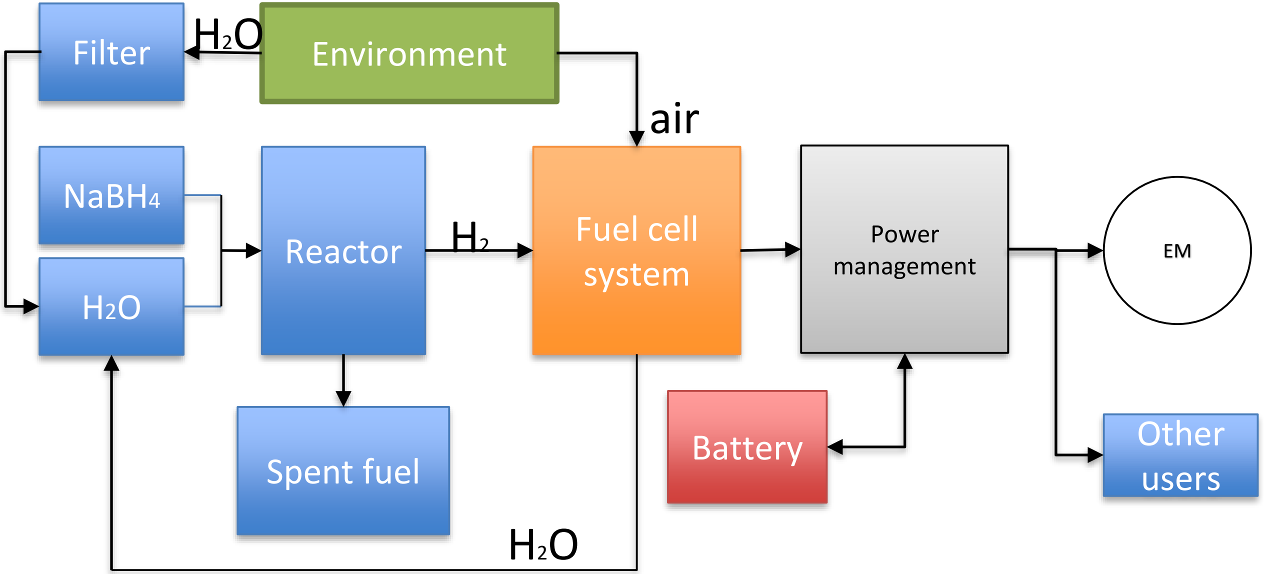
# A concept for maritime Sodiumborohydrid



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# Proof of Concept in Rotterdam

Drivers

Which strategy?

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Courtesy: *H2Fuel-Systems B.V.*

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# What are the urgent maritime storage challenges?

- a. hyperbaric 350-700 bar? Certification complex, lower density, high TRL, logistic availability gas in ports?
  b. liquid (-253 degrees Celsius)? Certification very complex, high TRL, low density, lesser support of captains?, logistic availability liquefied in ports?
  c. chemical storage in molecules: $CH_3OH$, $CH_4$, $NH_3$? Not directly applicable for PEMFC (reforming required), logistic availability better, methanol liquid in ambient conditions, certification LNG complex, $CO_2$ as exhaust gas?
  d. chemical storage in chemical hydrides: $NaBH_4$? Experimental, proof of concept performed, certification process much less complicated?, potential higher storage density, new logistical process with solid states and spent fuel disposal/regeneration, regeneration process needs update technology for higher scale and efficiency..

# *Implementation as part of the H2SHIPS INTERREG project*





## Helping H2 become a widespread solution for shipping in NWE

**From the**  **to the** 

- Sub- objectives:
  - ➢ Determine appropriate technology
  - ➢ Develop favorable regulatory framework
  - ➢ Help creating a market

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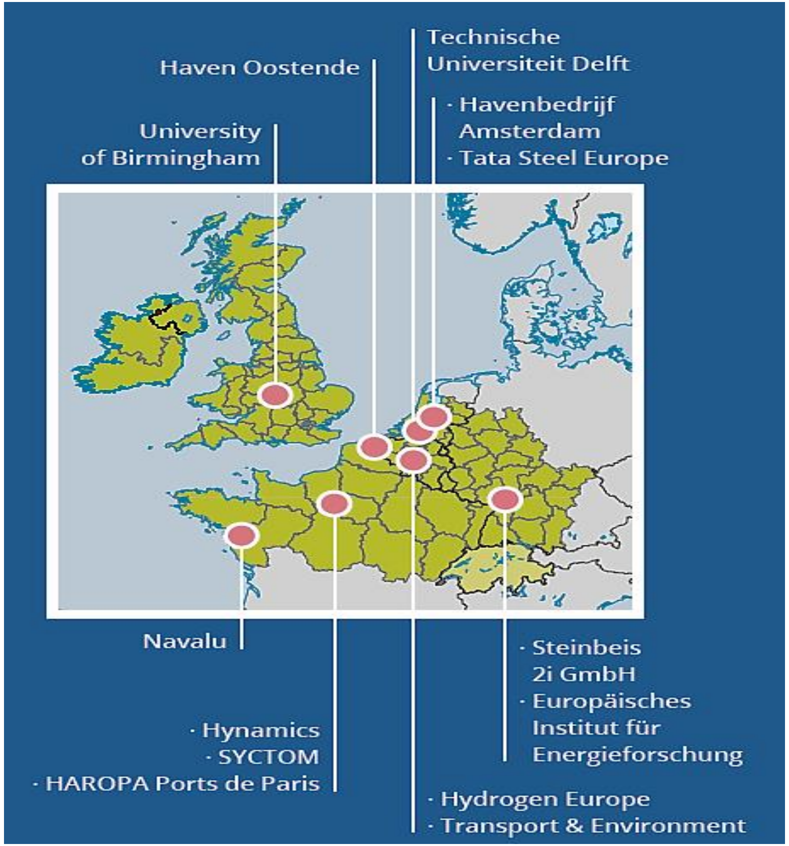
H2SHIPS
European Regional Development Fund

Port Oostende
University of Birmingham

+ 2 Sub-partners
+ 15 Associated Partners

Navalu
hynamics EDF GROUP
syctom
HAROPA Ports de Paris Seine Normandie

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Port of Amsterdam
TATA STEEL
EIFER
STEINBEIS 2i
Hydrogen Europe
TRANSPORT & ENVIRONMENT

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# *3 ports ...*

# *... 3 core areas*

- USAGE: *Amsterdam* H2 system on newbuilt ship
- LOGISTICS: *Oostende* Bunkering solutions
- PRODUCTION: *Paris* Local electrolysis

Interreg North-West Europe
H2SHIPS
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# Budget and Timeline



**Total budget: 6,3 M€**

**ERDF funding: 3,5 M€**

**Total project duration: 3,5 years**

- **1st reports on regulatory frameworks: Apr. 2021**
- **Complete roadmap: Apr. 2022**
- **1st things to see in Ostend and Amsterdam: End of 2020**

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Interreg North-West Europe H2SHIPS European Regional Development Fund

# The Amsterdam Demonstrator in H2SHIPS



The NL demo will take place on a new Port Authority Vessel of Port of Amsterdam. The vessel will have a zero emission propulsion and will sail in the Amsterdam urban and port area.

- The configuration will be battery-electric, with a maritime fuel cell as range extender and sodiumborohydrid as hydrogen carrier.
- NL partners: Port of Amsterdam, Tata Steel and Delft University of Technology.
- Port of Amsterdam and TATA find it very important, that existing small inland ships with small destinations at the end of inland waterway logistical lines towards the Netherlands, Belgium and France can be sustained by a retrofit modification of zero-emission propulsion power. This demo enables this process.

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# Amsterdam Demo Design Data

Drivers

Which strategy?

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**Dimensions:**

Max length: 20 meters

Max. beam: 4.25 meters

Max. draft: 1.50 meters

Max height above waterline: 1.90 meters

Accommodation: 25 persons.

Map Courtesy Waternet Amsterdam

**Operational profile and propulsion data**:

-the requirement to sail with an average speed of **12.5 km/h** (3.5 m/sec) for a period of **10 hours**

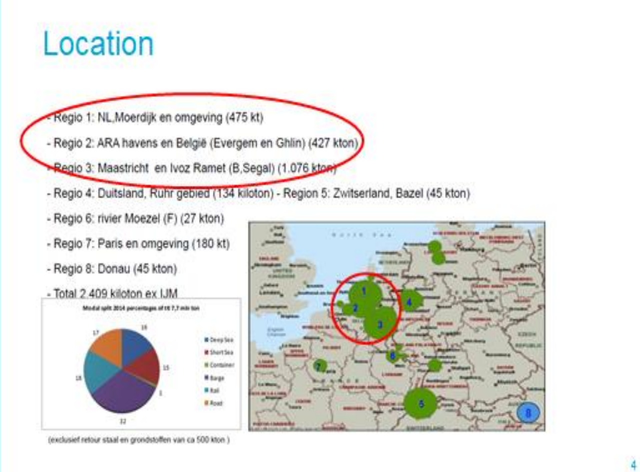
-propeller power: 220 hp (162 kW), expected for this vessel a maximum of **200 kW**

-Electrical power should facilitate operation of a bow thruster and a stern thruster (bot not at full speed) and the heating of the ship.

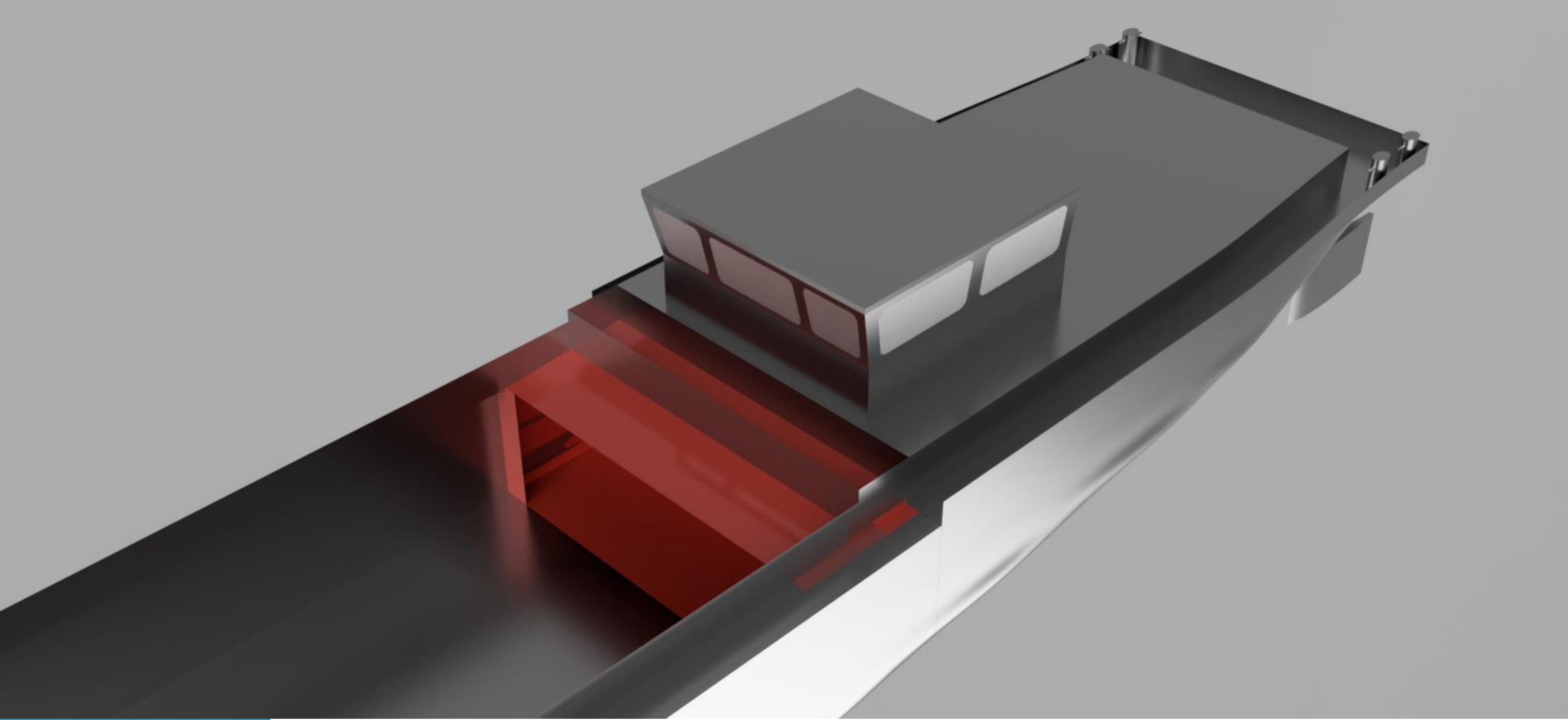
-Storage of hydrogen in a metal hydride

# Future plan






-Small inland ship
-2 propeller shafts, 250 kW, 1 H2-electric, 1 conventional
-Retrofit of existing ship, commercial cargo test
-Modular hydrogen power pack with Sodiumborohydrid fuel and PEM fuel cells



250 kW PEM. 5 cum NaBH4 for operation of 70+ hours

# Way ahead for NaBH4-as-a-fuel

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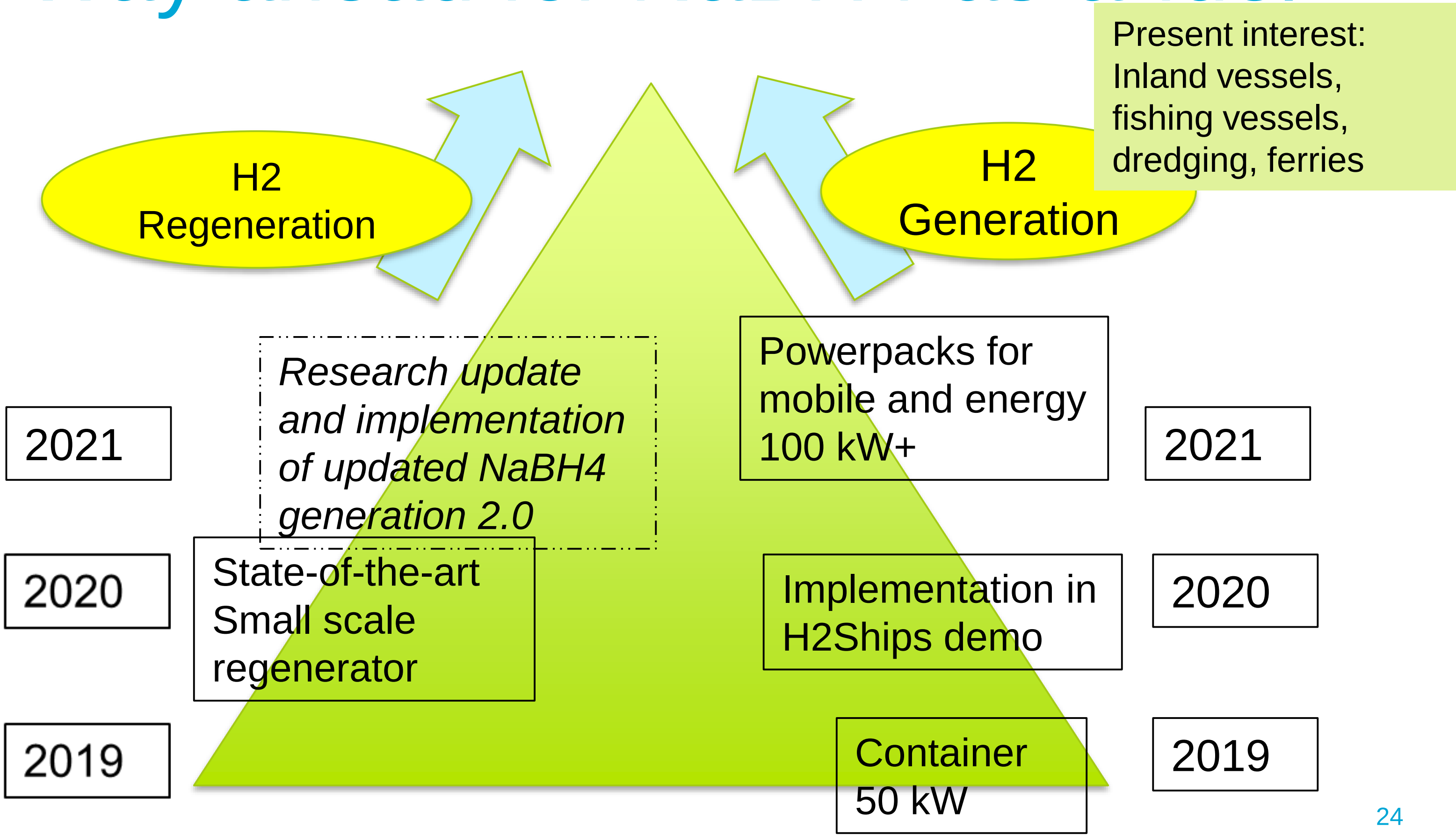


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Thank you!   k.visser@ tudelft.nl

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