Use of ammonia as fuel in fuel cells in maritime frameworks

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Outline

- Shipping
- Ammonia fuel
- Fuel cells
- Aegir concept

Shipping

- Significant greenhouse gas (GHG) emissions from shipping – 2% of the global numbers
- International maritime organization's (IMO) strategy
  - 50% reduction by 2050
  - complete phase out of CO_2 emissions by 2100
- Organisation for Economic Co-operation and Development OEC
  - Forecast: international maritime trade is expected to triple by 2050

Low- and zero-emission solutions for maritime transport

Ammonia fuel

- Zero GHG emission at point of power production
- Attractive power density & storage properties
- Production of a zero-carbon footprint ammonia possible (renewable electricity, water, and air)

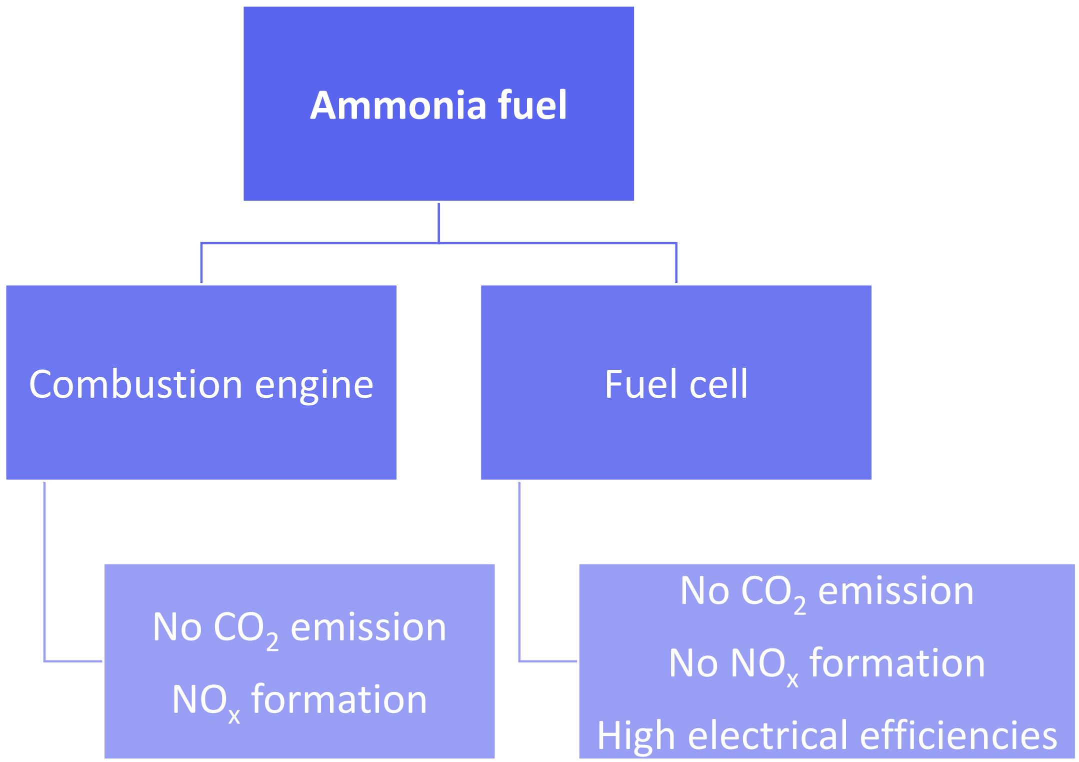
- Carbon and sulfur free fuel: Ammonia combustion with no SOx, CO_2, or particulate emissions
- Use in fuel cells

Ammonia fuel

- **AVAILABILITY AND PRODUCTION SCALABILITY**
  - 120 ports already equipped with ammonia trading facilities worldwide.
  - Annual ammonia production: 180 million tons.
  - Conventional production over-capacity of 60 million tons/year ensures availability
  - Additional ammonia production to meet 30 % marine fuel demand in 2050: 150 million tons/year.
- **DEMAND FOR RENEWABLE ENERGY TO PRODUCE GREEN AMMONIA**
  - 400 GW power needed to meet 30 % of future marine fuel demand.
  - In 2019 alone, 184 GW additional power production was installed.
- **SAFETY AND APPLICABILITY**
  - 17.5 million tons ammonia safely traded and transported yearly by ship, truck, and train.
  - Existing practices and know-how for a safe ammonia handling are established in the Marine and other industries and adaptable for ammonia as a fuel.

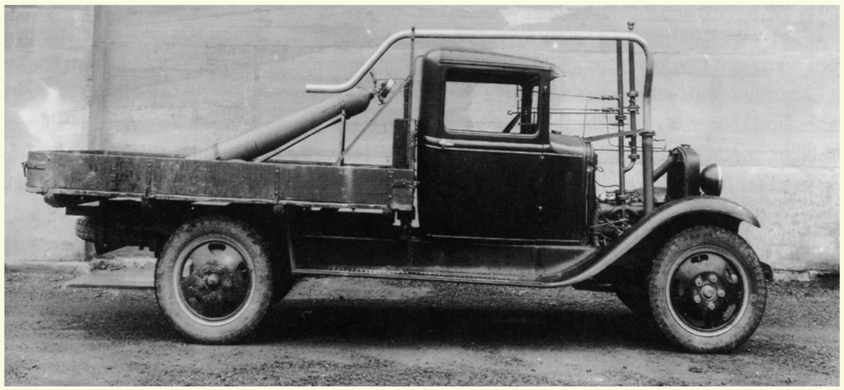
Ammonfuel – an industrial view of ammonia as a marine fuel, ALFA LAVAL, HAFNIA, HALDOR TOPSOE, VESTAS, SIEMENS GAMESA

Ammonia fuel



Ammonia fual

- **Ammonia as fuel: It is not new**



Norway's Norsk Hydro's Ammonia Truck 1933

There were dozens of privately owned ammonia powered vehicles, primarily in Italy, Germany and Belgium the middle 1930s.

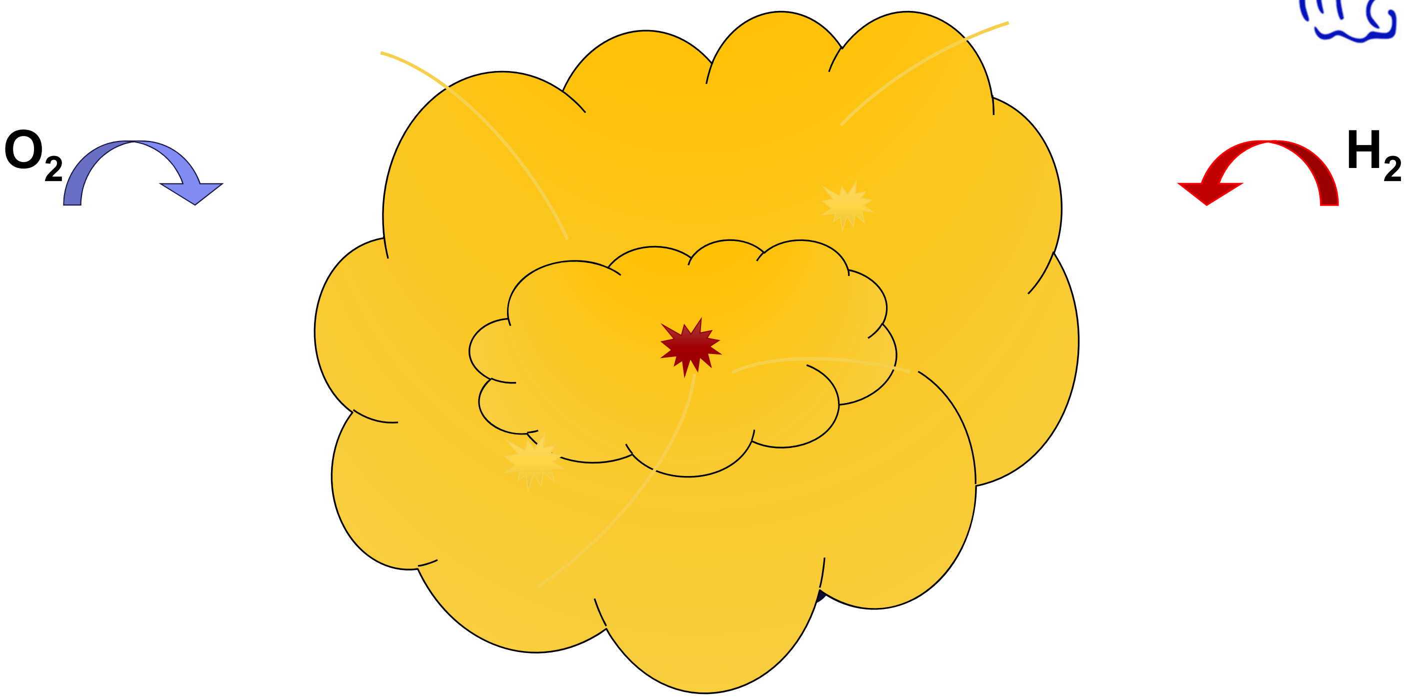
[Invest Pitch (nh3fuel.com)](nh3fuel.com)

Brussels Belgium's Municipal Ammonia Bus 1944

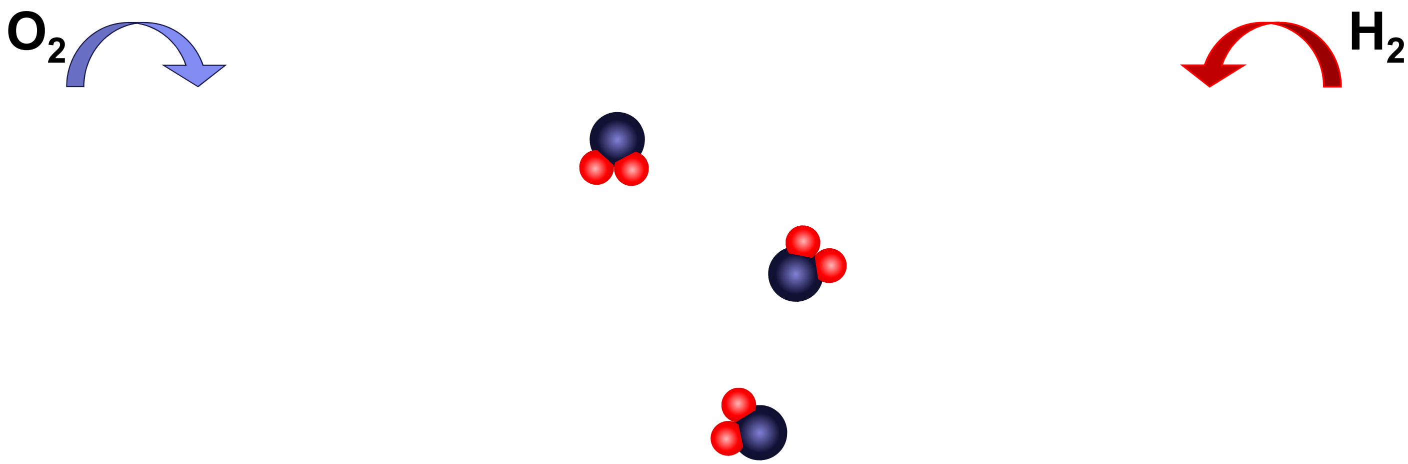
Between 1944 and 1946 Brussels ran 12 ammonia powered buses over 100,000 km without a single accident.

Fuel cell

No Fuel Cell

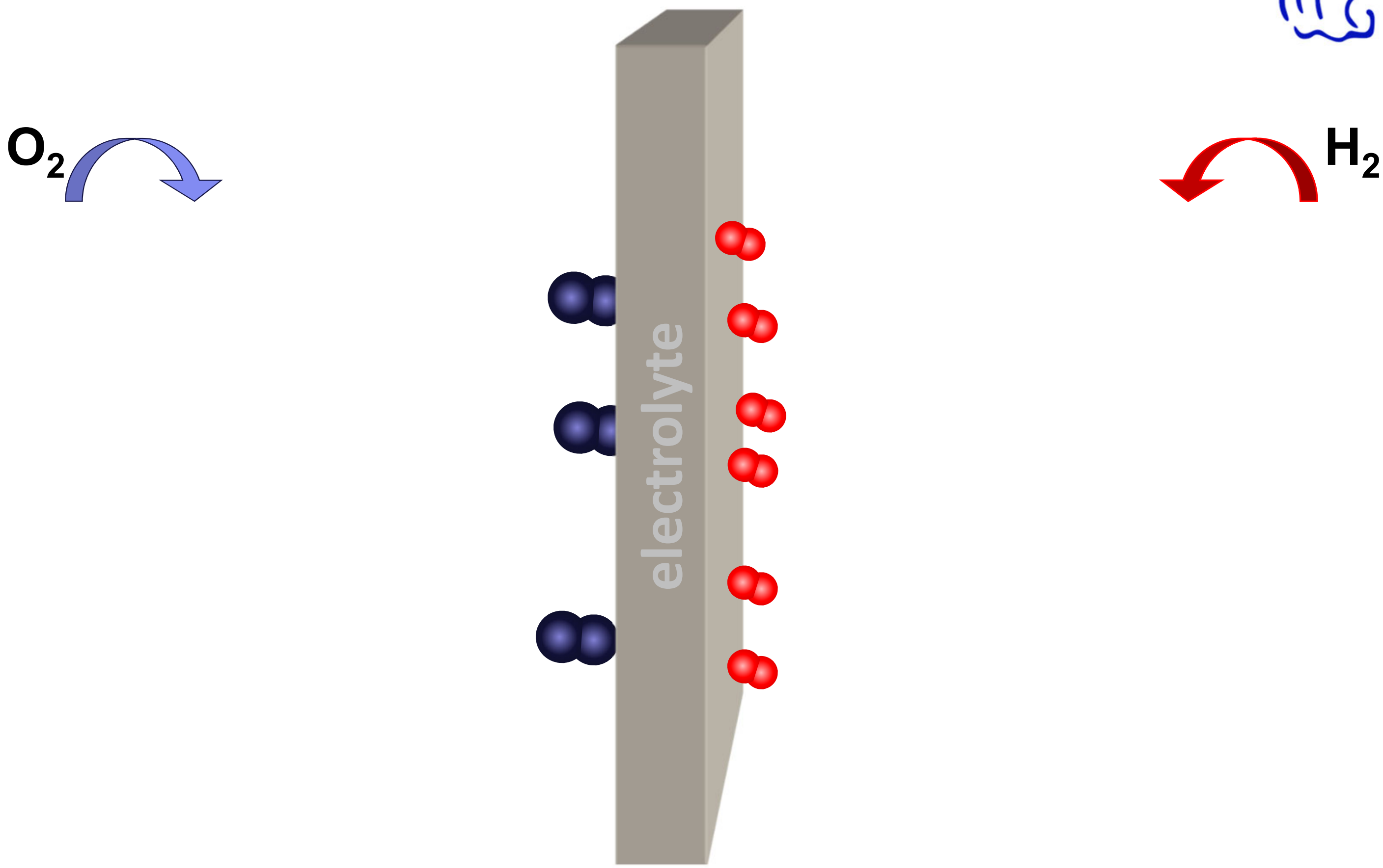


No Fuel Cell

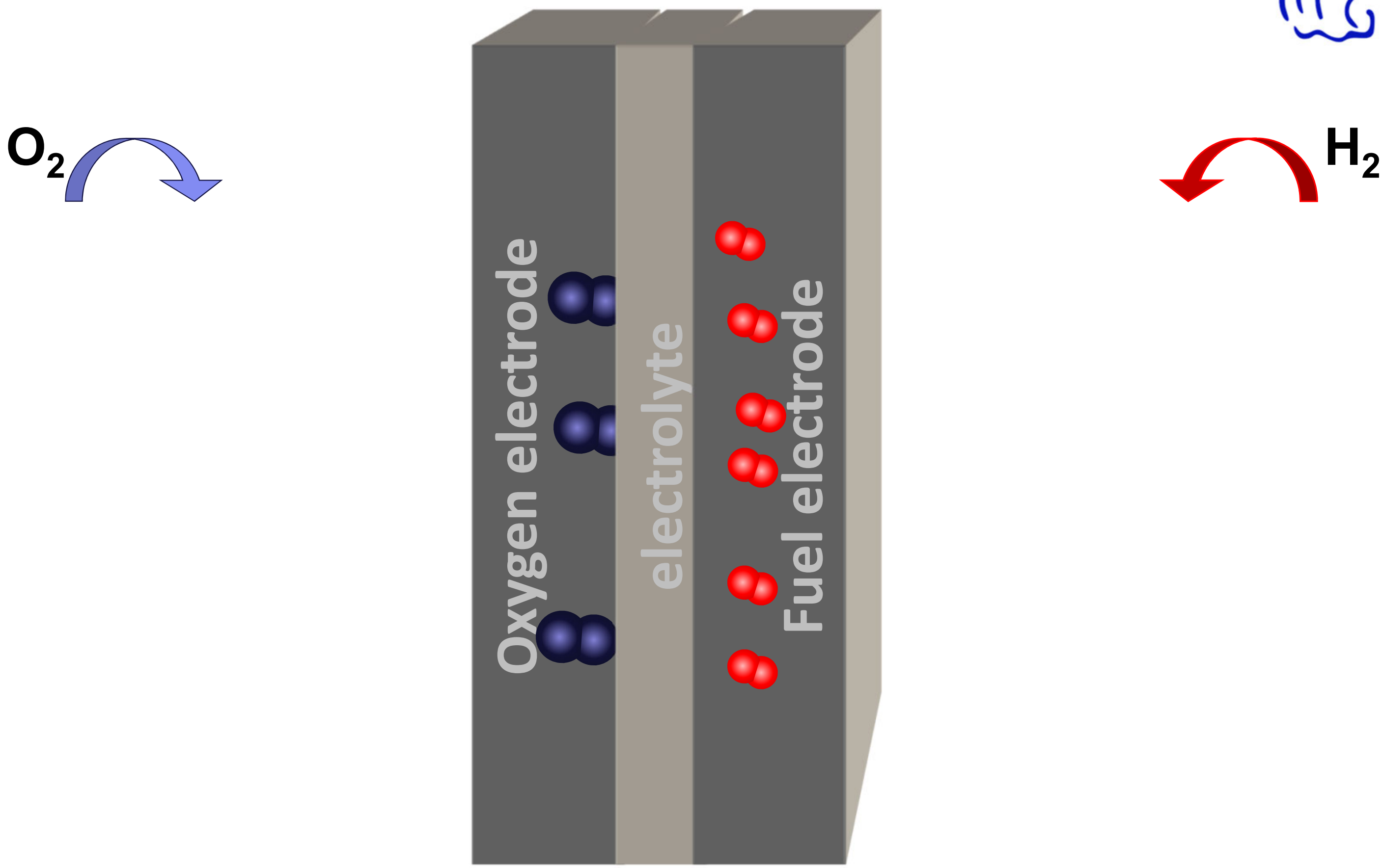


$$2H_2 + O_2 \rightarrow 2H_2O$$

With Fuel Cell



With Fuel Cell



Theoretic efficiency

- First law of thermodynamics: energy conversion

$$efficiency = \frac{What\ you\ get\ out}{What\ you\ put\ in}$$

Theoretic efficiency: *Heat driven engines*

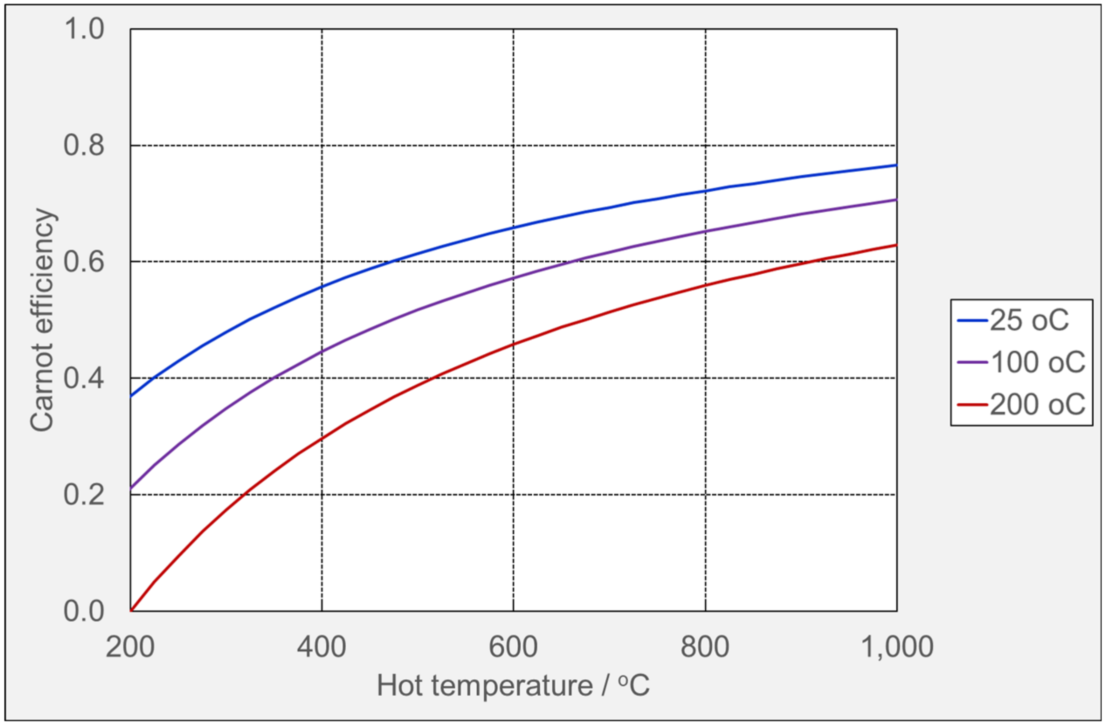
- *Carnot efficiency*

$$\eta_{Carnot} = \frac{T_{hot} - T_{cold}}{T_{hot}}$$

η_{Carnot}: Carnot efficiency
T_{hot}: Temperature of the hot reservoir in Kelvin
T_{cold}: Temperature of the cold reservoir in Kelvin

Theoretic efficiency: *Heat driven engines*

- *Carnot efficiency*



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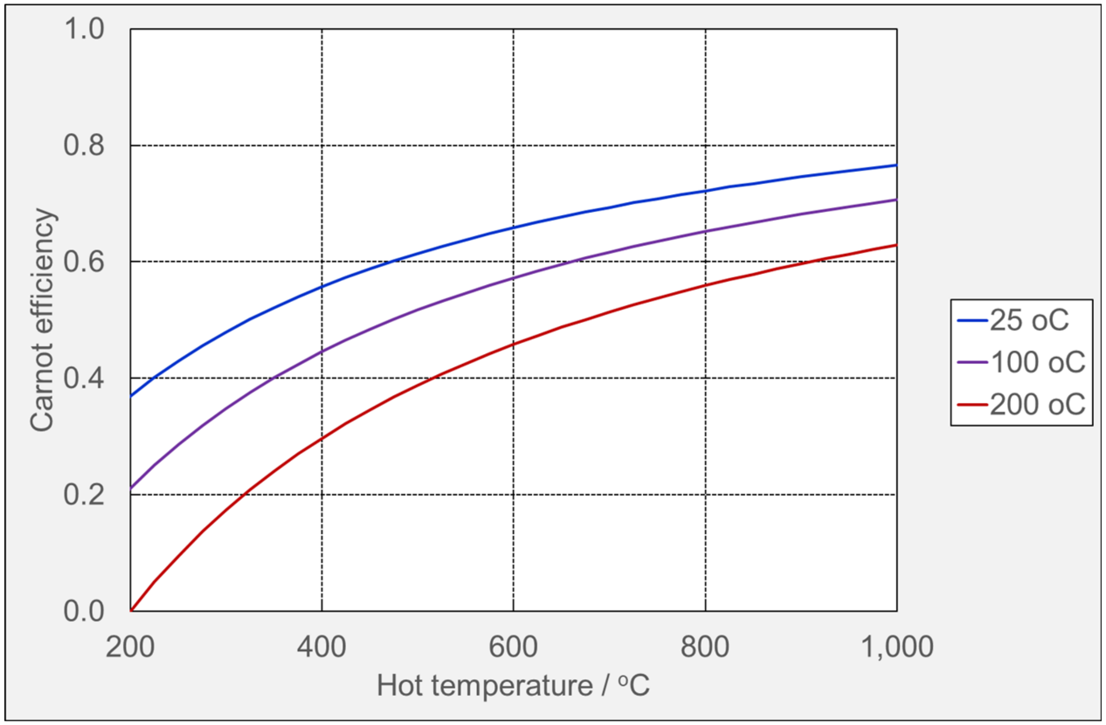


- High temperatures
- Low cold temperatures

Theoretic efficiency: *Fuel cells*

- *Obtainable work*

$$\eta_{Theory-FC} = \frac{\Delta G(T)}{\Delta H} \cdot 100\%$$

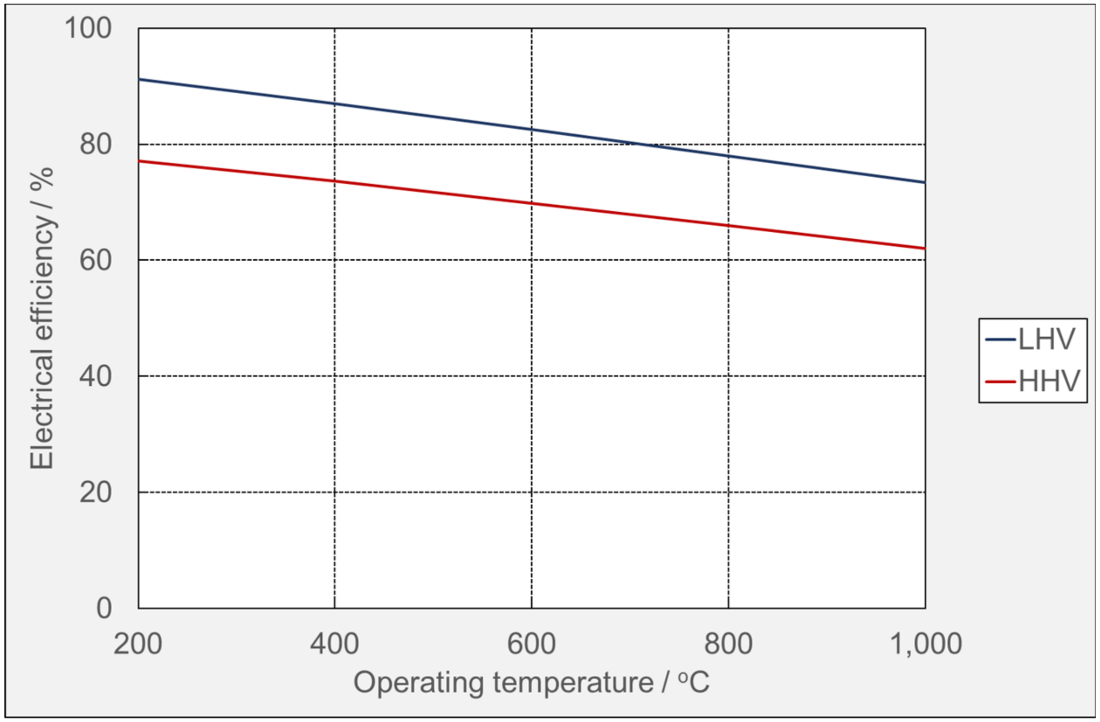
$\eta_{Theory\text{-}FC}$: Maximum achievable fuel cell efficiency in %
ΔG: Gibbs free energy of the fuel cell reaction in kJ/mol
ΔH: Reaction enthalpy of the fuel oxidation/combustion in kJ/mol
LHV: amount of heat released by combusting
HHV: amount of heat released by combusting and steam condensation

Theoretic efficiency: *Fuel cells*

- *Obtainable work*

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$$

Higher heating value (HHV)
Lower heating value (LHV)



Theoretic efficiency: *Fuel cells*

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$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$$

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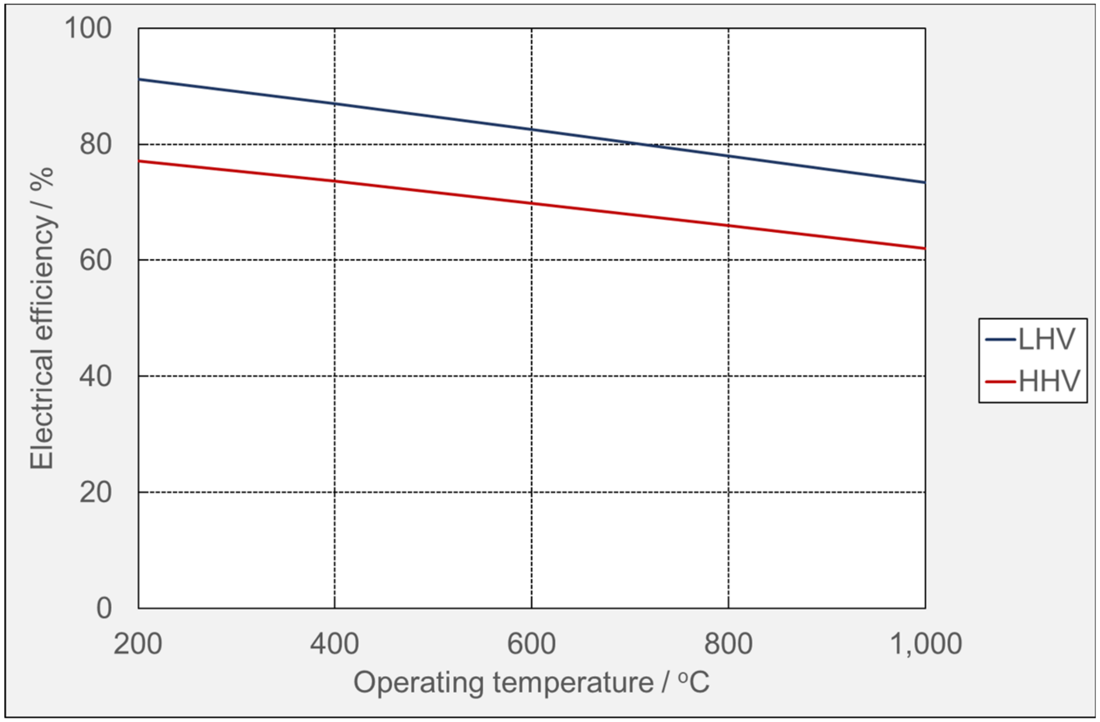
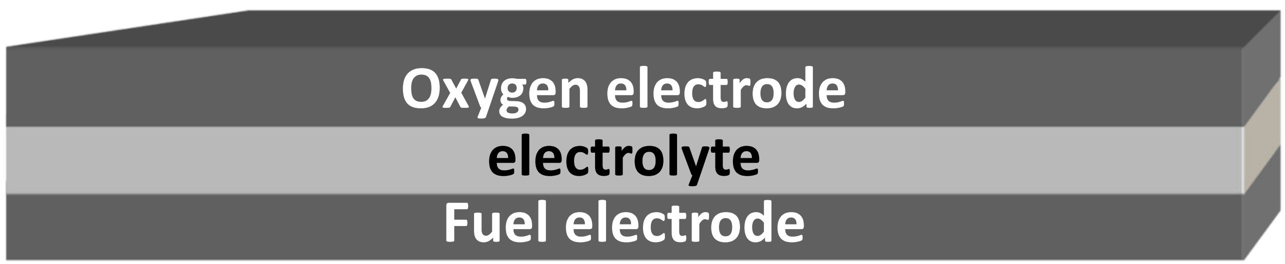
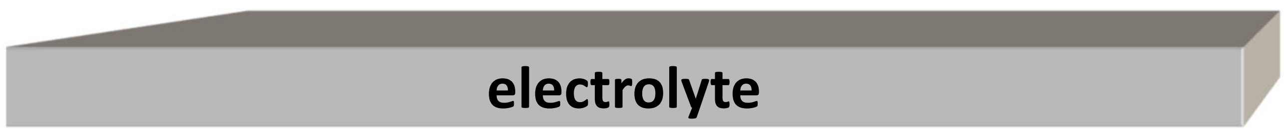


- High efficiencies at lower temperatures

Fuel cells: Major Types

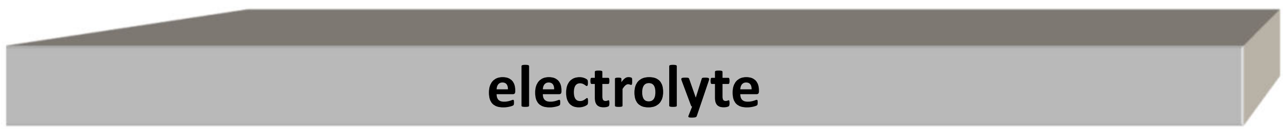


Fuel cells: Major Types



Fuel cells: Major Types

- Electrolyte type determines
  - Fuel cell type
  - Elementary reactions
  - Operating conditions & fuels

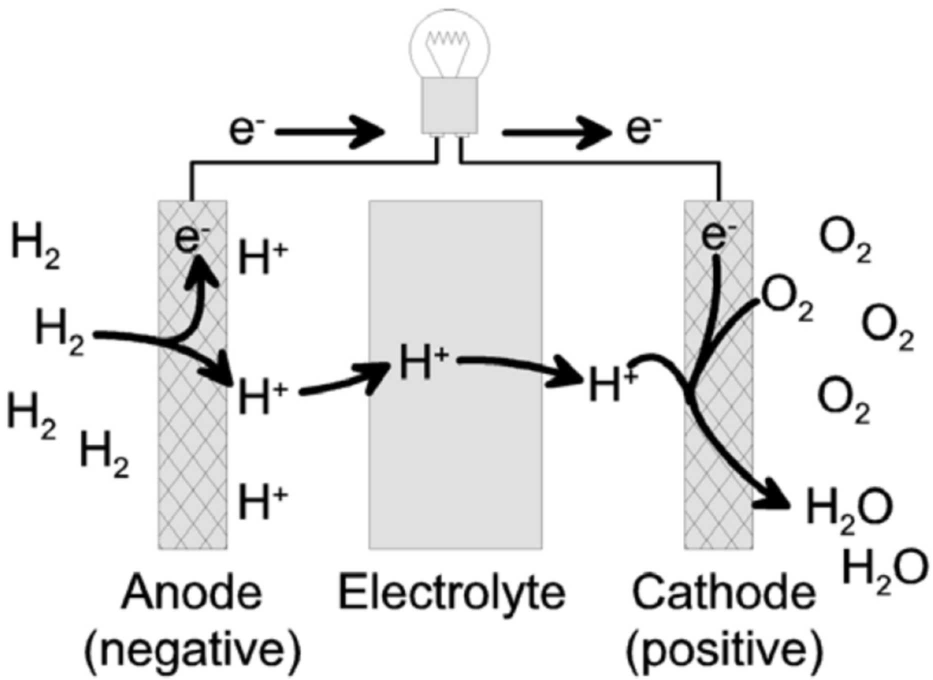


Fuel cells: Major Types

Name	PE(M)FC	SOFC
Electrolyte	Polymer	Ceramic (Solid Oxide)
Charge carrier (through electrolyte)	H^+	O^{2-}
Typical	Nafion	Yttria stabilised zirconia
T (^oC)	80	700-900
Fuel	H_2	HCs/CO/H_2
η_{el} (%) LHV	40-45	50-70

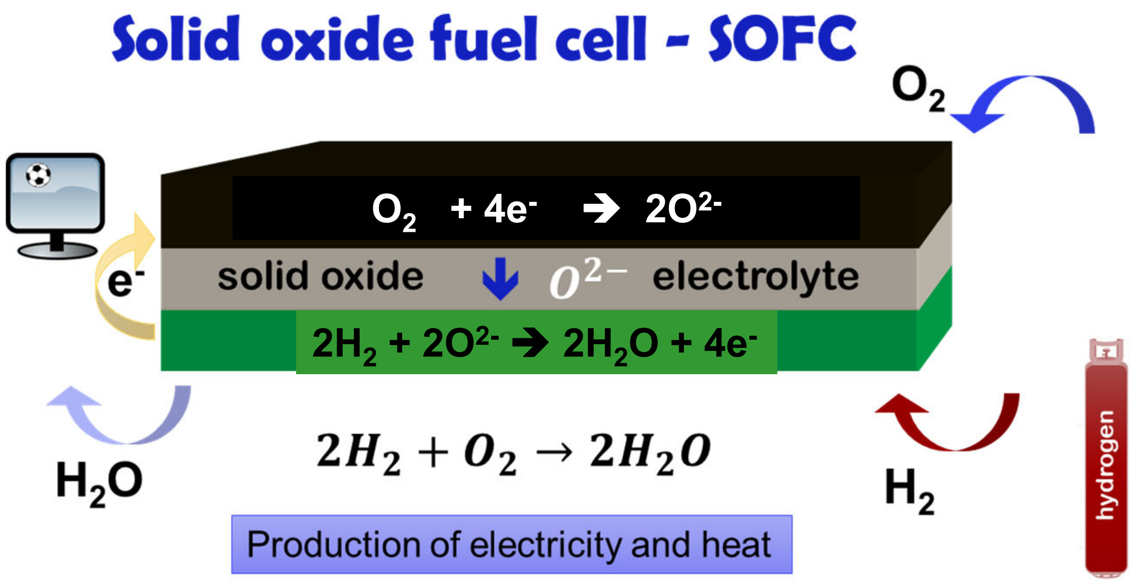
Fuel cells

- PEMFC



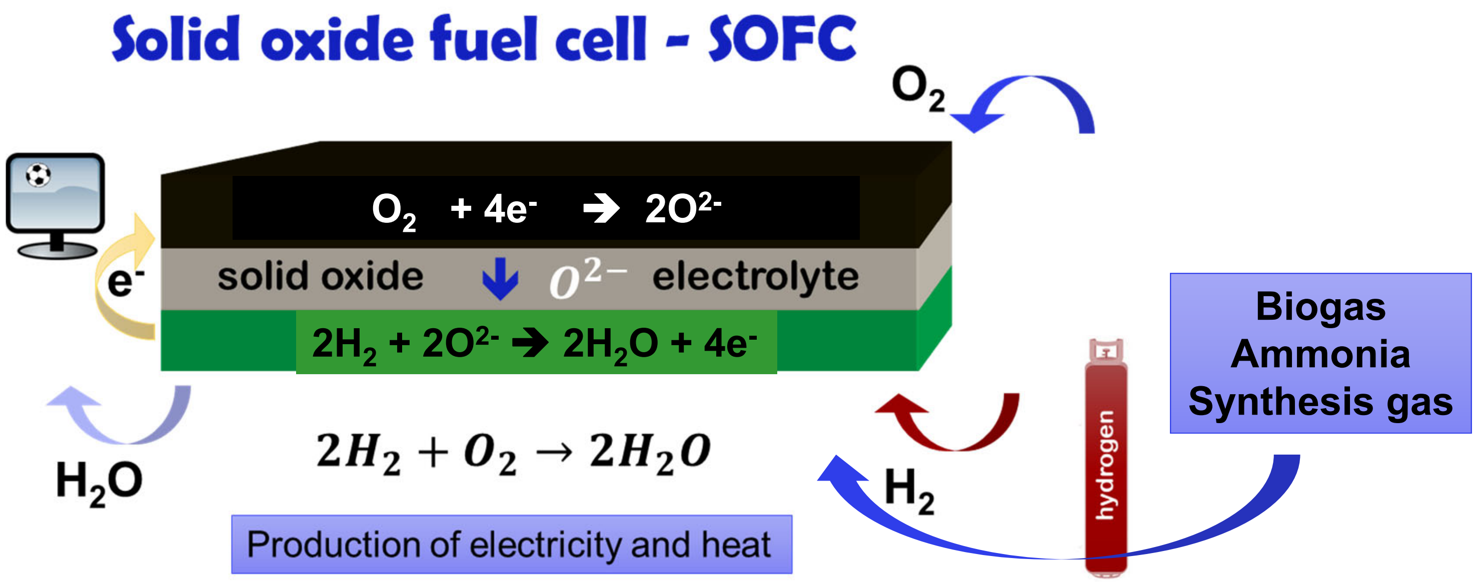
Fuel cells

- SOFC



Fuel cells

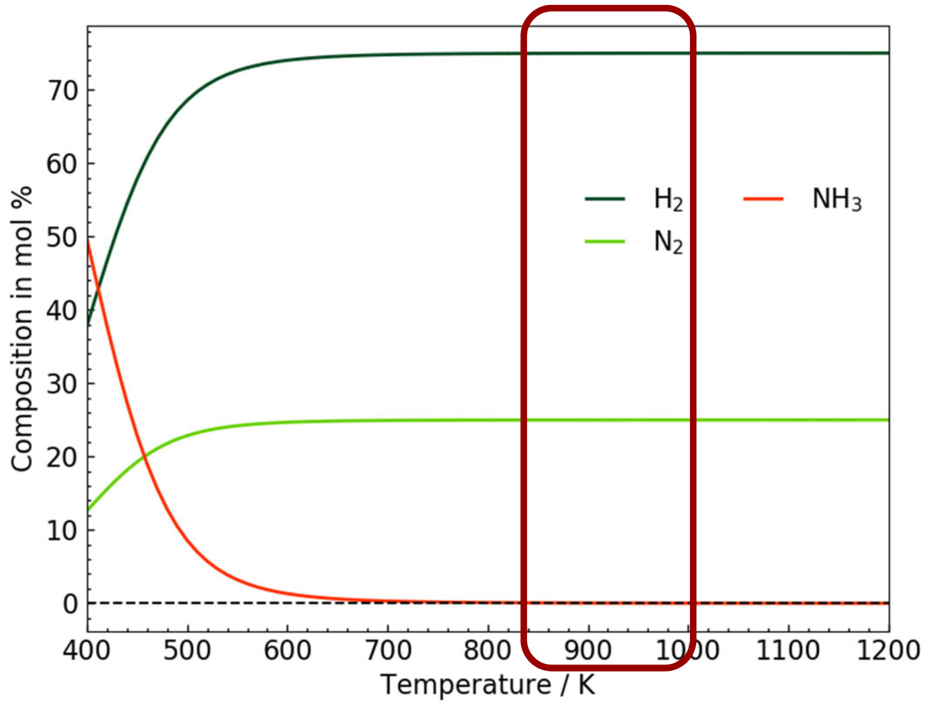
- SOFC



Fuel cells

- Thermodynamics

- Ammonia decomposition at relevant temperatures for SOFC
- SOFC anode contains an ammonia cracking catalyst (Ni)

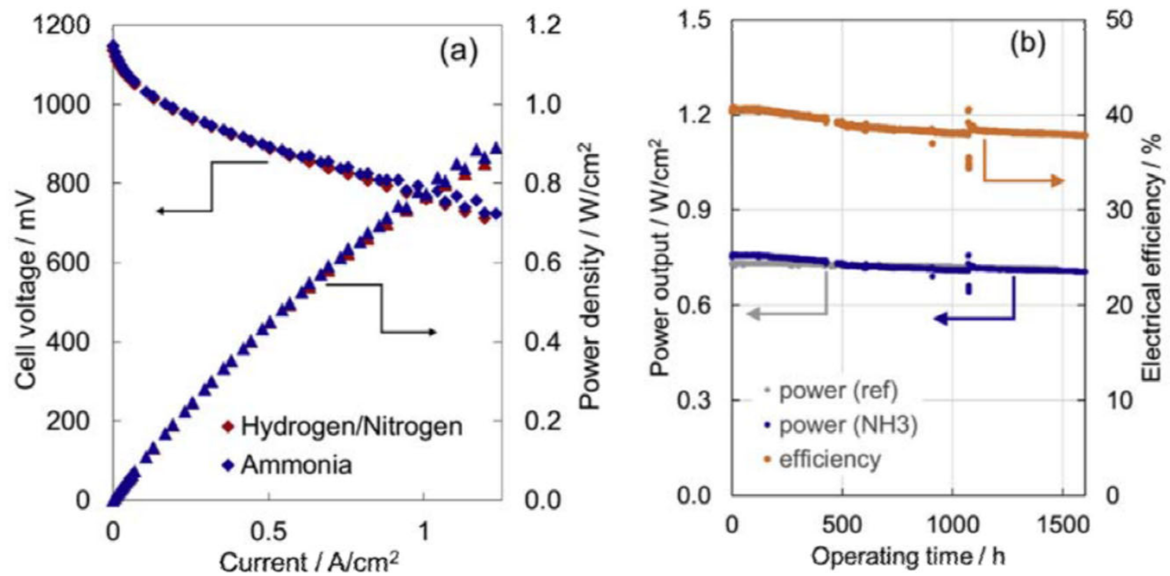


Fuel cells

- SOFC performance % durability

- Same SOFC performance using ammonia or N_2/H_2 mixture as fuel
- Same durability as reference test

New SOFC have been developed since



A. Hagen, H. Langnickel, X. Sun, Operation of Solid Oxide Fuel Cells with Alternative Hydrogen Carriers, Int. J. Hydrogen Energy, 44 (2019) 18382-18392.

Aegir concept

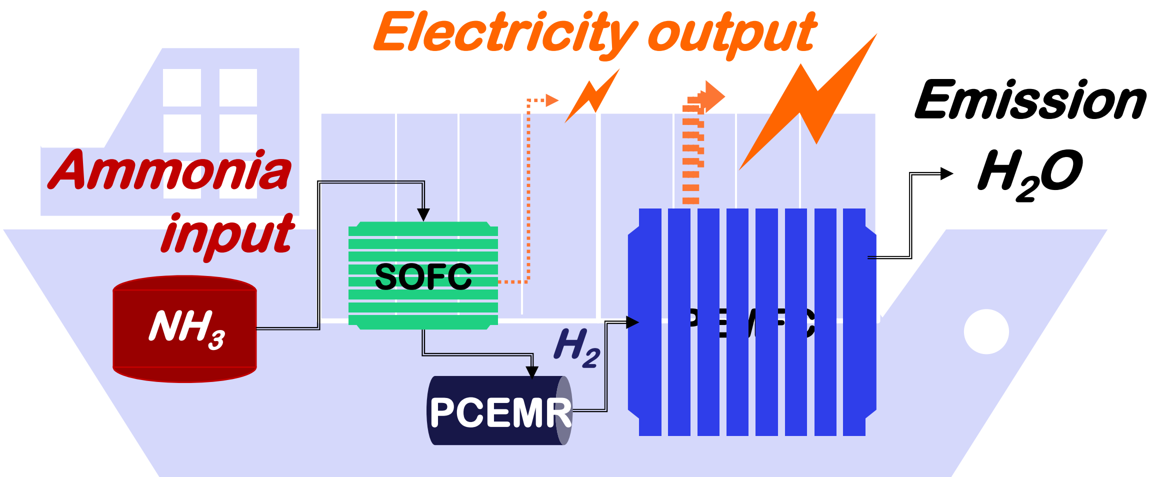
- Idea: Ammonia as fuel using fuel cells
  - Considering matureness and scale of fuel cell technology

Aegir concept

- Idea: Ammonia as fuel using fuel cells
  - Considering matureness and scale of fuel cells
    1. Ammonia cracking and part power production using a SOFC
    2. H_2 extraction and purification using a proton conducting electrochemical ceramic membrane
    3. Electricity production using a PEMFC
  - By combining these three technologies AEGIR aims at developing an ammonia-fuelled ship propulsion system that offers high efficiency in combination with a low total system volume and weight. In addition, the AEGIR concept avoids emissions of NO_x and allows for a drastic reduction of CO_2 emissions; the product of the fuel cell electricity process is water.

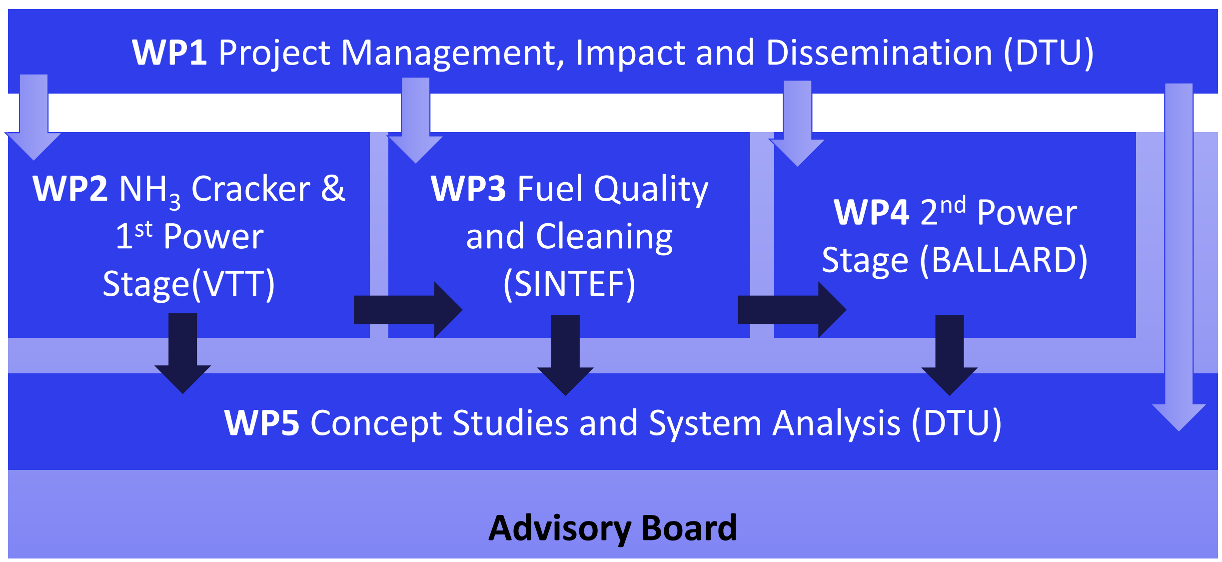
Aegir concept

- Idea: Ammonia as fuel using fuel cells



Aegir concept

- Project organisation



Aegir concept

- Consortium

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