HySeas III:
Prospects for the use of hydrogen and fuel cells on RoPax ferries
9. Zukunftskonferenz der maritimen Wirtschaft MV

Juan Camilo Gomez
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Agenda

1. About the German Aerospace Center (DLR)
2. Motivation
3. Alternative energy supply for ships
4. HySeas III:
    - 4.1. Full Size Testing in Norway
    - 4.2. Environmental and Economic Assessment and Multi-Criteria Decision Analysis
5. Conclusions

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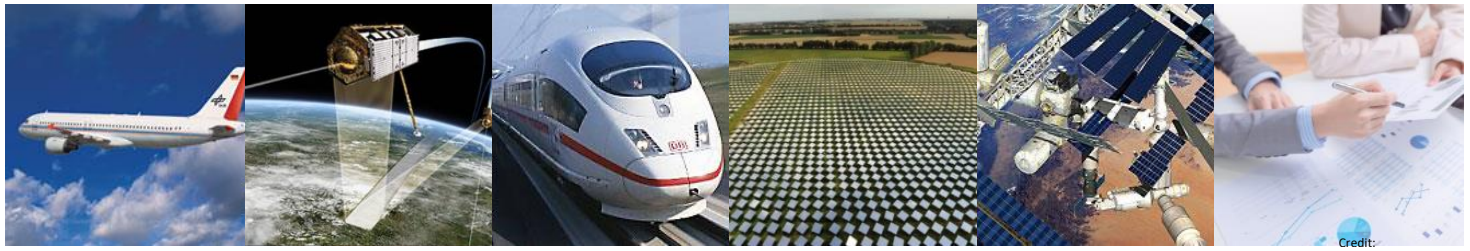
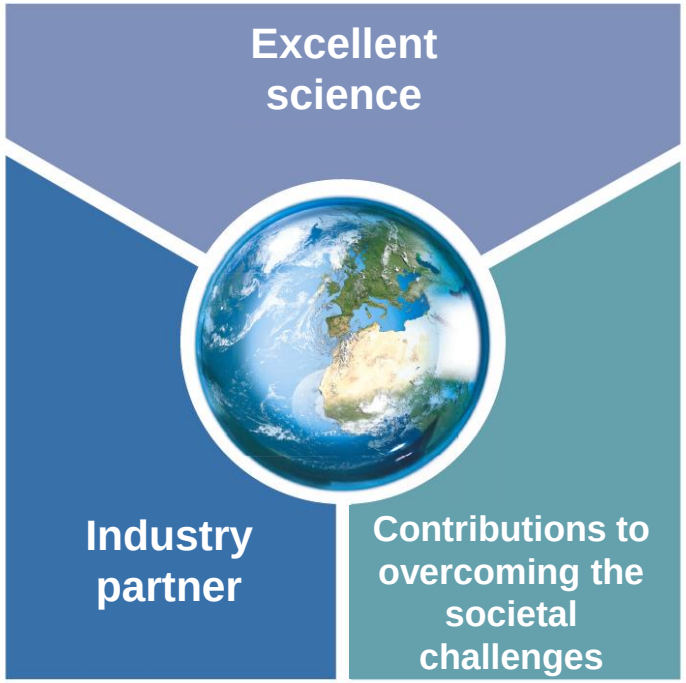
German Aerospace Center (DLR)

DLR Institute of Networked Energy Systems, Oldenburg
Department: Energy Systems Analysis



- Research institution, space agency project management agency
- Aeronautics, space, energy, transport, digitisation and security
- More than 9,000 staff in 54 institutes and facilities in 30 locations; offices in Brussels, Paris Tokyo and Washington
- Member of the Helmholtz Association



Multidimensional and prospective assessment

- Multidimensional approaches that integrate economic, ecological, technical and social aspects
- Prospective assessments of technologies as a basis for system modelling

Energy Scenarios and Technology Assessment

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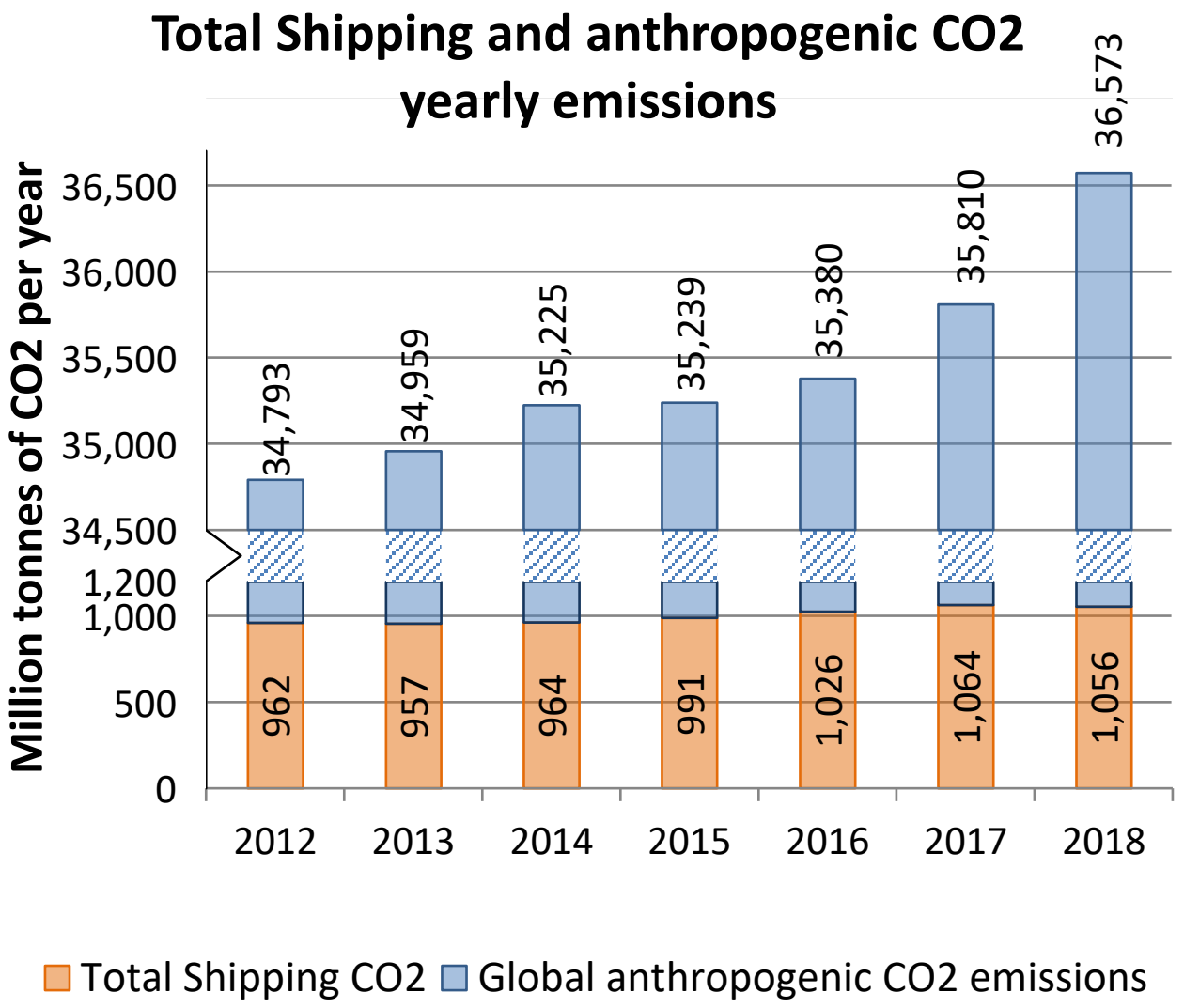
HySeasIII

Motivation

- Total Shipping contribution to GWP: 2.89% of total anthropogenic yearly CO_2 emissions (2018)
- IMO MEPC 72: Long-term measures: *„pursue the development and provision of zero-carbon or fossil-free fuels“*
- ...but first, this has to be implemented in a small scale
- RoPax ferries have regular routes and some sizes are interesting for the implemention of new solutions



FABER, Jasper; ZHANG, S. H. Shuang; PEREDA Paula; COMER, Bryan; HAUERHOF, Elena; VAN SCHIM, Wendela, et al. (2020). Fourth IMO GHG Study 2020.

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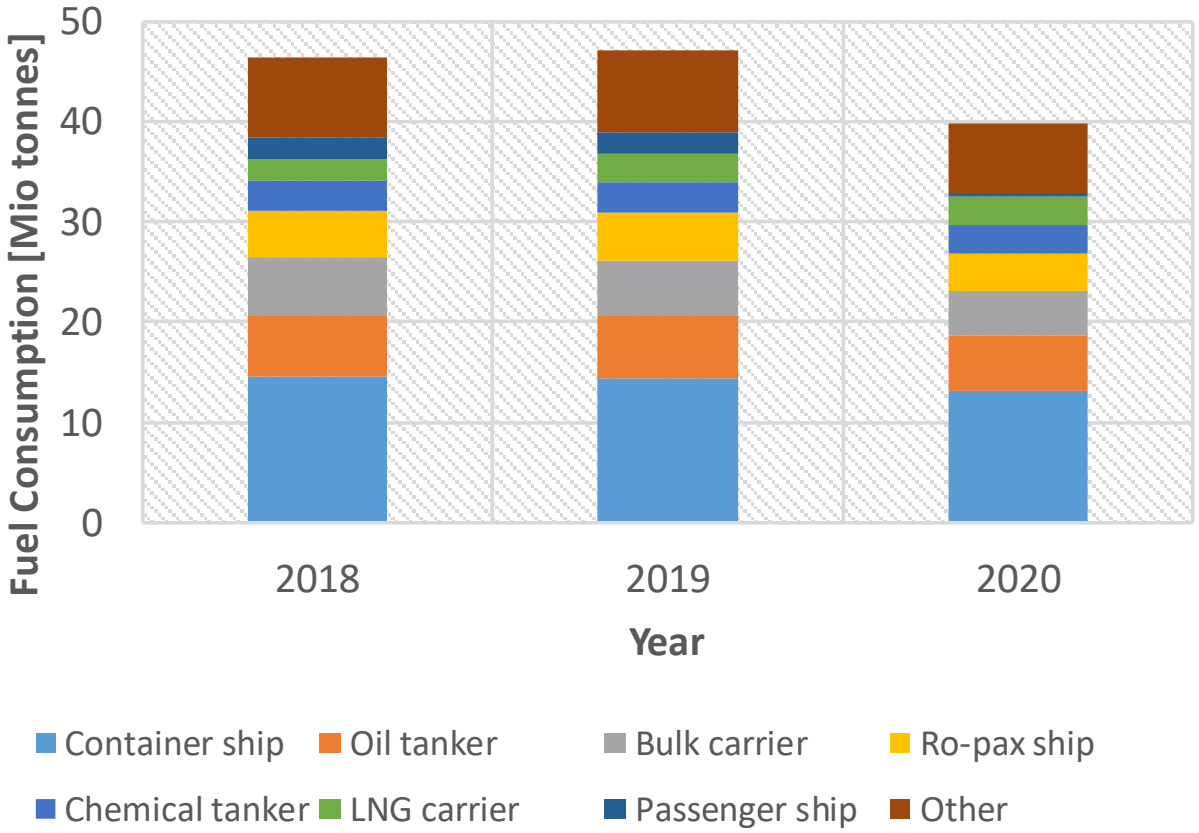
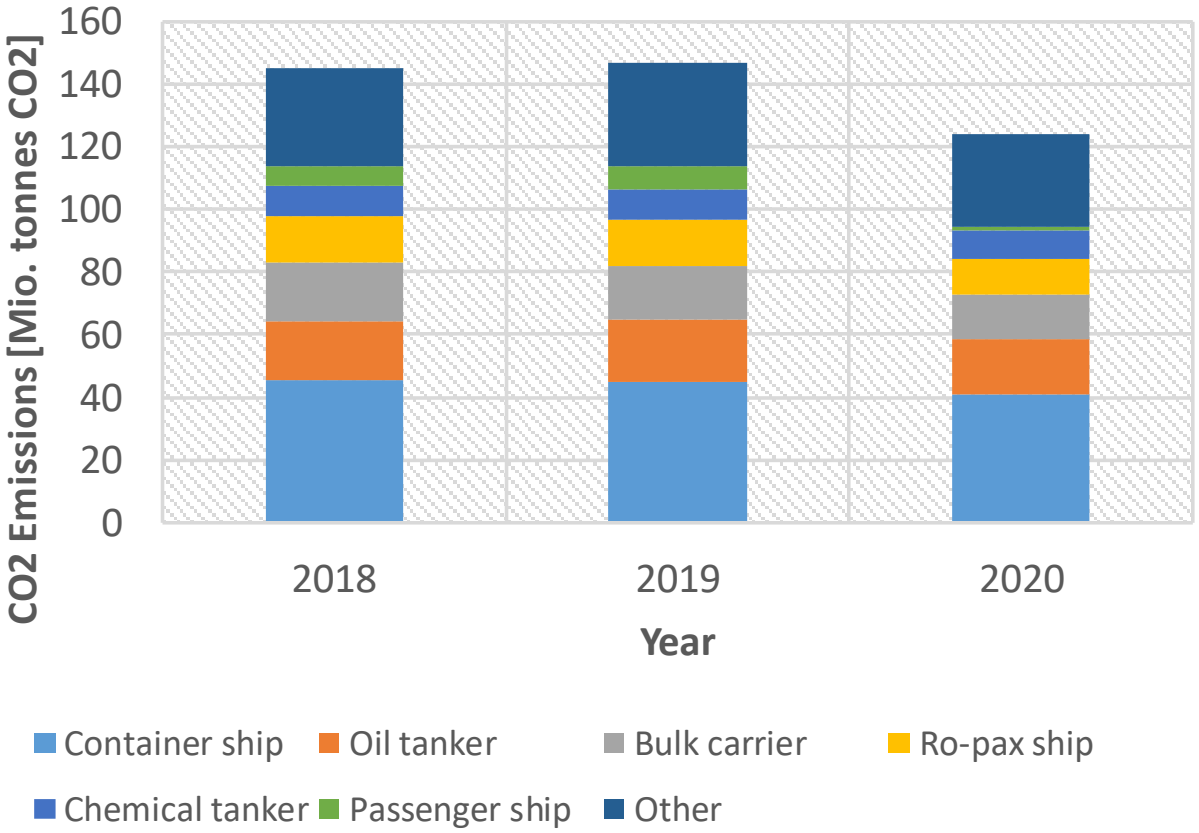
Motivation

Fuel Consumption Shipping (EU)



CO_2 Emissions Shipping (EU)



*Only ships of over 5000GT are obliged to report in accordance with Article 19 of Regulation (EU) 2015/757
Data: CO2 Emission Report. EMSA/THETIS. File versions: 2018: 258/2019: 189/ 2020:42. Available at: https://mrv.emsa.europa.eu/#public/emission-report

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Motivation

- Although the long-term seems to be far away, ships are relatively long-lived (RoPax ferries more than 30 years).
- The future starts now if we want to reduce green house gases by 2050!

Age of Current RoPax Ferry Fleet

Gomez J.C., Vogt, T., Brand, U., Wilken, D., Remler, M. (2019). Market Potential Analysis of RoPax Ferry Market in Europe. Deliverable 6.1 Project HySeas III
Based on data of IHS Markit SeaWeb.

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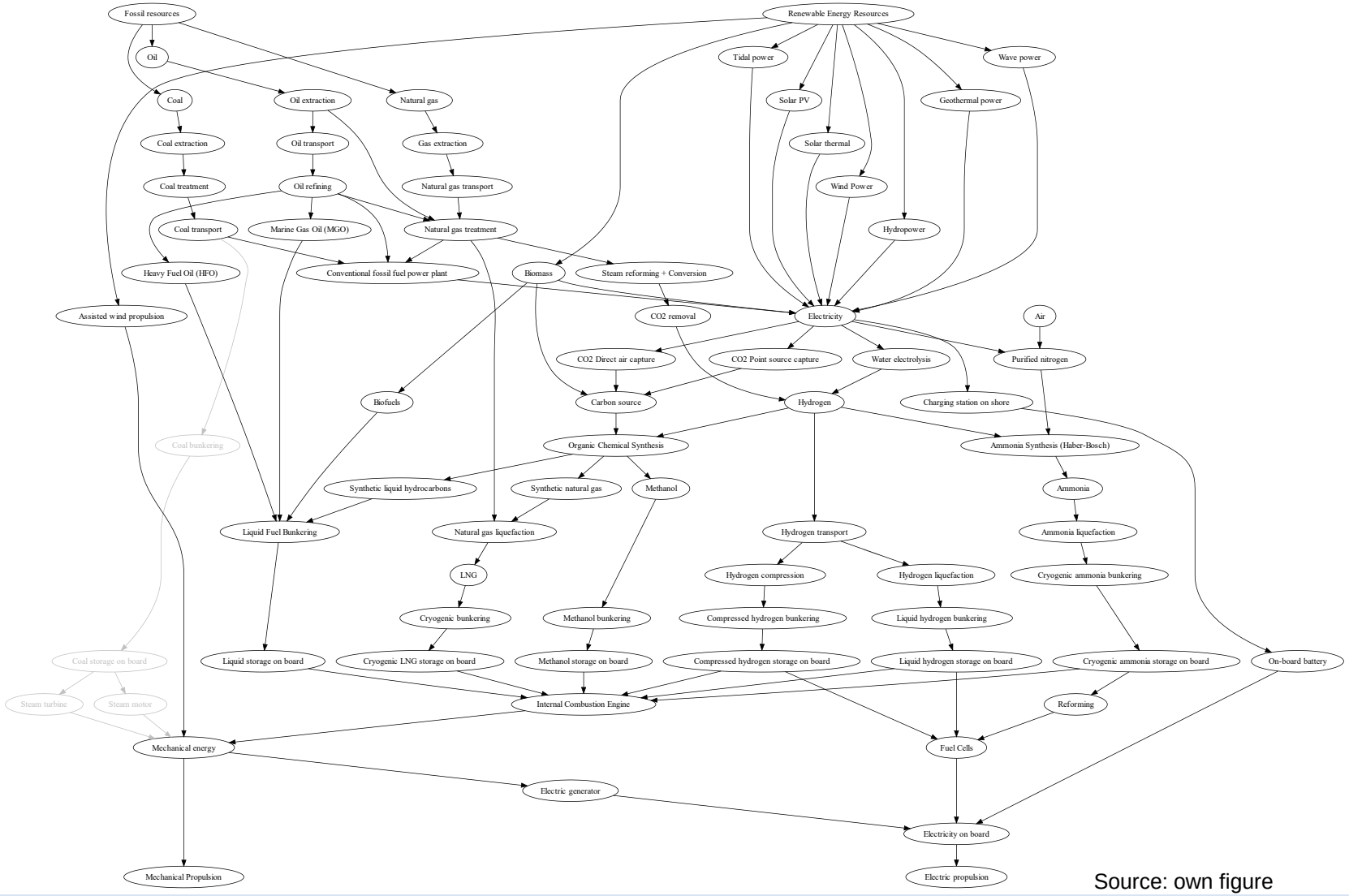
Alternative Energy Supply for Ships

- The energy supply for ships is mainly based on oil and natural gas
- Possible alternative energy supply routes: Direct electrification, hydrogen (compressed and liquid), biofuels, synthetic liquid hydrocarbons, synthetic natural gas, methanol, ammonia, wind assisted propulsion



Source: own figure

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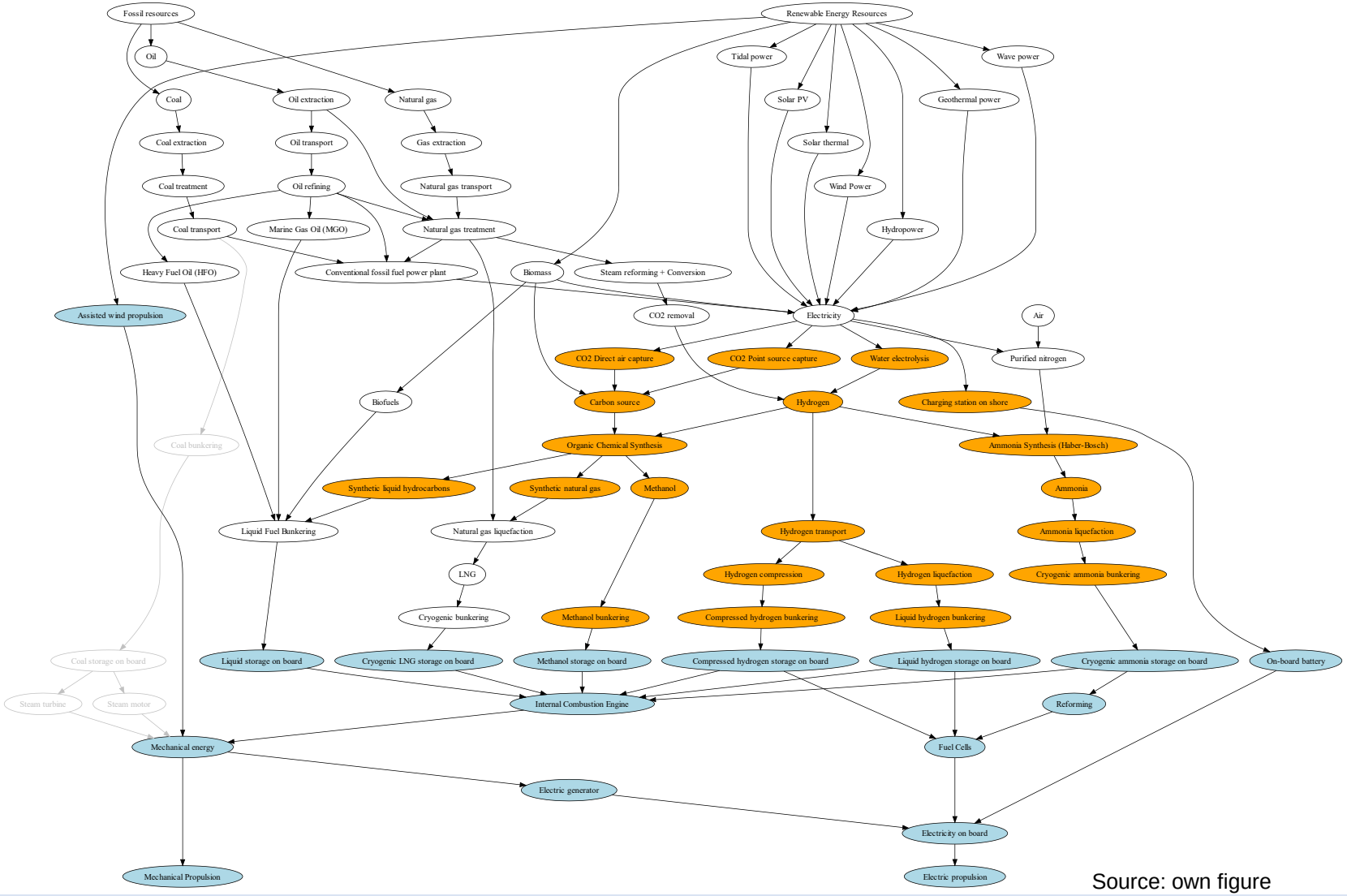
Alternative Energy Supply for Ships

Blue: energy conversion and storage on the ship

Orange: Energy supply chain

- <u>Consensus:</u> although there are several alternatives, the development of both power conversion and energy storage on board and energy supply on shore are necessary
- Hydrogen will be needed for several energy supply routes



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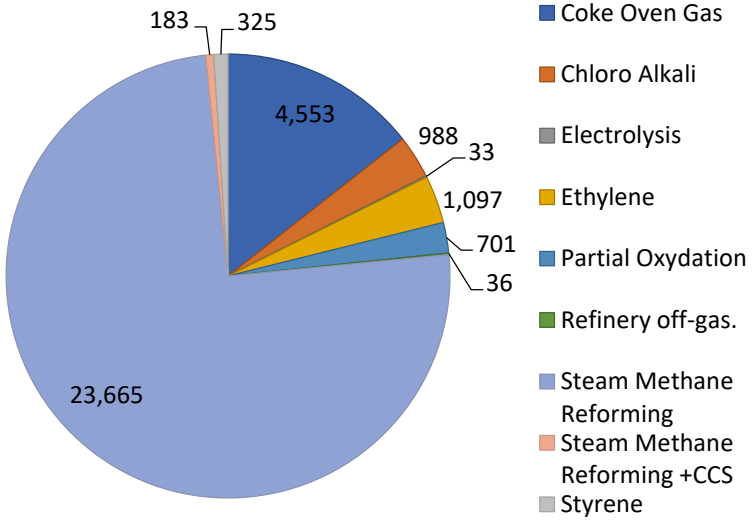
Hydrogen Supply: Availability in Europe

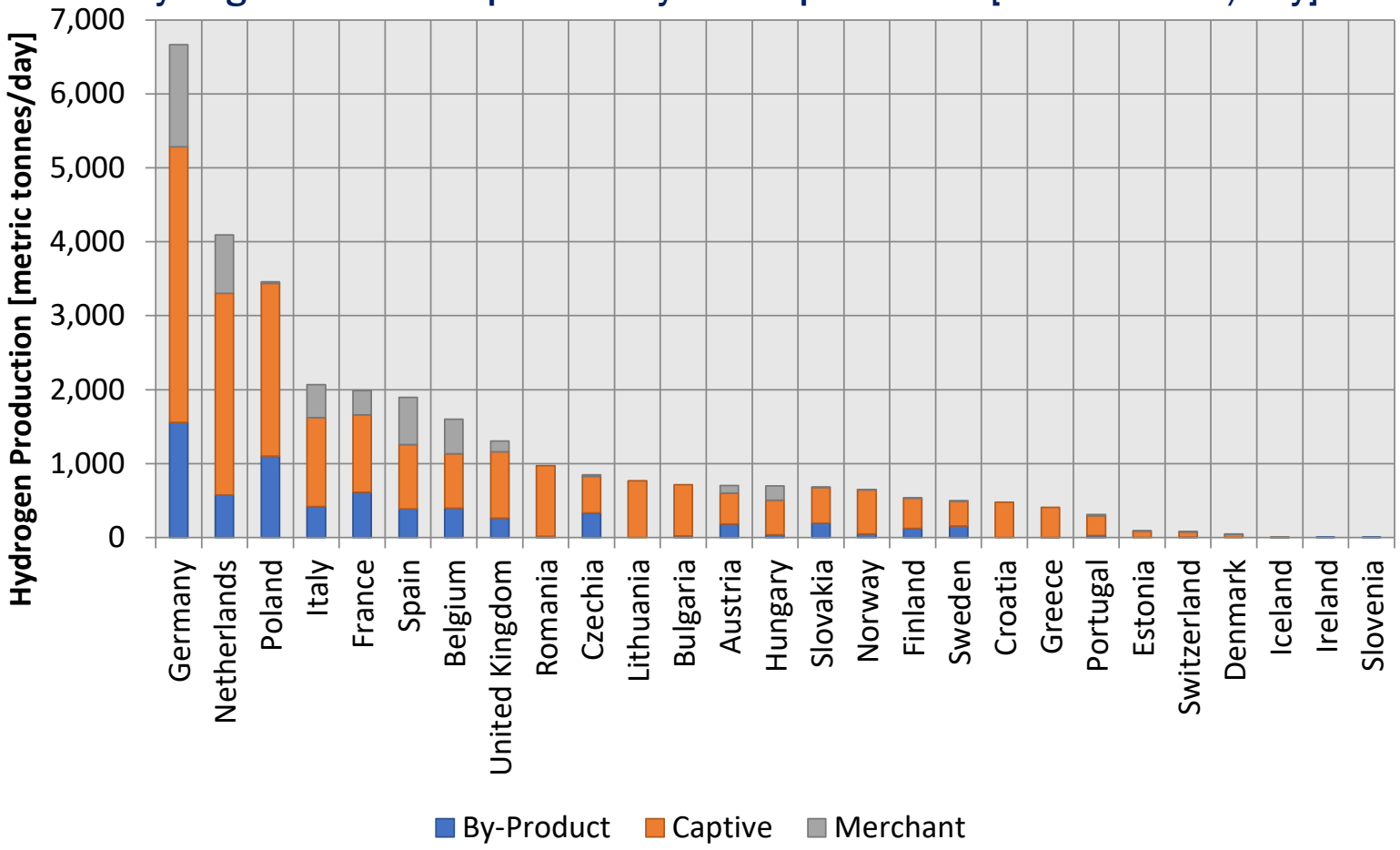
- Merchant: sold as product
- Captive: internal use
- By-product: recovered
- Global H_2 demand: 70 MMT+40MMT mixed*

*MMT: Million metric tonnes

Source of H_2 in Europe in 2018 [metric tonnes/day]



Hydrogen Production per country in Europe in 2018 [metric tonnes/day]



Source: Fuel Cells & Hydrogen Observatory; Available at: https://www.fchobservatory.eu/sites/default/files/reports/Chapter_2_Hydrogen_Molecule_Market_070920.pdf

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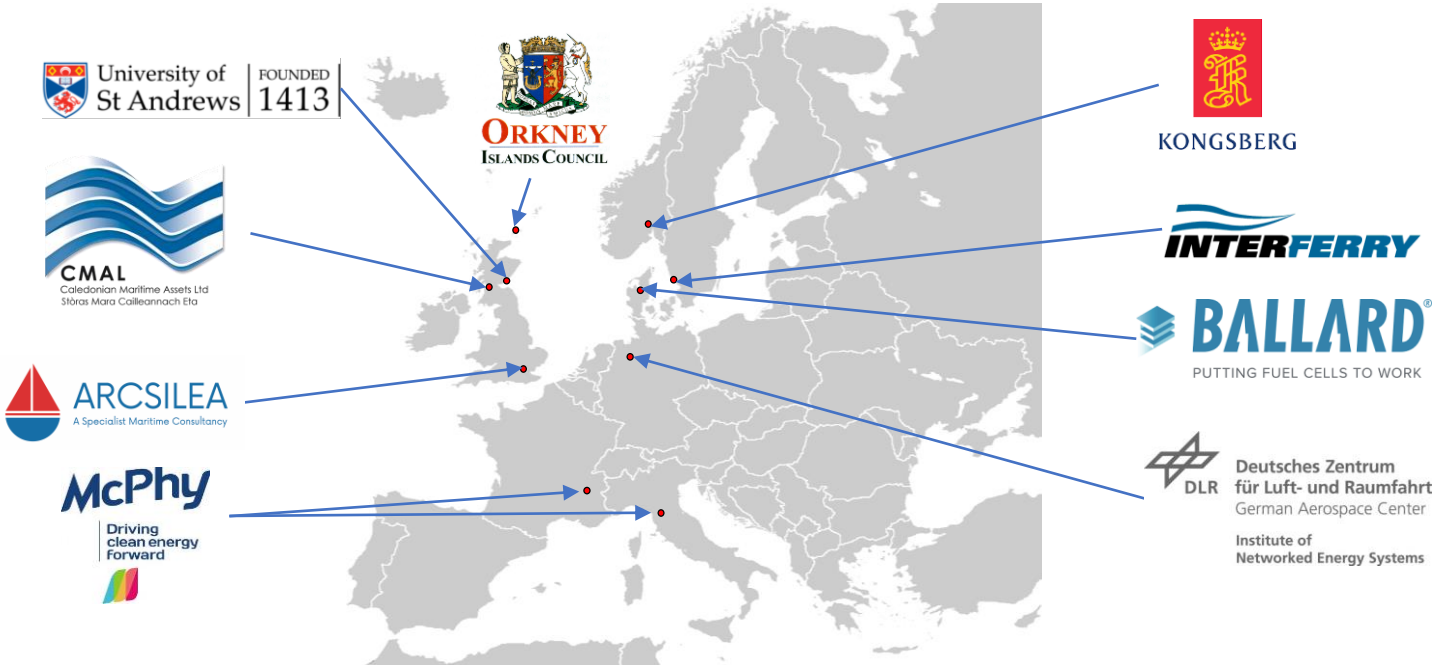
HySeas III Project

- Combine fuel cells with batteries to test with typical loads of a Roll-on/Roll-off passenger ferry (RoPax), which would operate in the 7 km route Kirkwall/Shapinsay (Scotland)
- Constructing and testing a powertrain on land with 600kW fuel cell power and 720 kWh Li-ion battery packs
- DLR contributes to the project with market and job-creation potential analyses as well as with environmental and economic assessments of the future implementation of this alternative propulsion system



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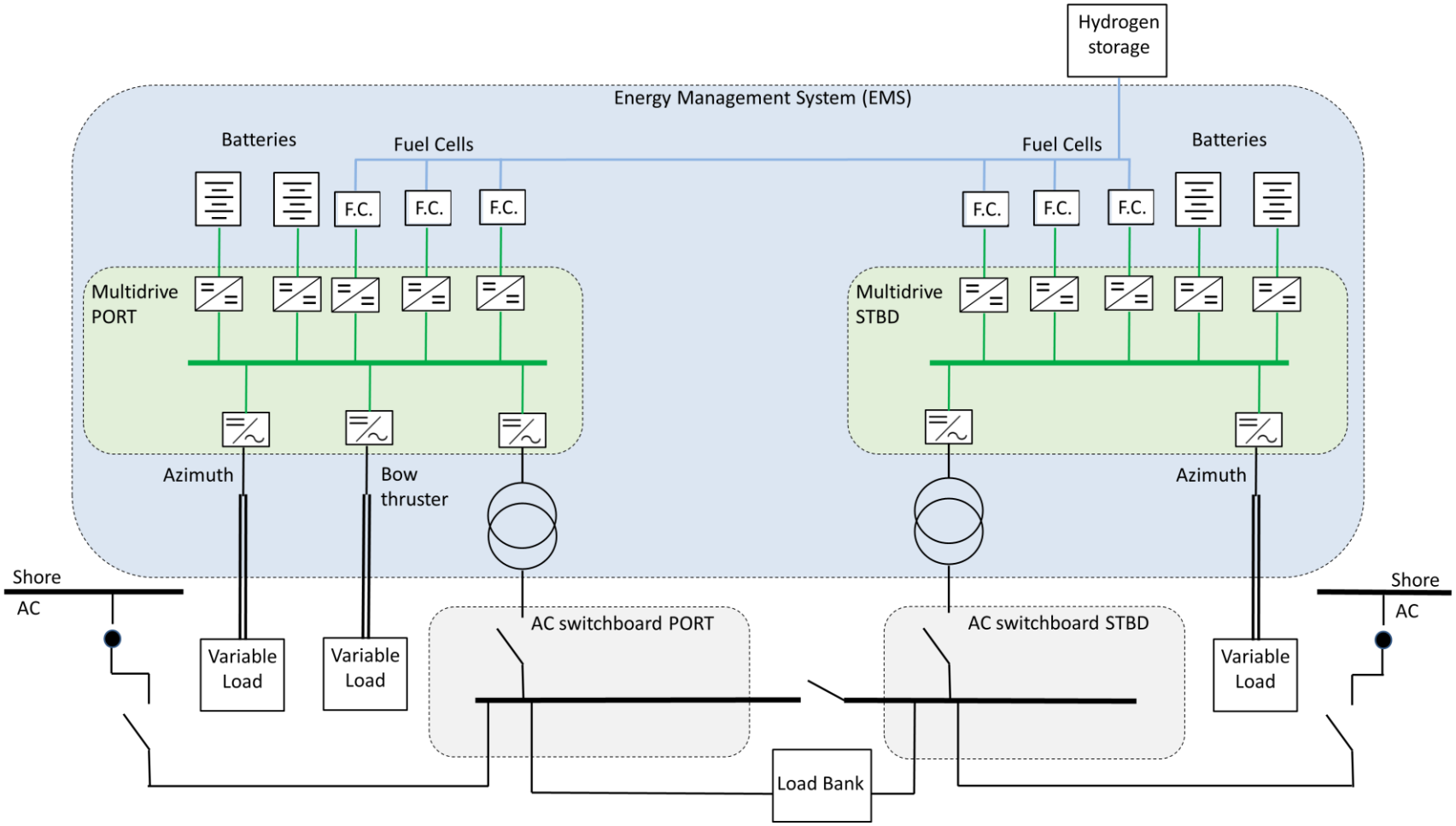
HySeas III: Full Size Testing in Norway

Full-size tests in Norway

In practice:

https://www.youtube.com/watch?v=O8KTwnhIB4Y



Source: Kongsberg

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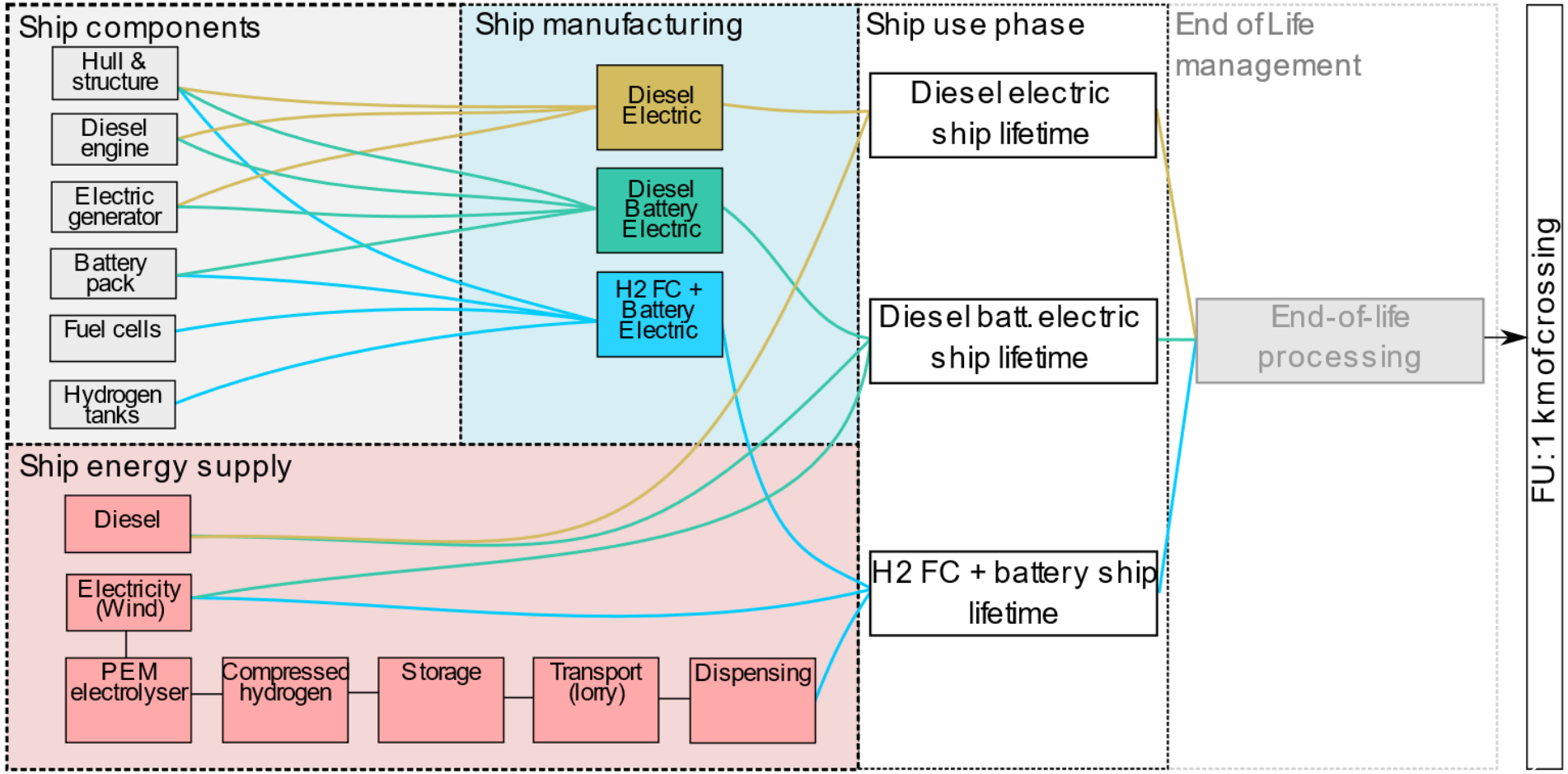
HySeas III: Environmental and Economic Assessment



Modified from TRILLOS, Juan Camilo Gomez et al. Life cycle assessment of a hydrogen and fuel cell ropax ferry prototype. In: Progress in Life Cycle Assessment 2019. Springer, Cham, 2021. S. 5-23.

Hydrogen Fuel Cell and Battery Electric RoPax Ferry

- 600 kWh Fuel Cells
- 600 kg H_2 on-board storage
- 720 kWh Li-ion batteries
- H_2 produced with wind power
- Charging electricity from grid

Diesel Battery Electric RoPax Ferry

- 600 kW Diesel Engines
- 720 kWh Li-ion batteries
- Electric generator
- Charging electricity from grid

Diesel Electric RoPax Ferry

- 600 kW Diesel Engine
- Electric generator

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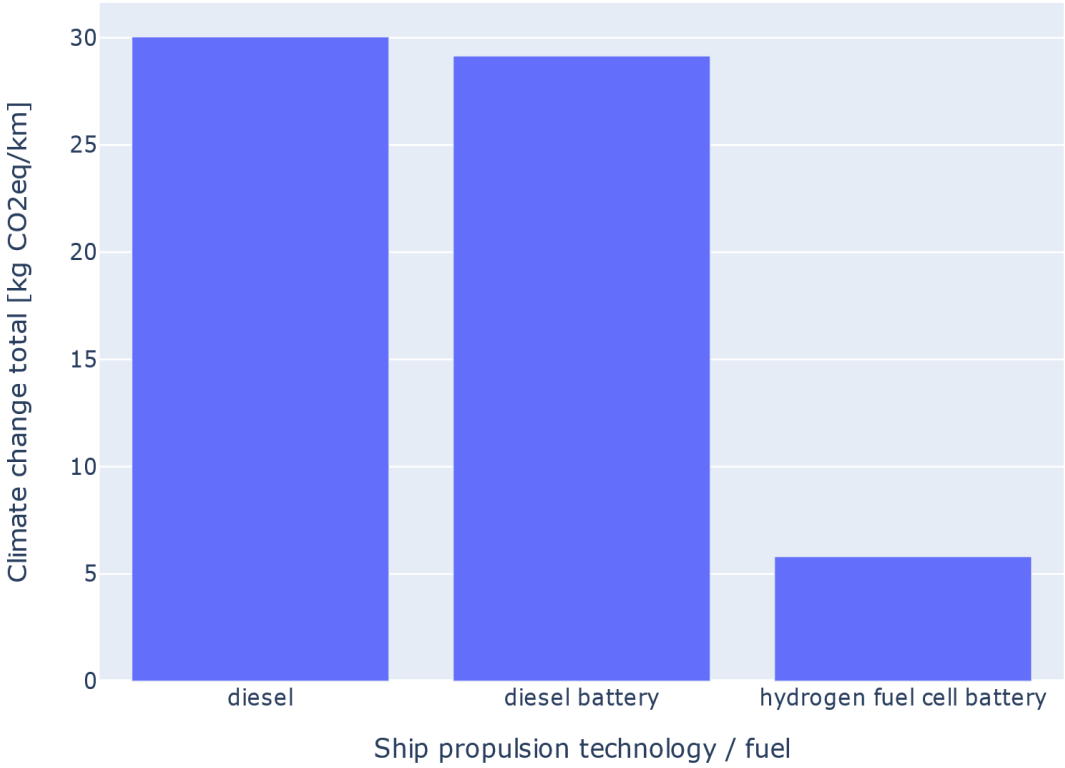
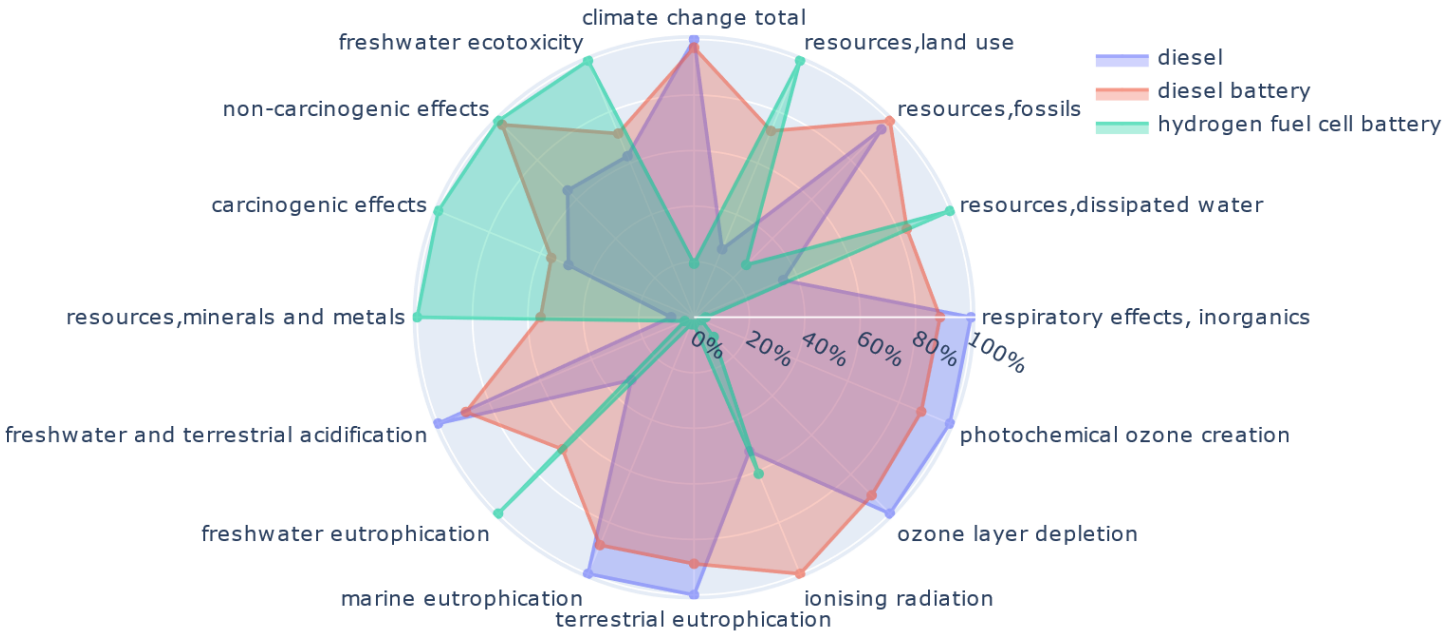
HySeas III: Results of Life Cycle Assessment

Climate Change per km



Source: own plot

Comparison of Impacts Normalized to the highest result



Source: own plot

Using hydrogen derived from wind power electricity, fuel cells and batteries allows life cycle CO_2eq reductions of up to 80% compared to to the base diesel electric case

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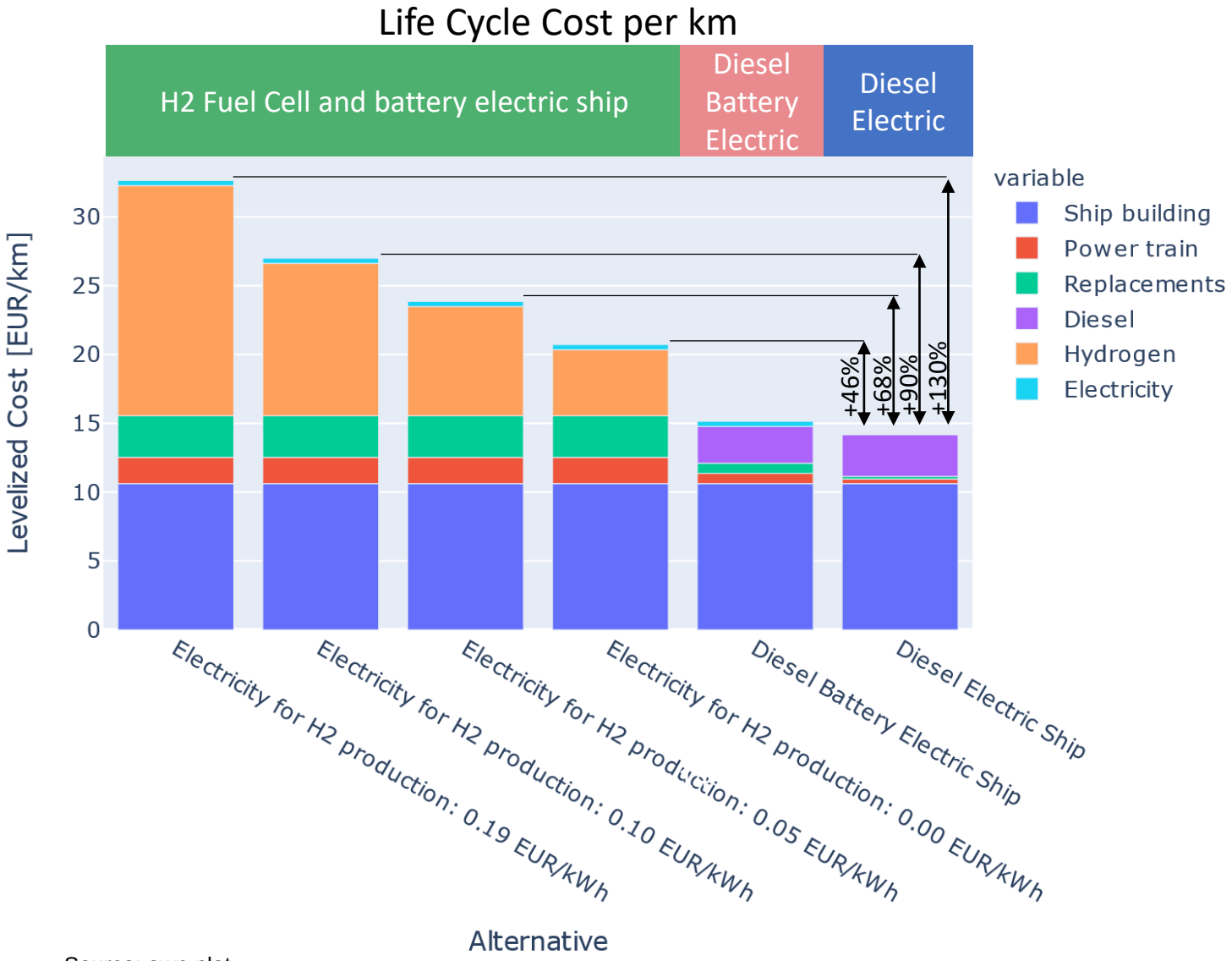
HySeas III: Results of Life Cycle Costing

Power train and replacements of batteries and fuel cells are considerably higher than the ones of the traditional alternatives employing only internal combustion engines

Hydrogen production cost depends heavily on the electricity price

Considering an electricity price for hydrogen production of 10 Euro cent/kWh, the levelized cost per km are almost 90% higher compared to the diesel electric alternative



Source: own plot

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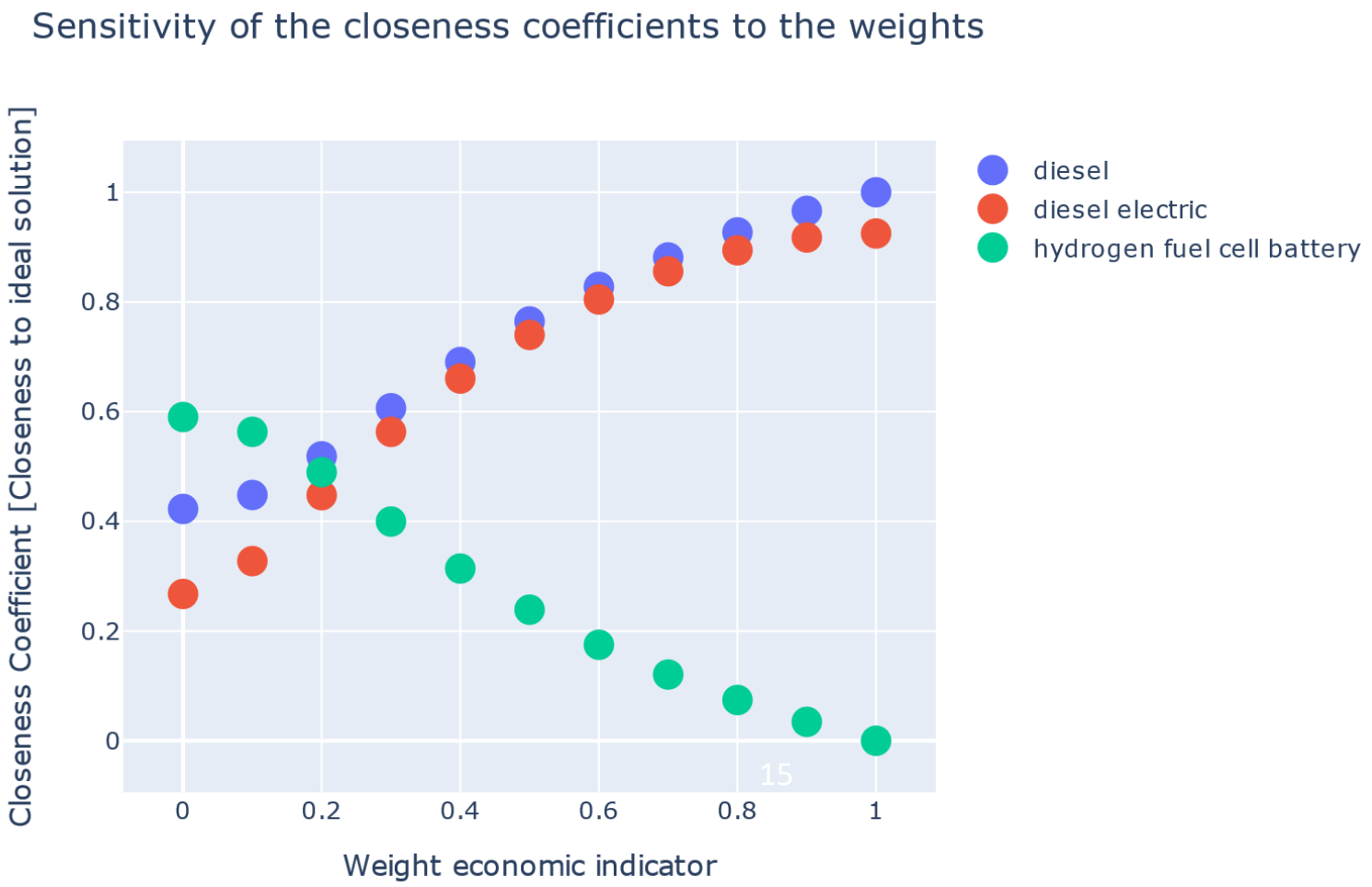
Results of Multi-Criteria Decision Analysis

Closeness coefficient in TOPSIS measures how close one alternative is to the „ideal“ solution (the closer, the better)

The hydrogen fuel cell and battery alternative is closer to the ideal solution when the weight of the economical dimension is reduced to less than 0.2

The results depend heavily on the weights we assign to the indicators



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Conclusions

For defossilisation, the innovation must happen in several fronts:

- Energy collection and conversion from renewable energies (i.e. solar PV, wind power) or direct conversion on ships (wind-assissted propulsion)
- Energy supply to ships (electricity, compressed hydrogen, ammonia, synthetic fuels, among others)
- Energy storage on ships (i.e. compressed hydrogen, liquid hydrogen, LOHC, liquid ammonia, Synthetic LNG or electricity in batteries)
- Energy conversion on the ships (internal combustion engines for other fuels, fuel cells)

For a future use of hydrogen for shipping:

- A supply chain of hydrogen produced using renewable energies is necessary
- Most of today‘s hydrogen production is captive, meaning that is produced and consumed in the same place
- Bunkering of hydrogen (both compressed and liquid) are still to be proven and needs upscaling

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HySeasIII

Conclusions

HySeas III develops a hydrogen and fuel cell propulsion system for a RoPax ferry. From our analysis, we have seen:

- Lower lifetime environmental impacts from the use of hydrogen, fuel cells and battery have been seen in comparison with diesel and diesel hybrid RoPax alternatives
- However, other impacts, mainly related with the sourcing and production of the materials necessary for the production of batteries and fuel cells increase when compared with the diesel and diesel hybrid options
- The levelized cost per km of crossing is highly dependent on the price of the electricity used for hydrogen production. At a reference cost of 10 EUR cents, the estimated costs (excluding personal costs) are estimated to be 90% higher than those of an diesel ship.
- Using the TOPSIS multi-criteria decision analysis method, the hydrogen fuel cell and battery alternative is only selected when the environmental impact are given an 80% weight, with the aim of minimising those impacts.

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HySeasIII

Outlook

- The string test and the ship design excercise done under HySeas III will reduce the uncertainty for the future development of hydrogen and fuel cell on ships

- The data produced by the tests and the design will be integrated into the current analysis to come to more accurate results.

- Social analysis, such as the job-creation potential, are yet to be integrated into the analysis to have a holistic view

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Thank you for your time!

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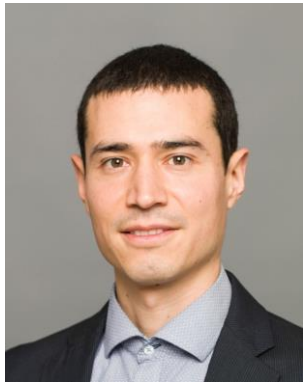

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Fuel Cells & Hydrogen Observatory; Available at: https://www.fchobservatory.eu/sites/default/files/reports/Chapter_2_Hydrogen_Molecule_Market_070920.pdf

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https://www.iea.org/reports/hydrogen

https://h2tools.org/hyarc/hydrogen-production

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HySeasIII

Backup slides

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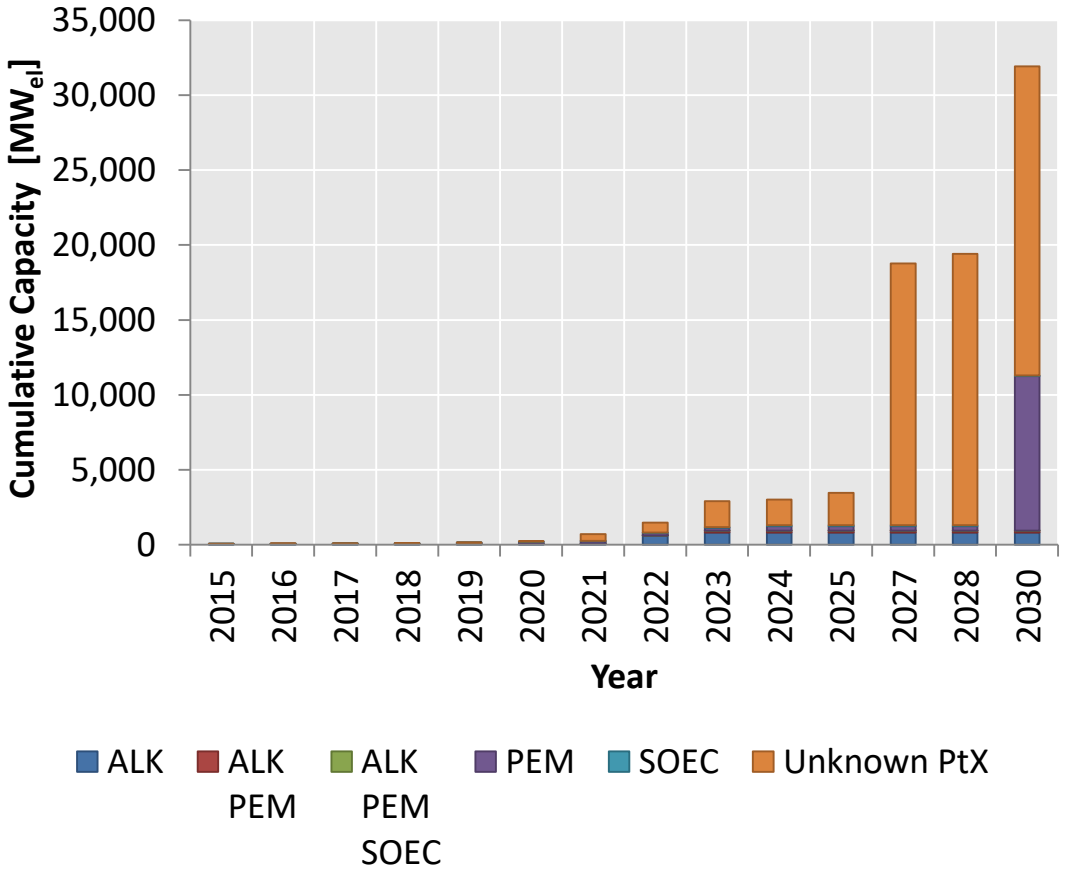
Hydrogen Supply: Electrolysis Additions and Cost

H_2 Electrolysis Expected Cumulative Capacity in Europe [Mw_{el}]



Source of data: https://www.iea.org/reports/hydrogen

Prospects for Electrolysis CAPEX reduction: experience rates of electrolysis: 18±6%

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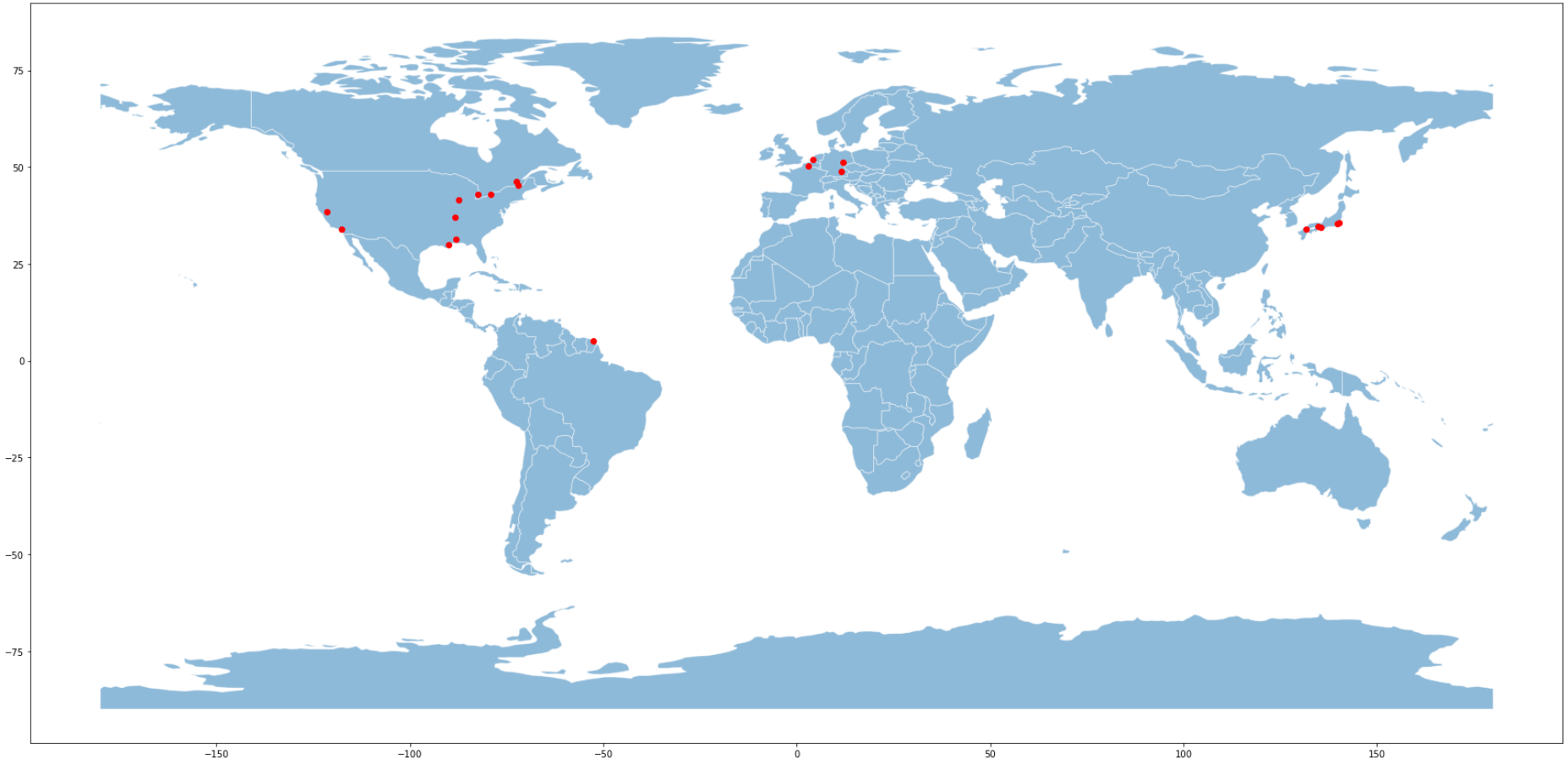
Hydrogen Supply: Liquid Hydrogen

It also depends on the physical state of hydrogen…

Country	Output kg/day
USA	209,167
Canada	51,461
Japan	35,607
France	10,500
Germany	10,100
Netherlands	5,400
Guiana	2,500
Australia	250

*Port of Hastings: https://hydrogenenergysupplychain.com/port-of-hastings/



Own plot/Data source: https://h2tools.org/hyarc/hydrogen-production

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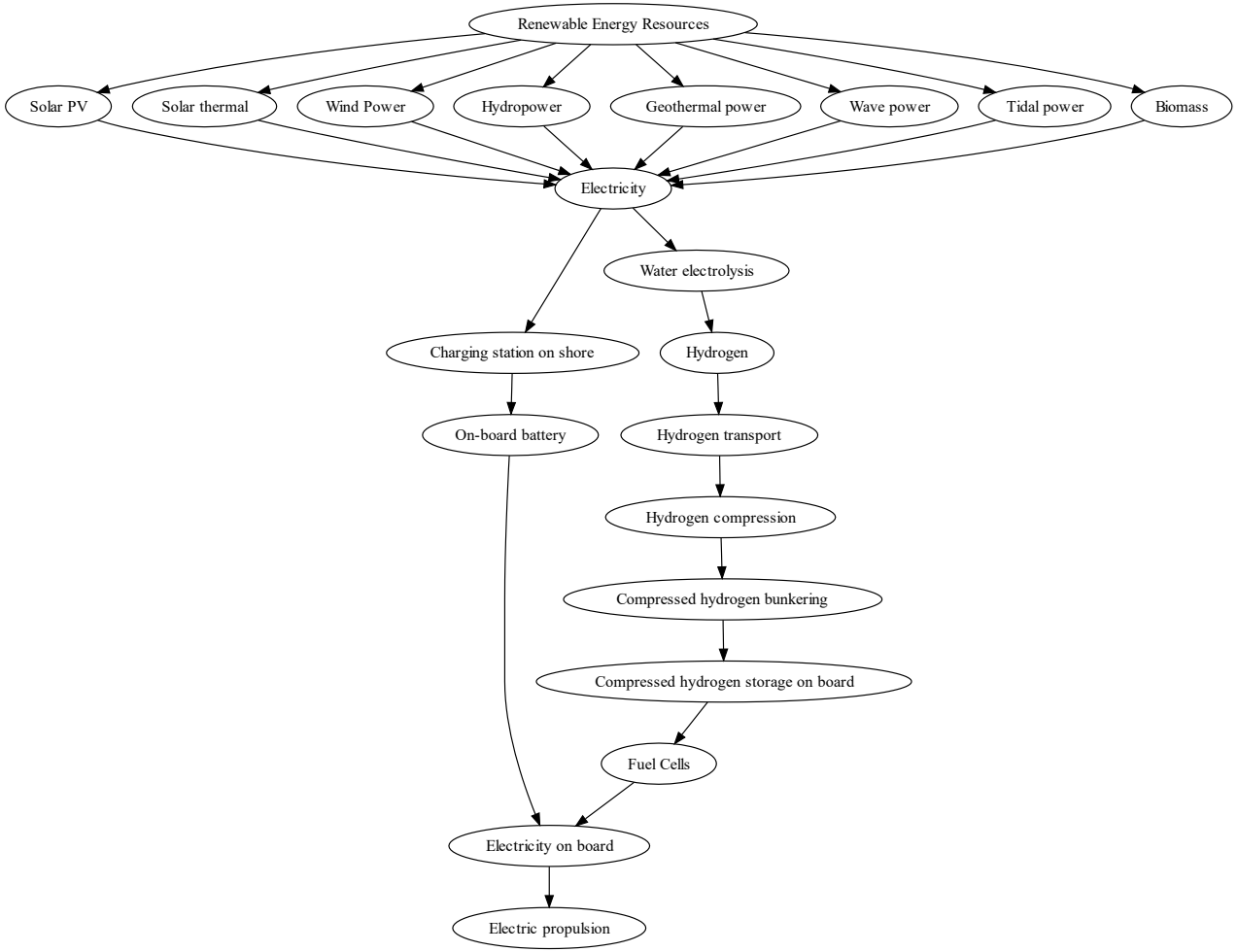
HySeasIII

Alternative Energy Supply HySeas III

- Direct energy supply with electricity to load the batteries and using hydrogen as energy carrier
- Fuel cells are the main energy conversion element in the propulsion system



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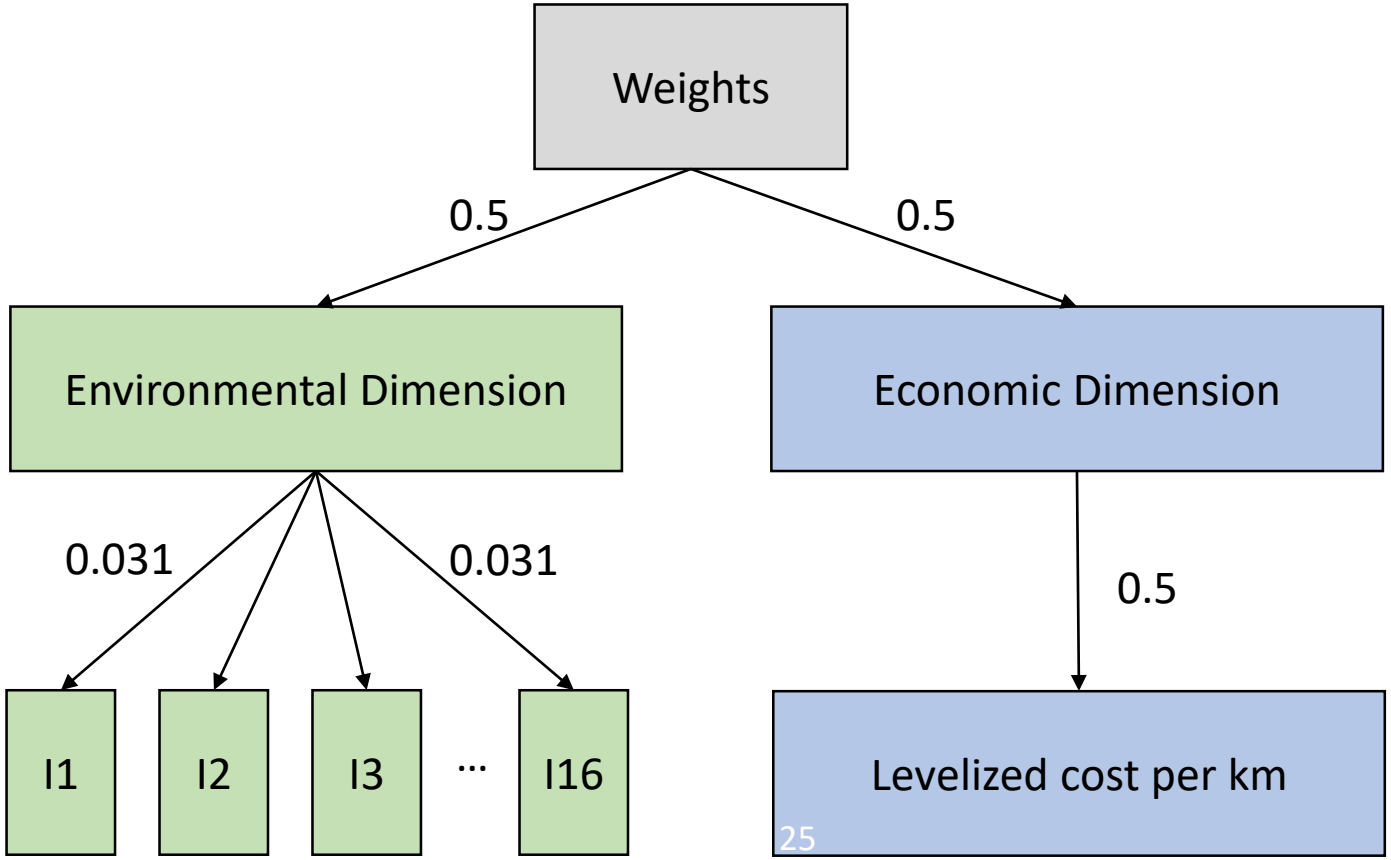
Results of Multi-Criteria Decision Analysis

TOPSIS steps

1. Normalization
2. Weighting
3. Ideal and anti-ideal solution
4. Calculate the distance for each alternative to the ideal action and anti-ideal action
5. Calculate the relative closeness coefficient of each alternative#



Source: own plot

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