HYDROGEN SHIP

Technical book for the Youth@STEM4SF project

HYDROWAVE

Group name:

HydroWave

Author:

Maks Zagode, Anton Mlinar

Group members:

Maks Zagode, Anton Mlinar,

Eva Zvonareva, Irena Tišler, Nace Kenda

Mentor: Adela Žigert

BIC LJUBLJANA

Gimnazija in veterinarska šola

Cesta v Mestni log 47

1000 Ljubljana

Ljubljana, Avgust 2024

Introduction

In this technical book, we will present our project entitled Hydrogen Ship. In the following chapters we will go through the ship's operating system, a description of the ship's individual components and theoretical calculations regarding the ship's consumption and endurance. The type of ship we have chosen is a cargo ship, as we believe that the transformation of cargo ships to hydrogen fuel would contribute significantly to a cleaner environment.

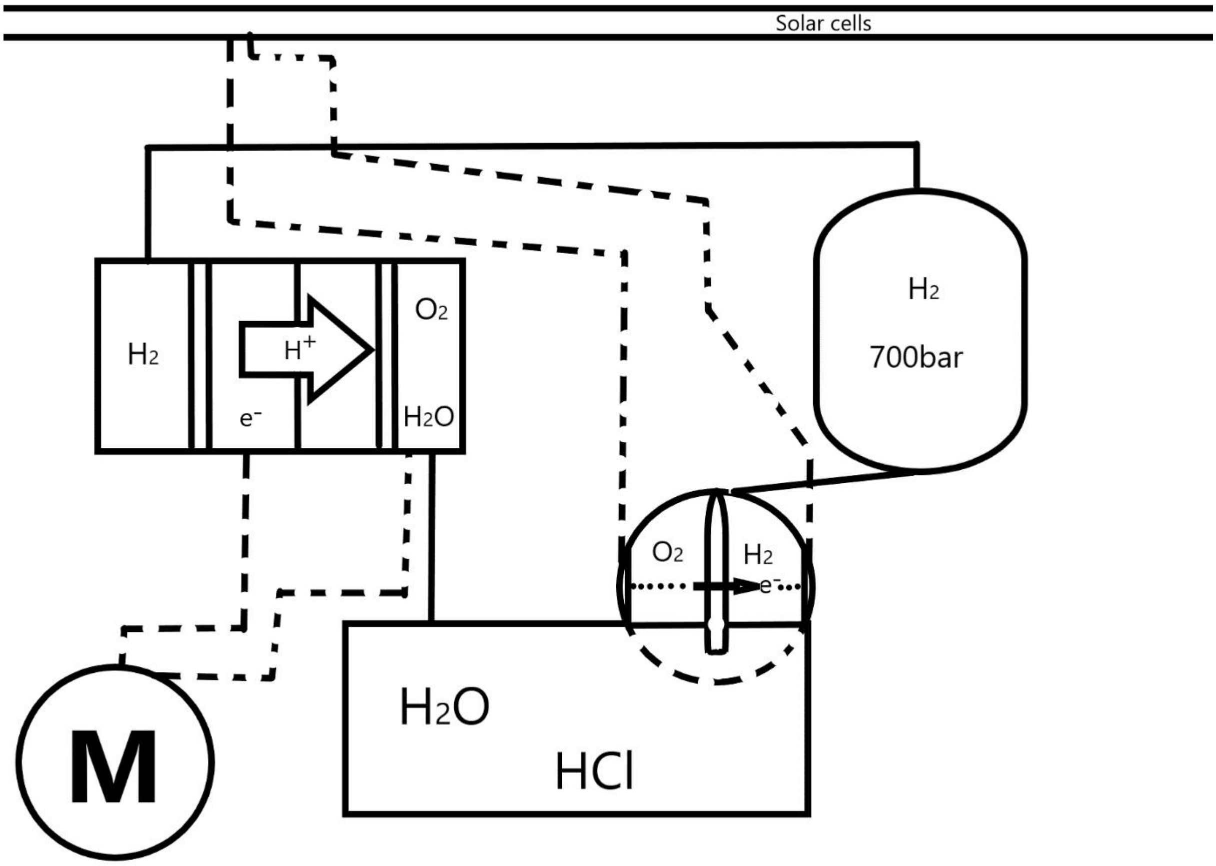
Keywords:

Technical book, cargo ship, hydrogen ship, hydrogen, project

Kazalo

1.1 System operation

The concept of a hydrogen ship consists of a set of fuel cells, hydrogen tanks, water tanks, a set of electrolyzers, an electric motor, and solar cells based on carbon nanotubes/photovoltaic cells. In this principle, while the ship consumes its hydrogen supplies via the fuel cell, it also produces them via the solar cells. This enables the ship to have greater autonomy than it would otherwise have.



Picture 1: Scheme of the shipes operation system

1.2 Description of system components

In this chapter we will delve into the individual parts of the system that were mentioned in the previous chapter. We will present, the components of the components, its tasks and mode of operation.

1.2.1 Hydrogen Fuel Cell

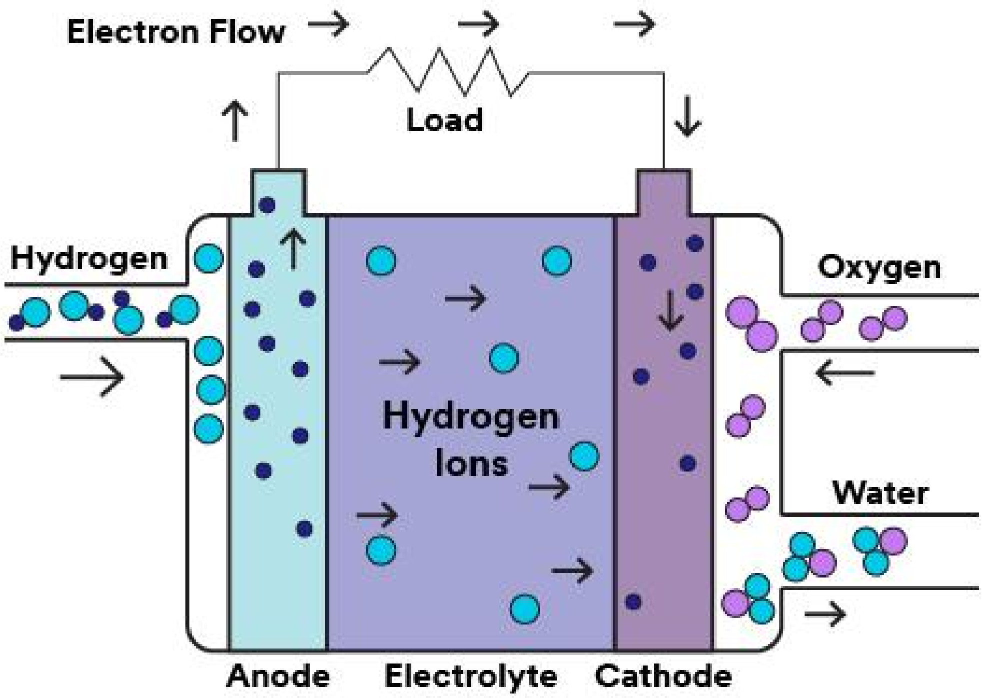
A hydrogen fuel cell converts the chemical energy of hydrogen and oxygen directly into electricity, heat, and water. It works on the basis of electrochemical reactions that take place in several key components: anode, cathode, electrolyte, membrane and catalyst.

Hydrogen enters the cell at the anode, where the catalyst, usually made of platinum, facilitates the breakdown of hydrogen into protons and electrons. The protons travel through the electrolyte membrane to the cathode, while the electrons travel through an external electrical circuit, generating an electric current to power devices. At the cathode, the protons, electrons, and oxygen combine, also with the help of a catalyst, to form water and release heat.

The overall chemical reaction is:

$$2H_2 + O_2 \rightarrow 2H_2O + \text{electrical energy} + \text{heat}$$

Hydrogen fuel cells are highly efficient and environmentally friendly, as they produce only water as a by-product. However, they face challenges such as the high cost of catalysts and the complex storage of hydrogen. Despite these challenges, they have significant potential for use in transportation, stationary power systems, and portable devices.



Picture 2: Scheme of hydrogen fuel cell

1.2.2 Electrolyzer

An electrolyzer is a device that uses electrical energy to drive chemical reactions that would not occur spontaneously. The main components of an electrolyzer are the power source, electrodes, and electrolyte. The power source provides the necessary electrical energy, the electrodes (cathode and anode) are immersed in the electrolyte, which enables the transfer of electric current.

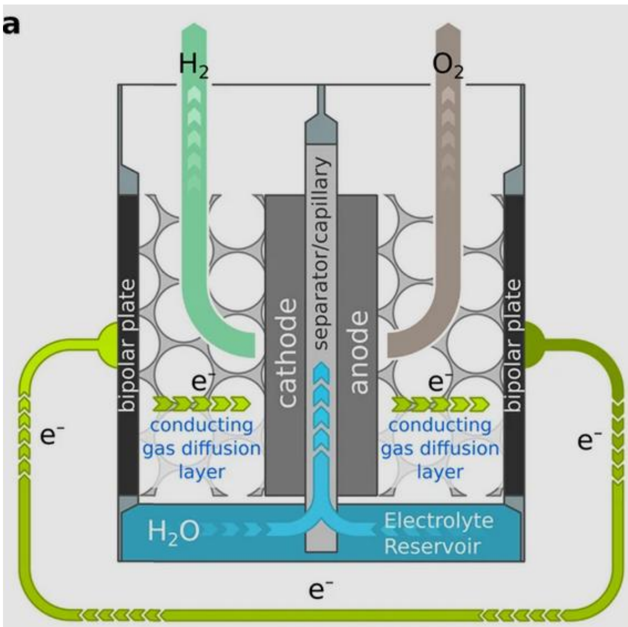
The electrolysis process begins by connecting the electrolyzer to an electrical source, causing ions in the electrolyte to move. Positive ions (cations) move toward the cathode, where they gain electrons and are reduced, while negative ions (anions) move toward the anode, where they lose electrons and are oxidized. This way, different products form on the electrodes depending on the used electrolyte and electrodes.

In the electrolysis of water, a typical application of an electrolyzer, water (H_2O) with the addition of an acid or base decomposes into hydrogen (H_2) and oxygen (O_2). The equations for water electrolysis are as follows:

- At the cathode (reduction): $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$
- At the anode (oxidation): $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$

In the electrolyzer, a small amount of acid or base is added to water to increase conductivity. When the current flows through the system, water decomposes, forming hydrogen at the cathode and oxygen at the anode.

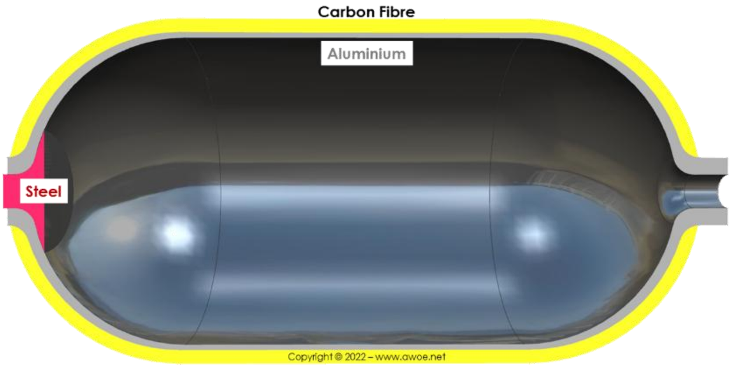
Electrolyzers that perform water electrolysis are crucial in various industrial processes, such as producing hydrogen for fuel cells, where hydrogen is used as a clean energy source. They are also important for producing oxygen for medical and industrial purposes. The water electrolysis process is environmentally friendly and offers promising possibilities for sustainable energy production and industrial gases.



Picture 3: Scheme of PEM electrolyzer - Hysata

1.2.3 Type III Hydrogen Tank

A Type III hydrogen tank is an advanced container designed for storing compressed hydrogen, capable of handling high pressures up to 700 bars. Its structure includes an inner liner made of aluminum, which is impermeable to gases, and a composite outer layer made of carbon fiber, which further enhances strength and reduces weight. Due to these properties, Type III tanks are ideal for use in fuel cell vehicles, industrial processes, and stationary energy storage systems. In addition to high performance, they are also very safe, being resistant to physical damage and corrosion, and undergo stringent testing and certification. Combining high pressure resistance with reduced mass, they



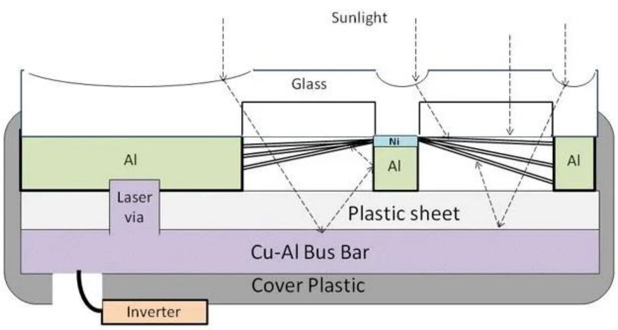
Picture 4: Scheme of type III hydrogen tank

represent a significant innovation in hydrogen storage technology.

1.2.4 Solar Cells Based on Carbon Nanofibers

Solar cells based on carbon nanofibers represent an innovative technology in photovoltaics. Carbon nanofibers, due to their unique electronic and optical properties, enable the efficient conversion of solar energy into electricity. Carbon nanofibers effectively absorb a broad spectrum of sunlight, causing electron excitation and the creation of electron-hole pairs. These pairs then separate, with electrons and holes quickly moving towards the electrodes due to the high mobility within the nanofibers, generating an electric current with minimal losses.

Solar cells based on carbon nanofibers offer several advantages. Their efficiency is higher than that of traditional silicon cells, and they are lightweight, durable, and flexible, allowing the creation of flexible solar modules. They also have the potential for lower production costs compared to silicon cells. While these solar cells are still under development, laboratory experiments show promising results. With continuous advancements in research, they could become a key part of sustainable

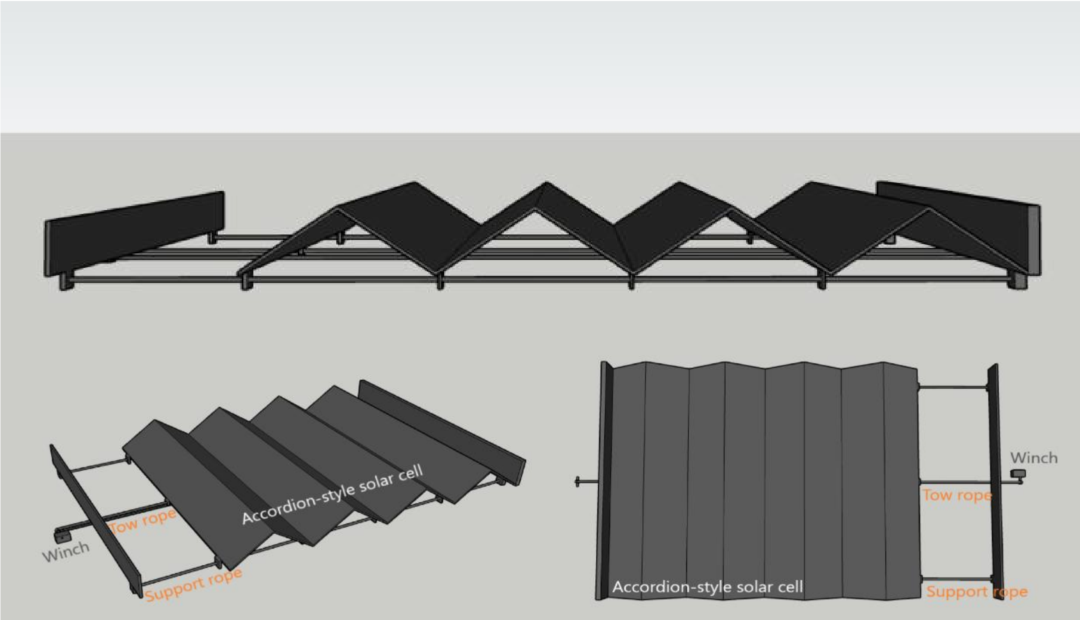


Picture 5: Scheme of carbon nanofiber based solar cells - NovaSolix

energy infrastructure due to their high efficiency, flexibility, and low costs.

1.2.4.1 Opening/Closing System of Solar Cells – Principle I

One option for a solar cell system is to staple solar cells together in the form of an origami accordion. In this principle, only one winch is needed to open and close the solar cells, and two auxiliary side

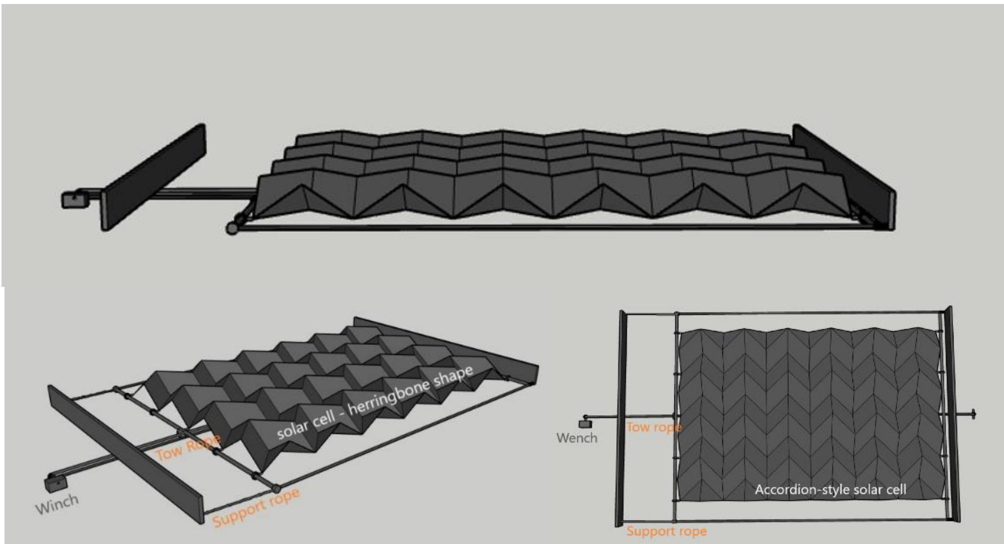


Picture 6: 3D scheme of principle I - Acordion

ropes to serve as stretchers.

1.2.4.2 Opening/Closing System of Solar Cells – Principle II

The second principle of solar cells is an origami shape called herringbone pleating of first-order. In this case we have to use three winches because in this form of origami, unlike the accordion origami, it is reduced in both length and width. This principle is slightly more difficult as the two side, supporting ropes also have to move slightly to remain taut in the



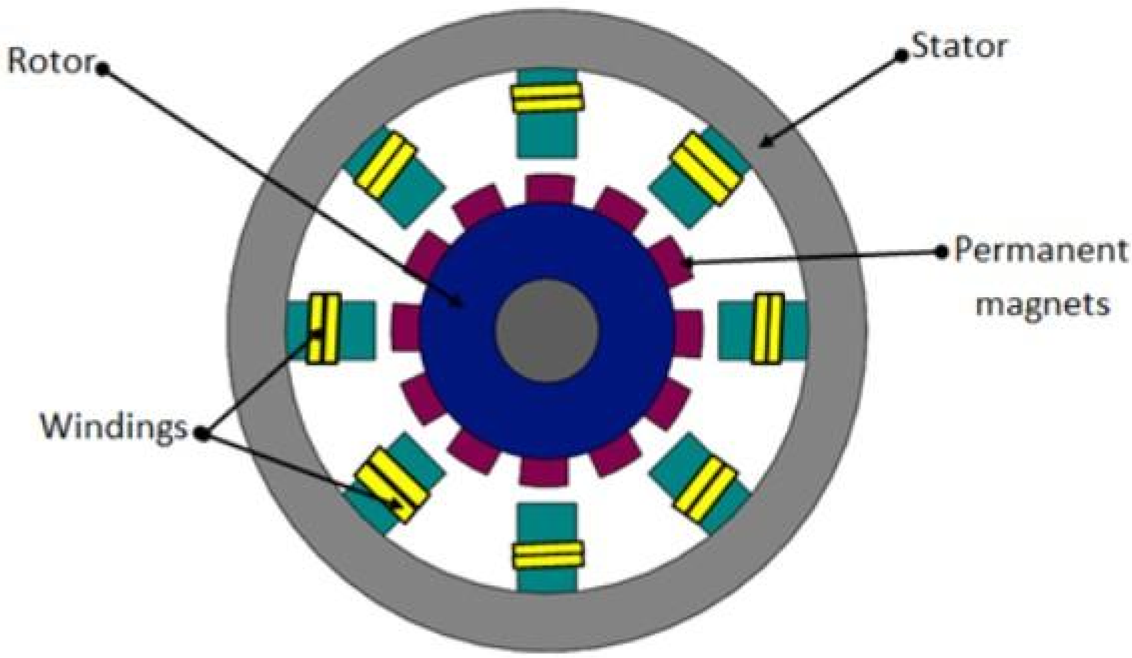
Picture 7: 3D scheme of princip II - herrigbone pleating

open and folded state of the solar cells.

1.2.5 Electric motor

Electric motors in ships operate on the principle of electromagnetic induction. They consist of a stator (the stationary part that creates a magnetic field) and a rotor (the rotating part that turns due to interaction with the stator's magnetic field). The rotation of the rotor transfers kinetic energy to the propeller, which drives the ship.

Electric motors are efficient, environmentally friendly, allow precise control of speed and direction, and are quieter than diesel engines. The most commonly used are alternating current (AC) motors, especially three-phase asynchronous or synchronous motors, as well as permanent magnet synchronous motors (PMSM), known for their high efficiency and reliability.



Picture 8: Scheme of electric motor

1.3 Production/Consumption Calculations

In this chapter, we will demonstrate the theoretical autonomy of the ship.

1.3.1 Ship Model: Post-Panamax

cca. $l = 366$ m

cca. $w = 49$ m

cca. $h = 31$m

↳ under water 15 m (draught)

$d = 15$ m

cca. $S = l \times w + (h - d) \times l \times 2$

$S = 366 \text{ m} \times 49 \text{ m} + (31 \text{ m} - 15 \text{ m}) \times 366 \text{ m} \times 2$

$S = 17{,}934 \text{ m}^2 + 11{,}712 \text{ m}^2$

$S = 29{,}646 \text{ m}^2$

cca. S_{SIDE}: 5,856 m²

cca. S_{DECK}: 17,934 m²

cca. S_{TOTAL}: 29,646 m²

$m_{SHIP} = 165{,}000$ t

$m_{CARGO} = 150{,}000$ t

$m_{TOTAL} = 315{,}000$ t

$V_{SHIP} = 555{,}954 \text{ m}^3$

$V_{CARGO} = 174{,}695 \text{ m}^3$

↳ Cargo above the hull

$V_{TOTAL} = 730{,}649 \text{ m}^3$

1.3.2 Hydrogen Production

- Water electrolysis
- Electricity from solar cells
- Water from reservoir

	Carbon Nanofiber Cells	Photovoltaic Cells
Efficiency	Up to 90% $\eta = 0.9$ kW/m²	Up to 23% $\eta = 0.23$ kWh/m²
The sun is at an angle of 30° ↳ reflection of light from the sea is 65% ↳ follows:	2 × 0.65 × 0.9 kW/m² × 5,856 m² = 6,851.5 kWh	2 × 0.65 × 0.23 kW/m² × 5,856 m² = 1,750.9 kWh
The sun is at an angle of 30° ↳ reflection of light from the sea is 8% ↳ follows:	2 × 0.08 × 0.9 kW/m² × 5,856 m² = 842.3 kWh	2 × 0.08 × 0.23 kW/m² × 5,856 m² = 215.5 kWh
Production after 12 hours of sunshine is	46,182.7 kWh	11,798.64 kWh
Deck An ideal 90° angle	0.9 kW/m² × 17,934 m² = 16,140.6 kWh	0.23 kW/m² × 17,934 m² = 4,124.8 kWh
Production for 12 hours of sunlight	193,687.2 kWh	49,497.6 kWh
Total production under ideal conditions	239,849.9 kWh ↳ 5,780 kg H_2	61,296 kWh ↳ 1,477 kg H_2

$2H_2O \rightarrow 2H_2 + O_2$

$$\frac{n\,(H_2)}{n\,(H_2O)} = \frac{2}{2}$$

$n\,(H_2) = n\,(H_2O)$

$n\,(H_2O) = \frac{1{,}000 \text{ g mol}}{2.02 \text{ g}}$

$n\,(H_2O) = 495.05 \text{ mol}$

$m\,(H_2O) = \frac{495.05 \times 18{,}02 \text{ g}}{\text{mol}}$

$m\,(H_2O) = 8{,}920.79 \text{ g}$

1 kg H_2 . . . . 8.92 kg H_2O
↳ 8.92 ℓ H_2O

1 kg H_2 . . . . 41.5 kWh
↳ Hysata

1.3.3 PEM fuel cell efficiency

$2H_2O \rightarrow 2H_2 + O_2$

$\Delta G = -237.13 \text{ kJ/mol}$

$\Delta H = -25.84 \text{ kJ/mol}$

$$\eta_{MAX} = \frac{\Delta G}{\Delta H} \times 100$$

$$\eta_{MAX} = \frac{-273.12\ kJ\ mol}{-285.84\ kJ\ mol} \times 100$$

$\eta_{MAX} = 85.96\ \%$

$\rho_E = 39.39 \text{ kWh/kg} \times 0.8296 = 32.7 \text{ kWh/kg}$

ENERGY VALUE

1kg H_2. . . . . 39.39 kWh

MAXIMUM EFFICIENCY

1kg H_2 . . . . 32.70 kWh

1.3.4 Forces and Power

Data

V = 15.28 m/s

d = 366 m

S = 11,715 m^2

ρ =1,025 kg/m^3

ν =1.19×10^{-6} m^2/s

Reynolds Number

$$Re = \frac{V \times d}{\nu}$$

$$Re = \frac{15.28m \times 366m \times s}{1.19 \times 10^{-6}\, m^2 \times s}$$

$$Re = 4.7 \times 10^9$$

Coefficient of friction

$$C_f = \frac{0.075}{(log_{10}(Re) - 2)^2}$$

$$C_f = \frac{0.075}{(9.673 - 2)^2}$$

$$C_f \approx 0.00127$$

Friction

$$R_f = \frac{1}{2} \times \rho \times V^2 \times S \times C_f$$

$$R_f = \frac{1}{2} \times 1{,}025\, kg/m^3 \times (15.28\, m/s)^2 \times 11{,}715\, m^2 \times 0.00127$$

$$R_f \approx 1{,}785{,}670\, N \approx 1.79\, MN$$

Power

$$P = R_f \times V$$

$$P = 1.79\, MN \times 15.28\, m/s$$

$$P \approx 27{,}281{,}073\, W \approx 27.28\text{ MW}$$

ENGINE POWER DONE
24h .... 654.72 MWh
↳20,022 kg H_2

Power in one day

$$P_{dan} = P \times day$$

$$P_{dan} = 27.28\text{ MW} \times 24\text{ h}$$

$$P_{dan} \approx 654.72\, MWh$$

Hydrogen consumption per day

$$m_{H_2} = \frac{P_{day}}{\rho_E}$$

$$m_{H_2} = \frac{654.72\, MWh\, kg}{32.7\, kWh}$$

$$m_{H_2} \approx 20{,}022\, kg$$

1.3.5 Size of tanks

Hydrogen tank: 3 million gallons (≐ 11,356,235.352 ℓ)

The water tank → intended for electrolysis only

p = 70,000 kPa

T = 293 K

$$m = \frac{p \times V \times M}{T \times R}$$

m = 664,663.5 kg

	Carbon nanofiber cells	Photovoltaic Cells
H_2	Production: 481.6 kg/h Consumption: 834.3 kg/h Difference: -352.7 kg/h	Production: 123.1 kg/h Consumption: 834.3 kg/h Difference: -711.2 kg/h
H_2O	Production: 4,172.8 kg/h Consumption: 7,441.9 kg/h Difference: -3,146.1 kg/h	Production: 1,066.8 kg/h Consumption: 7,441.9 kg/h Difference: -6,343.9 kg/h
H_2O VOLUME	1 m^3	1 m^3

*Excess water is discharged into the sea or used to supplement the potable water tank

1.3.6 Autonomy

m_{FUEL} = 664,663.5 kg H_2 → full tank

$m_{CONSUMPTION}$ = 20,022 kg H_2/24h

V_{MAX} = 30 knots ≐ 55 km/h.

$m_{PRODUCTION}$ = 5,780 kg H_2/12h → 90% cell efficiency

1,477 kg H_2/12h → 23% cell efficiency

$$Autonomy = \frac{m_{FUEL}}{m_{CONSUMPTION}}$$

$$Autonomy = \frac{664{,}663{,}5\ kg}{20{,}022\ kg}$$

$$Autonomy = 30\ days$$

FULL TANK . . . . 30 days
↳ 39,600 km

1.3.7 Production of hydrogen

- Produces 42 days
  ↳ the first stage → the consumption of the initial full tank → 439,500 kg
- average sun time: 12h

CYCLE		Carbon nanofiber cell	Photovoltaic cells
	Production*	481.6 kg/h	123.1 kg/h
0	Endurance	$\frac{30\text{ days} \times 481.6\text{ kg} \times 12\text{h}}{20.022\text{ kg h}} = 9\text{ days}$ After the first stage, there is enough fuel for additional 9 days	$\frac{30\text{ days} \times 123.1\text{ kg} \times 12\text{h}}{20{,}022\text{ kg h}} = 3\text{ days}$ After the first stage, there is enough fuel for additional 6 days
1	Endurance	$\frac{9\text{ days} \times 481.6\text{ kg} \times 12\text{h}}{20{,}022\text{ kg h}} = 3\text{ days}$ After the first stage, there is enough fuel for additional 3 days	$\frac{3\text{ days} \times 481.6\text{ kg} \times 12\text{h}}{20.022\text{ kg h}} = 7{,}2\text{ h}$ After the first stage, there is enough fuel for additional 7.2h
2	Endurance	$\frac{3\text{ days} \times 481.6\text{ kg} \times 12\text{h}}{20{,}022\text{ kg h}} = 1\text{ day}$ After the first stage, there is enough fuel for an additional day	
3	Endurance	$\frac{1\text{ day} \times 481.6\text{ kg} \times 12\text{h}}{20{,}022\text{ kg h}} = 7{,}2\text{h}$ After the first stage, there is enough fuel for additional 7.2h	
	TOTAL AUTONOMY	**43.3 DAYS → 57,156 km**	**33.3 DAYS → 43,956 km**

* With each cycle, some more hydrogen is produced, so we use it for further stages

1.4 Comparing a hydrogen ship with a fossil fuelled ship

In this chapter, as we can already infer from the title, we will focus on the technical data of the ship and compare them.

1.4.1 Impact on the environment

When it comes to environmental impact, we can say that hydrogen-powered ships are much more environmentally friendly than fossil fuel-powered ships. This is clearly seen in the resulting products, as hydrogen-powered ships only produce water (H_2O), whereas fossil fuel-powered ships produce greenhouse gases that poison water, warm, and pollute the atmosphere, and can also be harmful when inhaled. However, we must also consider the extraction and production of fossil fuels and hydrogen. The extraction and processing of fossil fuels significantly impact the earth's crust, which can lead to subsidence in those areas, and we must not forget the dangers of spills, which can severely damage the entire ecosystem in the affected area. In hydrogen production, we must mention that electricity is needed since hydrogen is a form of energy storage. Here we encounter a problem, as most of the world's electricity is produced by burning fossil fuels, which can be a significant drawback because we do not avoid the production of greenhouse gases. The solution to this is so-called green and pink hydrogen. Green hydrogen refers to hydrogen produced using electricity from natural sources (water, air, sun). Pink hydrogen describes hydrogen produced using electricity from a nuclear power plant.

1.4.2 Comparison with a fossil fuel ship

	Fossil fuel ship	Ship with photovoltaic	Ship powered by carbon nanofiber cells
Motor power	27.28 MW	27.28 MW	27.28 MW
Initial fuel mass	664,663.5 kg	664,663.5 kg	664,663.5 kg
Final fuel mass	664,663.5 kg	666,732.6 kg	866,952.6 kg
Fuel volume	730.4 m^3	11,356.2	11,356.2
Fuel density	910 kg/m^3	59 kg/m^3	59 kg/m^3
Fuel price (1.000 kg)	560 €	1,360 €	1,360 €
Consumption (100 km)	4,240.6 kg	1,516.8 kg	1.516.8 kg
Fuel price	2,374.736 €	2.,062.848 €	2,062.848 €
Autonomy	**11.9 DAYS ↳ 15,708 km**	**33.3 DAYS ↳ 43,956 km**	**43.3 DAYS ↳ 57,156 km**

Fossil fuel ship

Data

m = 664,663.5 kg

$\rho = 910\ kg/m^3$

$\rho_E = 11.7\ kWh/kg$

P = 27.28 MW

Tank size

$$V = \frac{m}{\rho}$$

$$V = \frac{664{,}663.5\ kg\ m^3}{910\ kg}$$

$$V \approx 730.4\ m^3$$

Power per day

$$P_{day} = P \times day$$

$$P_{day} = 27.28\ \text{MW} \times 24\ \text{h}$$

$$P_{day} \approx 654.72\ MWh$$

Fuel consumption per day

$$m = \frac{P_{day}}{\rho_E}$$

$$m = \frac{654.72\ MWh\ kg}{11.7\ kWh}$$

$$m \approx 55{,}958.9\ kg$$

Autonomy

$$Autonomy = \frac{m_{FULL\ TANK}}{m}$$

$$Autonomy = \frac{664{,}663.5\ kg}{55{,}958.9\ kg}$$

$$Autonomy \approx 11.9\ days$$

$$Autonomy = 11.9\ days\ \times 24\ h\ \times 55\ {}^{km}/_{h}$$

$$Autonomy = 15{,}708$$

1.5 Indicative calculation of the price of the ship

The approximate calculation of the price of the ship will be calculated on the basis of the indicative prices of all system parts of the ship. We will get this data by estimating the value with data from the Internet. To the resulting price we will then add the obstacle price of the ship's frame.

1.5.1 Hydrogen Fuel Cell Price

$P_{FUEL\ CELL} = 12.9$ MW

$P_{HORIZON\ FUEL\ CELL} = 1$ MW

$\eta_{MAX} = 85.96$ %

cca. Price $_{HORIZON\ FUEL\ CELL}$ = 500,000 €

$P_{MAX} = P_{HORIZON\ FUEL\ CELL} \times \eta_{MAX}$

$P_{MAX} = 1MW \times 85.96\%$

$P_{MAX} = 0.86$ MW

$n_{FUEL\ CELL} = \frac{P_{FEUL\ CELL}}{P_{MAX}}$

$n_{FUEL\ CELL} = \frac{12.9\ MW}{0.86\ MW}$

$n_{FUEL\ CELL} = 16$

Price = Price $_{HORIZON\ FUEL\ CELL} \times n_{FUEL\ CELL}$

Price = 500,000 € × 16

Price = 8,000,000 €

1.5.2 Electrolyzer price

$m_{HYDROGEN} = 420$ kg/h

$\eta_{MAX} = 41.5$ kW/kg

Price $_{ELEKTROLYZER}$ = 900 €/kW

$P_{ELEKTROLYZER} = \eta_{MAX} \times m_{HYDROGEN}$

$P_{ELEKTROLYZER} = 41.5$ kW/kg × 420 kg/h

$P_{ELEKTROLYZER} = 17{,}430$ kW

cca. Price = Price $_{ELEKTROLYZER} \times P_{ELEKTROLYZER}$

Price = 900 €/kW × 17,430 kW

cca. Price = 15,687,000 €

1.5.3 Solar Panel Price

When calculating the indicative price for solar cells, we have two options (photovoltaic cells and carbon cells).

1.5.3.1 Photovoltaic solar panels

cca. l = 366 m

cca. w = 49 m

cca. h = 31 m

↳ under water 15 m (draught)

d = 15 m

1 m² . . . . 320 €

cca. S = l × w + (h - d) × l × 2

S = 366 m × 49 m + (31 m – 15 m) × 366 m × 2

S = 17,934 m² + 11,712 m

S = 29,646 m²

cca. S_{SIDE} = 5,856 m²

cca. S_{DECK} = 17,934 m²

cca. S_{TOTAL} = 29,646 m²

cca. $P = S_{TOTAL} \times \frac{320\ €}{m^2}$

$P = 29{,}646\ m^2 \times \frac{320\ €}{m^2}$

cca. P = 9,486,720 €

1.5.3.2 Solar cells based on carbon nanofibers

cca. l = 366 m

cca. w = 49 m

cca. h = 31 m

↳ under water 15 m (draught)

d = 15 m

1 m² . . . . 30 €

cca.

S = l × w + (h - d) × l × 2

S = 366 m × 49 m + (31 m – 15 m) × 366 m × 2

S = 17,934 m² + 11,712 m

S = 29,646 m²

cca. S_{SIDE} = 5,856 m²

cca. S_{DECK} = 17,934 m²

cca. S_{TOTAL} = 29,646 m²

cca. $P = S_{TOTAL} \times \frac{30\ €}{m^2}$

$P = 29{,}646\ m^2 \times \frac{30\ €}{m^2}$

cca. P = 889.380 €

1.5.4 Type III Hydrogen Tank Price

V_{TOTAL} = 11,356.2 m^3

V_{TANK} = 6.5 m^3

cca. Price $_{TANK}$ = 12,000 €

$n_{TANK} = \frac{V_{TOTAL}}{V_{TANK}}$

$n_{TANK} = \frac{11{,}356.2\ m^3}{6.5\ m^3}$

n_{TANK} = 1,747

Price $_{TOTAL}$ = Price $_{TANK}$ × n $_{TANK}$

Price $_{TOTAL}$ = 12,000 € × 1,747

Price $_{TOTAL}$ = 20,965,292 €

1.5.5 Electromotor price

P = 27,281 kW

cca. Price $_{ELECTROMOTOR}$ = 500 €/kW

Price $_{TOGETHER}$ = P × Price $_{ELECTROMOTOR}$

Price $_{TOGETHER}$ = 27,281 kW × 500 €/kW

Price $_{TOGETHER}$ = 13,640.500 €

1.5.6 Total price for the operating system

$Price_{FUEL\ CELL}$ = 16.000.000 €

$Price_{ELECTROLYZER}$ = 30.122.445 €

$Price_{SOLAR\ PANELS}$:

- Photovoltaic cells = 9.486.720 €
- Cells with carbon nanofibers = 889.380 €

$Price_{TANK}$ = 20.965.292 €

$Price_{ELECTROMOTOR}$ = 13.640.500

---

1. $Price_{TOTAL}$ (photovoltaic) = 90.214.957 €
2. $Price_{TOTAL}$ (carbon nanofiber) = 81.617.617 €

1.6 Neo-Panamax Cargo Ship Hull Cost Analysis

1.6.1 Calculations of material and equipment costs

The calculation of the price of the hull without the propulsion system can be calculated as follows:

1.6.1.1 Calculation of steel costs

Hull area:

- Lenth (l): 366 metrov
- Width (w): 49 metrov
- Height (h): 50 metrov

$S = 2 \times\ l\ \times w + 2\ \times l\ \times\ h$

$S = 2 \times 17{,}934\ m^2 + 2 \times 18{,}300\ m^2$

$S = 72{,}468\ m^2$

Prostornina jekla:

- Average thickness (at) = 0.02 m

$V =\ S \times at$

$V = 72{,}468\ m^2\ x\ 0.02\ m$

$V = 1{,}452.96\ m^3$

Mass of steel:

- Density (ρ) = 7,850 kg/m^3

$m =\ V\ \times \rho$

$m =\ 1{,}452.96\ m^3 \times 7{,}850\ \mathrm{kg/m^3}$

$m =\ 11{,}405{,}736\ kg$

Price of steel:

- Price of steel (p) = 850 €/t

$Price_{STEEL} = m \times p$

$Price_{STEEL} = 11{,}406\ t\ \times\ 850\ €/t$

$Price_{STEEL} = 9{,}695{,}100\ €$

- Consumables (co) = +10%

$Price_{FINAL} = Price_{STEEL} \times (co + 1)$

$Price_{FINAL} \approx 10{,}664{,}610\ €$

1.6.1.2 Calculation of equipment costs

Hull fitting involves adding various components and elements. These costs roughly amount to between 100 and 150 €/ m².

- Average price (ap) = 125 €/m²

$$Price_{EQUIPMENT} = S \times ap$$

$$Price_{EQUIPMENT} = 72{,}468\ m^2 \times 125\ €/m^2$$

$$Price_{EQUIPMENT} = 9{,}058{,}500\ €$$

1.6.1.3 Total Estimated Price

$$Price_{TOGETHER} = Price_{EQUIPMENT} + Price_{FINAL}$$

$$Price_{TOGETHER} = 9{,}058{,}500\ € + 10{,}664{,}610\ €$$

$$Price_{TOGETHER} = 19{,}723{,}110\ €$$

1.6.2 Calculations of manufacturing and assembly costs

Estimated labor hours for these procedures range between 200,000 and 400,000 hours, with an average of 300,000 hours.

1.6.2.1 Low cost region (Asia)

Hourly assumption between 20 and 40 €/h:

- Salary (sl) = 30 €/h
- Time (t) = 300,000 h

$$Payment = t \times sl$$

$$Payment = 300{,}000\ h \times 30\ €/h$$

$$Payment = 9{,}000{,}000\ €$$

- Shipyard costs (syc) = +15%

$$Payment_{FINAL} = Payment \times (syc + 1)$$

$$Payment_{FINAL} = 10{,}350{,}000\ €$$

1.6.2.2 Overall score for the low-cost region

- Unforeseen costs (ufc) = +5%

$$Costs = (Payment_{FINAL} + Price_{TOGETHER}) \times (ufc + 1)$$

$$Costs = \left(19{,}723{,}110\ € + 10{,}350{,}000\ €\right) \times (0.05 + 1)$$

$$Costs = 30{,}073{,}000\ € \ \times 1.05$$

$$Costs = 31{,}576{,}650\ €$$

1.6.2.3 High cost region (Europe, North America)

Hourly rate between 50 and 100 €/h:

- Salary (sl) = 75 €/h
- Time (t) = 300,000 h

$$Salary = t\ \times p$$

$$Salary = \ 300{,}000\ h \times \ 75\ €/\mathrm{h}$$

$$Salary = \ 22{,}500{,}000\ €$$

- Shipyard costs (syc) = +15%

$$Payment_{FINAL} = Salary\ \times (syc + 1)$$

$$Payment_{FINAL} = 25{,}875{,}000\ €$$

1.6.2.4 Overall score for high cost region

- Unforeseen costs (ufc) = +5%

$$Costs = (Payment_{FINAL} + Price_{TOGETHER}) \times (ufc + 1)$$

$$Costs = \left(19{,}723{,}110\ € + 25{,}875{,}000\ €\right) \times (0.05 + 1)$$

$$Costs = 45{,}598{,}110\ € \ \times 1{,}05$$

$$Costs = 46{,}891{,}860\ €$$

1.7 Estimated purchase price of the boat

- Hull with equipment:
  - Low cost region (lr): 31.576.650 €
  - Region with high costs (hr): 46.891.860 €
- Drive system:
  - Photovoltaic cells (fc): 90,214,957 €
  - Cells based on carbon fibers (kc): 81,617,617 €

$$Price_{LOW} = lr + kc$$

$$Price_{LOW} = 31{,}576{,}650 \text{ €} + 81{,}617{,}617 \text{ €}$$

$$Price_{LOW} = 113{,}194{,}267 \text{ €}$$

$$Price_{HIGH} = hr + fc$$

$$Price_{HIGH} = 46{,}891{,}860 \text{ €} + 90{,}214{,}957 \text{ €}$$

$$Price_{HIGH} = 137{,}106{,}817 \text{ €}$$

Conclusion

In this technical book, we have presented a comprehensive project for a hydrogen-powered ship, focusing on the transformation of cargo ships. We thoroughly analysed the key components such as hydrogen fuel cells, electrolyzers, hydrogen tanks of type III, solar cells based on carbon nanotubes, and electric motors. We highlighted the advantages, including high efficiency, environmentally friendly energy production, and increased autonomy of the vessels. The use of these advanced technologies enables the reduction of harmful emissions and the improvement of energy efficiency, which is crucial for the sustainable development of the maritime sector.

Converting cargo ships to hydrogen fuel represents an important step towards cleaner and more sustainable maritime transport. Implementing innovative solutions from this project can significantly contribute to reducing the environmental footprint of global logistics. Our hydrogen-powered ship project offers a promising and sustainable solution that can positively impact the global environment and contribute to a more sustainable future in the maritime industry.

Index of pictures

Sources

Types of cargo ships (27.5.2024)

Sizes of Panamax type cargo ships (27.5.2024)

Panamax and Neopanamax (27.5.2024)

Description of hydrogen fuel cell operation (28.5.2024)

Description and comparison of hydrogen tanks (28.5.2024)

Hysata original website (1.6.2024)

NovaSolix original website (1.6.2024)

NovaSolix description of solar cell operation (1.6.2024)

Description of the operation of an electric motor (6.6.2024)

Data of oil fuel usage and description of tank (31.7.2024)

Motor power New Panamax (31.7.2024)

Data of fuel oil (31.7.2024)

Physical properties of fuel oil (31.7.2024)

Cost of photovoltaic cell (27.7.2024)

Cost of carbon nanotube-based cell (27.7.2024)

Cost of 1MW hydrogen fuel cell system (29.7.2024)

Cost of Type III hydrogen storage tank (29.7.2024)

Cost of electrolyzer $/kW (29.7.2024)

Cost of electric motor $/kW (29.7.2024)

Price of steel (1.8.2024)

Hull thickness (1.8.2024)

Sources of pictures

Picture 1: Maks Zagode Drawing by hand

Picture 2: https://www.3m.com/3M/en_US/hydrogen-technology-us/applications/fuel-cells/

Picture 3: https://voteclimateone.org.au/efficient-electrolysis-makes-hydrogen-economy-look-good/

Picture 4: https://didionvessel.com/hydrogen-storage-tanks/

Picture 5: https://www.solarfabric.com/a-90-efficient-solar-panel/

Picture 6: Anton Mlinar 3D modeling

Picture 7: Anton Mlinar 3D modeling

Picture 8: https://www.powerelectronictips.com/basics-ac-motors-and-their-applications-faq/