The first Hydrogen – Electric Cargo schip Antonie

D2.17 Design specifications of the FC-powered Barge

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2 Background WEVA1 project.

At the initiative of Nobian, Coöperatie NPRC has sought an entrepreneur who can develop and operate a hydrogen- powered inland waterway vessel. This inland vessel will be used exclusively for Nobian internal transport. Lenten Scheepvaart, long-term member of the NPRC Cooperative, has taken on the challenge of designing and building a new inland vessel that can meet Nobian's transport demand.

The WEVA1 project, Hydrogen Electric Freight Vessel Antonie, has been set up for this purpose. Since hydrogen has never been used as a fuel in inland vessels before and the investment costs for such a project are double that of a conventionally powered inland vessel, European and Dutch subsidies have been applied for to close the financing gap.

Nobian will supply green hydrogen for the WEVA1 ship, with which the Antonie will carry out the logistics transport 100% emission-free and climate neutral.

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3 Principles of the WEVA1 ship design.

The design parameters for the WEVA1 H2 powered freighter are:

- Sufficient storage of green hydrogen on board to be able to complete at least one round trip under ideal conditions.
- Equipped with a fuel cell as main drive.
- Fully integrated electric propulsion installation.
- Battery pack to provide peak power
- Maximum efficiency through a new design of the underwater ship.
- Lightweight airframe
- Vessel dimensions adapted to the waterway.
- Dimensions 135 m. length, 11.45 m. width, maximum draft 3.75 m. Air draugt 6.50 when empty. Load capacity approx. 3900T at a draft of 3.50 m.
- For the purpose of 'redundancy', a back-up generator system must be installed.
- Adapted to the transport of salt.

Extensive discussions were held with various ship designers, shipyards, suppliers of H2 systems and suppliers of H2 storage systems and the waterway manager of the main waterway Lemmer – Delfzijl in order to make the right choice regarding the specifications for the propulsion systems.

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4 Historical data of energy consumption per round trip.

To determine the required power fot the fuel cell system, the maximum power consumption of a similar conventional ship on the Rotterdam – Delfzijl route was investigated. Based on this, a layout for the fuel cell power was designed.

Example raw data.

Reis no;	Zout reis no:	begin datum	leeg datum	totaal dagen	van	naar	lading	geladen MT	Smeerolie peil	Smeerolie verbruik	gasolie verbruik Hoofdaandrijving	GTL voorschip Boegschroef en Gensets
1	1	27-dec	1-jan	5	Delfzijl	Rotterdam	Zout	2749			3,762	0,65
2	2	2-jan	7-jan	6	Delfzijl	Rotterdam	Zout	2965			3,712	0,65
3	3	8-jan	12-jan	5	Wagenborg	Rotterdam	Zout	2912,369			3,943	0,65
4	4	13-jan	17-jan	5	Delfzijl	Rotterdam	Zout	2935			3,687	0,65
5	5	18-jan	22-jan	5	Delfzijl	Rotterdam	Zout	2929			3,941	0,65
6	6	23-jan	27-jan	5	Delfzijl	Rotterdam	Zout	2933			3,979	0,65
7	7	28-jan	1-feb	5	Delfzijl	Rotterdam	Zout	2951	6		3,885	0,65
8	8	2-feb	6-feb	5	Delfzijl	Rotterdam	Zout	2965	Verv.64	80	3,759	0,65
9	9	7-feb	11-feb	5	Delfzijl	Rotterdam	Zout	2940			3,921	0,65
10	10	12-feb	16-feb	5	Delfzijl	Rotterdam	Zout	2936			4,02	0,65
11	11	17-feb	21-feb	5	Delfzijl	Rotterdam	Zout	2936			3,897	0,65
12	12	22-feb	26-feb	5	Delfzijl	Rotterdam	Zout	2947			4,248	0,65
13	13	27-feb	3-mrt	6	Delfzijl	Rotterdam	Zout	2970			3,946	0,78
14	14	4-mrt	10-mrt	7	Delfzijl	Rotterdam	Zout	2976			4,025	0,65
15	15	11-mrt	16-mrt	6	Delfzijl	Rotterdam	Zout	2932			3,831	0,91
16		17-mrt	18-mrt	1	Delfzijl	Wagenborg	Zout	3196			0,2	0,26
17	16	19-mrt	23-mrt	6	Delfzijl	Rotterdam	Zout	2933			3,583	0,65
18	17	24-mrt	28-mrt	5	Delfzijl	Rotterdam	Zout	2968			3,979	0,65
19	18	29-mrt	3-apr	6	Delfzijl	Rotterdam	Zout	2960			3,992	0,78
20	19	4-apr	11-apr	8	Delfzijl	Rotterdam	Zout	2953			3,736	1,04
21	20	12-apr	16-apr	5	Delfzijl	Rotterdam	Zout	2935			3,798	0,65
22	21	17-apr	21-apr	5	Delfzijl	Rotterdam	Zout	2942			3,892	0,65
23	22	22-apr	26-apr	5	Delfzijl	Rotterdam	Zout	2953			4,048	0,65
24	23	27-apr	1-mei	5	Wagenborg	Rotterdam	Zout	2960,176	20 l bijgevuld		3,97	0,65
25	24	2-mei	7-mei	6	Delfzijl	Rotterdam	Zout	2949			3,823	0,65
26	25	8-mei	12-mei	5	Delfzijl	Rotterdam	Zout	2925			3,701	0,65
27	26	13-mei	17-mei	5	Delfzijl	Rotterdam	Zout	2934			3,642	0,65
28	27	18-mei	21-mei	5	Delfzijl	Rotterdam	Zout	2941			3,939	0,65
29	28	22-mei	27-mei	5	Delfzijl	Rotterdam	Zout	2970			3,77	0,65
30	29	28-mei	1-jun	5	Wagenborg	Rotterdam	Zout	2974,018	ververst		3,832	0,65
31	30	2-jun	6-jun	5	Delfzijl	Rotterdam	Zout	2924	70		3,639	0,65
32	31	7-jun	11-jun	5	Delfzijl	Rotterdam	Zout	2931			3,796	0,65
33	32	12-jun	16-jun	5	Delfzijl	Rotterdam	Zout	2930			4,454	0,65
34	33	17-jun	21-jun	5	Delfzijl	Rotterdam	Zout	2959			3,81	0,65
35	34	22-jun	26-jun	5	Delfzijl	Rotterdam	Zout	2968			3,515	0,65
36	35	27-jun	1-jul	5	Delfzijl	Rotterdam	Zout	2961			3,732	0,65
37	36	2-jul	6-jul	5	Delfzijl	Rotterdam	Zout	2951			4,051	0,65
38	37	7-jul	11-jul	5	Delfzijl	Rotterdam	Zout	2948	60		3,823	0,65
39	38	12-jul	16-jul	5	Delfzijl	Rotterdam	Zout	2939			3,806	0,65
40	39	17-jul	20-jul	4	Delfzijl	Rotterdam	Zout	2961			3,819	0,65
41	40	21-jul	26-jul	6	Delfzijl	Rotterdam	Zout	2967			3,764	0,75
42	41	27-jul	1-aug	6	Delfzijl	Rotterdam	Zout	2940			4,016	0,75
43	42	2-aug	6-aug	5	Delfzijl	Rotterdam	Zout	2944			3,645	0,65
44	43	7-aug	12-aug	6	Delfzijl	Rotterdam	Zout	2934			3,859	0,65
45	44	13-aug	18-aug	6	Delfzijl	Rotterdam	Zout	2935	36		4,074	0,65

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5 Calculating data

From these historical data, it was possible to calculate the power required for propulsion. In collaboration with an engineer who can name hydrogen as his expertise, the data has been worked out in tables and graphs.

Chart power requirement per round trip

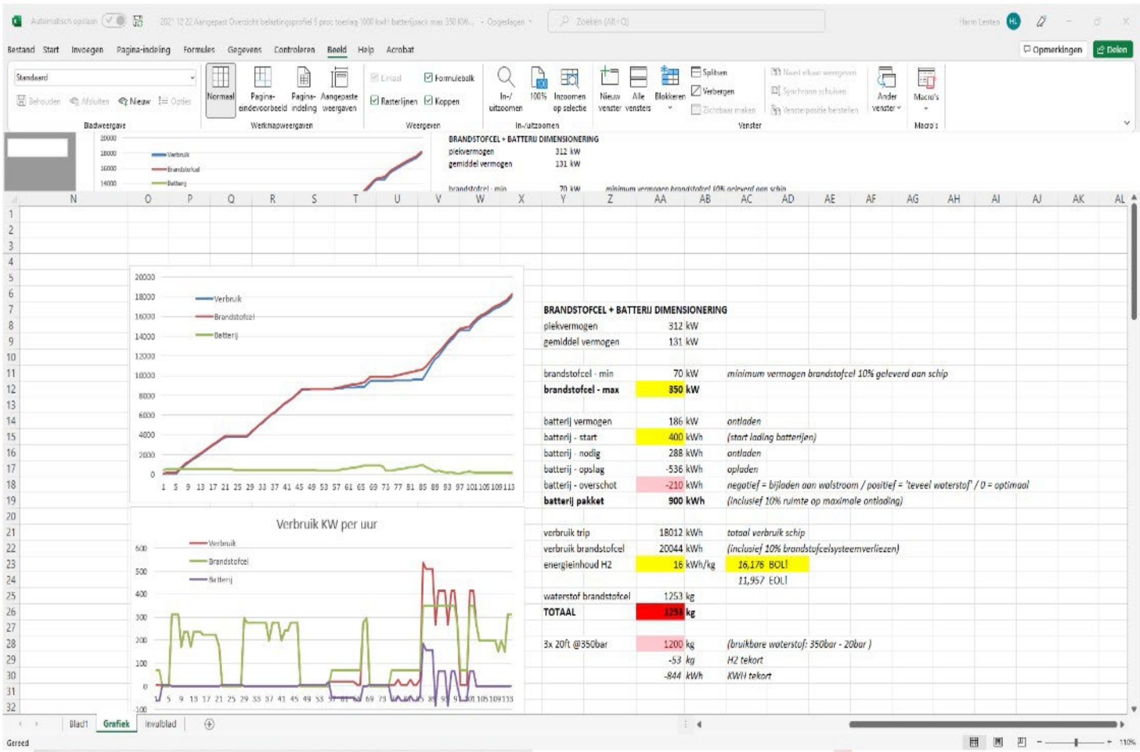

Table power requirement per round trip

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6 Fluid dynamics calculation.

We have commissioned Sip Marine, (a highly kwalified company with a large experience in optimizing ships hull and propellor design). to optimize the ship design line plan by means of a fluid dynamics program.

To determine the most efficient hull shape suitable for the sailing route, various calculations were made. The hull shape of the fore and aft sections of the ship directly affect the ship's energy consumption. A vessel designet for canal navigation has entiraly different specifications compared to one designed for river navigation.

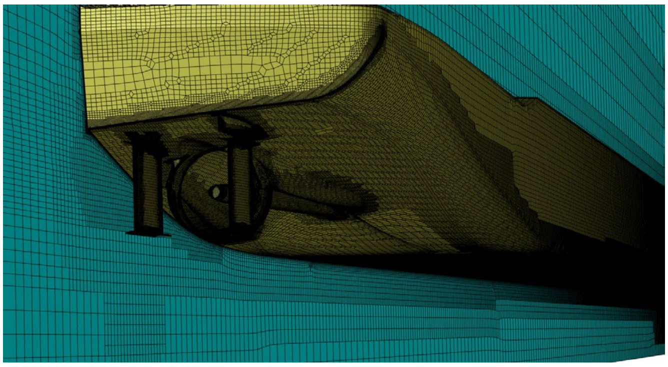
The required powers have also been calculated for two frequently occurring drafts and speeds.

The analyzes are done in FineMarine version 10.2 This is a CFD package that has proven similarity to reality. At Sip Marine it is used for every critical application and has ensured successful applications over the past 10 years.

The propellers in all applied models are represented by actuator disk models. These are disk-shaped areas in the fluid domain in which momentum is added to the passing water, in both axial and tangential direction. The applied rotation from the propeller is thus modeled sufficiently accurately..

Modeling

The 3D CAD model is loaded as half ship in the Hexpress mesher. This fills the fluid domain with cubic cells. Refinement takes place in details, such as thin layers on the surface (viscous layers, with which turbulence on the wall is well described) and, for example, square corners, such as the mirror edge. In total, about 5 million cells are created in this model



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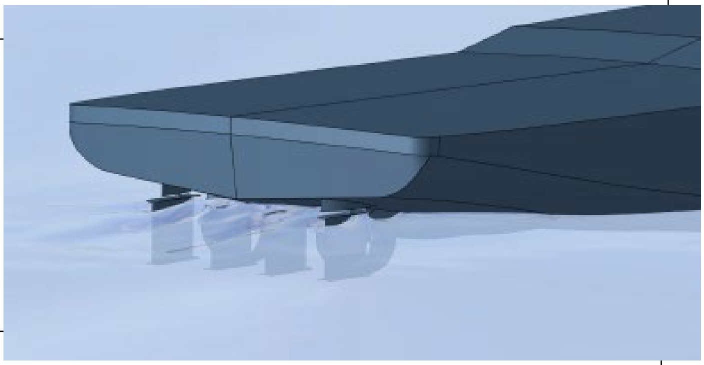
6.1 Key figures

Reference length: 135 [m] Reference speed: 17.0 [km/h] = 6.722 [m/ s] Fresh water: ρ = 998.4 [kg/m3]; μ = 0.001043 [Pa.s]
Froude: Fr = 0.1298

Reynolds: Re = 6.099*10-8
Power: 230 [kW] * (η = 0.95) = 218.5 [kW] Rotations per minute: 1800 [rpm]

Propellor diameter: 1600 [mm]



1. Water depth: 5 [m]
2. Empty:
    a. Displacement: 1184784 [kg]
    b. LCB: 64.293 [m]
    c. Draft: Taft = 1.3 [m]; Tfore = 0.55 [m]
    d. Speed: vS = 17 [km/h] = 4.722 [m/s]
3. Fully loaded:
    a. Displacement: 5025284 [kg]
    b. LCB: 67.895 [m]
    c. Draft: Taft = 3.5 [m]; Tfore = 3.5 [m]
    d. Speed: vS = 12 [km/h] = 3.333 [m/s]

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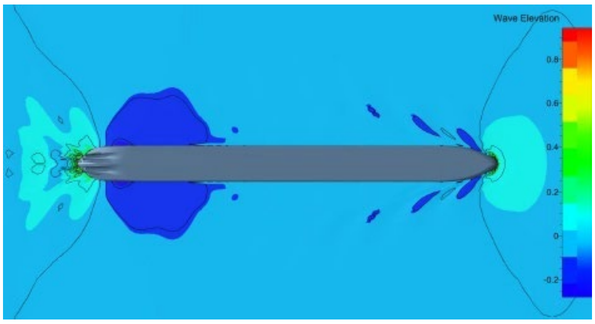
6.2 Results loaded and unloaded.

From here the results follow, first unloaded, then loaded.
The calculation has a 2-phase fluid. This means that the ratio of air and water is always included in the calculation. During the build-up over time of the flow results (especially the velocity components and the pressures), the amount of air and water also results. This also makes it possible to monitor the water surface and the amount of air. When sailing empty, in particular, the air in the tunnel can be followed. The wave formation can of course also be followed faithfully.

Result: wave formation sailing empty.

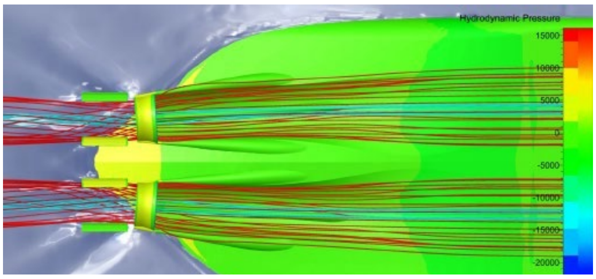
In empty sailing condition there is a bow wave of 0.9 [m].

At the stern, the waterline creeps up to 0.525 [m] from the stationary waterline. That is the impoundment from the propellor wake.



Origin propellor wake, empty

All the water from the propeller comes from the face. The entry angle is well directed into the nozzle.
From the propeller you can clearly see the helical outflow between the rudders.



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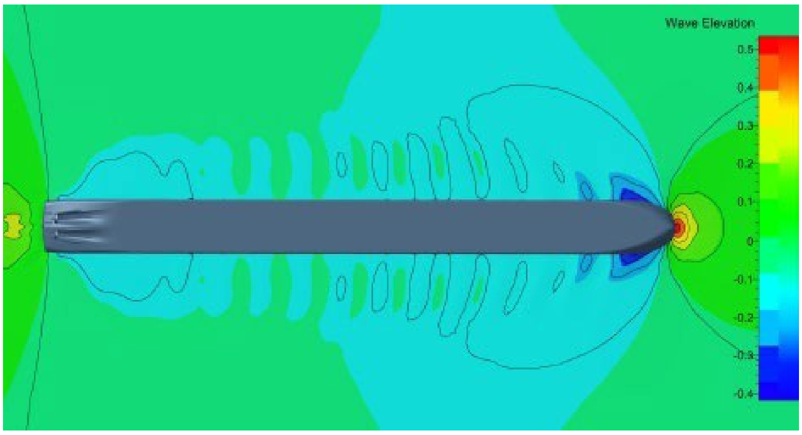
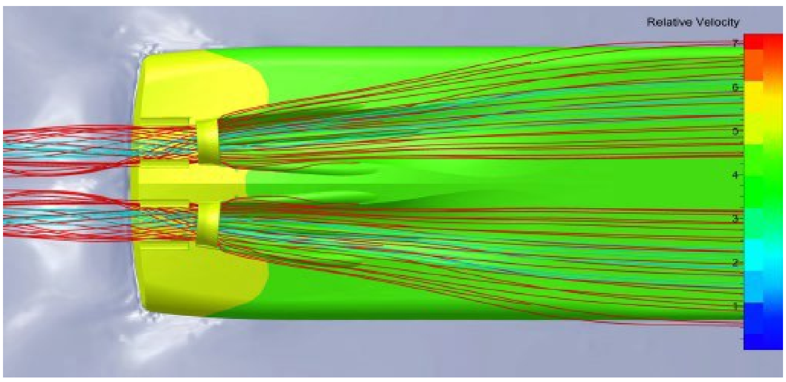
Result: wave formation sailing with cargo.

In loaded sailing condition, there is a bow wave (impediment) of 0.53 [m]. The wave through drops to -0.41 [m].
At the stern the waterline creeps up to 0.015 [m] from the stationary waterline.
In the wake, the backwater rises from the propellers to 0.23 [m].



Origin of water to the propellor, loaded



Almost all the water towards the propeller comes from under the keel. The entry angle is well directed into the nozzle.
From the propeller you can clearly see the helical outflow between the rudders.

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Results F.D. Resistance and power demand.

Unloaded sailing at (17 km/h):

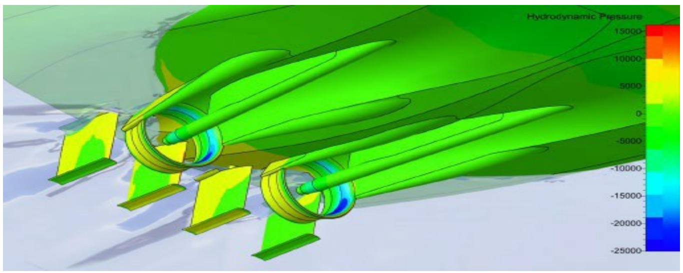
The resistance is R/2 = -19091.0 [N]
The contribution of the nozzle in this is Tnoz = +5376.2 [N] The screw+nozzle combination must yield: Ttotaal = -R/2+Tnoz = 24467.2 [N]

The power demand for this thrust, now including 5% surcharge for wind load, accretion, non-flat water, etc. is: Per propeller = 184 [kW].

Fully loaded sailing at maximum draft (12 km/h):

The resistance is R/2 = -14729.5 [N]
The contribution of the nozzle in this is Tnoz = +5735.3 [N] The screw+nozzle combination must yield: Ttotaal = -R/2+Tnoz = 20464.8 [N]

The power demand for this thrust, now including 5% surcharge for wind load, accretion, non-flat water, etc. is: Per propeller = 114 [kW].



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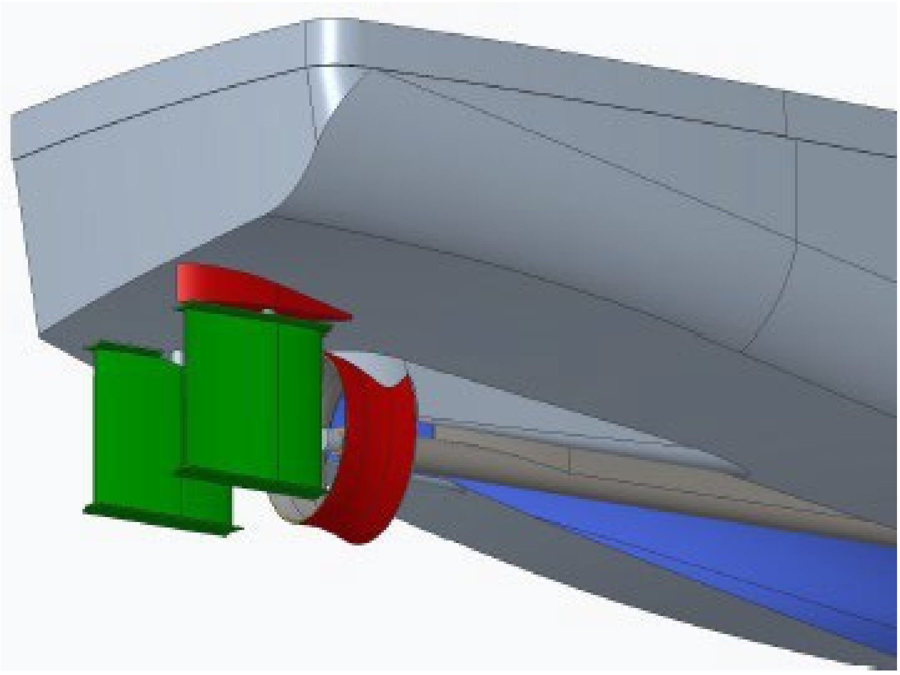
7 Updated geometry of the propellor tunnels.

The geometry of the tunnel has been adjusted.

It turned out that the tunnel edges, while protruding at the same depth and following the same direction, can be even thinner. Their rear surface and drag is thus reduced.



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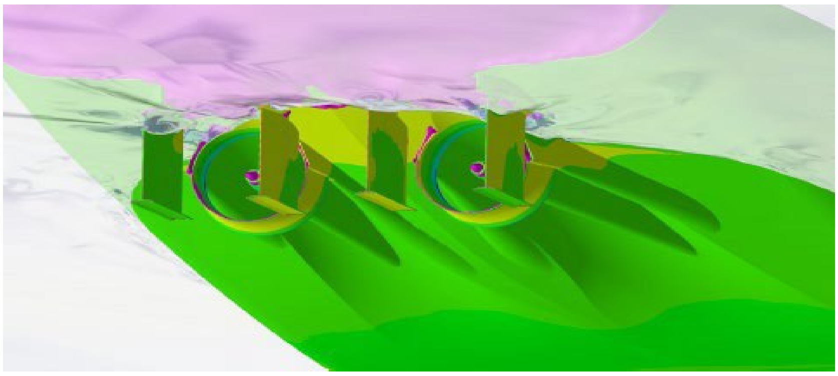
8. Conclusion on the fluid dynamics calculation.

For the analyzed cases: full sailing at 12 [km/h] and empty sailing at 17 [km/h], it is recommended to propel at about 300 [kW] to bridge the resistance found.

Ultimately, the ship has a relatively low drag, good nozzle operation and little wake, with a sufficiently large buoyancy.

The wake areas on the nozzle are concealed by making them thinner. Other wake areas, such as within the headboxes, are not always present. This is undesirable in the empty sailing part of the voyage because they would demand that the headboxes lean inwards when loaded. There they will impede the propeller outflow. The small wake area between the nozzles is also not an energy-consuming phenomenon anymore.



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9. Elaboration of propulsion data.

It is good to note that the data generated from the historical data is supported by the results from the fluid dynamics calculation. From this combined data is the table “Power absorbed by the propellers per sailing hour.” composed.

Power absorbed by the propellers per sailing hour.

Operating	hours	between	400	and	500 KW	4 H
Operating	hours	between	350	and	400 KW	8 H
Operating	hours	between	300	and	350 KW	0 H
Operating	hours	between	250	and	300 KW	0 H
Operating	hours	between	200	and	250 KW	21 H
Operating	hours	between	150	and	200 KW	22 H
Operating	hours	between	0	and	150 KW	0 H

The waiting time of 2.25 hours at locks does not consume any power in terms of drive, this time can be used for recharging the battery bank.

It should be noted that during the hours between 350 and 400 KW, no more than 368 KW is absorbed.

It has thus been established that the power consumed by the propellers for the drive is between 150 and 250 KW for the largest number of hours (43.5 hours). Also 8 hours 368 KW and four hours a peak power of 468 KW is required.

In addition to the power absorbed by the propellers, electrical power is used for the ship's systems and the

hotel consumption. This amounts to approximately 8 – 20 KW/ hour. Bow thruster power is also used during lock passages and maneuvers in ports.

We also take into account the system losses of the electric drive. Together with the necessary frequency controllers, the system consumes 40 kW per hour.

By correctly choosing the dimensions of the battery pack to be installed, the FC can be used optimally, while sufficient power remains available to deliver peak powers.

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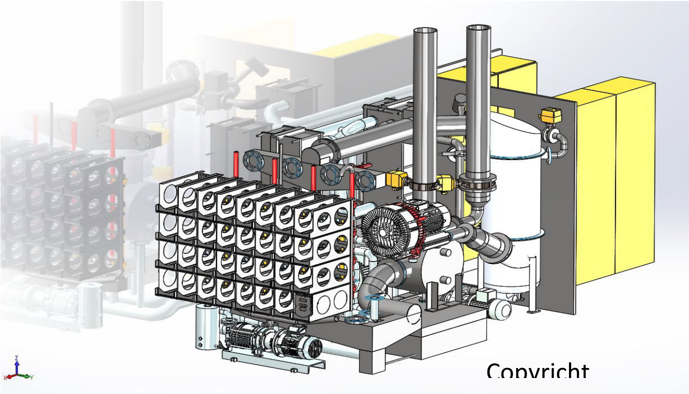
10. User Friendly.

The basic principle is that the hydrogen-powered ship responds to the skipper's input as he is used to from conventional ships. This means that fast power must be available for maneuvers in connection with expected nautical conditions.

The fact that the waterway manager demands that the ship can be kept stationary at all times also requires quickly available power for the bow thrusters and main drive.

Efficiency

A dual fuel option has been considered, but the efficiency of a combustion engine with 30% efficiency can be called meager compared to the efficiency of a fuel cell system with 50% after deducting the FC system losses. The advantage in terms of return more than makes up for the higher investment costs of the FC.
This makes the choice for a Fuelcell system clear.



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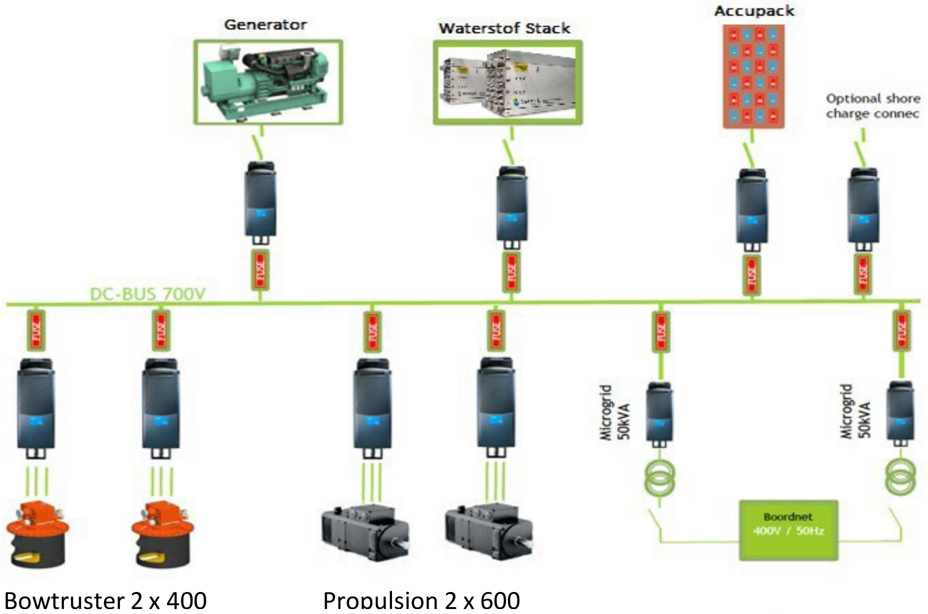
11. Electrical System Configuration.

Since a fuel cell system generates electricity, the connection with the other systems is easy to realize.

We prefer a 700V DC bus system.



The following systems are linked to this system:

- Fuel cell
- 2 x electric drive system
- 2 x bow thruster
- battery pack
- 2 x microgrid for the onboard systems and hotel load.
- Backup generator system

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12. PEM Fuelcell 300 KwE output.

The systems must at least meet the following specifications and be suitable to function in an inland vessel in the chosen configuration. All systems must also be approved by the Shipping Inspectorate and Lloyds.

Voltage DC to the grid:	600 – 750 V DC
Voltage DC stack output:	390 – 820 V DC
Current DC stack output:	0 – 800 A
Power to the grid:	300 KwE nominal
Hydrogen consumption:	17 kg/h @ 275 kwe @ BOL 23 kg/h @ 275 kwe @ EOL
Dynamics: power from	0-100% in 5 seconds
Starting:	Fuel cell fully available to the grid within 5 minutes
Lifetime:	Stacks al least 30.000 hrs. Total plant at least 100.000 hrs
Cooling:	Heat exchanger.
Dimensions:	Should not be larger than 4 x 2,5 x 3 meter (L, W, H)
System availability:	95 % per year

Remote response time in case of reported failure: Immediate

Response at the location if necessary: 2 hours during working hours 4 hours out of working hours

Training and familiarizing:	40 hours

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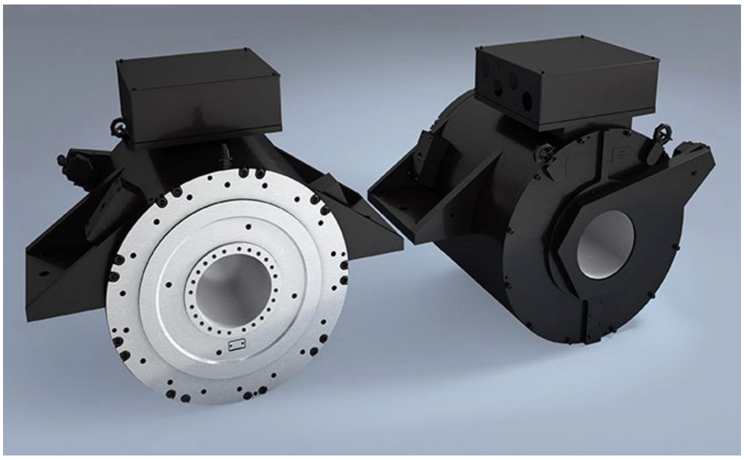
2 x 600 KWE electric motor.

Two propellers in nozzles, driven by High Torque Electric Motors mounted directly on the propeller shaft and equipped with an integrated thrust bearing.

Nominal power per propellorshaft: 600 KW
Torque: 35000 NM
Cooling by means of heatexchanger
Safety: IP 32



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14. Battery Pack.

Capacity 1000 KwH. lithium NMC or similar.

Cycle Life at 80% D.O.D and 80% E.O.L.	>4.600 cycles at 1C charge/discharge
Cycle Life at 50% D.O.D and 80% E.O.L	>20.000 cycles at 1C charge/discharge
Cycle Life at 20% D.O.D and 80% E.O.L	>75.000 cycles at 1C charge/discharge
Max Charge	0,5C
Max Discharge	1.0C
Module Voltage Minimum	45V
Module Voltage Nominal	52V
Module Voltage Maximum	58V
Balancing Type (BMS)	Continuously Active Balancing
Certification	DNV-GL Type Approval NMA Level 1 Propagation Approval
Communication	ModBus, CANbus or Hardwired
I/O	
Cooling	Ambiant cooling
Racking	Steel

Clean Hydrogen Partnership

Co-funded by the European Union

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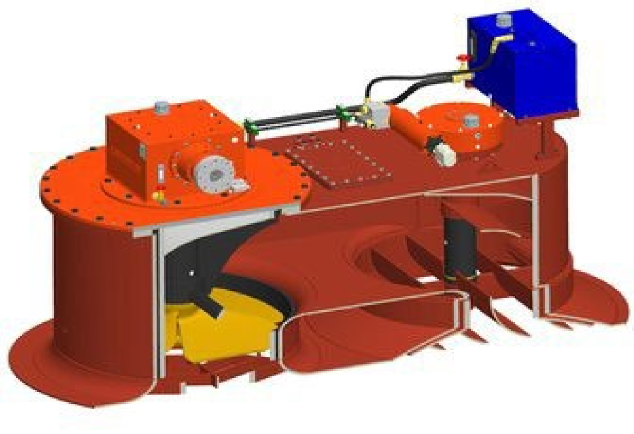
15. Double steering grid bowthruster system.



Bow thruster type	Steering grid
Number of bow thrusters	2
Applied power	400 kW [550 HP]
Applied speed	1800 RPM
Application	Bowthruster (auxiliary) 4 : 1
Propellor diameter	1280 mm
Screw class	II (ISO 484-2:1981)
Tip speed	30 m/s
Electric motor type	Squirrel-cage motor
Power	404 kW
Rpm	1800 RPM
Voltage	440 V
Frequency	60 Hz
Operating time	30 minutes
Protection	IP 32

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In order to be able to absorb the required amount of 1200 kg of hydrogen on board the ship, we opt for existing technology.
Namely storage under high pressure. H_2 containers are offered in the market, with high-pressure bottles, T3 or T4, in which hydrogen is stored under high pressure. Six containers are purchased, three of which are on board the ship and three at the filling station. The containers that are offered are ADR approved. In order to be allowed to use these containers on board the ship as a fuel tank, they must undergo a 'marine approved' inspection. And an upgrade of the safety systems.

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18. End sheet.

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For more information about Clean Hydrogen Partnership please visit website:

www.clean-hydrogen.europa.eu/media/visual-indentity_en

For more information about WEVAproject.nl please visit

WWW.WEVAproject.nl

Written and signed off by;

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C.E.O. Harm H.A. Lenten

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