WEVA1

The first Hydrogen – Electric Cargoschip Antonie

Specificaties voor de H2 aandrijving van het WEVA1 schip.

D 2.17 Design specifications of the FC-powered Barge boat.

Artist impression FC-powered barge boat 'Antonie'.

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FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

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.

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.

Historical data of energy consumption per round trip.

Since Lenten Scheepvaart BV has been carrying out transports on the Delfzijl – Rotterdam route with a comparable ship since April 2008, a lot of historical data has been collected regarding the fuel consumption per round trip. The fact that the ship sails on a fixed route and the hydrogen-powered ship will be deployed on the same route in the future also provides major advantages compared to a situation in which the ship would be deployed in tramp shipping.

Example raw data.

Reis no;	Zout reis no:	begin datum	leeg datum	totaal dagen	van	naar	lading	geladen MT	Smeerolie peil	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

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

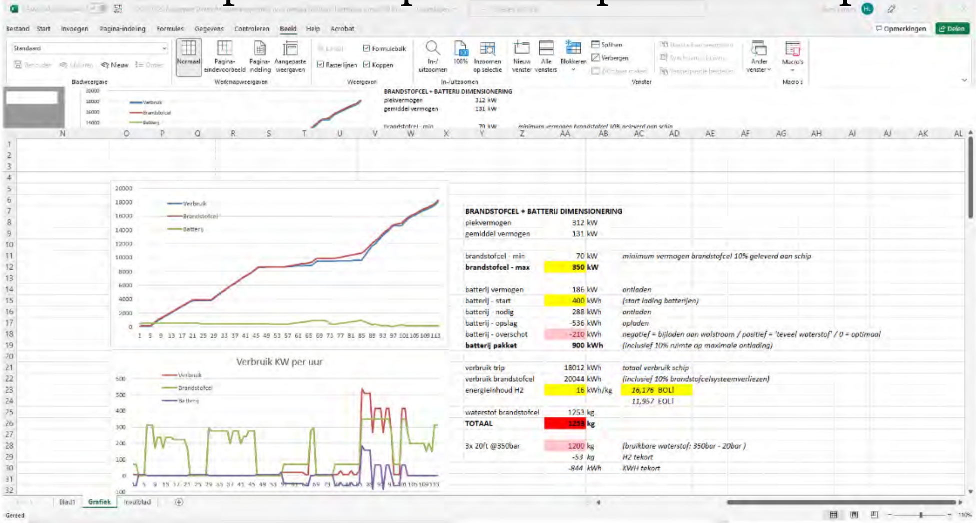


Table power requirement per round trip

Traject	uren cumulatief			Instantaan [kWh]			Cumulatief [kWh]				
	Dag	uur/dag		Verbruik	FCE	RESS	Lading	Verbruik	FCE	RESS	KG H2
Laden Delfzijl	1	1	1	8	70	-62	462	8	70	-62	0,6
Laden Delfzijl Verhalen		2	2	8	70	-62	524	16	140	-124	1,1
Nacht		3	3	8	0	8	516	24	140	-116	1,7
Nacht		4	4	8	0	8	508	32	140	-108	2,2
Nacht		5	5	8	0	8	500	40	140	-100	2,8
Geladen Delfzijl - Groningen		6	6	312	312	0	500	352	452	-100	24,2
Geladen Delfzijl - Groningen		7	7	312	312	0	500	664	764	-100	45,7
Geladen Delfzijl - Groningen		8	8	312	312	0	500	976	1076	-100	67,1
Geladen Groningen - Lemmer sluispassage		9	9	170,5	170,5	0	500	1147	1247	-100	78,8
Geladen Groningen - Lemmer		10	10	235	235	0	500	1382	1482	-100	95,0
Geladen Groningen - Lemmer		11	11	235	235	0	500	1617	1717	-100	111,1
Geladen Groningen - Lemmer sluispassage		12	12	170,5	170,5	0	500	1787	1887	-100	122,9
Geladen Groningen - Lemmer		13	13	235	235	0	500	2022	2122	-100	139,0
Geladen Groningen - Lemmer		14	14	235	235	0	500	2257	2357	-100	155,2
Geladen Groningen - Lemmer		15	15	235	235	0	500	2492	2592	-100	171,3
Geladen Groningen - Lemmer		16	16	223	223	0	500	2715	2815	-100	186,7
Geladen Groningen - Lemmer		17	17	223	223	0	500	2938	3038	-100	202,0
Geladen Groningen - Lemmer		18	18	223	223	0	500	3161	3261	-100	217,3
Geladen Groningen - Lemmer		19	19	223	223	0	500	3384	3484	-100	232,7
Geladen Groningen - Lemmer		20	20	223	223	0	500	3607	3707	-100	248,0
Geladen Groningen - Lemmer sluispassage		21	21	170,5	170,5	0	500	3777,5	3877,5	-100	259,7
Nacht		22	22	8	0	8	492	3785,5	3877,5	-92	260,3
Nacht		23	23	8	0	8	484	3793,5	3877,5	-84	260,8
Nacht		24	24	8	0	8	476	3801,5	3877,5	-76	261,4
Nacht	2	1	25	8	0	8	468	3809,5	3877,5	-68	261,9
Nacht		2	26	8	0	8	460	3817,5	3877,5	-60	262,5
Nacht		3	27	8	0	8	452	3825,5	3877,5	-52	263,0
Nacht		4	28	8	0	8	444	3833,5	3877,5	-44	263,6
Geladen Lemmer - Vreeswijk		5	29	296	296	0	444	4129,5	4173,5	-44	283,9
Geladen Lemmer - Vreeswijk		6	30	276	276	0	444	4405,5	4449,5	-44	302,9
Geladen Lemmer - Vreeswijk		7	31	276	276	0	444	4681,5	4725,5	-44	321,9
Geladen Lemmer - Vreeswijk		8	32	276	276	0	444	4957,5	5001,5	-44	340,8
Geladen Lemmer - Vreeswijk sluispassage		9	33	276	276	0	444	5233,5	5277,5	-44	359,8
Geladen Lemmer - Vreeswijk		10	34	276	276	0	444	5509,5	5553,5	-44	378,8
Geladen Lemmer - Vreeswijk		11	35	276	276	0	444	5785,5	5829,5	-44	397,8
Geladen Lemmer - Vreeswijk		12	36	276	276	0	444	6061,5	6105,5	-44	416,7
Geladen Lemmer - Vreeswijk sluispassage		13	37	197	197	0	444	6258,5	6302,5	-44	430,3

Geladen Lemmer - Vreeswijk		14	38	276	276	0	444	6534,5	6578,5	-44	449,2
Geladen Lemmer - Vreeswijk		15	39	276	276	0	444	6810,5	6854,5	-44	468,2
Geladen Lemmer - Vreeswijk		16	40	276	276	0	444	7086,5	7130,5	-44	487,2
Geladen Lemmer - Vreeswijk sluispassage		17	41	197	197	0	444	7283,5	7327,5	-44	500,7
Geladen Vreeswijk - Schoonhoven		18	42	241	241	0	444	7524,5	7568,5	-44	517,3
Geladen Vreeswijk - Schoonhoven		19	43	241	241	0	444	7765,5	7809,5	-44	533,9
Geladen Vreeswijk - Maashaven		20	44	276	276	0	444	8041,5	8085,5	-44	552,9
Geladen Vreeswijk - Maashaven		21	45	276	276	0	444	8317,5	8361,5	-44	571,8
Geladen Vreeswijk - Maashaven		22	46	276	276	0	444	8593,5	8637,5	-44	590,8
Nacht		23	47	8	0	8	436	8601,5	8637,5	-36	591,4
Nacht		24	48	8	0	8	428	8609,5	8637,5	-28	591,9
Nacht	3	1	49	8	0	8	420	8617,5	8637,5	-20	592,5
Nacht		2	50	8	0	8	412	8625,5	8637,5	-12	593,0
Nacht		3	51	8	0	8	404	8633,5	8637,5	-4	593,6
Nacht		4	52	8	0	8	396	8641,5	8637,5	4	594,1
Nacht		5	53	8	0	8	388	8649,5	8637,5	12	594,7
Nacht		6	54	8	0	8	380	8657,5	8637,5	20	595,2
Nacht		7	55	8	0	8	372	8665,5	8637,5	28	595,8
Nacht		8	56	20	0	20	352	8685,5	8637,5	48	597,1
Wachttijd		9	57	20	70	-50	402	8705,5	8707,5	-2	598,5
Wachttijd		10	58	20	70	-50	452	8725,5	8777,5	-52	599,9
Wachttijd		11	59	20	70	-50	502	8745,5	8847,5	-102	601,3
Wachttijd		12	60	20	70	-50	552	8765,5	8917,5	-152	602,6
Wachttijd		13	61	20	70	-50	602	8785,5	8987,5	-202	604,0
Wachttijd		14	62	20	70	-50	652	8805,5	9057,5	-252	605,4
Wachttijd		15	63	20	70	-50	702	8825,5	9127,5	-302	606,8
Wachttijd		16	64	20	70	-50	752	8845,5	9197,5	-352	608,1
Wachttijd		17	65	8	70	-62	814	8853,5	9267,5	-414	608,7
Wachttijd		18	66	8	70	-62	876	8861,5	9337,5	-476	609,2
Geladen Maashaven - Botlek		19	67	276	276	0	876	9137,5	9613,5	-476	628,2
Geladen Maashaven - Botlek		20	68	296	296	0	876	9433,5	9909,5	-476	648,6
Nacht		21	69	8	0	8	868	9441,5	9909,5	-468	649,1
Nacht		22	70	8	0	8	860	9449,5	9909,5	-460	649,7
Nacht		23	71	8	0	8	852	9457,5	9909,5	-452	650,2
Nacht		24	72	8	0	8	844	9465,5	9909,5	-444	650,8
Nacht	4	1	73	8	0	8	392	9473,5	9909,5	8	651,3
Nacht		2	74	8	0	8	384	9481,5	9909,5	16	651,9
Nacht		3	75	8	0	8	376	9489,5	9909,5	24	652,4
Opladen - Nacht		4	76	8	70	-62	438	9497,5	9979,5	-38	653,0
Opladen - Nacht		5	77	8	70	-62	500	9505,5	10049,5	-100	653,5
Verhalen (15 min)		6	78	28	70	-42	542	9533,5	10119,5	-142	655,4
Lossen		7	79	8	70	-62	604	9541,5	10189,5	-204	656,0
Lossen		8	80	8	70	-62	666	9549,5	10259,5	-266	656,5
Lossen		9	81	8	70	-62	728	9557,5	10329,5	-328	657,1
Verhalen (15 min)		10	82	28	70	-42	770	9585,5	10399,5	-370	659,0
Lossen		11	83	8	70	-62	832	9593,5	10469,5	-432	659,6
Lossen		12	84	8	70	-62	894	9601,5	10539,5	-494	660,1
Lossen		13	85	28	70	-42	936	9629,5	10609,5	-536	662,0
Leegvaart Rotterdam - Vreeswijk		14	86	536	350	186	750	10165,5	10959,5	-350	698,9
Leegvaart Rotterdam - Vreeswijk		15	87	508	350	158	592	10673,5	11309,5	-192	733,8
Leegvaart Rotterdam - Vreeswijk		16	88	508	350	158	434	11181,5	11659,5	-34	768,7
Leegvaart Rotterdam - Vreeswijk		17	89	508	350	158	276	11689,5	12009,5	124	803,7
Leegvaart Rotterdam - Vreeswijk sluispassage		18	90	267	350	-83	359	11956,5	12359,5	41	822,0
Leegvaart Vreeswijk - Lelystad		19	91	416	350	66	293	12372,5	12709,5	107	850,6
Leegvaart Vreeswijk - Lelystad		20	92	416	350	66	227	12788,5	13059,5	173	879,2
Leegvaart Vreeswijk - Lelystad		21	93	416	350	66	161	13204,5	13409,5	239	907,8
Leegvaart Vreeswijk - Lelystad sluispassage		22	94	267	350	-83	244	13471,5	13759,5	156	926,2
Leegvaart Vreeswijk - Lelystad		23	95	416	350	66	178	13887,5	14109,5	222	954,8
Leegvaart Vreeswijk - Lelystad		24	96	416	350	66	112	14303,5	14459,5	288	983,4
Leegvaart Vreeswijk - Lelystad sluispassage	5	1	97	267	267	0	112	14570,5	14726,5	288	1001,7
Opladen - Nacht		2	98	8	70	-62	174	14578,5	14796,5	226	1002,3
Opladen - Nacht		3	99	8	70	-62	236	14586,5	14866,5	164	1002,8
Opladen - Nacht		4	100	8	70	-62	298	14594,5	14936,5	102	1003,4
Leegvaart Lelystad - Lemmer		5	101	416	350	66	232	15010,5	15286,5	168	1032,0
Leegvaart Lelystad - Lemmer		6	102	416	350	66	166	15426,5	15636,5	234	1060,6
Leegvaart Lelystad - Lemmer sluispassage		7	103	267	267	0	166	15693,5	15903,5	234	1078,9
Leegvaart Lemmer - Groningen		8	104	199	199	0	166	15892,5	16102,5	234	1092,6
Leegvaart Lemmer - Groningen		9	105	199	199	0	166	16091,5	16301,5	234	1106,3
Leegvaart Lemmer - Groningen		10	106	199	199	0	166	16290,5	16500,5	234	1120,0
Leegvaart Lemmer - Groningen		11	107	199	199	0	166	16489,5	16699,5	234	1133,7
Leegvaart Lemmer - Groningen		12	108	199	199	0	166	16688,5	16898,5	234	1147,3
Leegvaart Lemmer - Groningen		13	109	199	199	0	166	16887,5	17097,5	234	1161,0
Leegvaart Lemmer - Groningen Sluispassage		14	110	150,5	150,5	0	166	17038	17248	234	1171,4
Leegvaart Lemmer - Groningen		15	111	199	199	0	166	17237	17447	234	1185,0
Leegvaart Lemmer - Groningen Sluispassage		16	112	150,5	150,5	0	166	17387,5	17597,5	234	1195,4
Leegvaart Groningen - Delfzijl		17	113	312	312	0	166	17699,5	17909,5	234	1216,8
Leegvaart Groningen - Delfzijl		18	114	312	312	0	166	18011,5	18221,5	234	1238,3
Laden Delfzijl		19	115	8	70	-62	228	18019,5	18291,5	172	1238,8
Laden Delfzijl		20	116	8	70	-62	290	18027,5	18361,5	110	1239,4
Laden Delfzijl Verhalen		21	117	28	70	-42	332	18055,5	18431,5	68	1241,3
Laden Delfzijl		22	118	8	70	-62	394	18063,5	18501,5	6	1241,9
Laden Delfzijl Verhalen		23	119	28	70	-42	436	18091,5	18571,5	-36	1243,8
Laden Delfzijl		24	120	28	70	-42	478	18119,5	18641,5	-78	1245,7

Fluid dynamics calculation.

We have commissioned Sip Marine to optimize the ship design line plan by means of a fluid dynamics program.

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

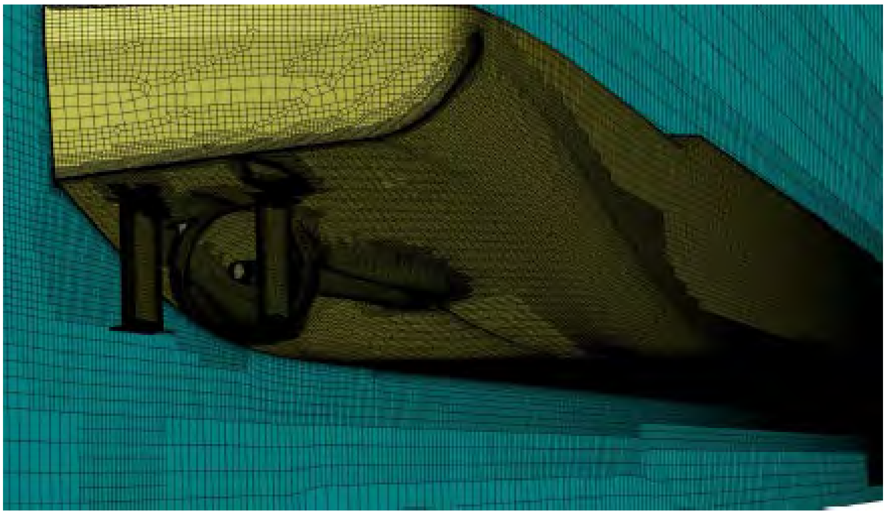
The analyzes are done in FineMarine version 10.2

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.

De schroeven in alle toegepaste modellen worden gerepresenteerd door actuator disk modellen. Dit zijn in het vloeistofdomein schijfvormige gebieden waarin aan het passerende water impuls wordt toegevoegd, in zowel axiale als tangentiële richting. De aangebrachte rotatie vanuit de schroef wordt daarmee voldoende nauwkeurig gemodelleerd.

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.



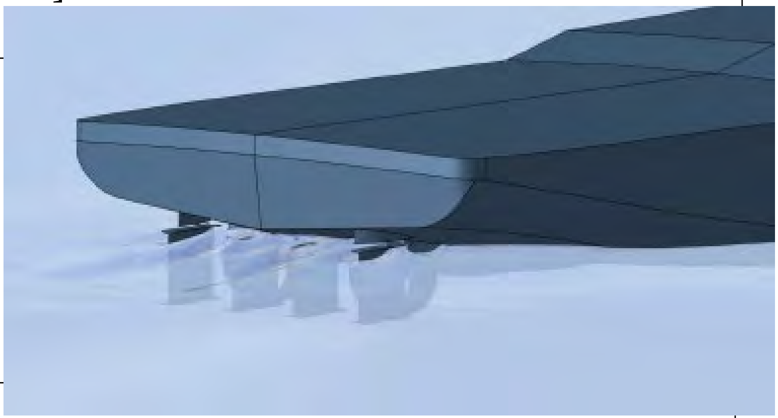
Key figures

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]



Loading conditions

1. Water depth: 5 [m]
2. Empty:
   a. Displacement: 1184784 [kg]
   b. LCB: 64.293 [m]
   c. Diepgang: Taft = 1.3 [m]; Tfore = 0.55 [m]
   d. Snelheid: 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]

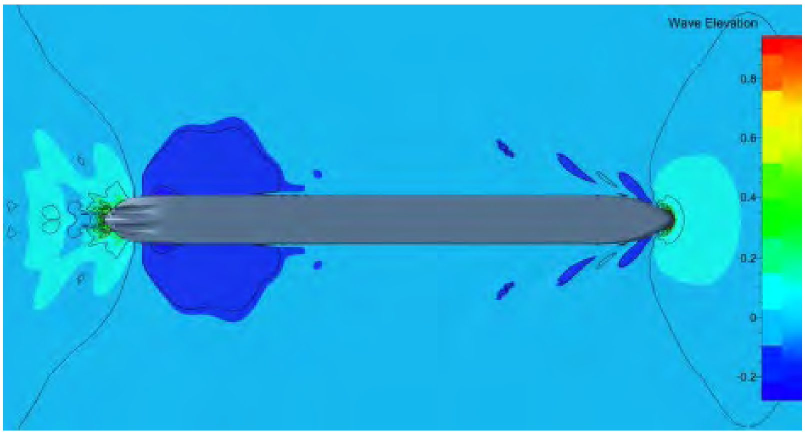
Results

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.

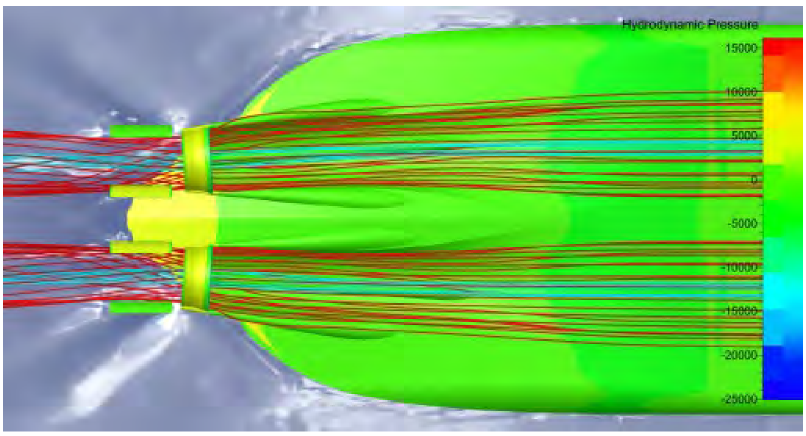
In empty sailing condition there is a bow wave of 0.9 [m].

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.

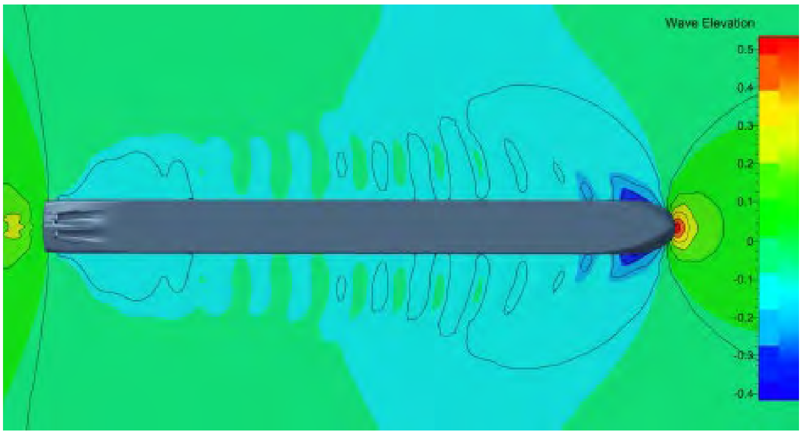


Result: wave formation charged sailing

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.

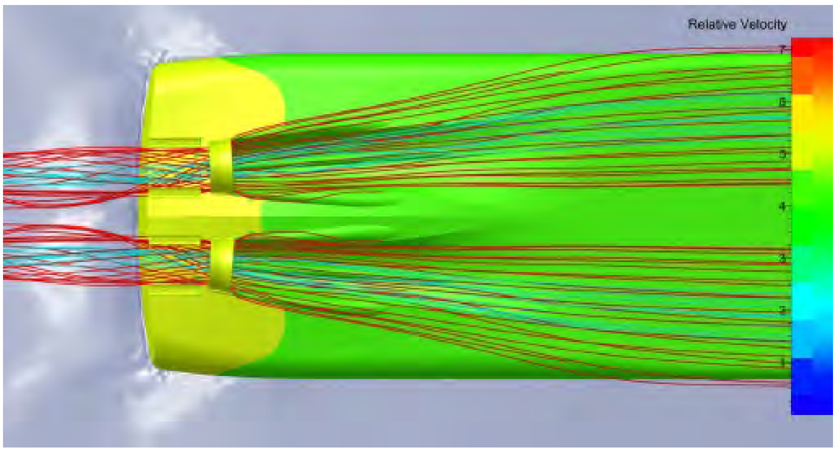
In the wake, the backwater rises from the propellers to 0.23 [m].



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.



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]

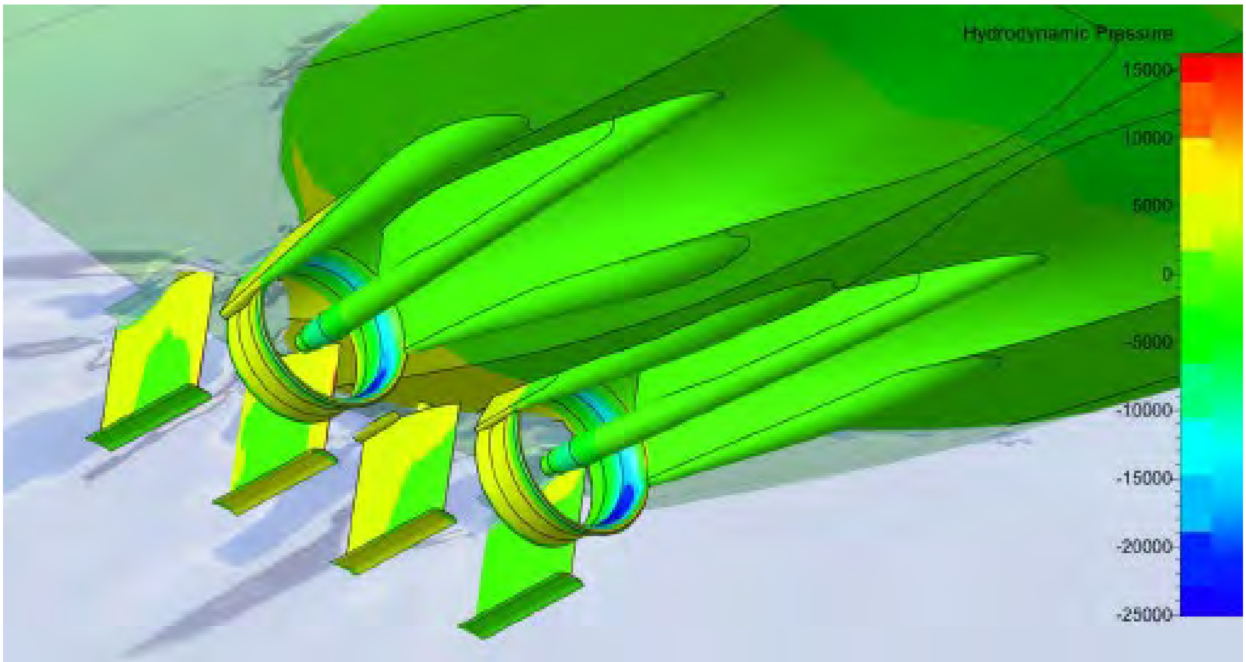
The power demand for this thrust, now including 5% surcharge for wind load, accretion, non-flat water, etc. is: Per propeller = 184 [kW].

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]

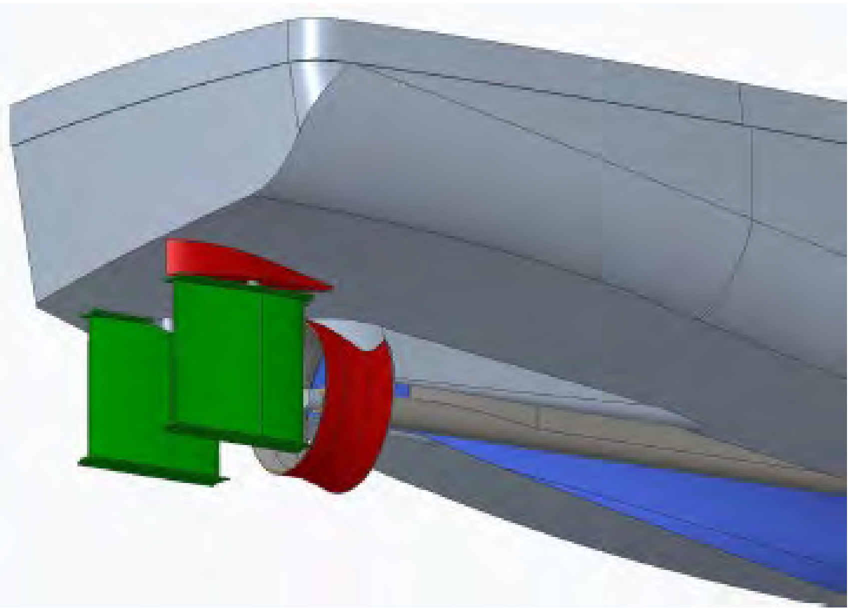
The power demand for this thrust, now including 5% surcharge for wind load, accretion, non-flat water, etc. is: Per propeller = 114 [kW].

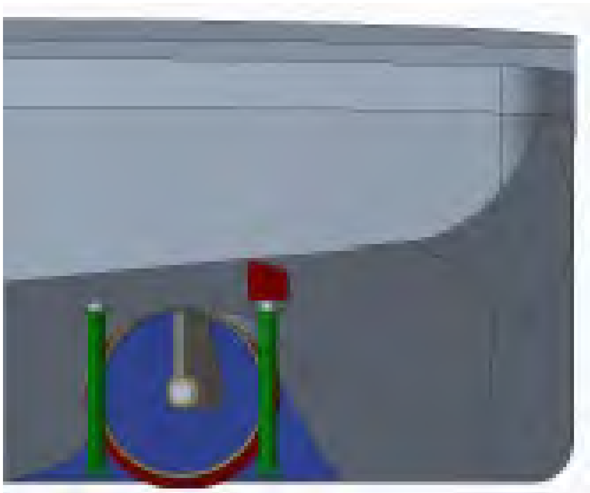


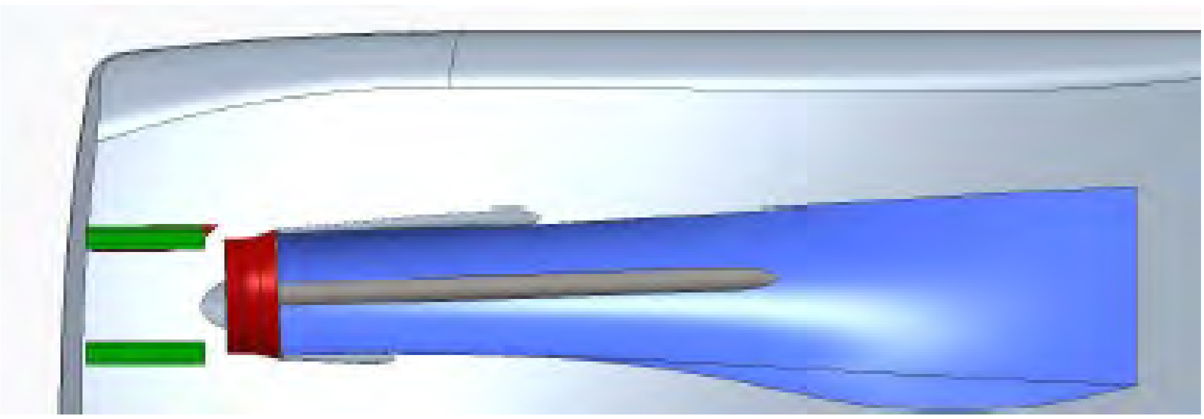
Update of geometry tunnels due to design.

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 is thus reduced.





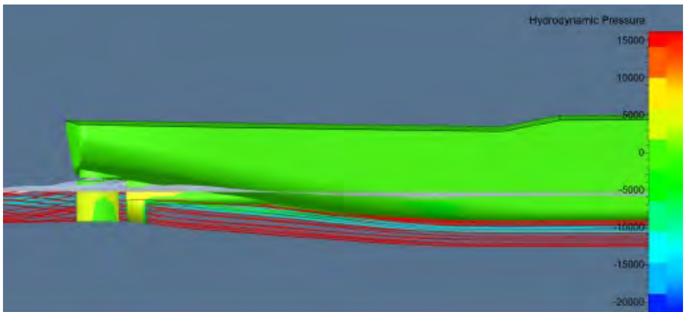


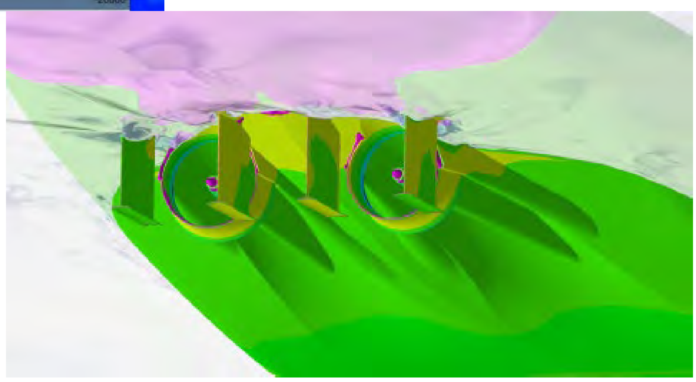
Conclusion on the fluid dynamics calculation.

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. The flow speed there is low and it is a slowly swirling area, which contains little energy due to the low speed.





Elaboration of 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 en 500 KW	4
Operating hours between 350 en 400 KW	8
Operating hours between 300 en 350 KW	0
Operating hours between 250 en 300 KW	0
Operating hours between 200 en 250 KW	21,5
Operating hours between 150 en 200 KW	22
Operating hours between 0 en 150 KW	0

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.

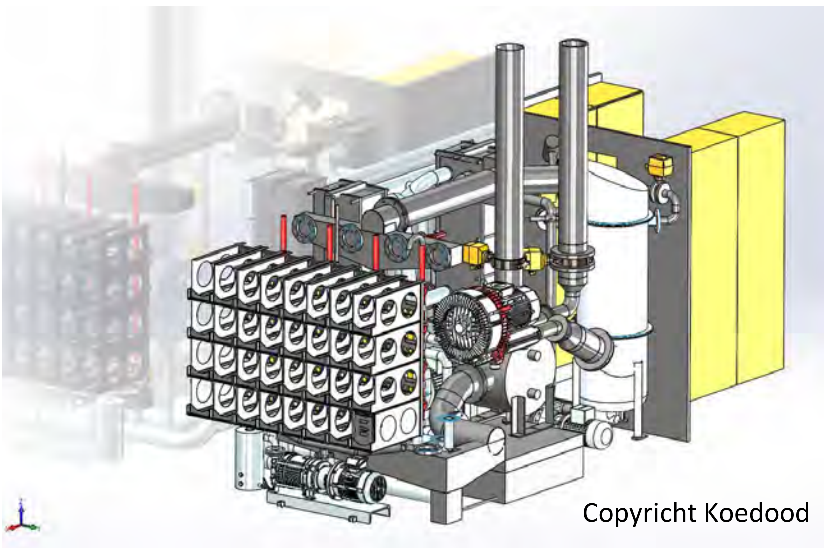
User friendly

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 the Fuelcell clear.



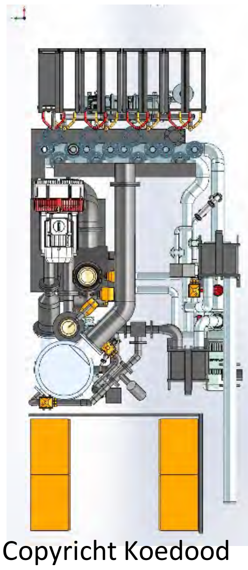
Electrical System Configuration

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 the crew quarters and ship's galley
- Backup generator system

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.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PEM Fuelcell 350 KWe output

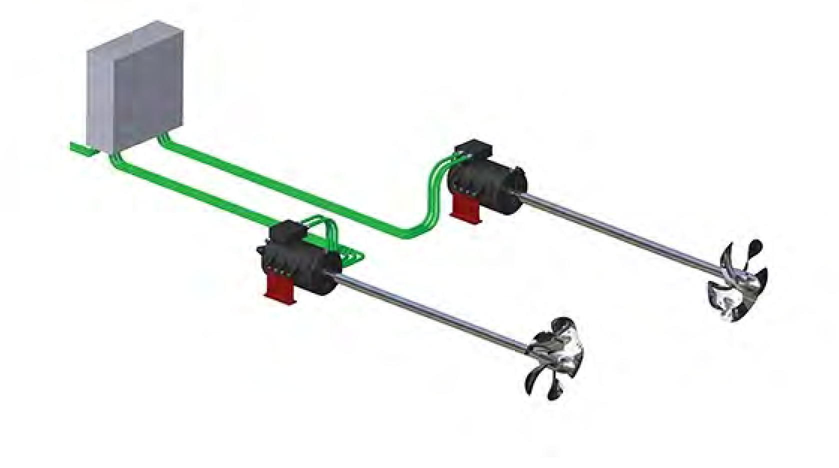
Should not be larger than 4 x 2,5 x 3 meter (L, W, H)

Voltage DC to the grid:	600 -750 V DC
Voltage DC stack output:	390-820 V DC
Current DC stack output:	0 - 800 A (align with Oechies)
Power to the grid:	350 kWe nominal
Hydrogen consumption:	16 kwh / H2
Dynamics:	power from 0-100% in 5 seconds.
Starting:	Fuel cell fully available to the grid within 5 minutes
Lifetime:	Stacks al least 25.000 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)

Warranty	1 year
System availability	95 % per year
Remote response time in case of reported failure	immediate
Response at the location in case necessary	2 hours during working hours 4 hours out of working hours
Training	40 hours

Main drive

2 x 600 KW.



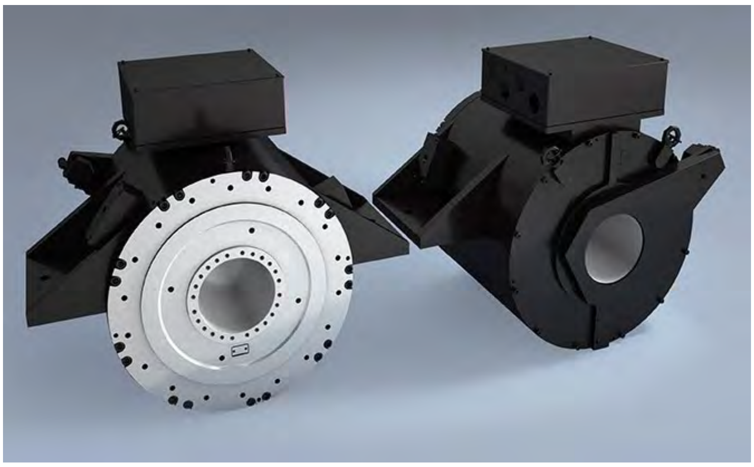
Two propellers in nozzles, driven by High Torque Electric Motors mounted directly on the propeller shaft and equipped with an integrated thrust bearing.

Nominal power per propellor shaft: 600 KW

Torque: 35000 NM

Cooling by means of heat exchanger.

Safety: IP 32



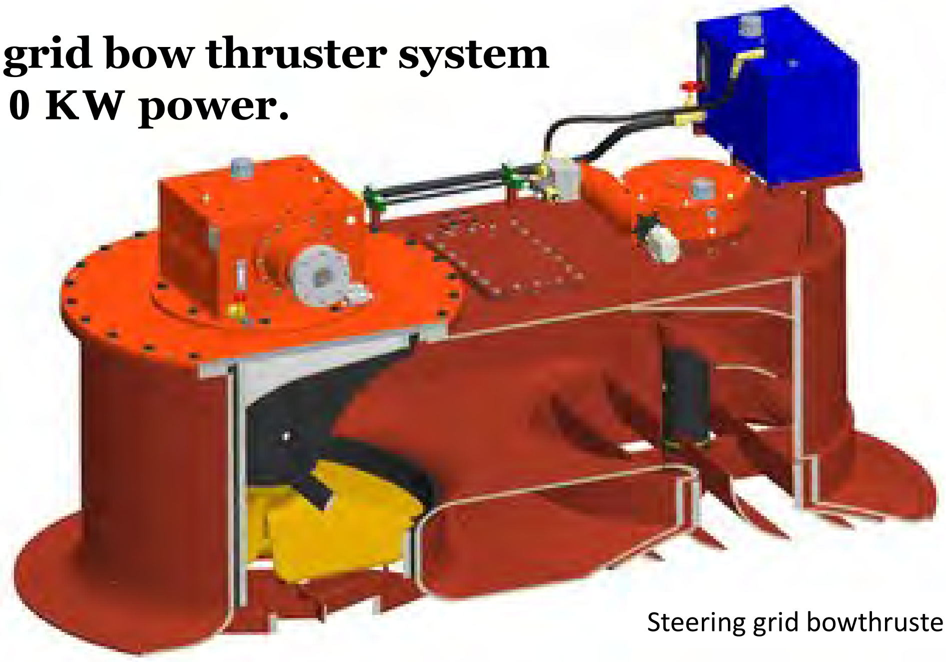
Battery pack

Capacity 1000 KwH.

lithium NMC or similar.

Capacity	1000 MwH
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	1C
Max Discharge	1.5C
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	Heat exchanger Cooled
Gas Exhaust System	Stainless steel
Racking	Aluminum

A Steering grid bow thruster system with 2 x 400 KW power.



Steering grid bowthruster

Bow thruster type	Steering grid
Number of bow thrusters	2
Applied power	400 kW [550 PK]
Applied speed	1800 RPM
Application	Bowthruster (hulpbedrijf) 4 : 1
Propellor diameter	1280 mm
screw class	II (ISO 484-2:1981)
Tipspeed	30 m/s
Electric motor type	Squirrel-cage motor
Number	2
Power	404 kW
Rpm	1800 RPM
Voltage	440 V
Frequency	60 Hz
Bedrijfsduur	S2
Bescherming	30 minuten
	IP23

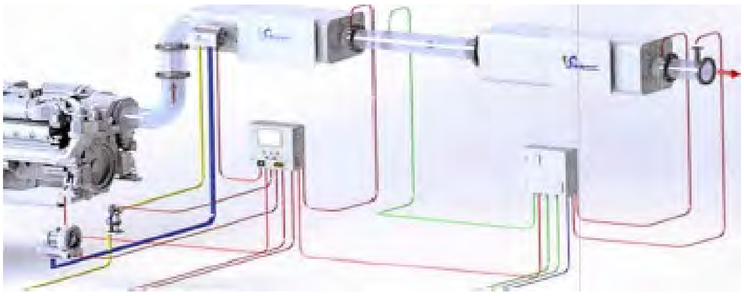
Two microgrids of 60 KvA.

A backup generator system of approx.600 KW.

Certification Stage V

Kooling Heat exchanger

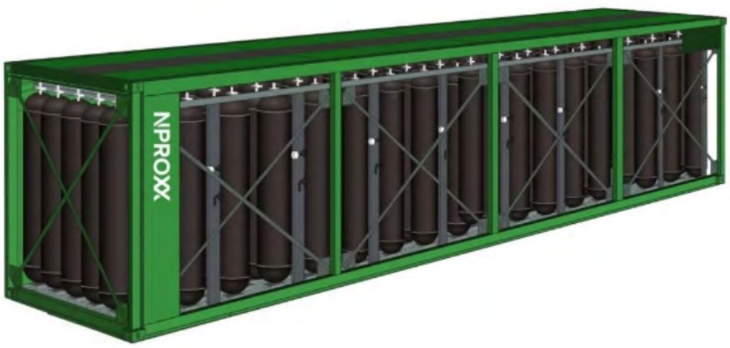
Aftertreatment DPF and NoX catalysator



Example Stage V
After treatment system.

Hydrogen storage system.

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. H2 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.



FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

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HEAVENN