UNIVERSITÀ DEGLI STUDI DI TRIESTE

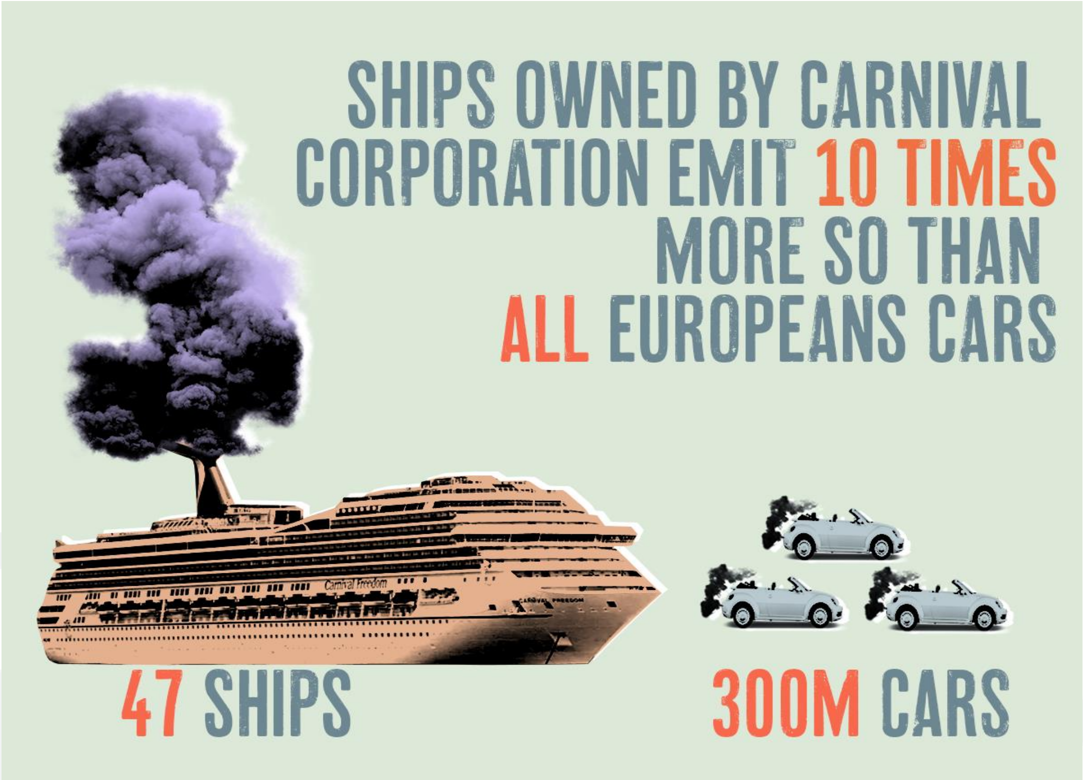
ISD LAB INTEGRATED SHIP DESIGN

Riconvertire la motorizzazione di navi in operatività

Vittorio Bucci

TRIESTE, 3 SETTEMBRE 2021

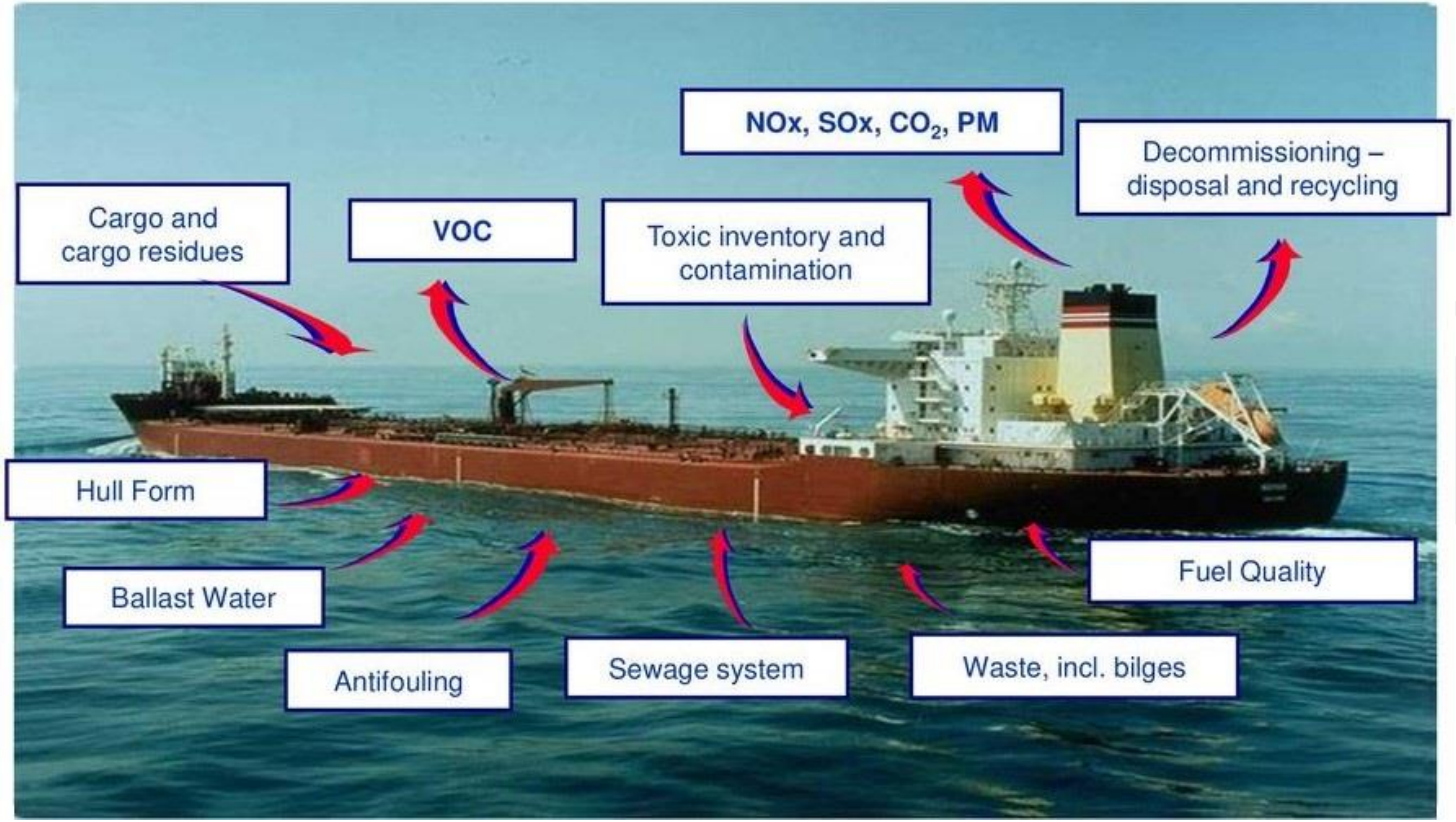
CLOSE UP 1/4



Ma è tutto vero?

È tutto qui?

CLOSE UP 2/4

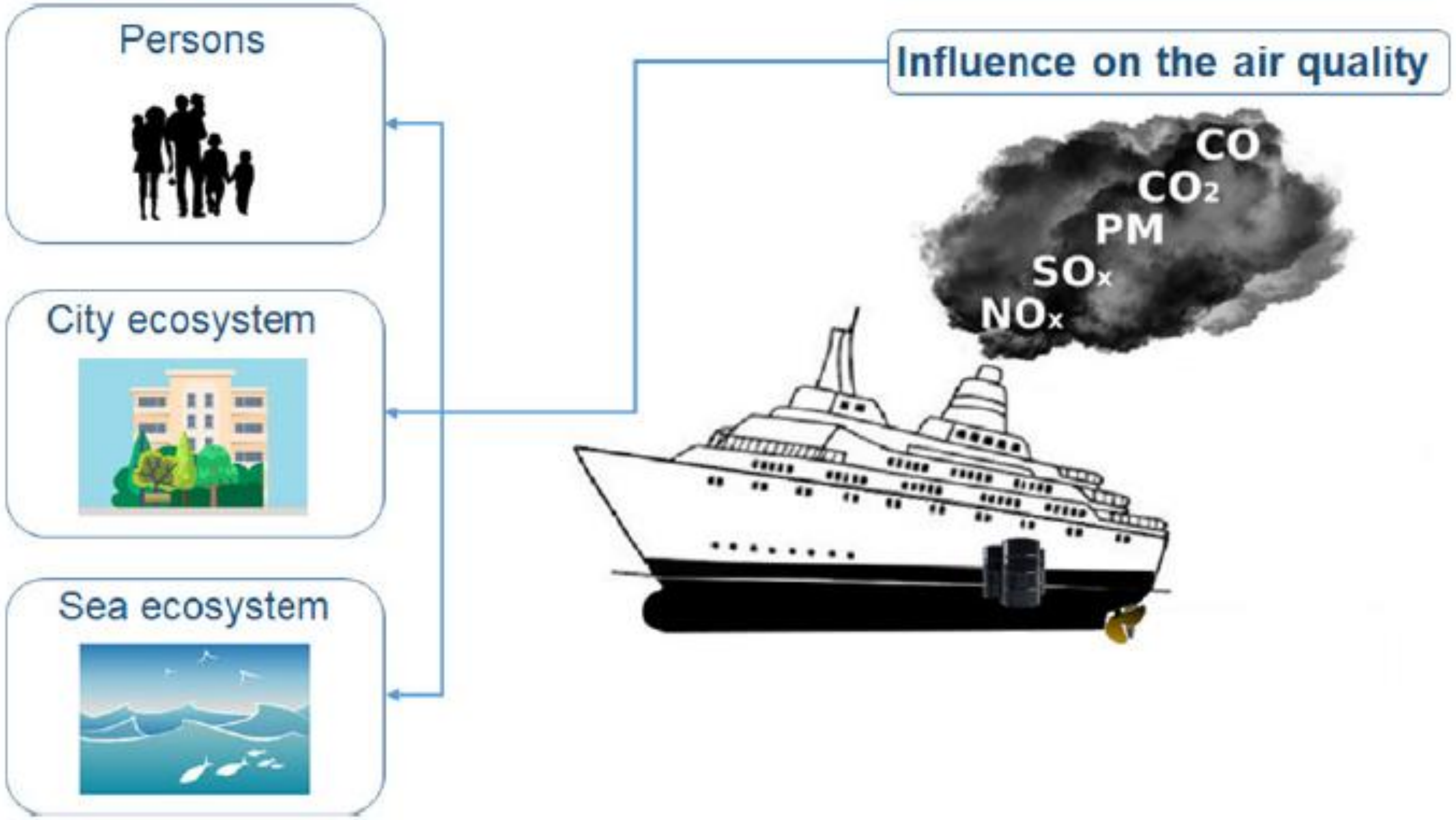


NOx, SOx, CO_2, PM
Decommissioning – disposal and recycling
Cargo and cargo residues
VOC
Toxic inventory and contamination
Hull Form
Ballast Water
Antifouling
Sewage system
Waste, incl. bilges
Fuel Quality

CLOSE UP 3/4

Conseguenze sull'ambiente:

- Piogge acide
- Eutrofizzazione acque interne
- Ozono al livello del suolo
- Buco dell'ozono
- Metalli pesanti nel cibo
- Effetto serra



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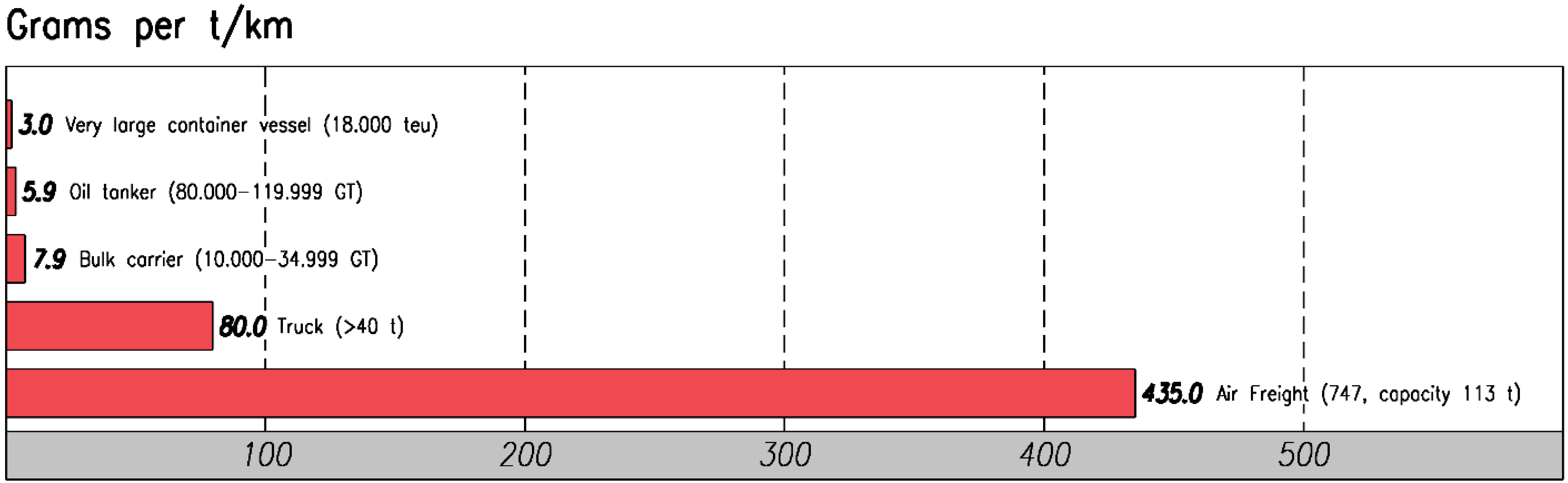
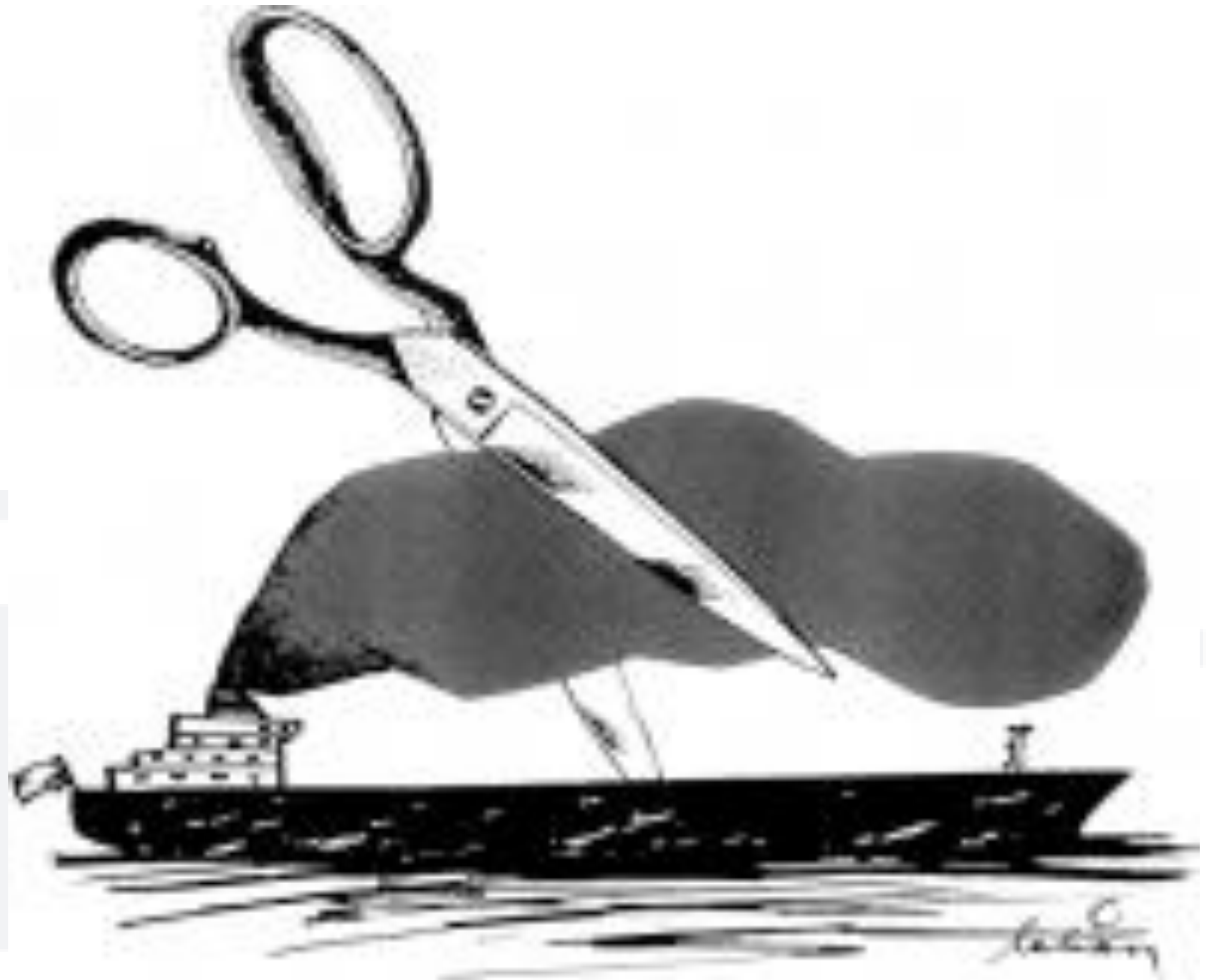


90% delle merci è trasportato via mare

Circa 25 milioni di persone all’anno

GREEN SHIPBUILDING 1/2



- **Green Shipbuilding**
  - Green Ship
  - Green Design
  - Green Logistics

Green shipbuilding aims to minimize the offal and harmful emissions during design, manufacturing, service and laying up in order to reduce the pollution to air, water and soil, save resources and improve economic and social benefits.

GREEN SHIPBUILDING 2/2

MARPOL Annex VI, Chapter 4 adopted July 2011, entered into force January 2013

2013	2015	2020	2025	2030		2050
Regulations enter into force for over 94% of wolrd fleet	*EEDI requires new ships to meet agreed efficiency targets*	*New ships must improve efficiency 10%*	*New ships must improve efficiency up to 20%*	*New ships must improve efficiency 30%*		
Ship Energy Efficiency Management Plan (SEEMP): mandatory implementation for all ships		*20% CO_2 reduction per t/km (industry goal)*				*50% CO_2 reduction per t/km (industry goal)*

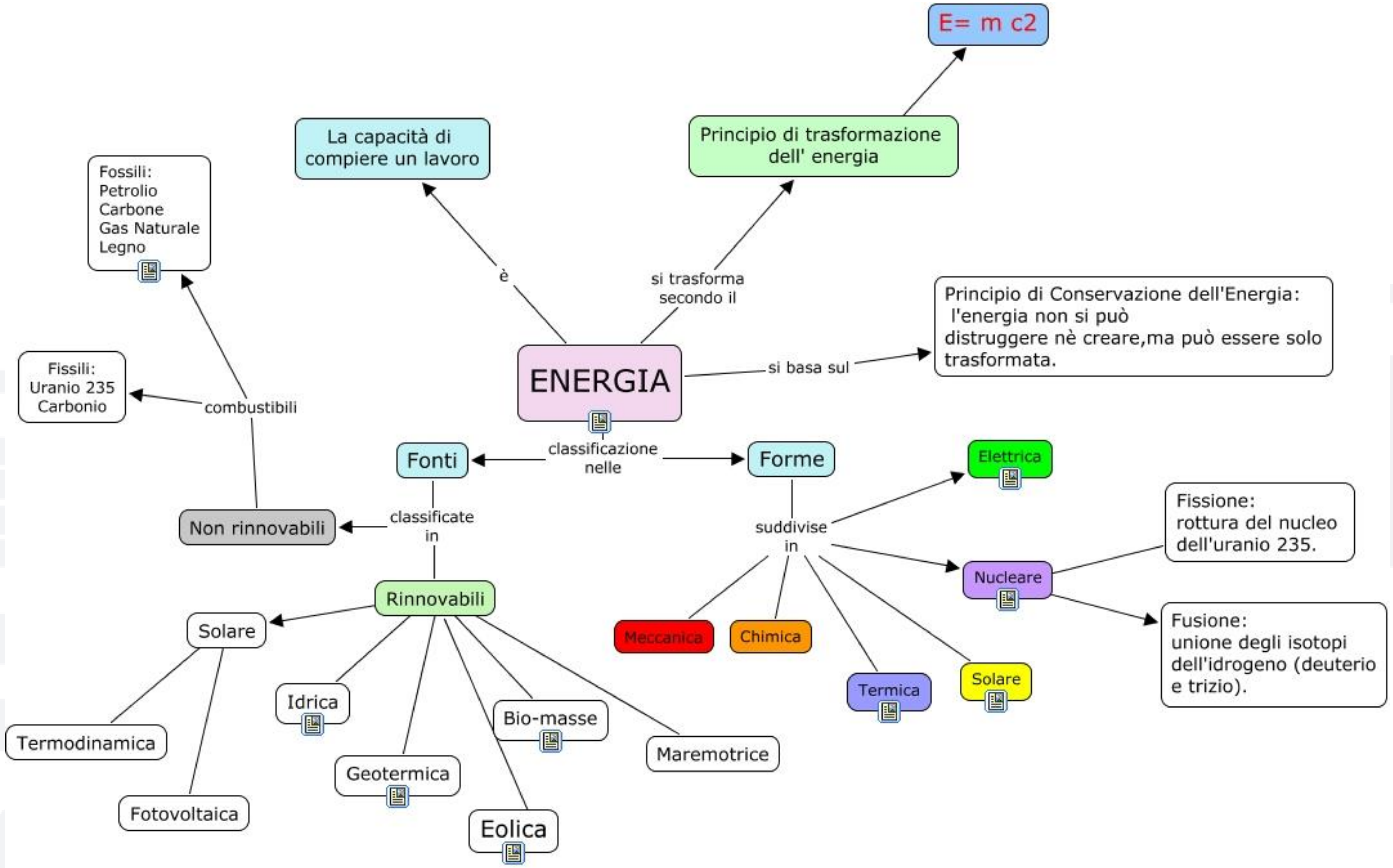
GREEN SHIP 1/33

Ogni unità navale deve gestire in modo autonomo la propria energia.

- Immagazzinare
- Convertire
- Distribuire
- Utilizzare

I diversi sistemi di bordo richiedono diverse forme di energia:

- Chimica
- Termica
- Elettrica
- Meccanica



GREEN SHIP 2/33

Tipo di nave	Potenza propulsiva [MW]	Potenza ausiliari [MW]		
		Servizi propulsione e generali	Potenza per funzioni operative	Totale potenza ausiliari
Porta contenitori (7000 TEU)	50÷70	2,5÷5	3,5÷6,5	6÷11,5
Porta contenitori (300 TEU)	2÷5	0,3÷1	0,3÷1	0,6÷2
Carico misto	5÷10	0,5÷1	0,5÷1,5	1÷2,5
Unità semi sommergibile	7,5÷12,5	1÷3	1,5÷3	2,5÷6
Peschereccio oceanico	5÷10	0,5÷1,5	2,5÷5	3÷6,5
Draga	15÷25	1÷3	12÷14	13÷17
Nave crociera	15÷40	0,6÷2	3÷8	3,6÷10
Fregata	20÷40	0,6÷1,2	0,3÷0,6	0,9÷1,8

GREEN SHIP 3/33

Macchina trasformatrice	Rendimenti [%]
Turbina a vapore	25 ÷ 30
Turbina a gas (ciclo semplice)	28 ÷ 34
Motore diesel (medium speed sovralimentato)	38 ÷ 52

Un ciclo di Carnot operante tra le stesse temperature estreme 300 K e 1500 K ha un rendimento di circa 80%

$$\eta = \frac{T_1 - T_2}{T_1}$$

GREEN SHIP 4/33

<u>Tre strategie di base</u>:

- Cambiare combustibile (fuel switch)
- Installazione di impianti di trattamento dei gas di scarico
- Elettrificazione dei mezzi navali (hybrid systems)

<u>Buone pratiche per incrementare l'efficienza delle navi:</u>

- Riduzione della velocità
- Upgrade dei propulsori e delle appendici di carena
- Pulizia di carena più frequente
- Vernici per ridurre l'attrito e il fouling di carena
- Recupero energetico
- Ottimizzazione assetto e zavorra
- Weather routing

GREEN SHIP 5/33

Fuel switch

Green hydrogen is an essential element in most synthetic fuels, but as a standalone fuel it will play a niche role due to its low energy density by volume and complex storage. In short-sea shipping with strict emissions legislation and frequent bunker opportunities can offset the low energy density.

Green ammonia will mostly be seen in deep-sea shipping as the investment required has a relatively lower impact on the business case. Due to its relatively low energy density by volume, it will mostly be feasible for vessels that don't have space limitations. Local availability and price can also make it viable for short-sea shipping. The toxicity of green ammonia is a challenge that will make it less suitable for passenger vessels, and rules and regulations will have a significant impact on required investment.

Green methanol is an interesting alternative with an easy storage onboard, although the fuel price will likely be higher due to higher production energy demands. As well as being toxic for humans, it is also explosive, although not in an aquatic environment. Methanol has already been used as a marine fuel (Stena Germanica). Its low energy density is compensated for by the ease of storage – the fuel tanks can take any shape. Green methanol production requires CO2, and one of the main uncertainties for green synthetic methane is carbon capture.

<u>NOTE</u>

Green implies a synthetic fuel based on hydrogen that is produced using renewable energy, or a fuel produced from sustainable biomass

GREEN SHIP 6/33

Fuel switch

Green biomethane is likely the most economical alternative for both deep-sea and short-sea shipping due to the maturity of the technology, fuel availability, existing rules and regulations, the fact that it's a good alternative for ECA compliance, the availability of feedstock for biomethane and its higher carbon efficiency than biodiesel. As biomethane is pure methane, it can also be used as a drop-in alternative to natural gas and its energy density is relatively high compared to hydrogen-based fuels (except for synthetic methane).

Green synthetic methane only differs from biomethane in its production, i.e. it is synthetically produced from green hydrogen and CO_2. The main uncertainty relates to the carbon capture technology. Due to the low concentration of CO_2 in air, the only likely economically viable solution will be capturing CO_2 in exhaust gases from the combustion of biofuels (not fossil fuels).

Biodiesels can already be used today in diesel engines without the need for additional investment, provided they comply with the fuel specification. Variations in local availability and price are the main challenges, as there will be competition from other industries that are ready to pay a premium.

NOTE

Green implies a synthetic fuel based on hydrogen that is produced using renewable energy, or a fuel produced from sustainable biomass

GREEN SHIP 7/33

Fuel switch

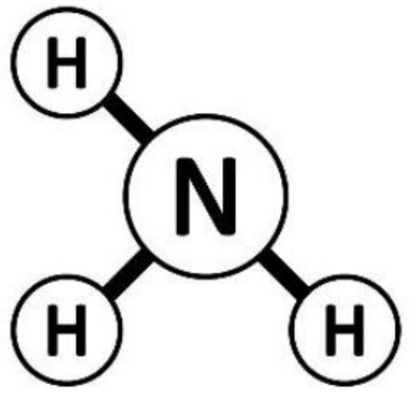
	Methane	Ammonia	Methanol	Hydrogen
Boiling temperature	-162 degC	-33 degC	64.7 degC	-253 degC
Density at boiling temperature	450 kg/m3	680 kg/m3	748 kg/m3	71 kg/m3
Flammability limits in air by volume	5-15%	15-28%	6.7-36%	4-75%
Auto – ignition temperature	595 degC	651 degC	470 degC	571 degC
Lower Heating value	49.6 MJ/kg	18.6 MJ/kg	19.9 MJ/kg	119 MJ/kg
Energy in 1 m3	22320 MJ	12648 MJ	14885 MJ	8500 MJ

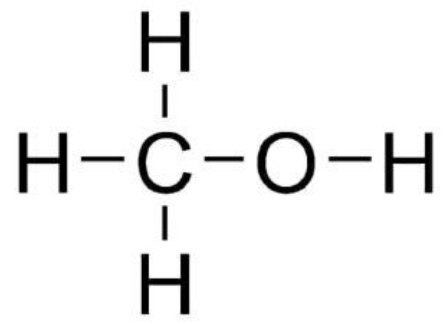
GREEN SHIP 8/33

Fuel switch

0.57 m^3 of oil fuel	=	1 m^3 of LNG	=	1.7 m^3 of NH_3	=	1.5 m^3 of CH_3OH	=	2.6 m^3 of H_2
1	:	1,7 X	:	2,9 X	:	2,6 X	:	4,5 X

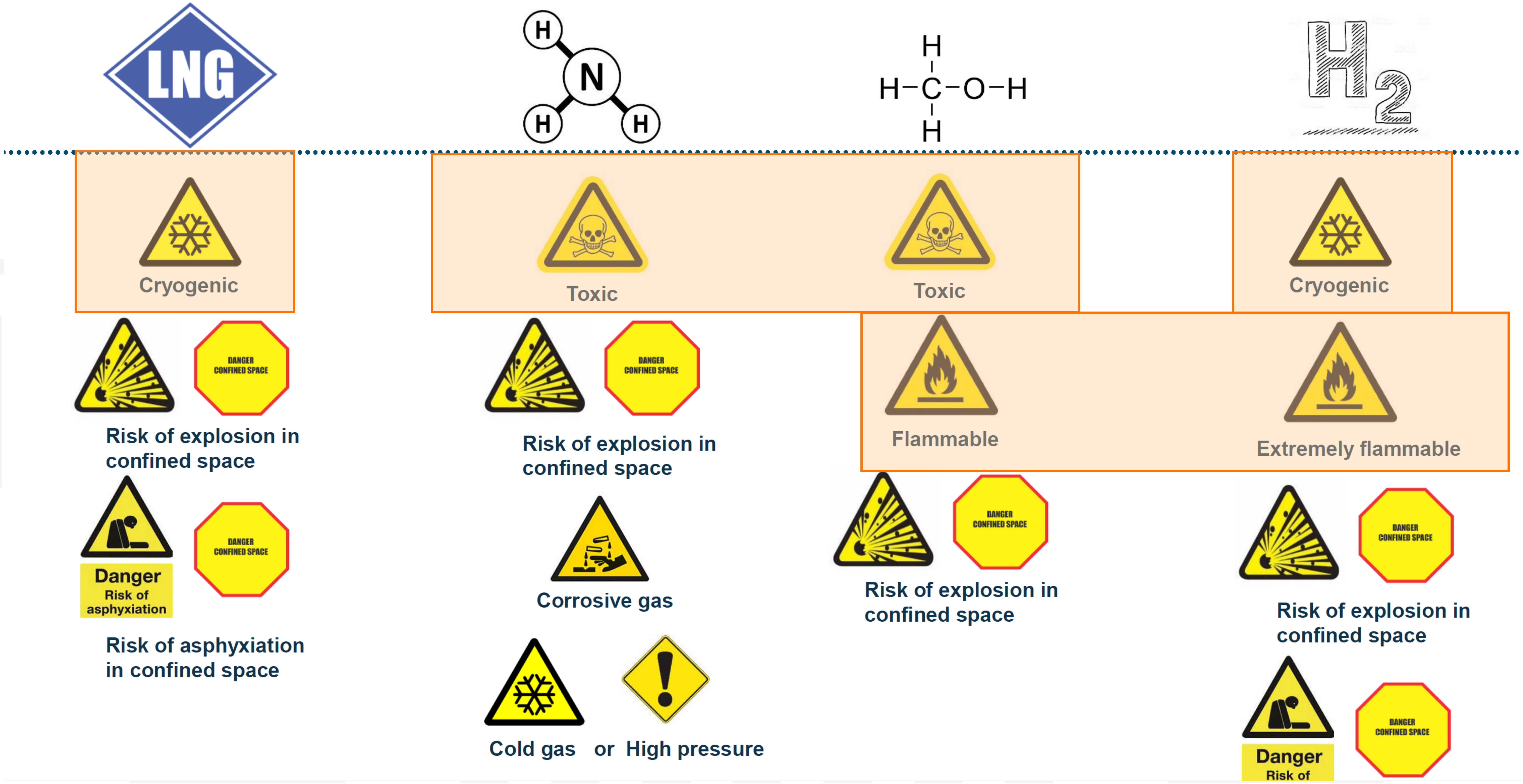
LNG





GREEN SHIP 9/33

Fuel switch



GREEN SHIP 10/33

Fuel cell

MOST PROMISING FC TECHNOLOGIES FOR MARINE

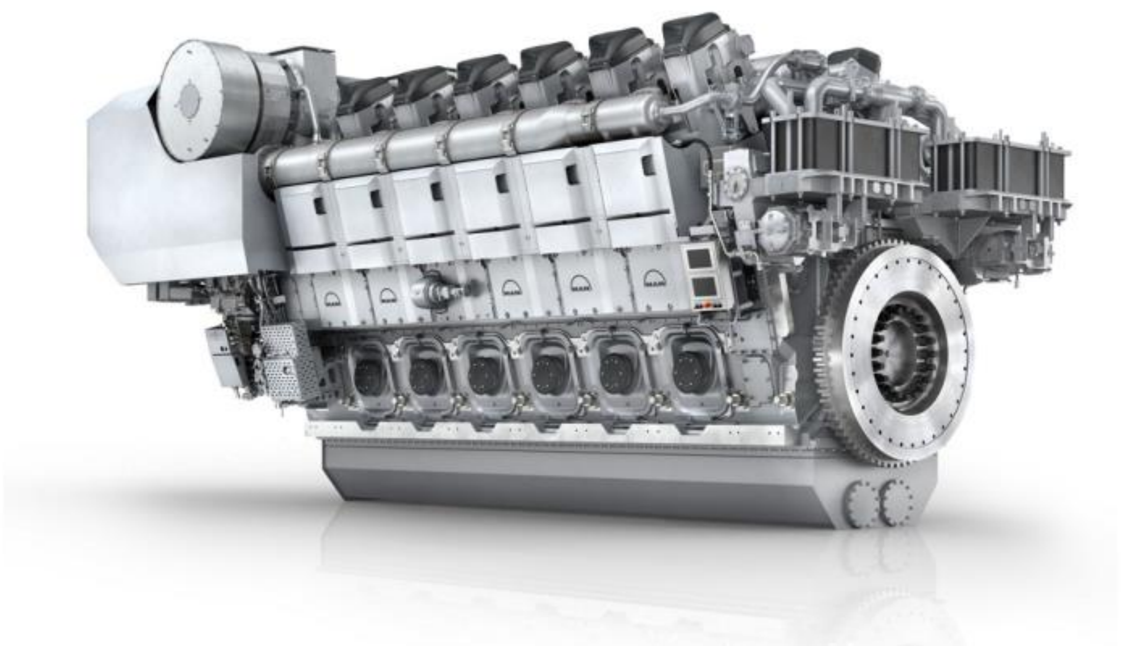
LT PEM (proton exchange membrane)	▪ **Automotive invests in this**
	▪ **High power density in stack / system level when excluding the fuel storage**
	▪ **Relatively quick start up time**
	▪ **No emissions**
	▪ **IGF rules applicable if reformed H2**
		▪ **H_2 only - related challenges**
		  ▪ Massive size H_2 fuel storage on board needed
		  ▪ H_2 production emissions depending on FC source
		  ▪ Safety concerns with H_2
		▪ **Fuel cost** (H_2) **?**
		▪ **High system cost** (€/kW)
		▪ **Sensitive to fuel quality**
		▪ **Stack lifetime 20'000 hrs (?)**
		▪ **No heat recovery**

HT PEM (high temperature PEM)	▪ **Fuel flexibility and compliance with existing marine fuels** (LNG, methanol, etc.)	▪ **Lower efficiency compared to LT-PEM** ▪ **Faster material degradation in the system compared to LT-PEM** ▪ **High system cost** (€/kW) ▪ **Stack lifetime 5'000 hrs?** ▪ **Limited heat recovery**
SOFC (solid oxide fuel cell)	▪ **Fuel flexibility and compliance with existing marine fuels** (LNG, methanol, etc.) ▪ **Fuel available** ▪ **IGF rules applicable** ▪ **High efficiency** ▪ **Heat recovery possible**	▪ **Expensive system** (€/kW) ▪ **Large footprint** (Fuel Cell itself) ▪ **Heavy** (Fuel Cell itself) ▪ **Long start up time** ▪ **Stack lifetime 30'000 hrs (?)** ▪ **CO_2 emissions**

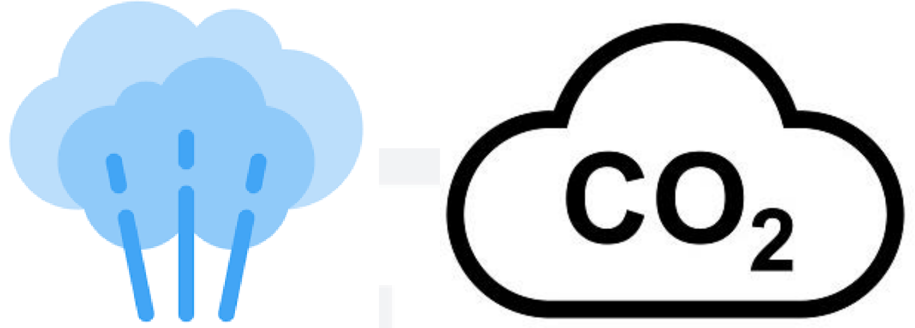
All fuel cells need to be supported by battery for transient loads

GREEN SHIP 11/33

Fuel switch

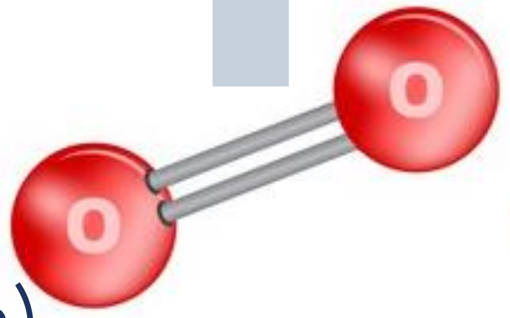


Potenza elettrica

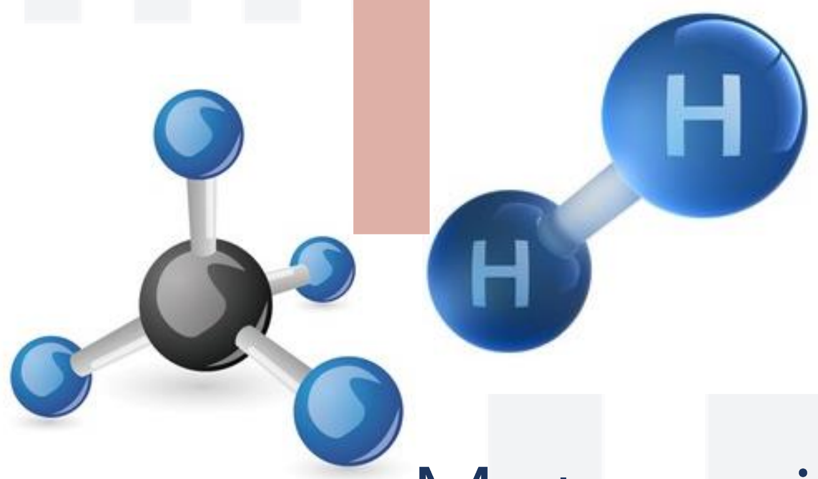


Vapore, CO_2

Due tipologie diverse di celle a combustibile distinte per alcune caratteristiche…



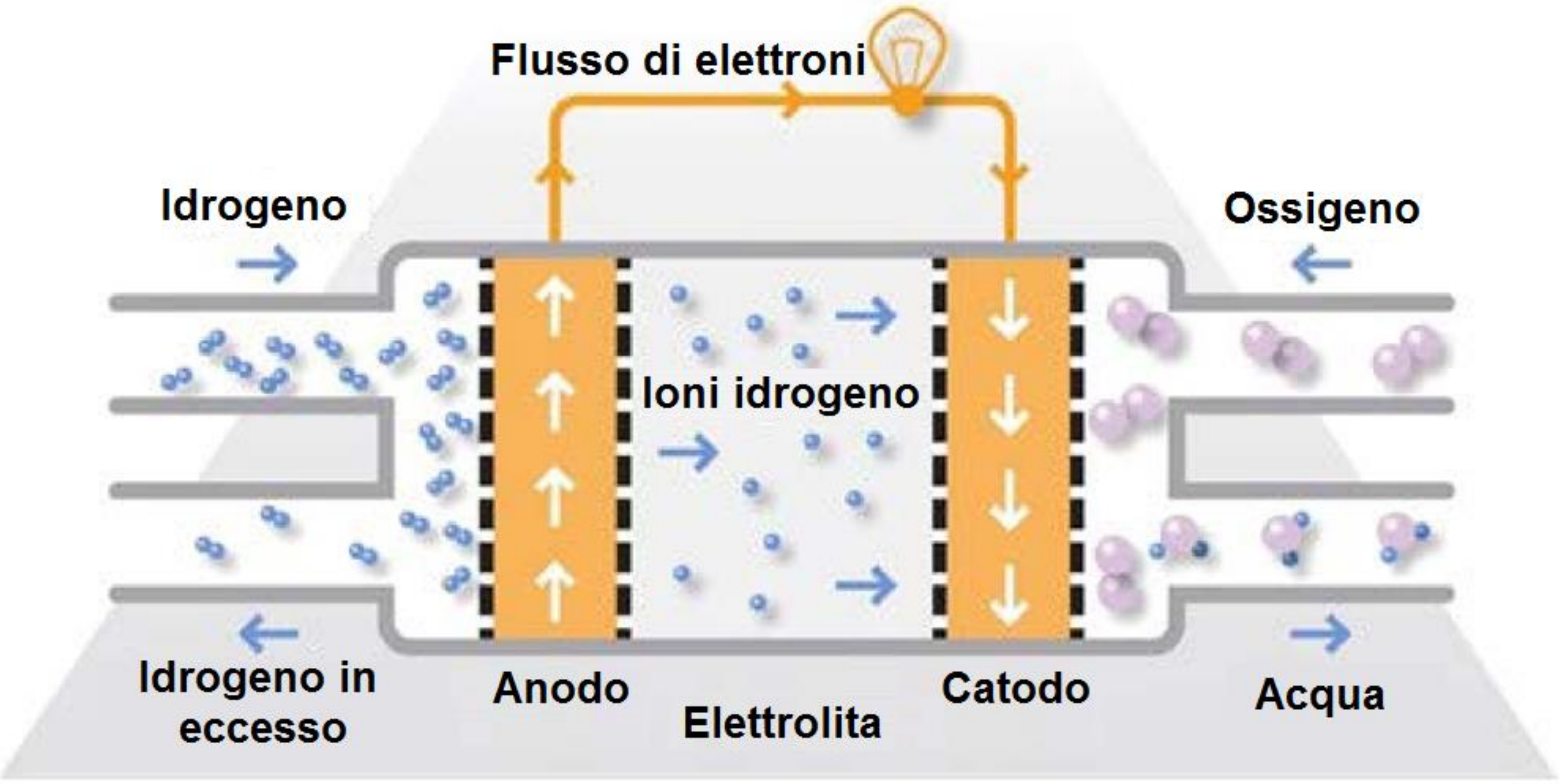
Ossigeno (ricavato dall'aria)

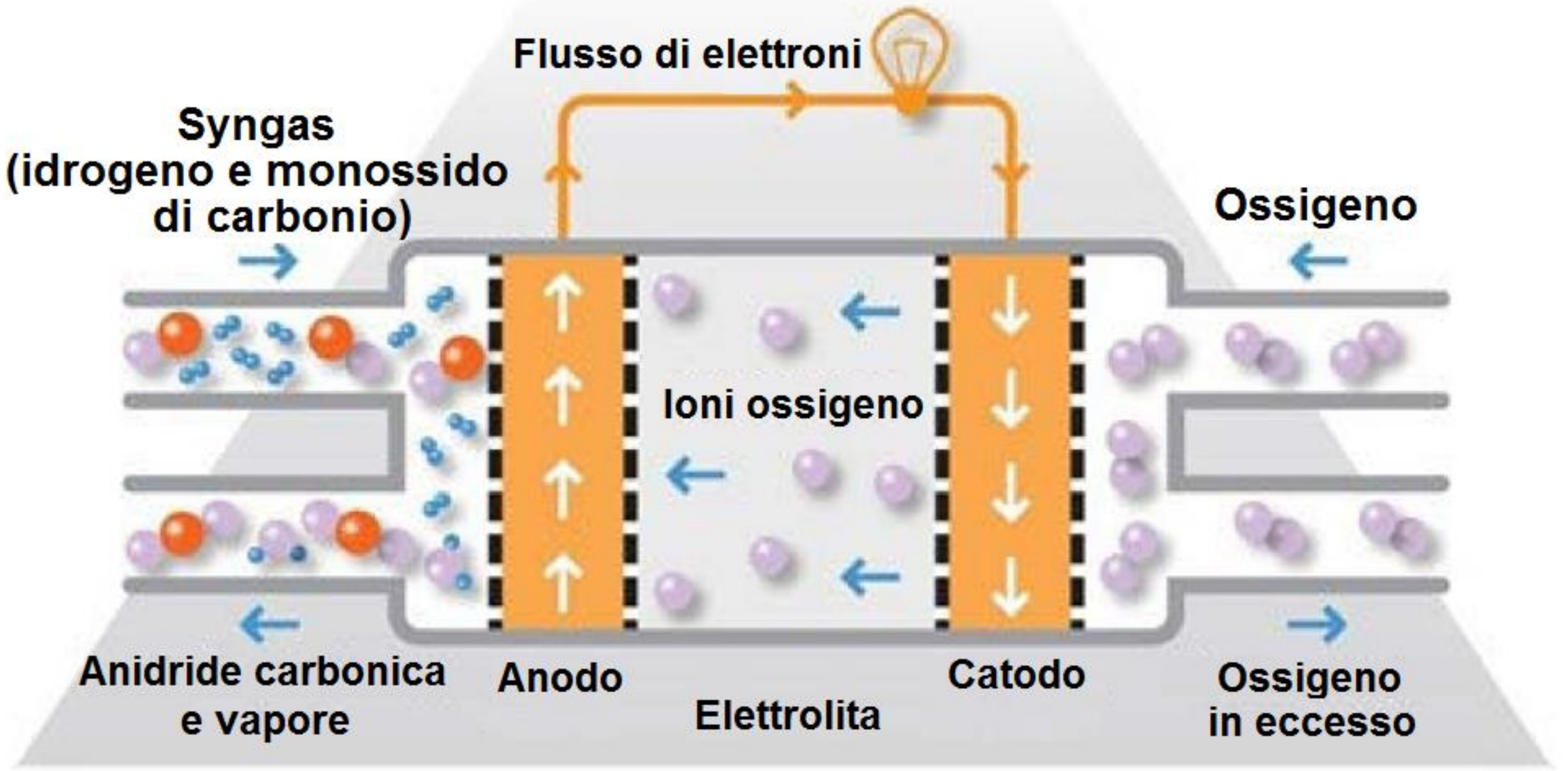


Metano, idrogeno…

GREEN SHIP 12/33

Fuel switch





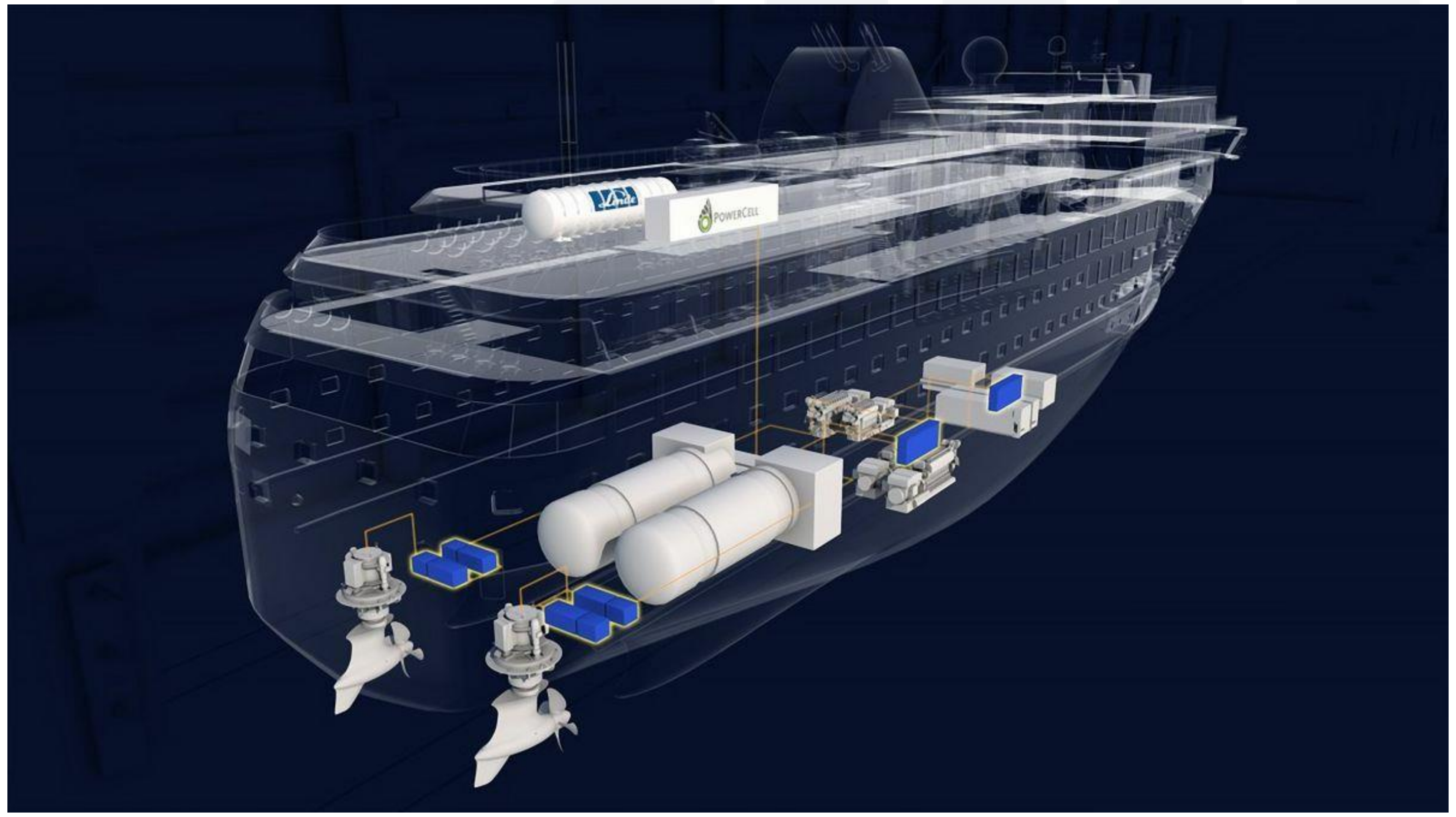
- Bassa temperatura operativa (~80°C);
- Idrogeno puro come combustibile;
- Zero emissioni;
- Efficienza elettrica comparabile a un motore.

- Alta temperatura operativa (~800°C);
- Gas naturale come combustibile;
- Emissioni di CO_2;
- Efficienza elettrica maggiore di un motore.

GREEN SHIP 13/33

Fuel switch

- Assenza di sistemi di stoccaggio e distribuzione di idrogeno;
- Assenza di normative per l'installazione a bordo e per le procedure di rifornimento;
- Scelta della tecnologia di fuel cell e scale-up del sistema dall'ordine dei kW ai MW;
- Definizione del sistema di distribuzione dell'energia;
- Power Management System da definire;
- Ridotto recupero di calore, necessario su particolari tipologie di navi;
- Presenza di alcuni progetti pilota e di numerosi studi di fattibilità, soprattutto per quanto riguarda navi fluviali o che operano come traghetti in zone limitate (lagune, baie…)



GREEN SHIP 14/33

Fuel switch

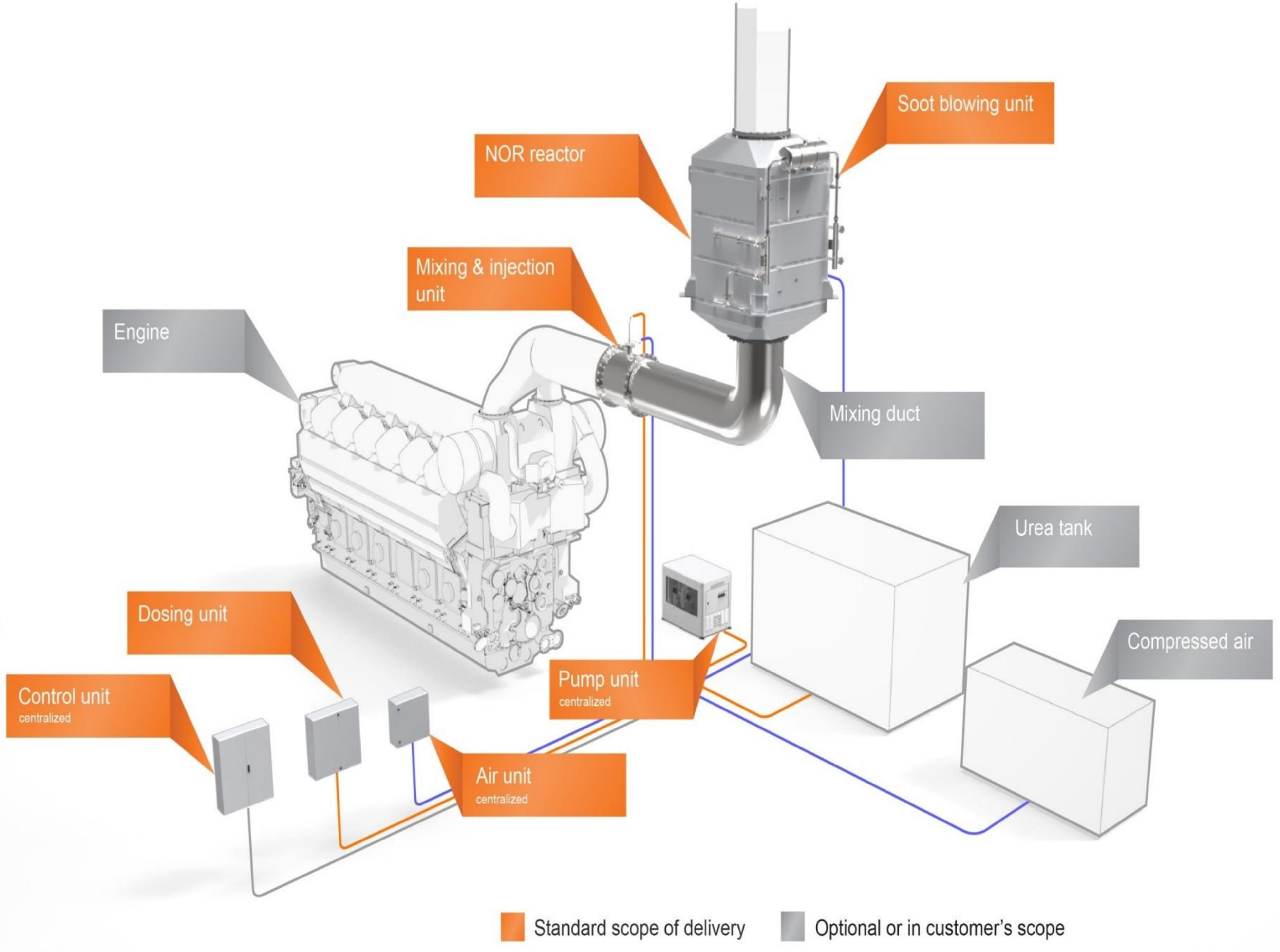
	LNG	Ammonia	Methanol	Hydrogen
CO_2	-45%* (up to)	-100%* +5%**	-75%* (up to) +10%**	-100%* +5%**
NO_x	- 85% (up to)	+ X % (N_2O slip)***	- 60% (up to)	- 85% (up to)
SO_x	- 100%	- 100%?	- 90%	- 100%?
Particulates	- 98%	?	-95% -98%**	- 100%?

Sources: Wartsila's engines Product guide (NG), DNV-GL (NH3 and H2), FCBI energy report for Methanol.
Disclaimer: Values are a rough order of magnitude as the impact on emissions depends on maker/technologies etc.

* if fuel is produced with renewable energies
** if fuel is produced from Natural Gas
***N_2O has a GWP 30X higher than methane and 300X higher than CO_2

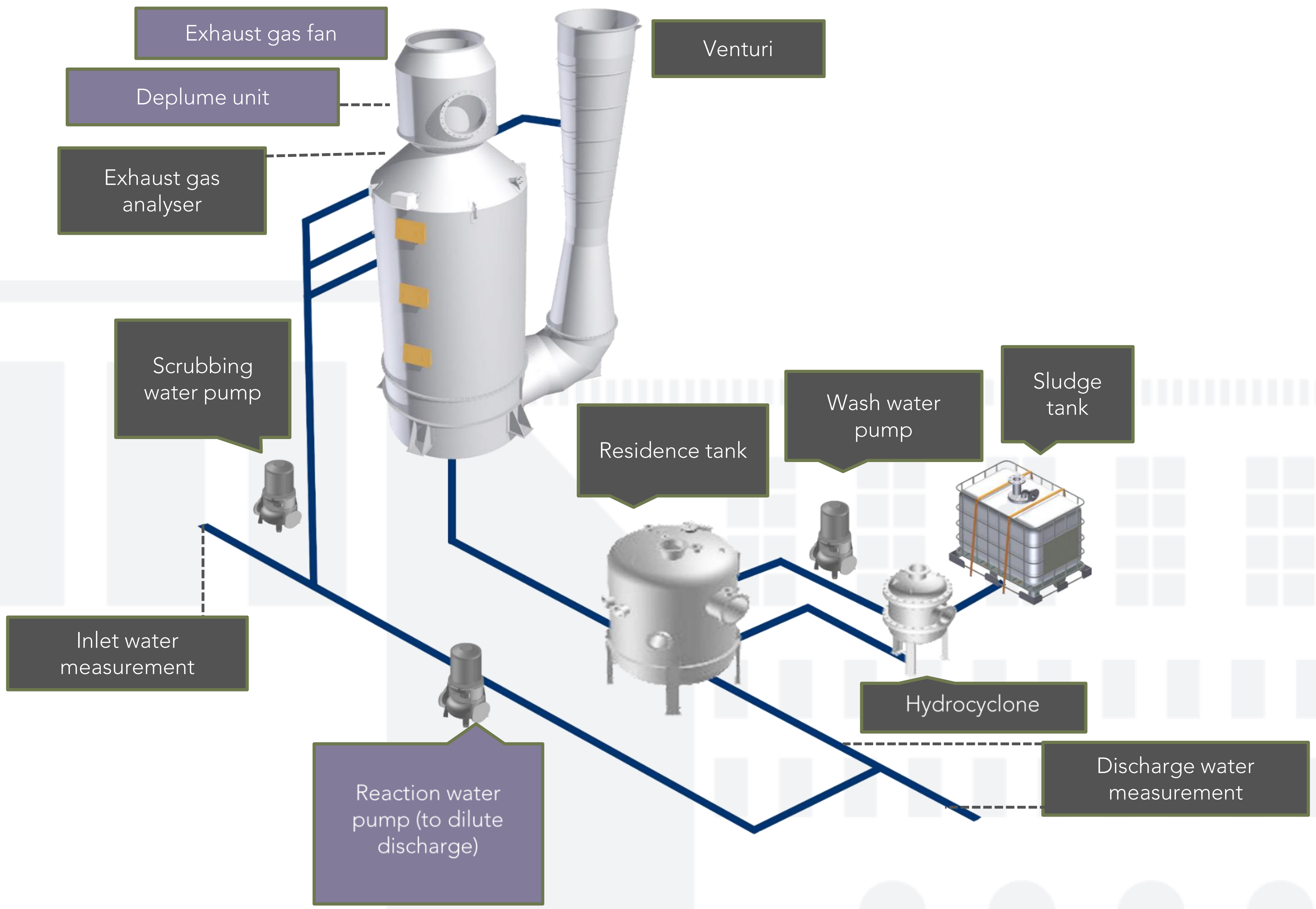
GREEN SHIP 15/33

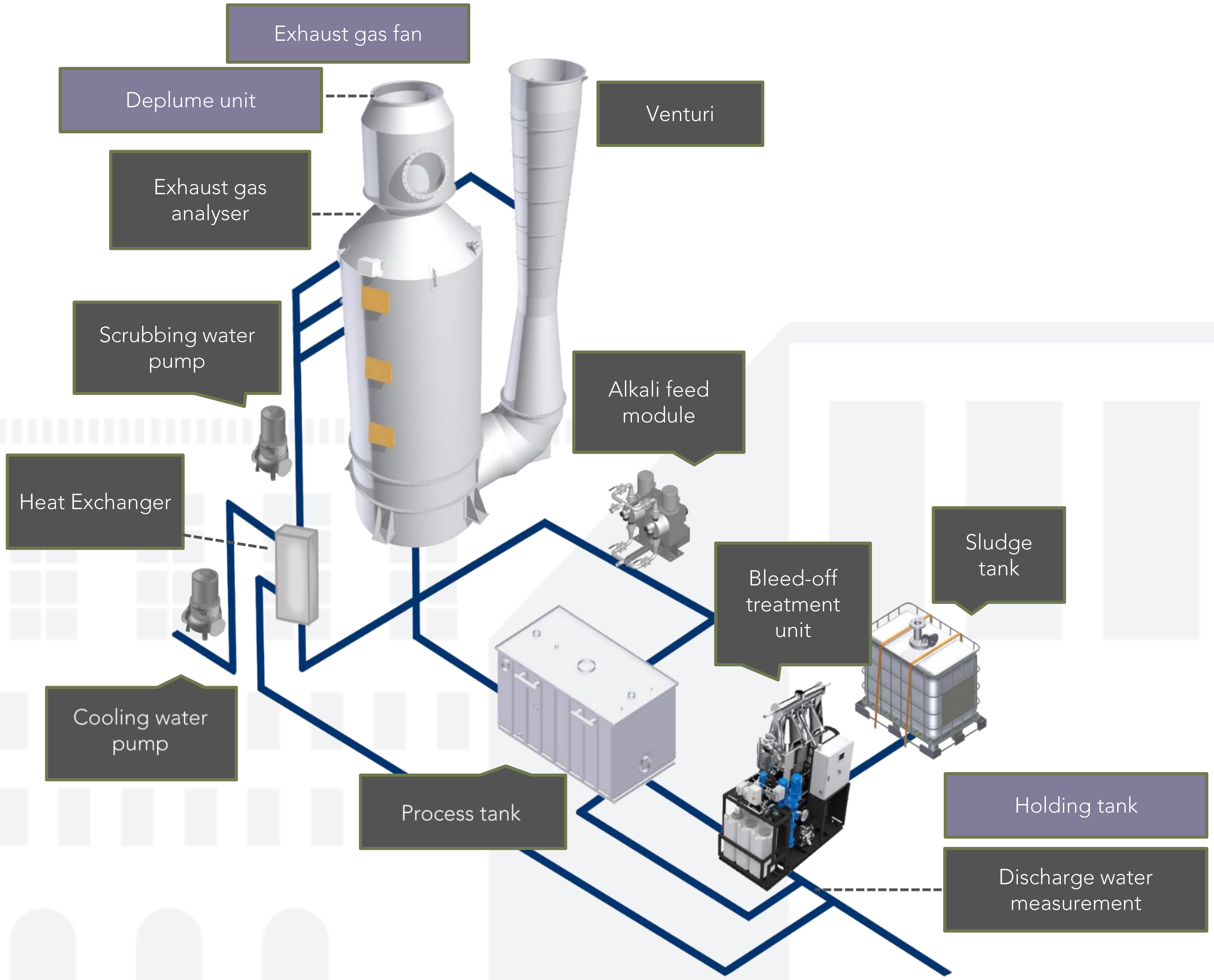
SCR



GREEN SHIP 16/33

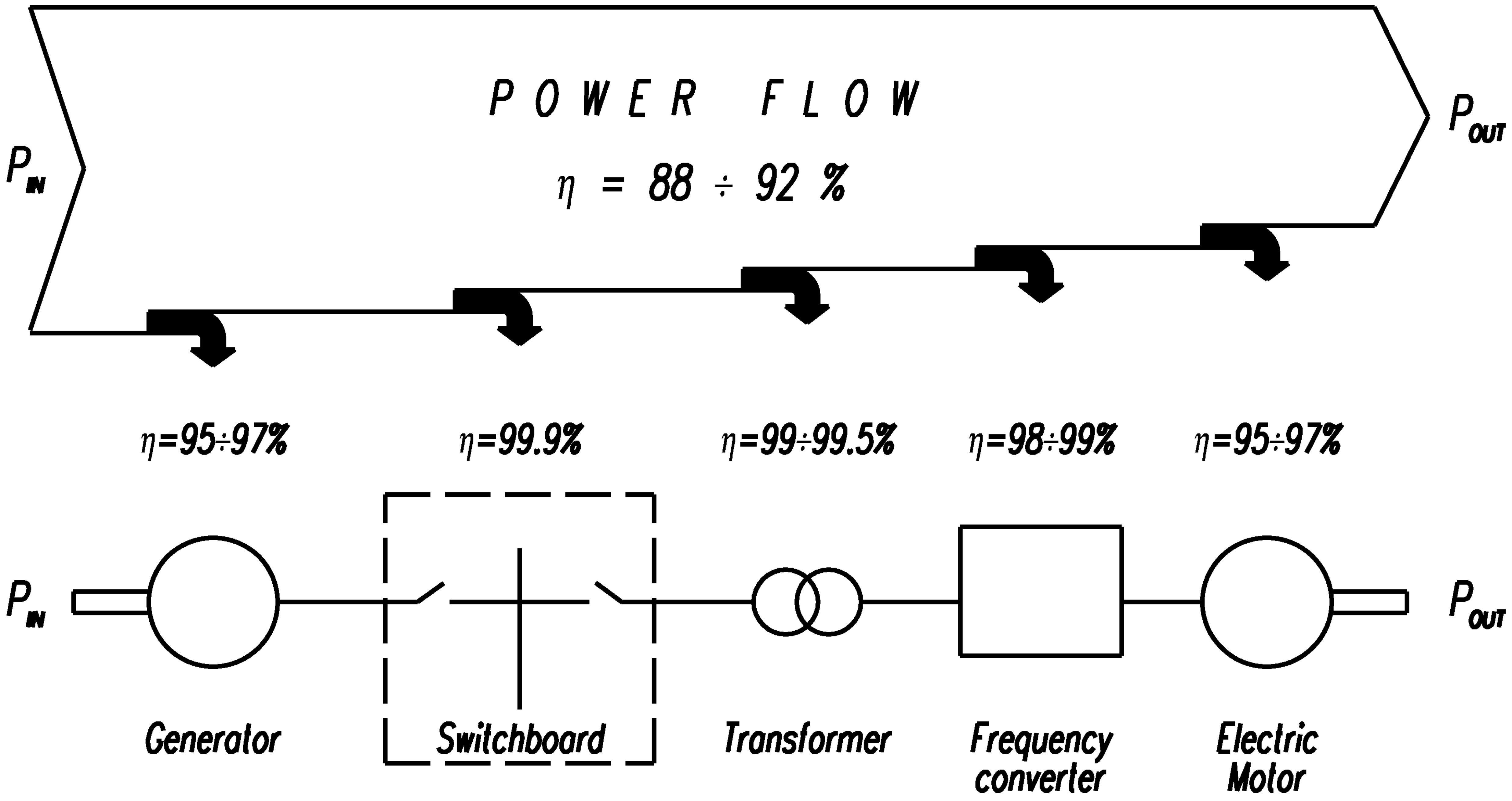
Scrubber open loop/closed loop

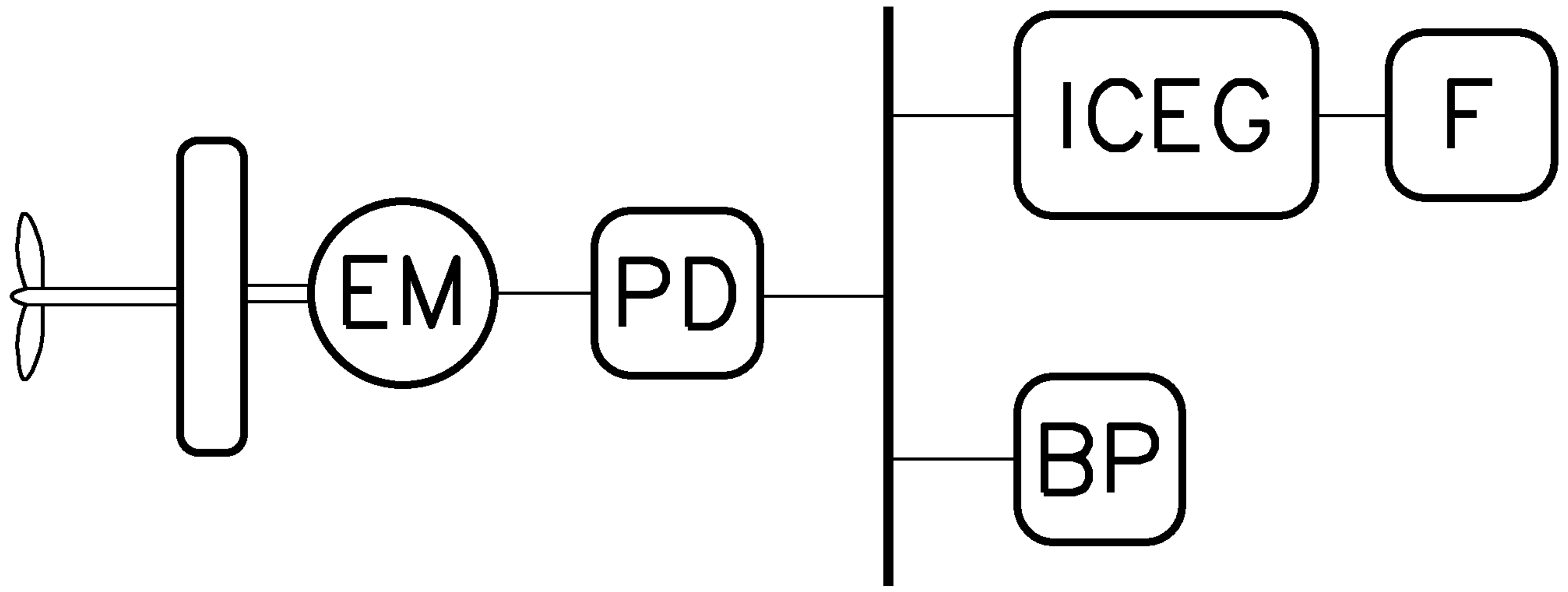




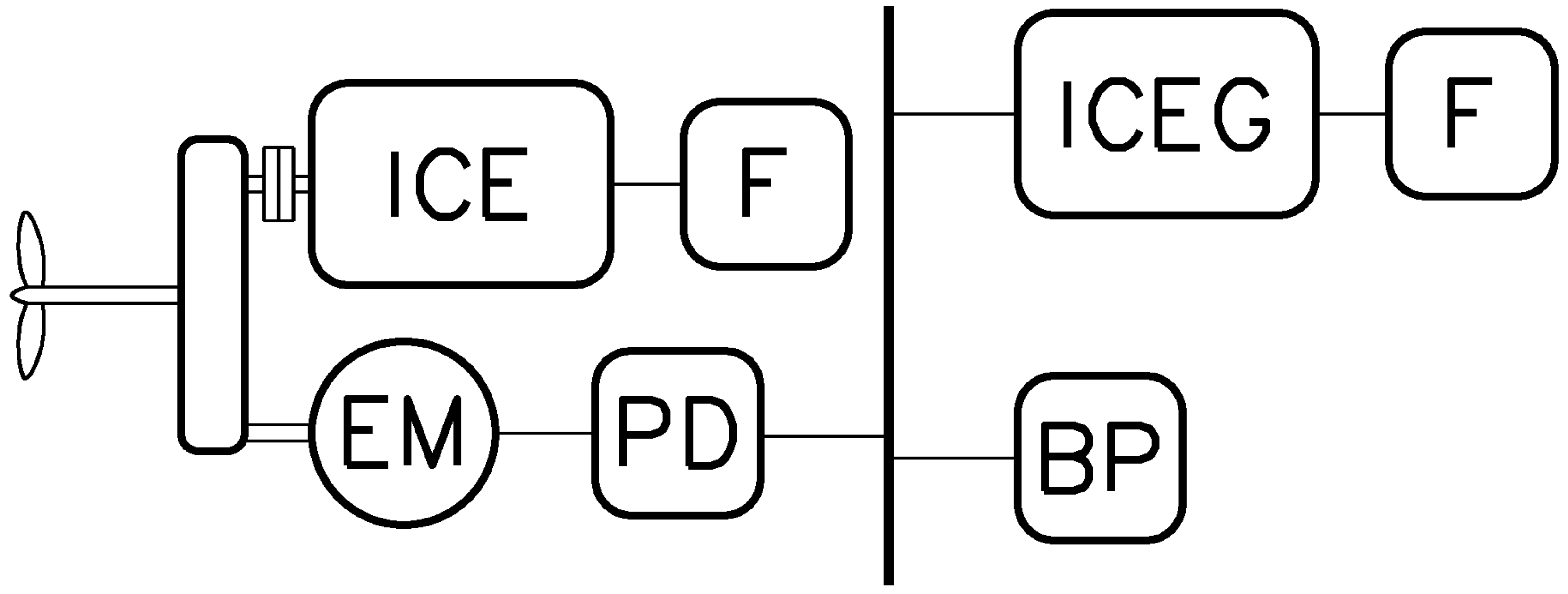
GREEN SHIP 17/33

Hybrid systems





PD	Power Drive	EM	Electric Motor	BP	Battery Pack
ICEG	ICE Generator			F	Fuel

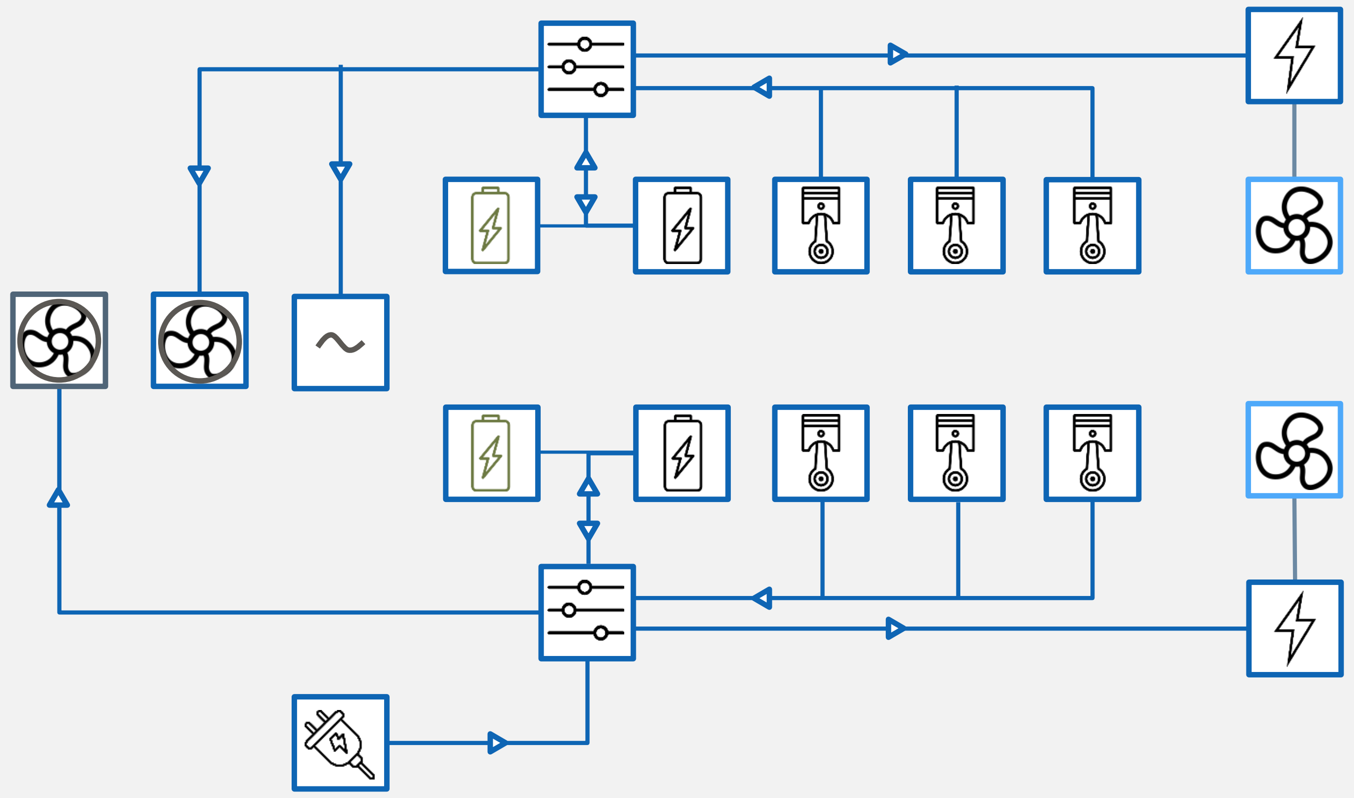


PD	Power Drive	EM	Electric Motor	BP	Battery Pack
ICEG	ICE Generator			F	Fuel
ICE	Internal Combustion Engine				

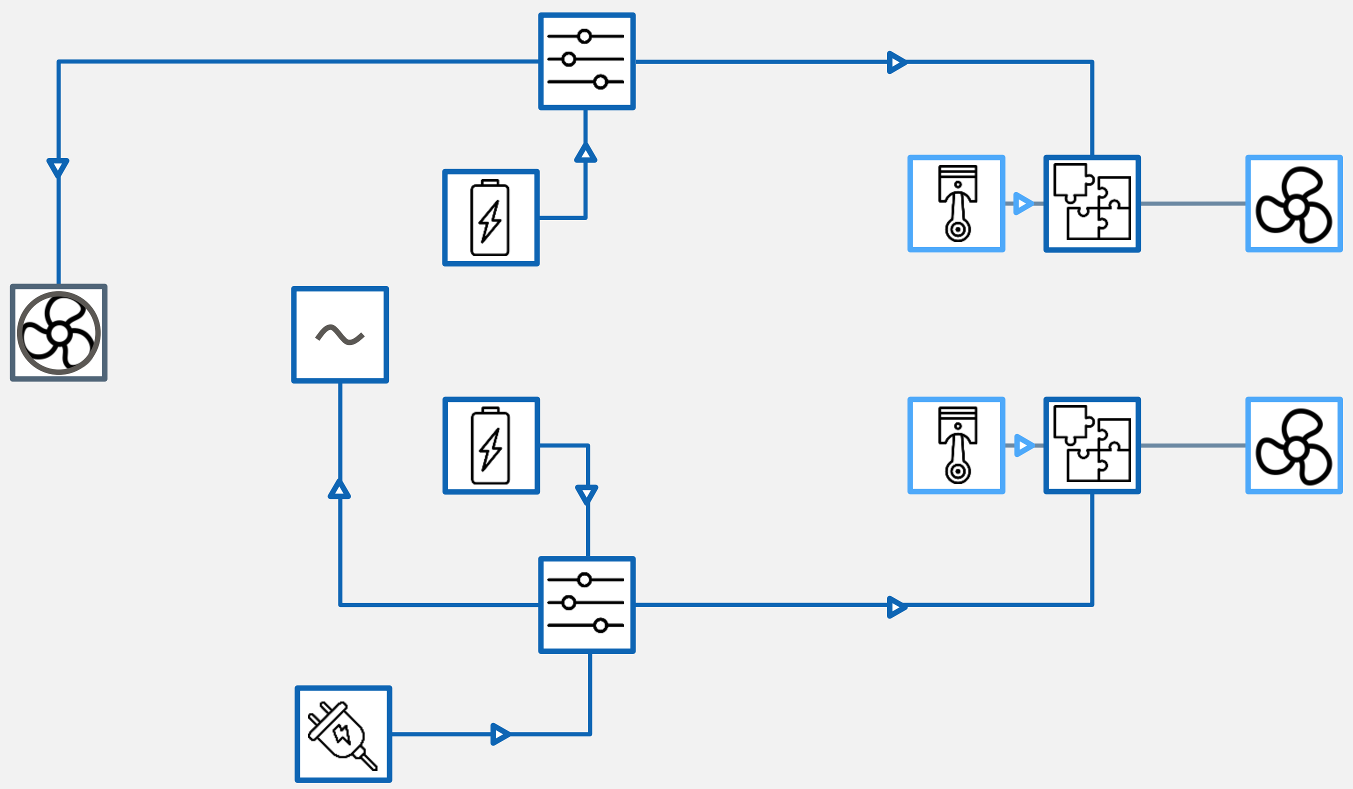
GREEN SHIP 18/33

Hybrid solutions

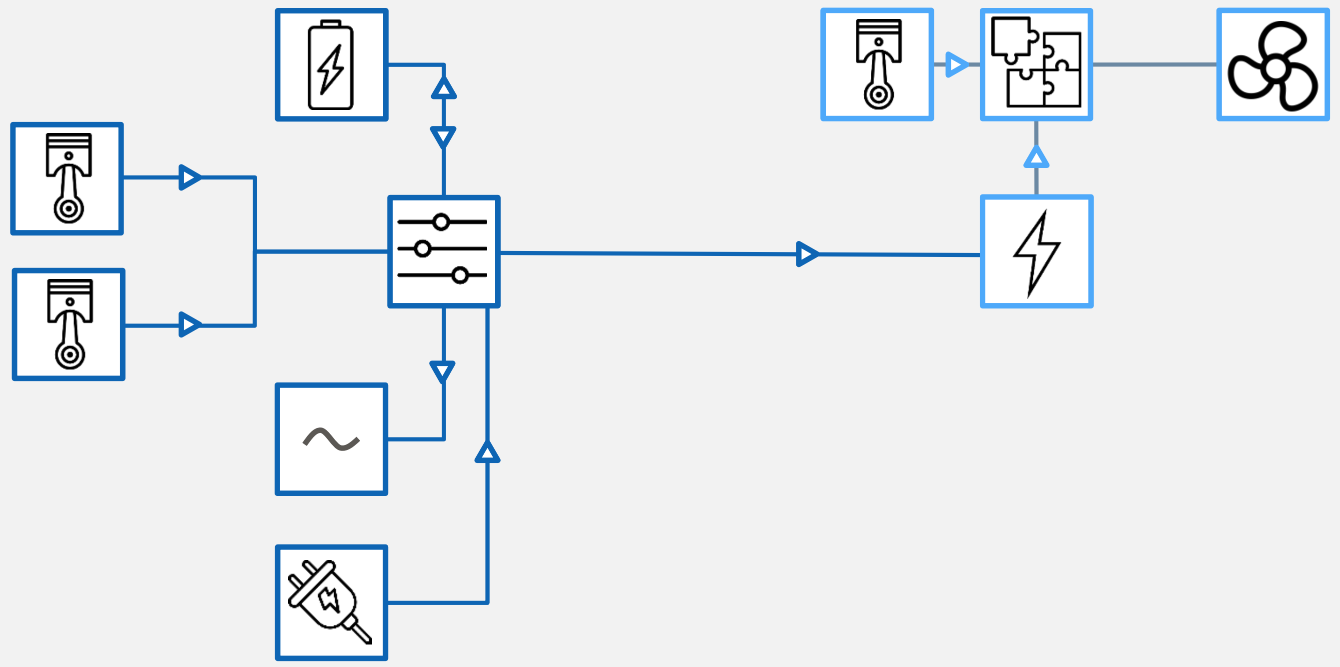
WÄRTSILÄ HY - Cruise



WÄRTSILÄ HY - Ferry



MAN HyProp ECO / Siemens SISHIP ECO PROP



GREEN SHIP 19/33

Batteries

		Pro	Con	Applicable for maritime
Lithium-ion	*Nickel Manganese Cobalt oxide - NMC*	Cost, safety, specific energy and energy density	Lifetime	✔
	Lithium iron phosphate - LFP	Safety	Specific energy	✔
	Nickel Cobalt Aluminium - NCA	Lifetime, specific energy and energy density	Cost and safety	✔
	Lithium Cobalt Oxide - LCO	Specific energy and energy density	Safety	✔
	Lithium Manganese Oxide spinel - LMO	Safety	Lifetime, specific energy and energy density	✔
	Lithium Titanate Oxide - LTO	Safety	Cost and specific energy	✔
Lead acid	*Lead acid*	Cost and safety	Lifetime, specific energy and energy density	
Rechargeable nickel	*Nickel cadmium*	Cost and safety	Specific energy and energy density	
	Nickel metal hydride	Cost and safety	Specific energy and energy density	✔
	Nickel iron	Safety and lifetime	Cost, specific energy and energy density	
	Nickel zinc	Cost	Specific energy and energy density	
	Nickel hydrogen	Lifetime	Cost, specific energy and energy density	
High temperature sodium	*High temperature sodium sulphur*	Cost and energy density	Safety	
	Zero Emission Batteries Research Activities - ZEBRA	Safety	Cost	

GREEN SHIP 20/33

Conversione di navi in operazione

- Prima di procedere occorre fare un'attenta analisi economica;
- Spesso gli interventi vengono giustificati anche con il valore storico delle navi prese in considerazione, ma è fondamentale un'analisi economica;
- Spesso si rileva l'assenza di documentazione progettuale di riferimento;
- Le prime attività da eseguire sono di reverse engineering;
- Analisi dettagliata del profilo operativo;
- Identificazione del contesto normativo corretto;
- Verifica della catena logistica;
- Scelta della configurazione innovativa più conveniente;
- Nuovo design guidato da approccio modulare (modular design)
- Continua verifica dei pesi, spesso a vantaggio della conversione perché macchine vecchie pesano di più, così si recupera peso per batterie e nuovi combustibili.

GREEN SHIP 21/33

Conversione di navi in operazione

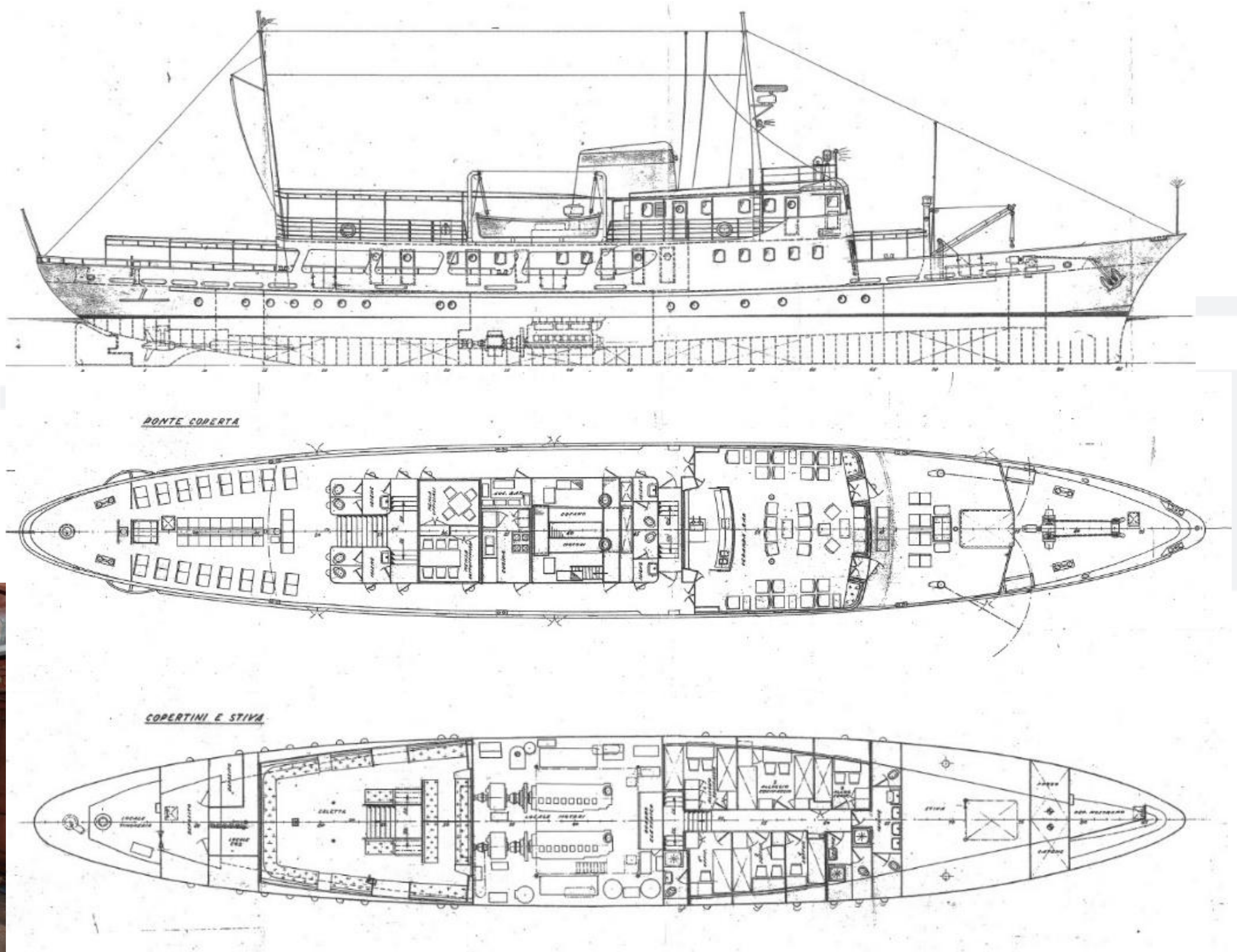
Symbol	Characteristic	value	Unit
L_{OA}	Length overall	51.85	m
L_{WL}	Length on waterline	47.00	m
L_{PP}	Length between perpendiculars	45.62	m
B	Breadth	7.40	m
T	Draught	2.21	m
D	Depth	3.25	m
Δ	Displacement in weight	425.00	t
GT	Gross tonnage	292.49	t
Np	Passengers	400	-
V_C	Cruise speed	15.40	kn
P_B	Installed propulsive power	1280	CV

MS **Ambriabella**
Built in 3362 - Out of service since 2009

Passenger transport on **short daily routes**

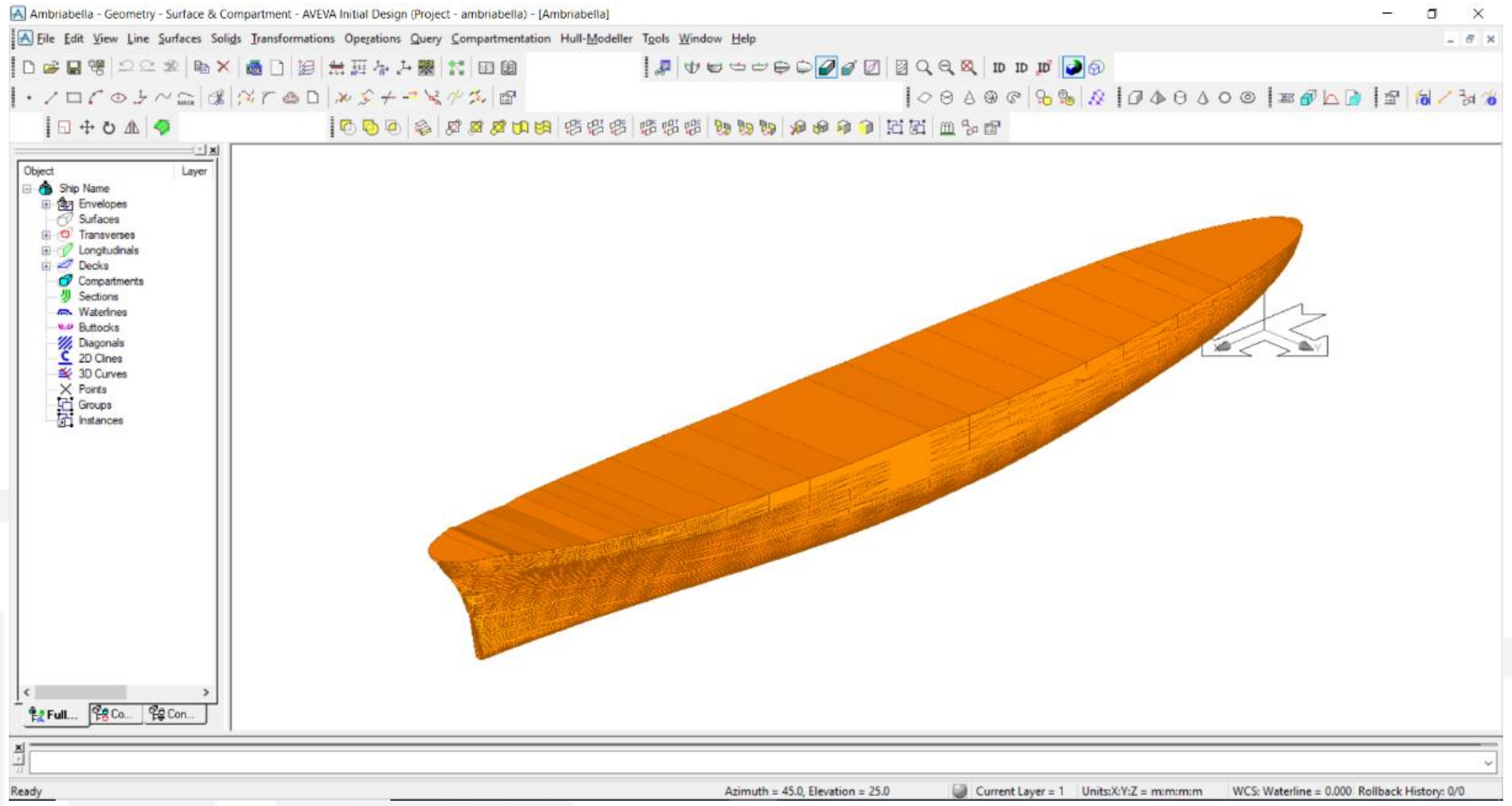
GREEN SHIP 22/33

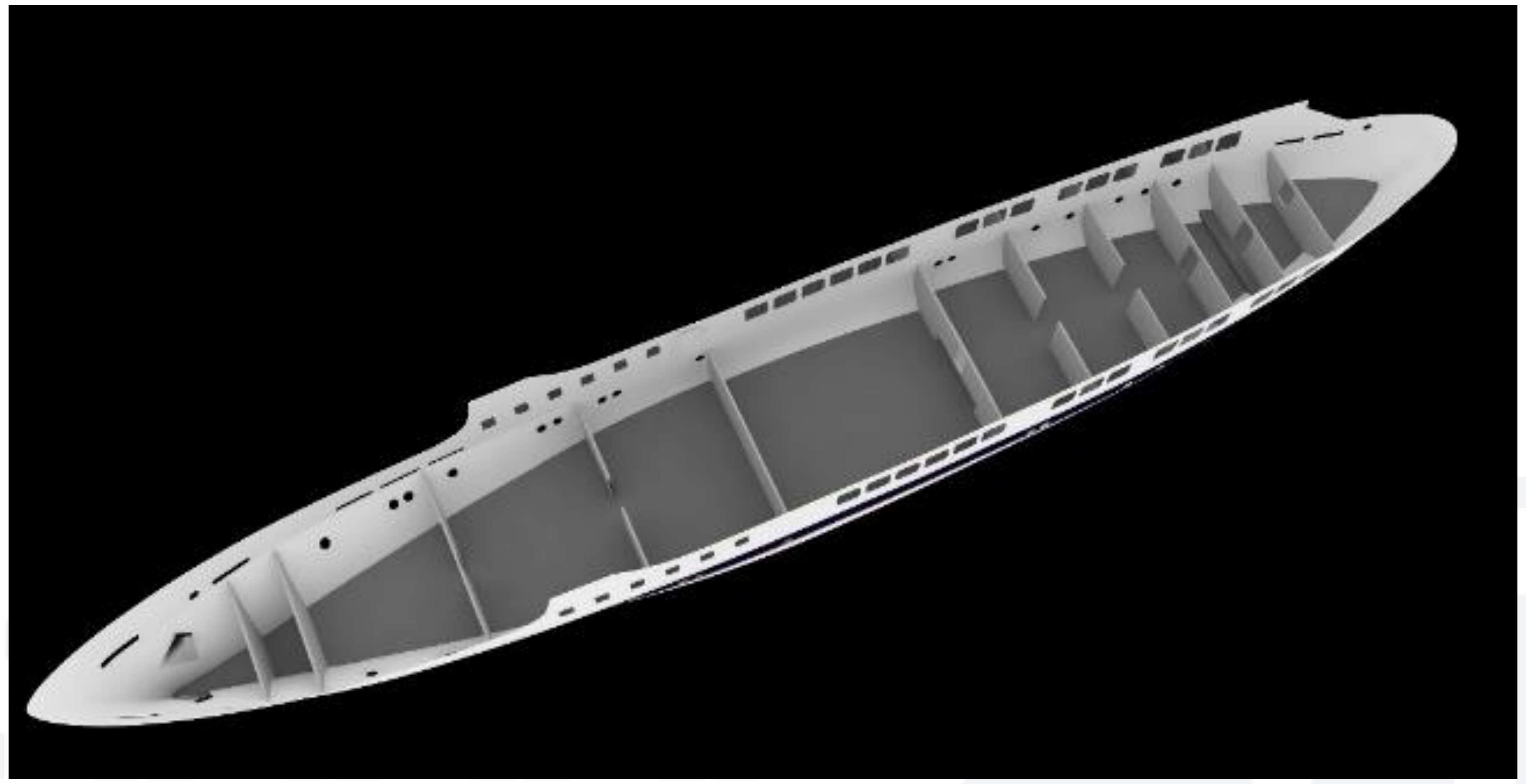
Conversione di navi in operazione

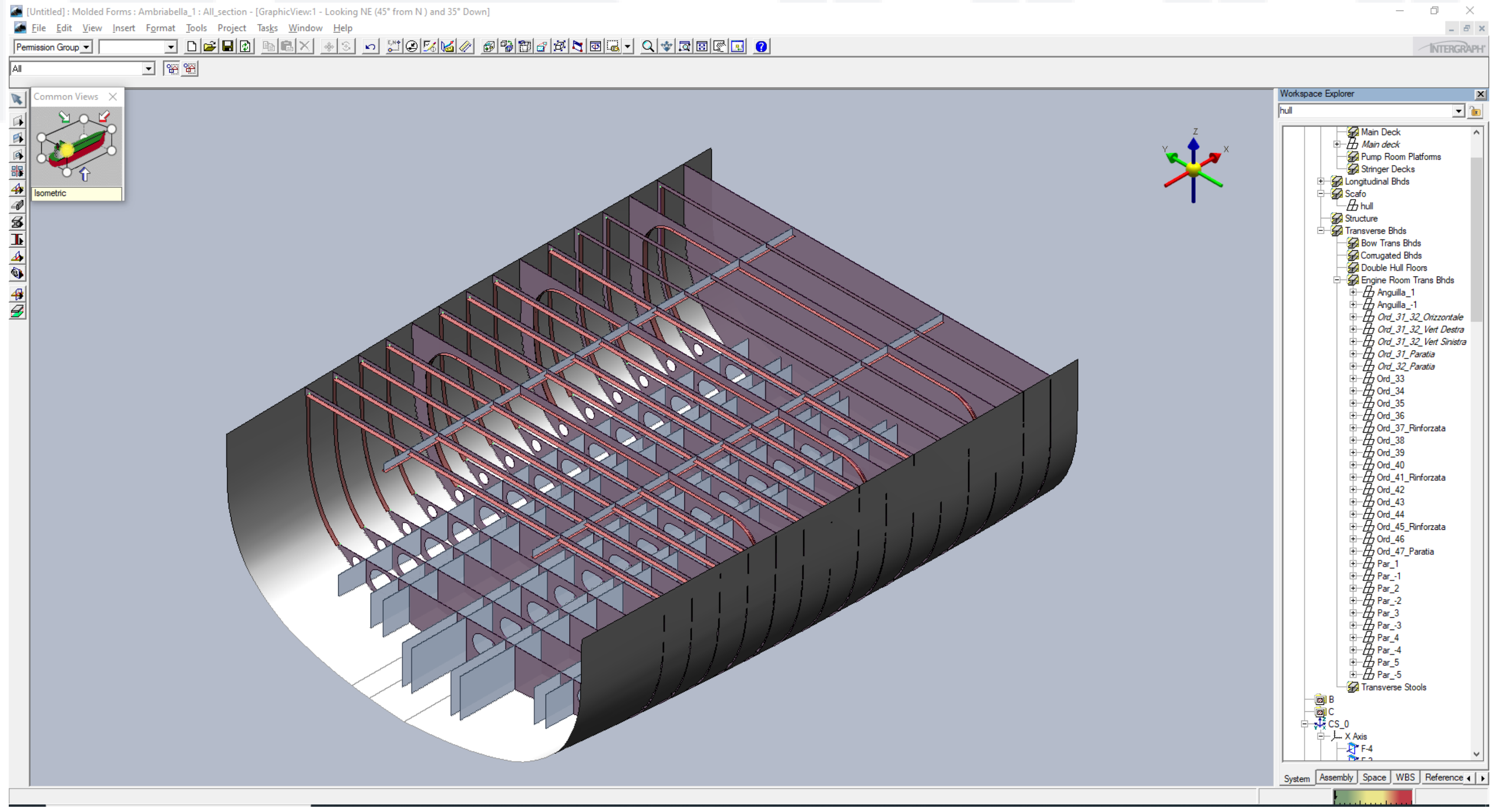


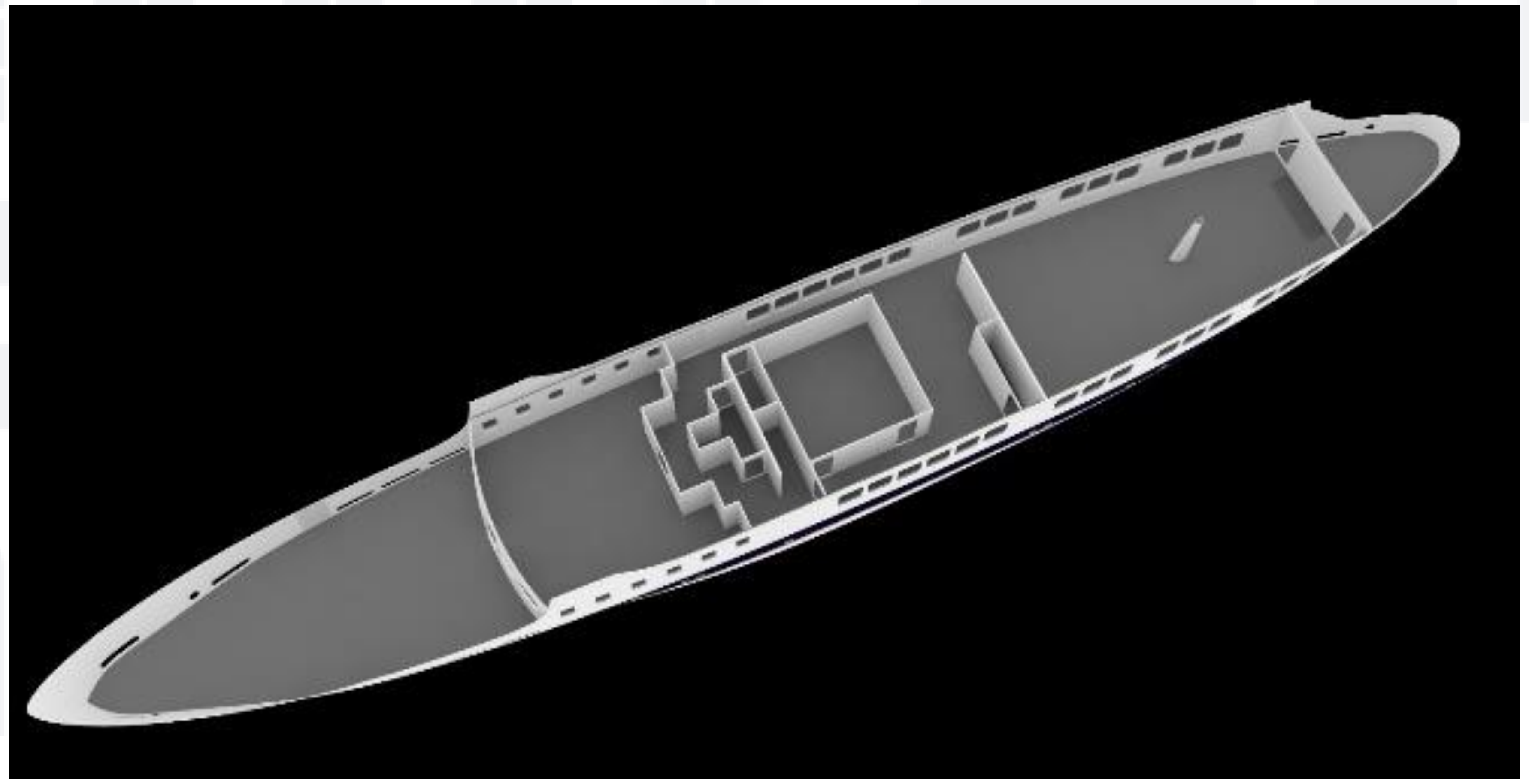
GREEN SHIP 23/33

Conversione di navi in operazione









GREEN SHIP 24/33

Conversione di navi in operazione

ISD LAB INTEGRATED SHIP DESIGN

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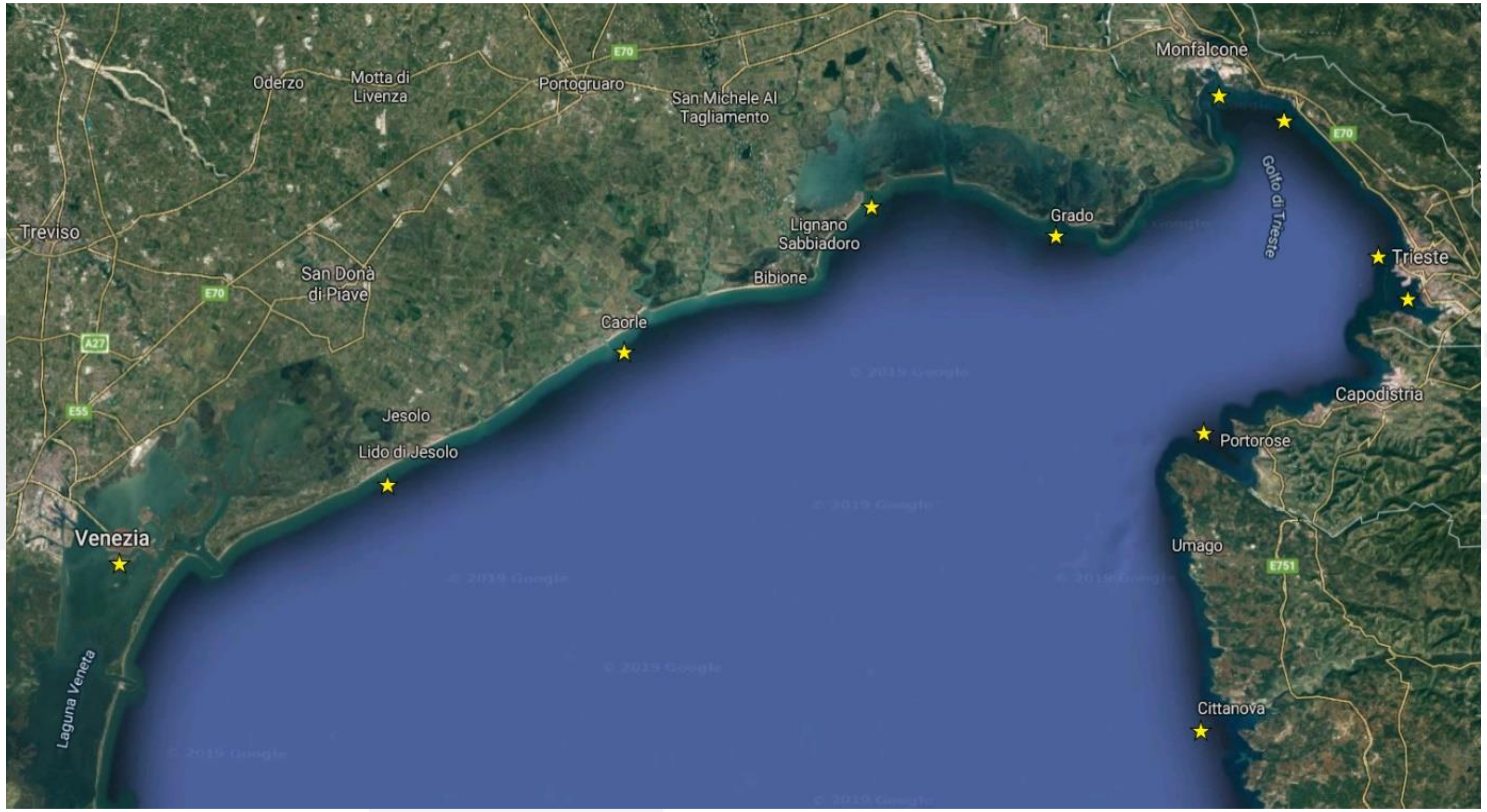
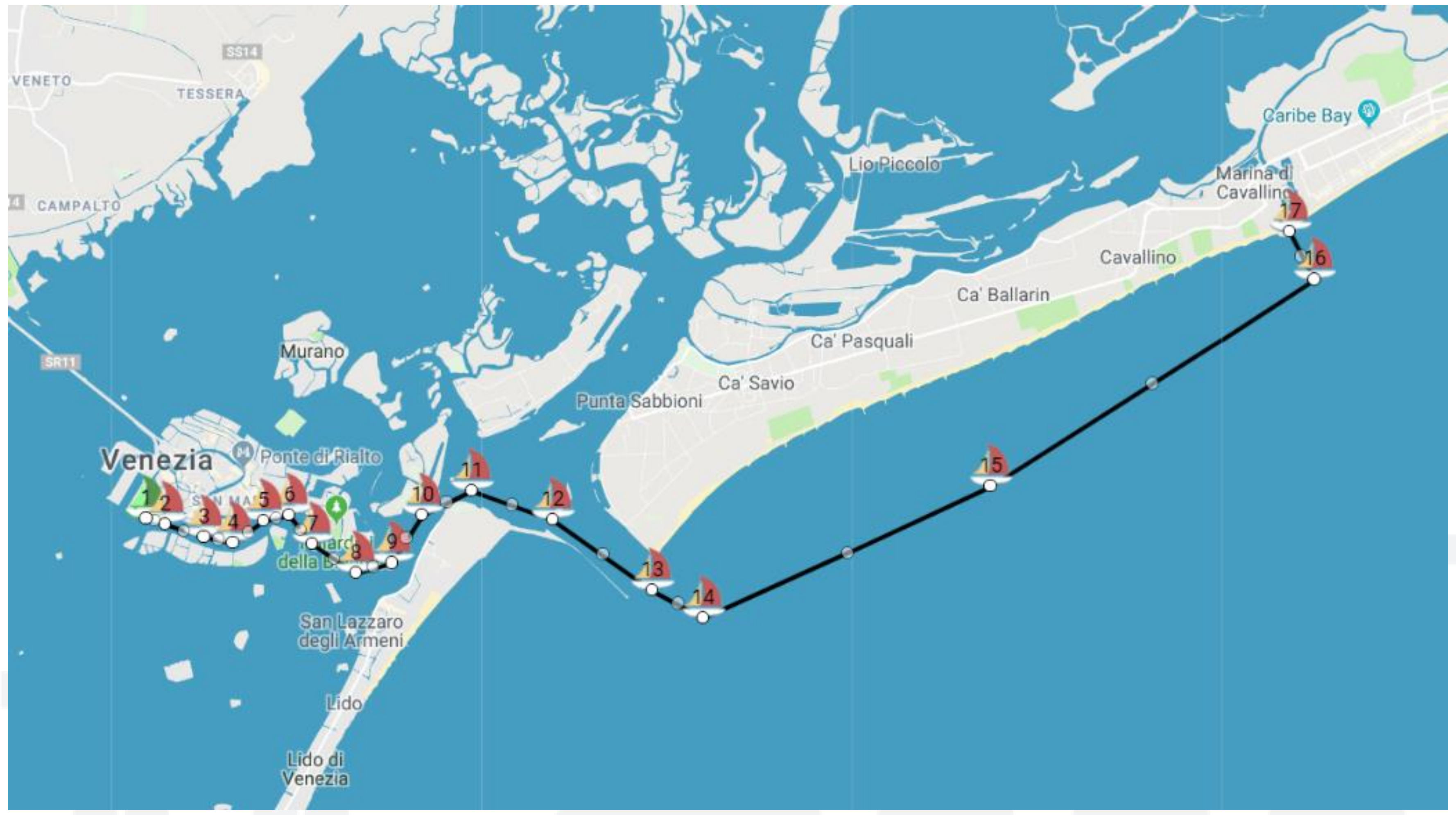
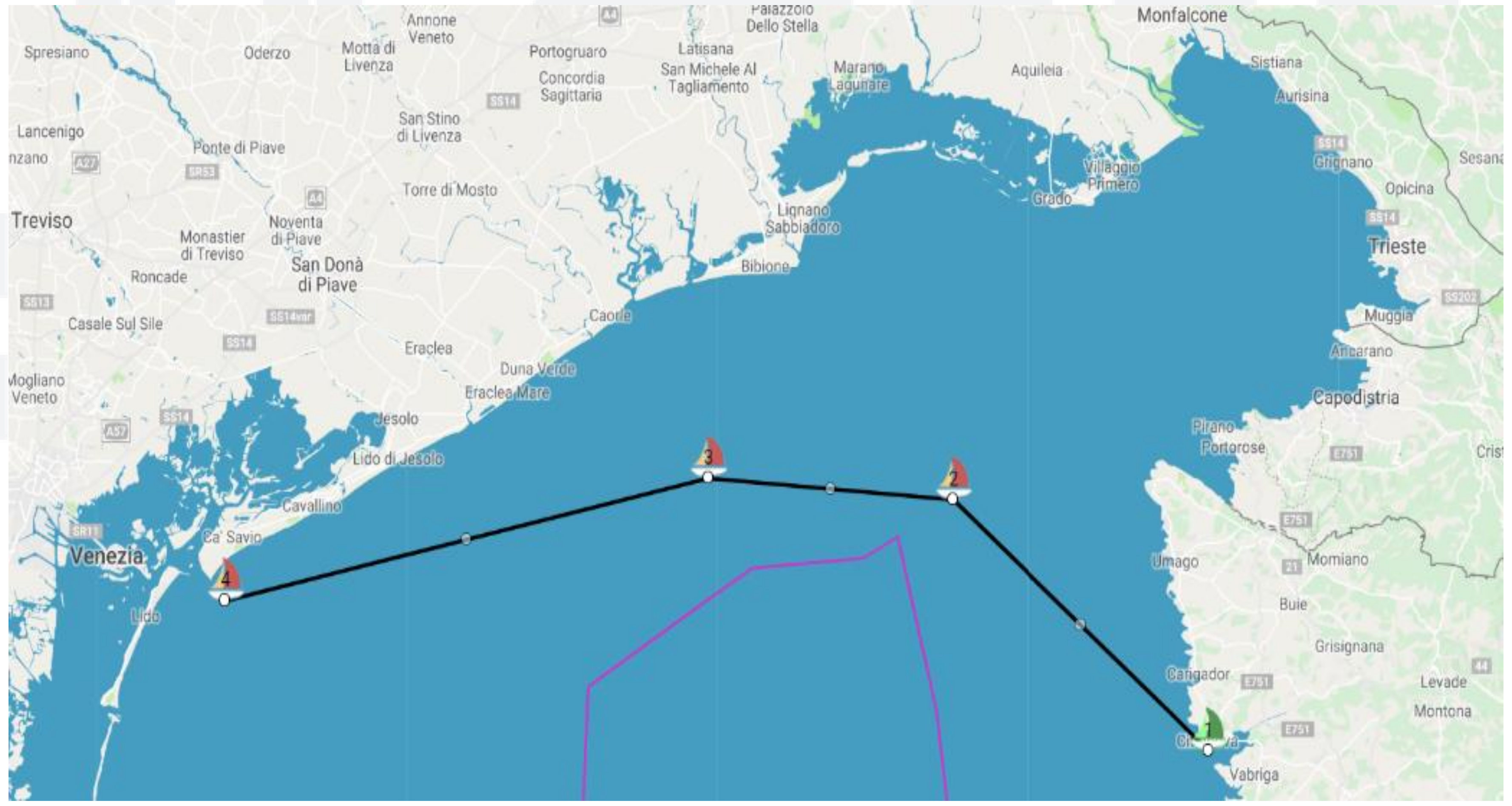
GREEN SHIP 25/33

Conversione di navi in operazione







GREEN SHIP 26/33

Conversione di navi in operazione

Route		Characteristics				
		Length	Mean depth	Speed	Time	Remarks
1	Venice-Marina del Cavalino	29.63 km	4.5 m	6 knots	2 h 40 min	Transit in shallow water
2	Marina del Cavallino – Porto S. Margherita	27.78 km	12.5 m	6 knots	2 h 30 min	-
3	Porto Santa Margherita - Lignano	31.48 km	12.5 m	6 knots	2 h 50 min	-
4	Lignano - Grado	24.00 km	5.8 m	8 knots	1 h 55 min	Transit in shallow water
5	Grado - Monfalcone	31.48 km	8.8 m	6 knots	2 h 50 min	Transit close to harbours
6	Monfalcone - Sistiana	11.11 km	11.8 m	8 knots	50 min	Transit close to harbours
7	Sistiana - Trieste	18.52 km	12.3 m	6 knots	1 h 40 min	-
8	Trieste - Muggia	7.41 km	12.5 m	8 knots	30 min	Transit close to harbours
9	Muggia - Portorose	27.78 km	>15.0 m	6 knots	2 h 30 min	-
10	Portorose - Cittanova	33.34 km	>15.0 m	6 knots	3 h	-
11	Cittanova – Venice (Lido)	96.30 km	>15.0 m	13 knots	4 h	-
12	Venice (Lido) - Venice	12.96 km	5.0 m	6 knots	1 h 10 min	Transit in shallow water

GREEN SHIP 27/33

Conversione di navi in operazione

A. Navigation at full speed
B. Navigation at cruise speed (b.c.)
C. Navigation at cruise speed
D. Navigation at low speed (b.c.)
E. Navigation at low speed
F. ZEM nav. at low speed
G. ZEM nav. at lower speed
H. ZEM nav. in restricted water
I. Maneuver
J. Berthed

1. Fuel treatment;
2. Air conditioning;
3. Machinery ventilation;
4. Manoeuvring system;
5. Auxiliaries;
6. Battery charger;
7. Switchboards;
8. Navigation system;
9. Propulsion (electric motors);
10. Propulsion (Diesel engines).

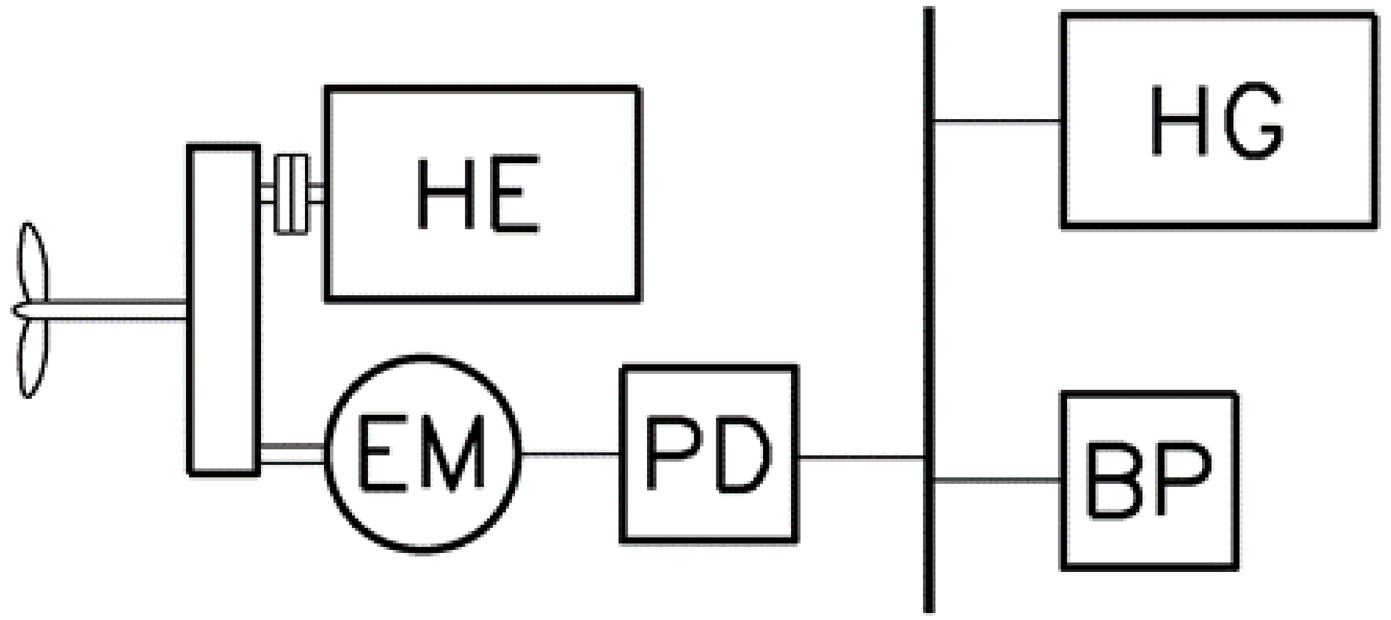
GREEN SHIP 28/33

Conversione di navi in operazione

		Operational profiles									
		A	B	C	D	E	F	G	H	I	J
User categories	1	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.0
	2	17.8	17.8	32.8	17.8	32.8	32.8	32.8	32.8	13.7	13.7
	3	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	5.5
	4	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	87.2	0.0
	5	23.0	27.0	27.0	27.0	26.3	26.3	26.0	26.0	26.0	8.5
	6	2.9	122.7	2.9	122.7	2.9	2.9	2.9	2.9	2.9	122.7
	7	90.4	107.1	107.1	107.1	92.6	92.6	83.4	83.4	90.4	75.0
	8	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	0.0
	9	100.0	0.0	0.0	0.0	0.0	78.8	30.5	49.2	0.0	0.0
	10	958.0	443.0	443.0	72.9	78.8	0.0	0.0	0.0	24.3	0.0
TOTAL (kW)		1218	742	639	373	259	259	201	220	257	220

GREEN SHIP 29/33

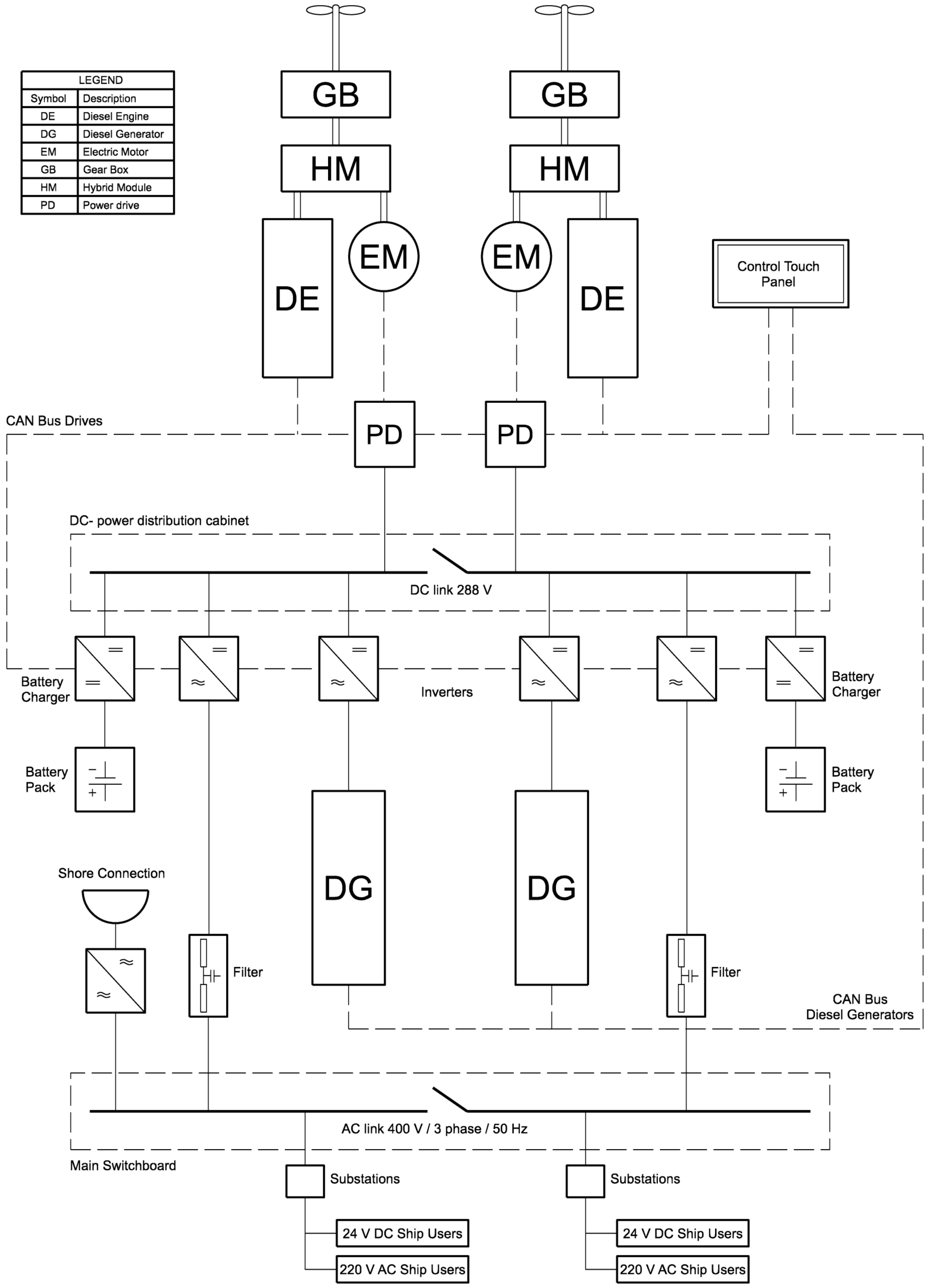
Conversione di navi in operazione



HE	Heat Engine	EM	Electric Motor	BP	Battery Pack
HG	Heat Generator	PD	Power Drive		

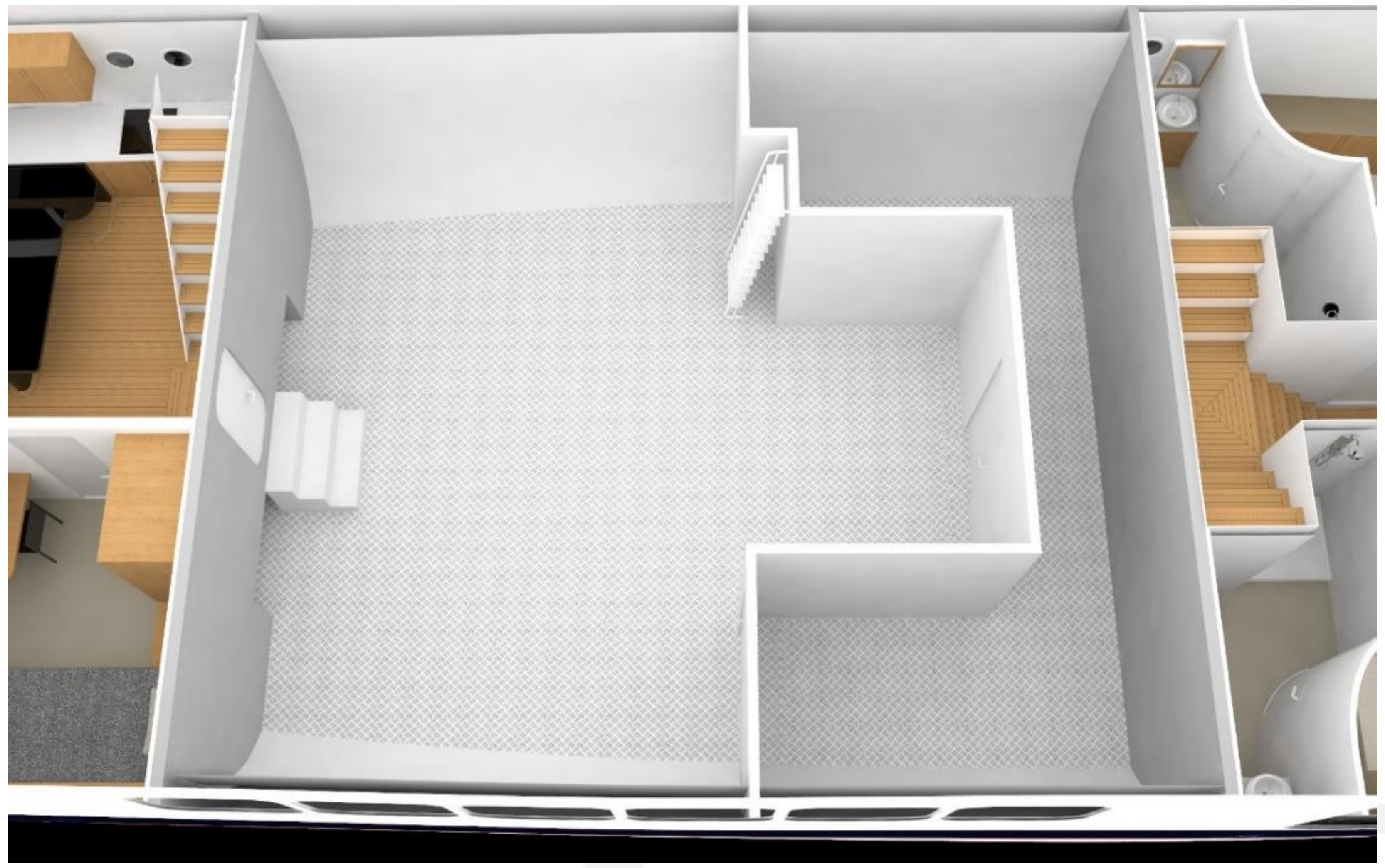
Parallel hybrid

2 main DE of 500 kW each
2 EM of 50 kW each
2 DG of 50 kW each
Battery pack total capacity of 2400 Ah
(3.5 hours autonomy in G mode)



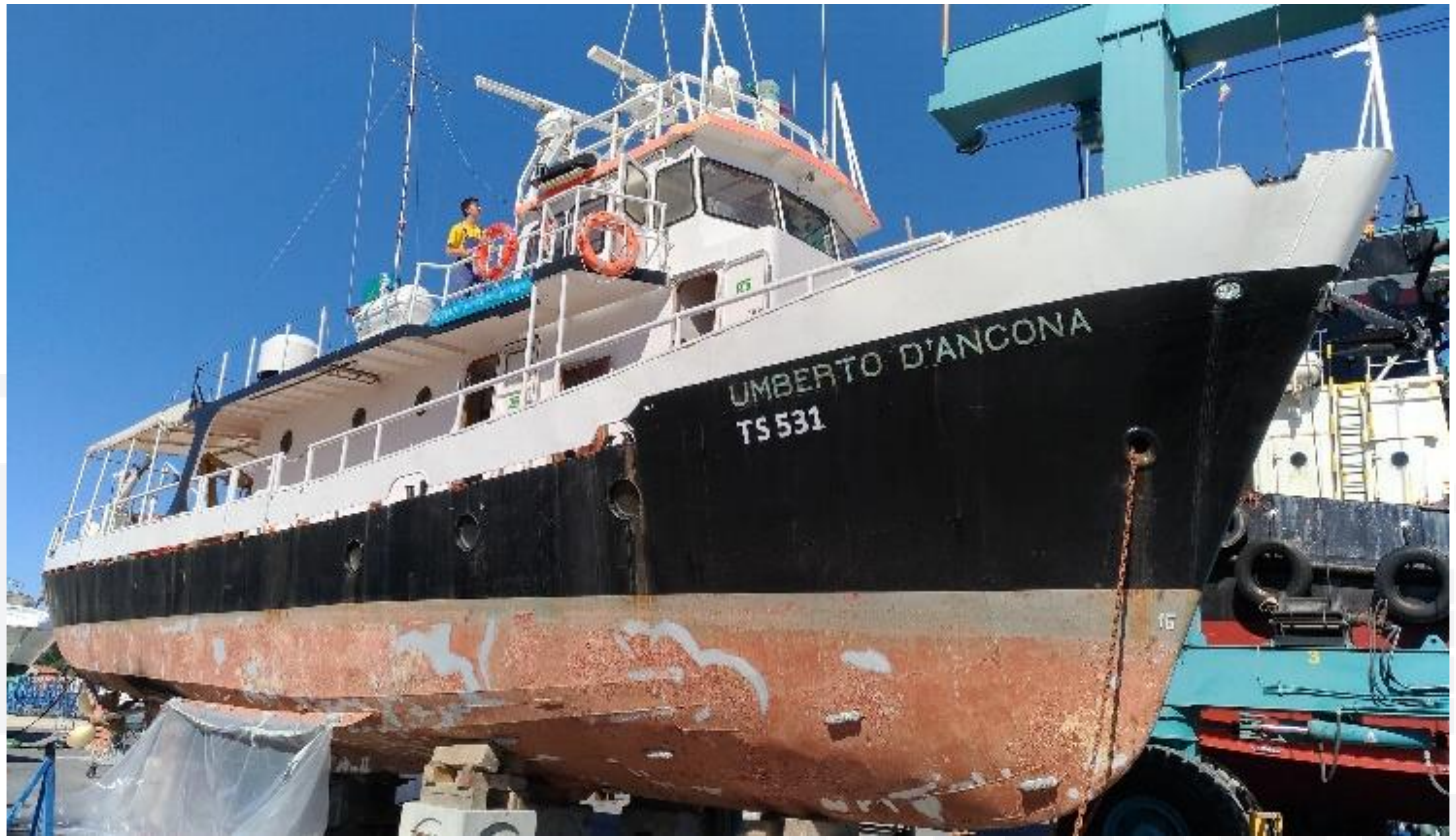
GREEN SHIP 30/33

Conversione di navi in operazione



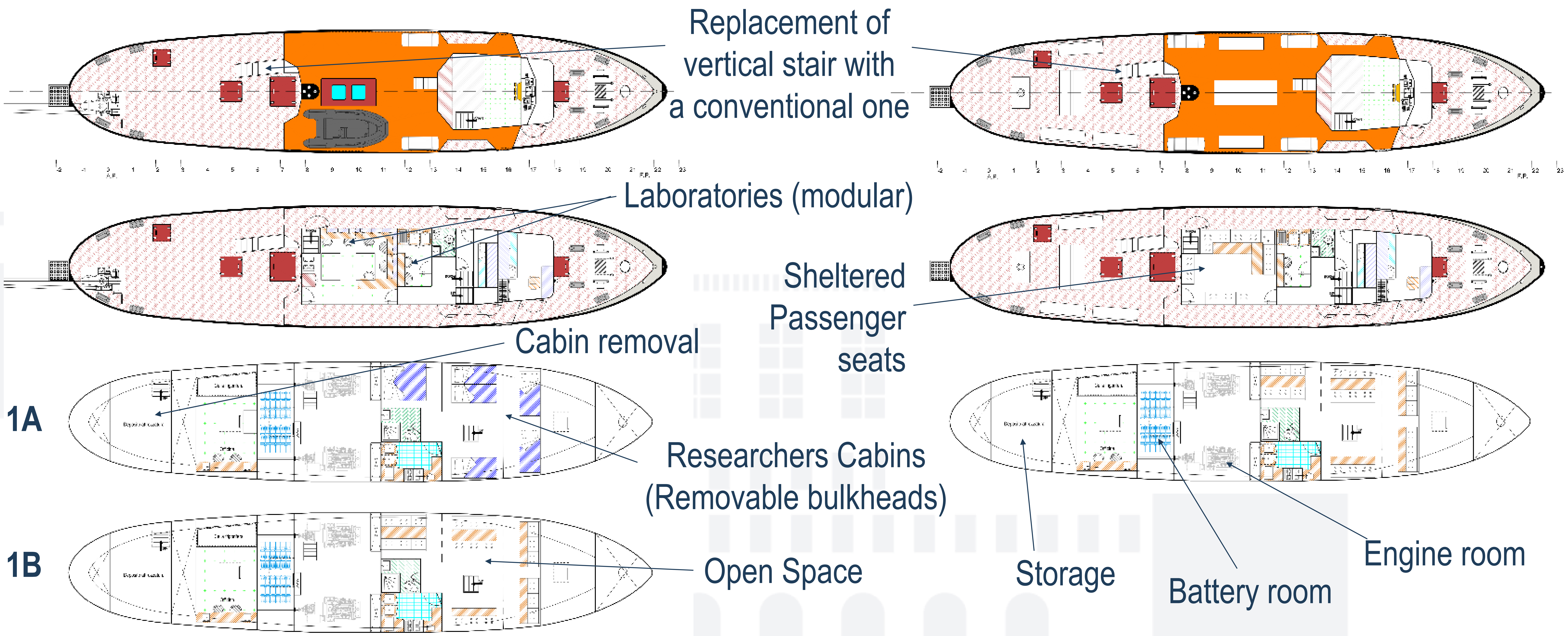
GREEN SHIP 31/33

Conversione di navi in operazione



GREEN SHIP 32/33

Conversione di navi in operazione



1. **Research/training vessel configuration**

2. **Passenger ship configuration**

GREEN SHIP 33/33

Conversione di navi in operazione

Converters 1 and 2 as bidirectional interfaces

AC-DC controlled converters to supply each EM (50 kW) during boost operation

AC-DC rectifying operation when reverse functioning

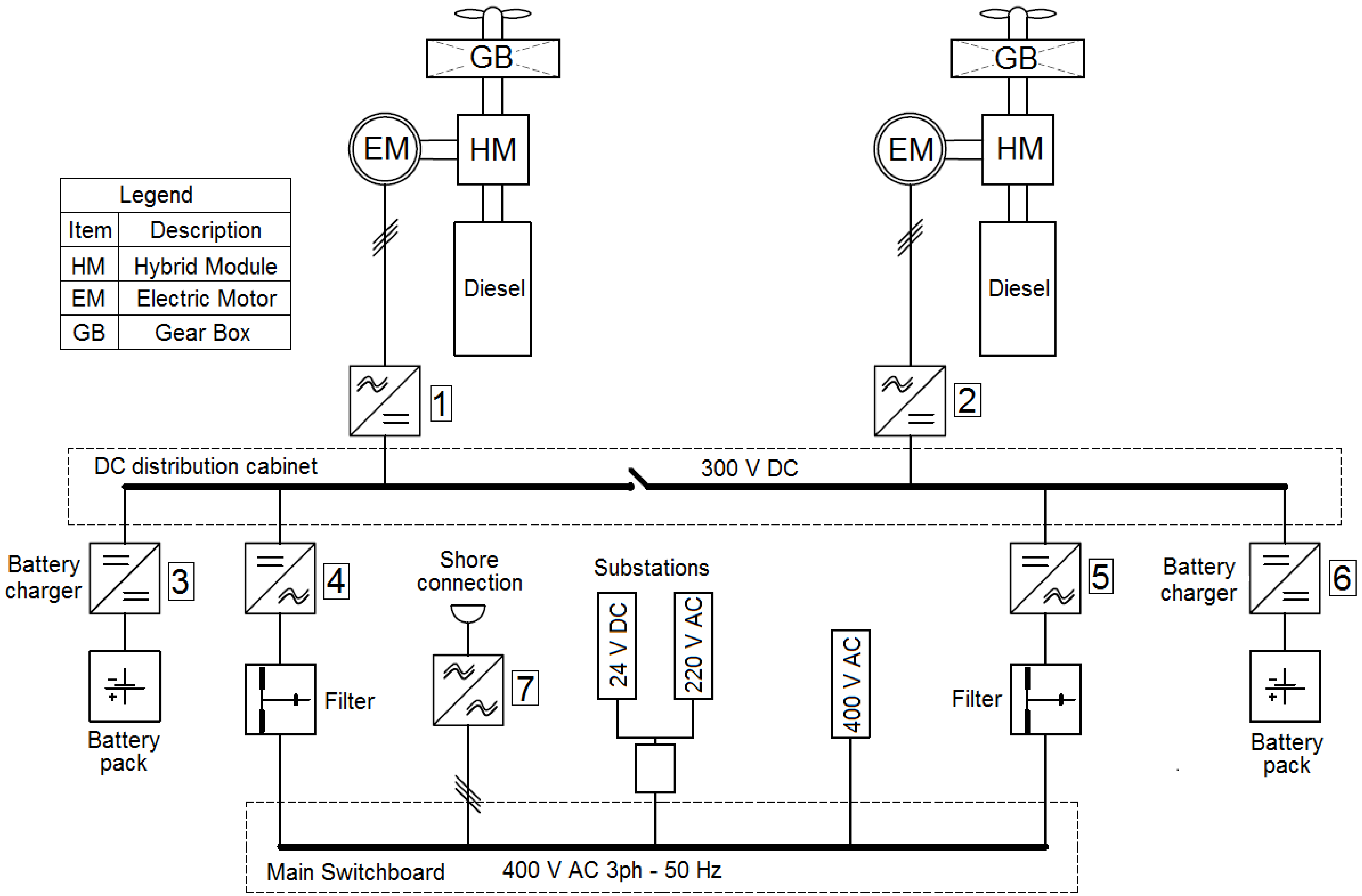
Converters 3 and 6 are the DC-DC interfaces to the storage systems

step-up boost VS step-down buck

36 Lithium battery packs to store 181 kWh

Converters 4 and 5 bidirectional operation (AC-DC or DC-AC)

Convert 7 for the cold ironing



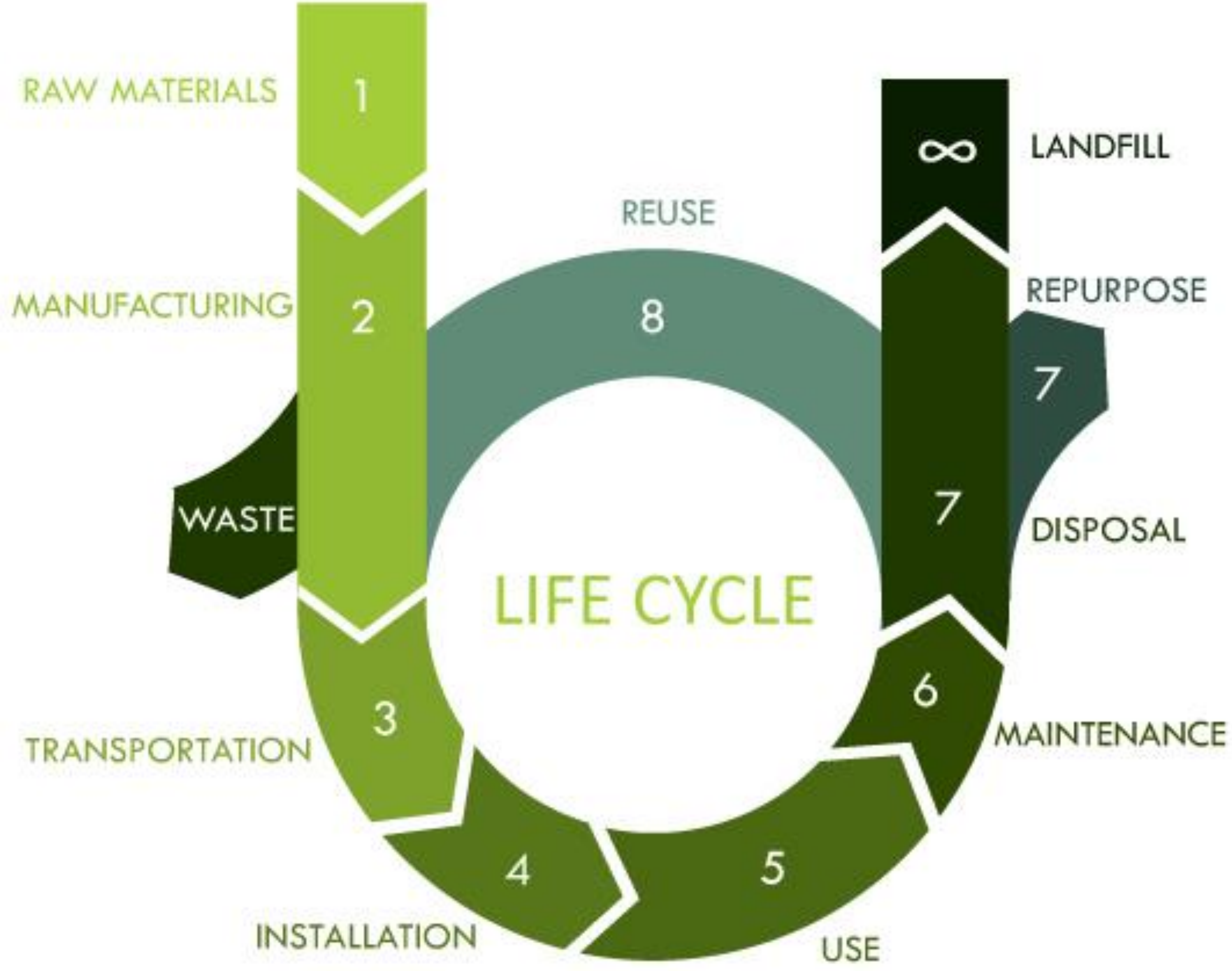
GREEN DESIGN 1/2

Ships should be designed to enable them give the minimal effect on the environment during manufacturing and service.

The keys to green design are 3R:

- **Reduce** the consumption of materials and energy and the pollution to environment in ship manufacturing and service.
- **Recycle** the parts and accessories in ship maintenance.
- **Reuse** the majority of materials after ship laying up.

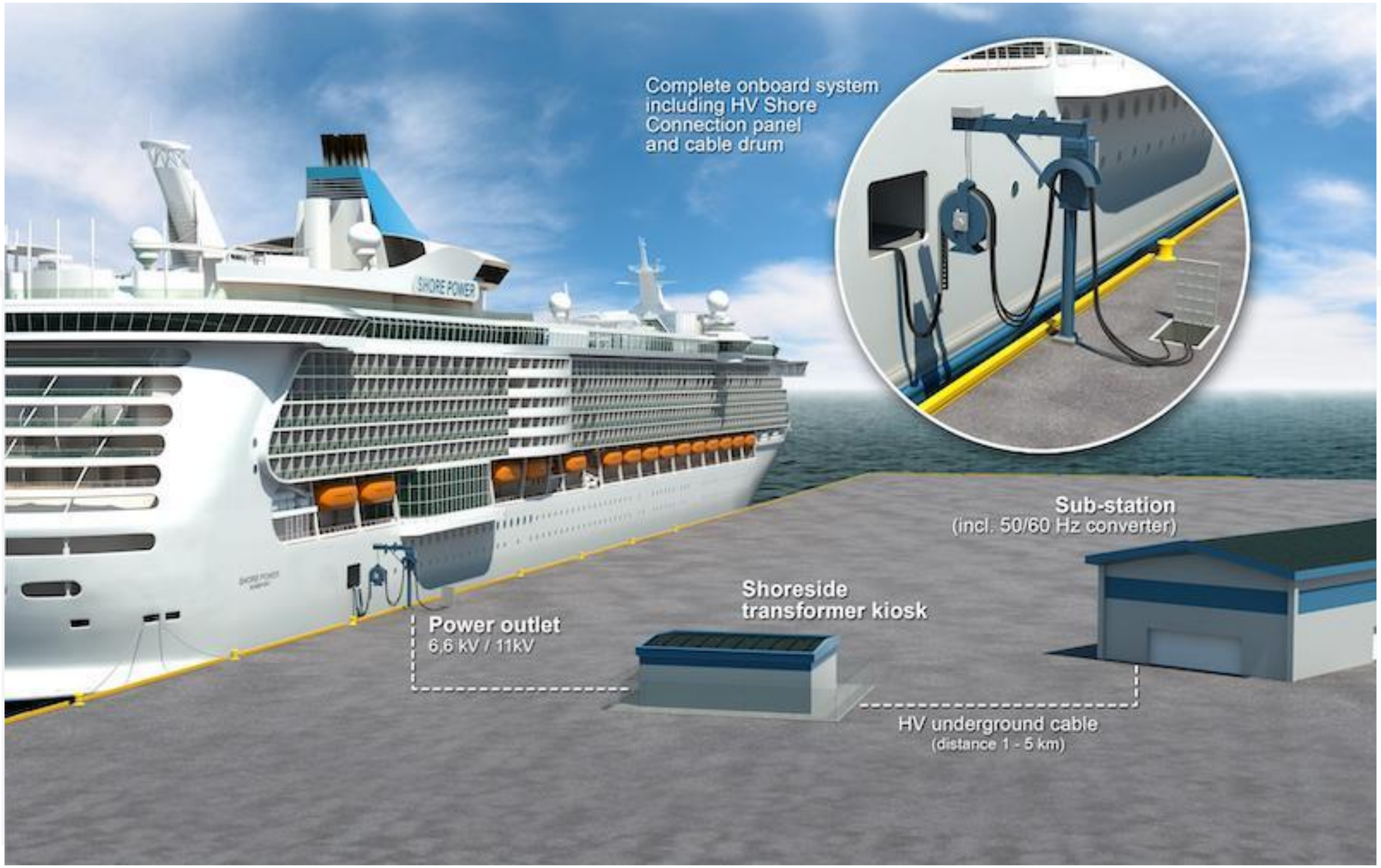
GREEN DESIGN 2/2



UNI EN ISO 14040 ed UNIEN ISO 14044

GREEN LOGISTICS 1/5

Cold ironing



GREEN LOGISTICS 2/5

Cold ironing

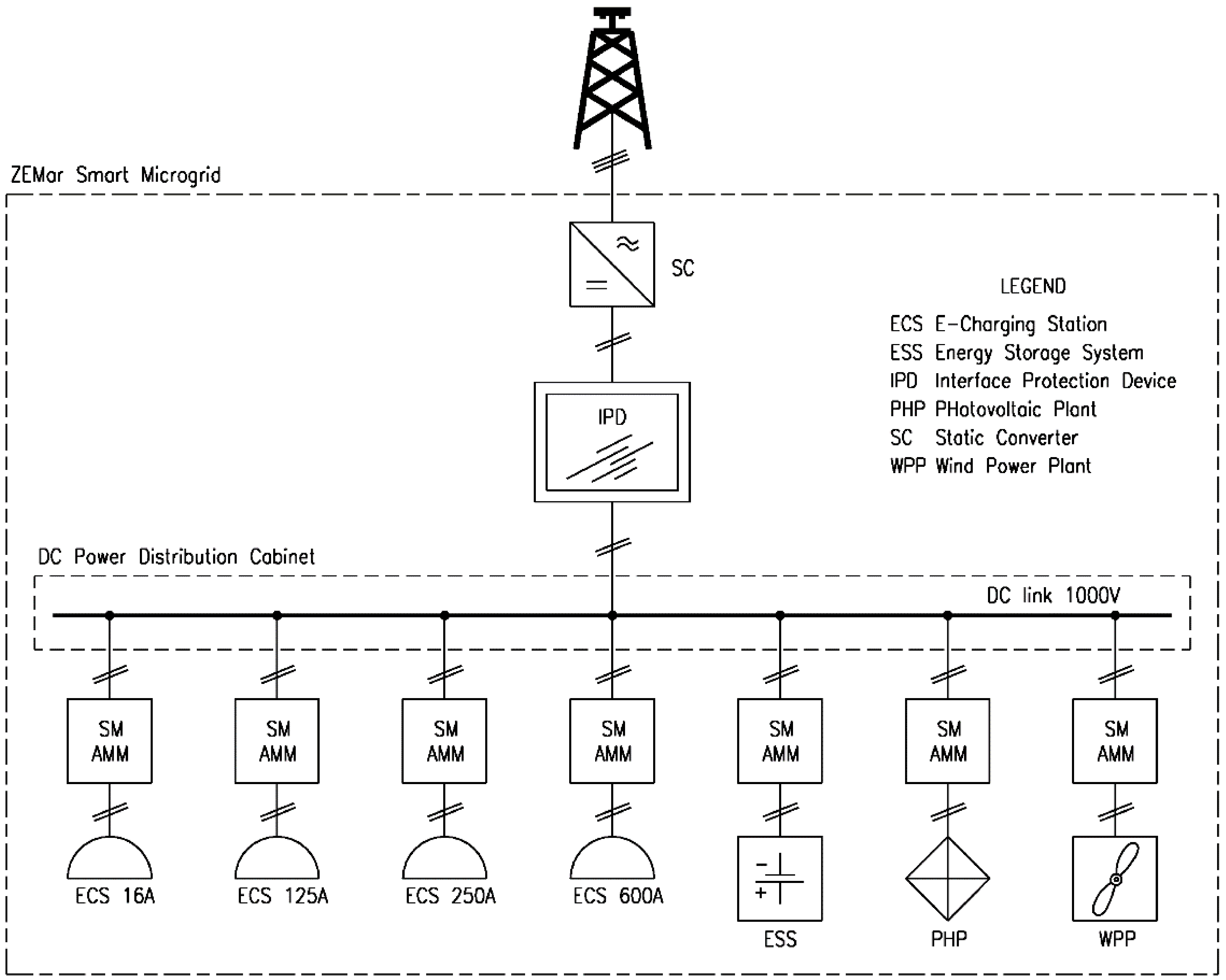
https://fb.watch/7JSmu4CGkW/

GREEN LOGISTICS 3/5

Smart grids

GREEN LOGISTICS 4/5

Smart Marinas



GREEN LOGISTICS 5/5

Smart Marinas

Renzo Piano a

Montecarlo!!!!

ISD LAB INTEGRATED SHIP DESIGN

UNIVERSITÀ DEGLI STUDI DI TRIESTE

UNIVERSITÀ
DEGLI STUDI
DI TRIESTE

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