MARIN

BETTER SHIPS, BLUE OCEANS

Sustainable Ships for our Blue Planet

Guilhem Gaillarde
Head of Ships Department

OUR BLUE PLANET

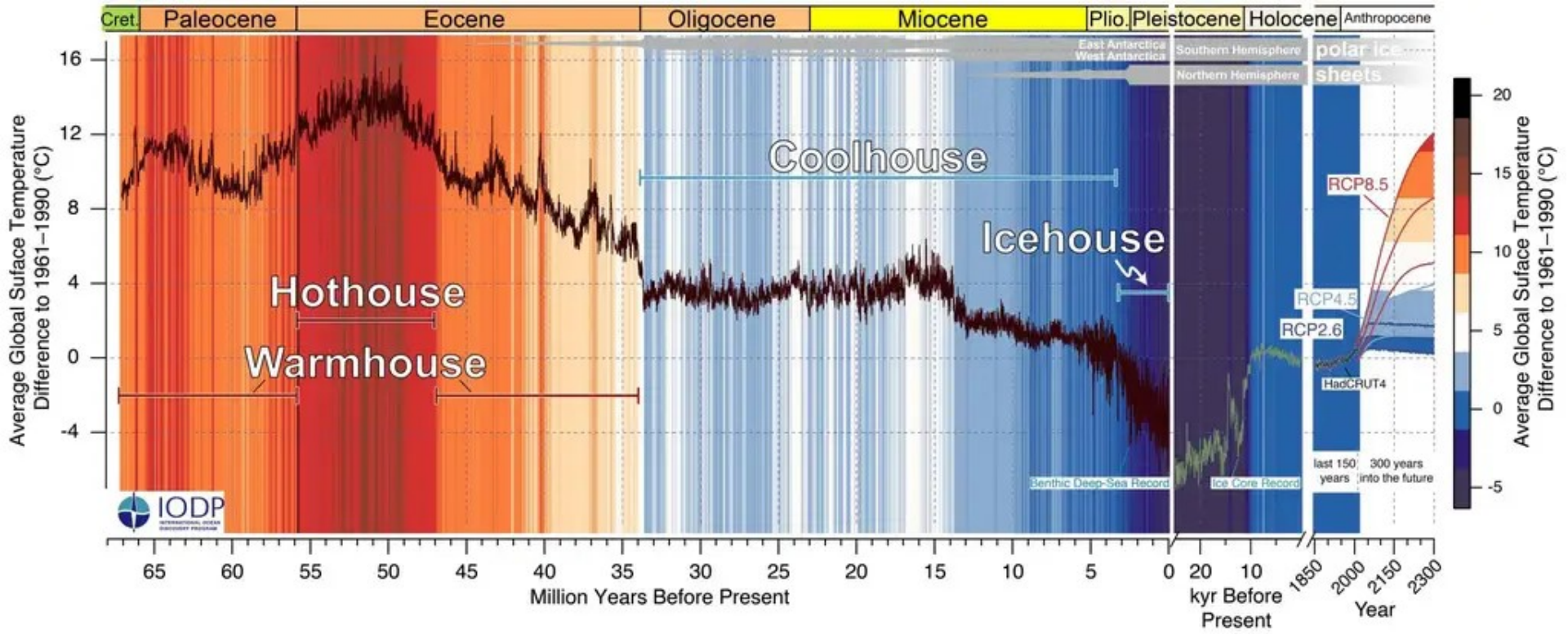
OUR BLUE PLANET

71% of its surface is covered by water
97.5% of water on earth is in the Oceans

90% of world trade is transported by seas
118.928 ships worldwide (>100 GT)
7.000 ships represent 51% of total GT

3% of annual GHG emission from shipping
expected to double in 2050 with same type of energy and power systems

OUR BLUE PLANET



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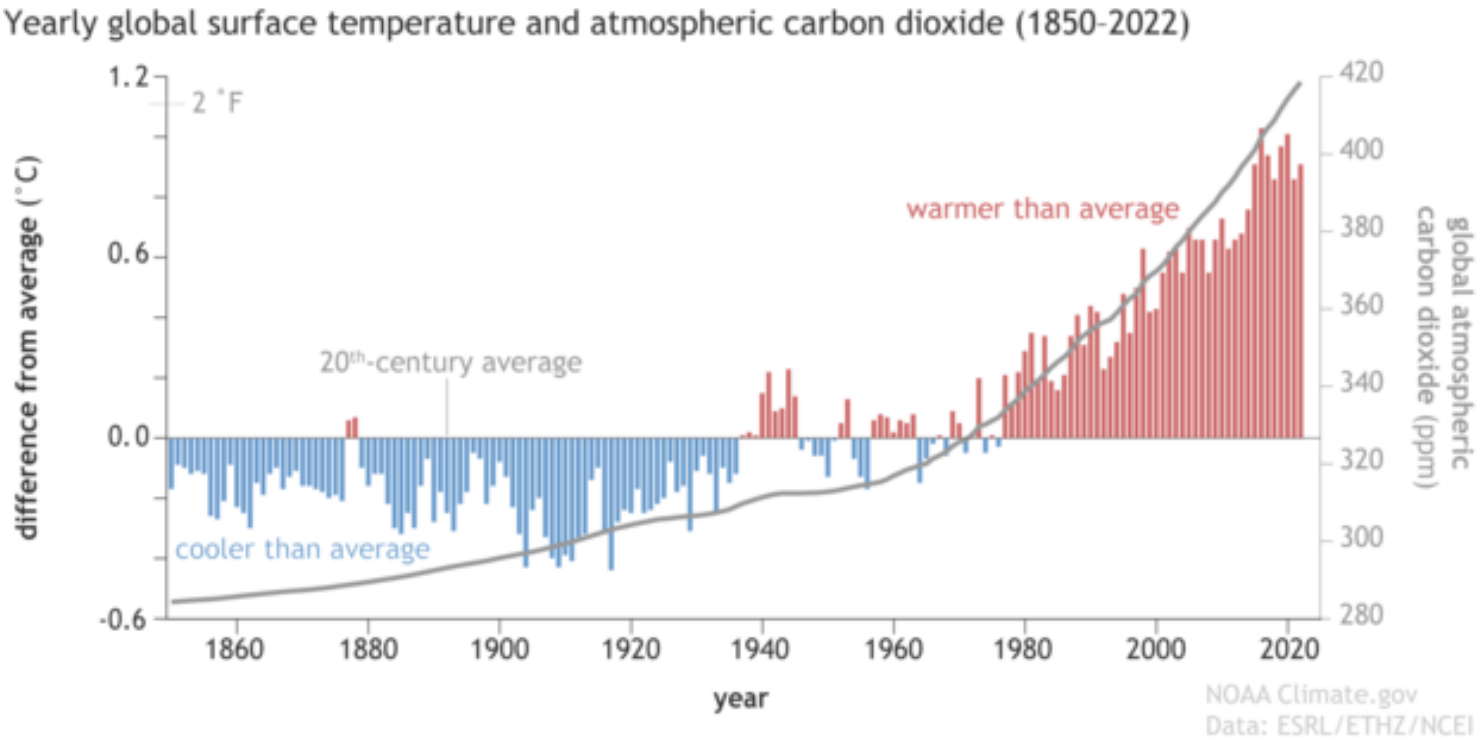


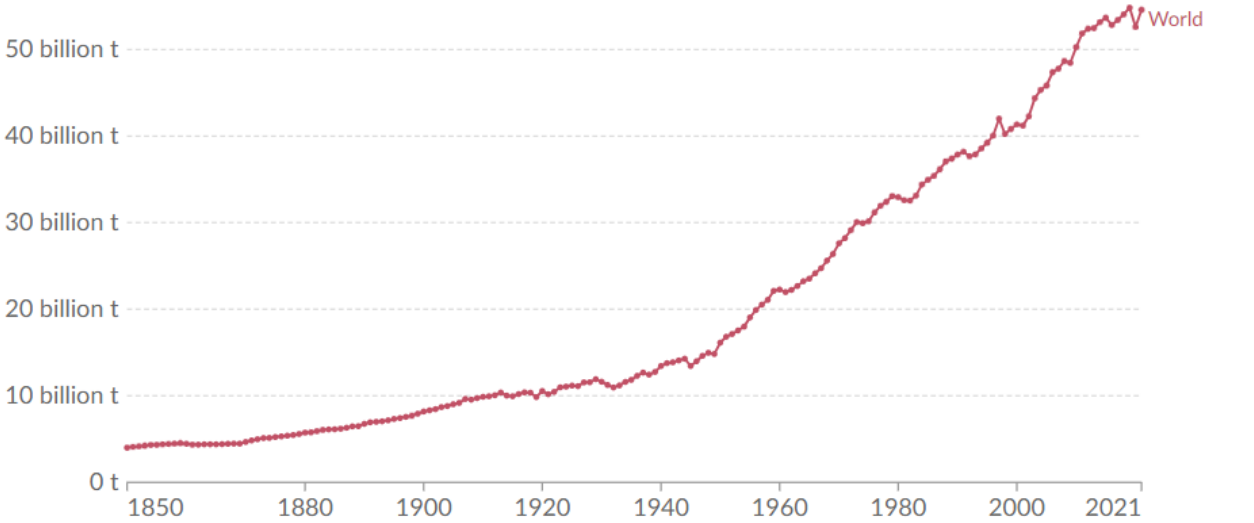
Greenhouse gas emissions

Our World in Data

Greenhouse gas emissions include carbon dioxide, methane and nitrous oxide from all sources, including agriculture and land use change. They are measured in carbon dioxide-equivalents over a 100-year timescale.

Table | Map | Chart

Edit countries and regions | Settings



1850 2021

Data source: Calculated by Our World in Data based on emissions data from Jones et al. (2023) - Learn more about this data

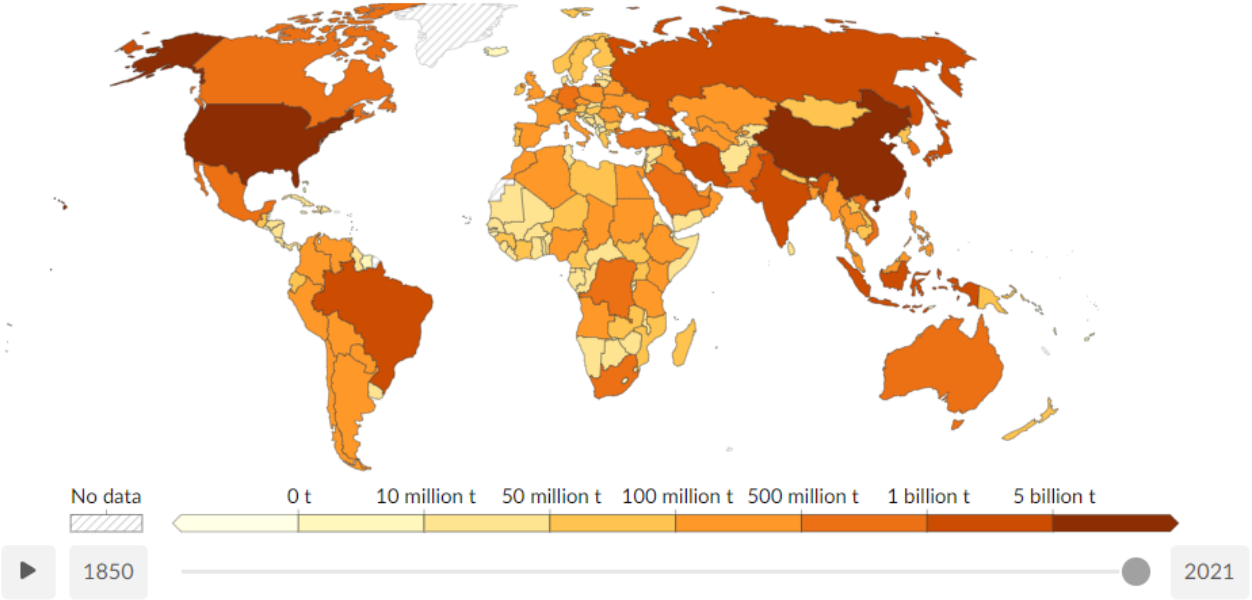
Greenhouse gas emissions, 2021

Greenhouse gas emissions include carbon dioxide, methane and nitrous oxide from all sources, including agriculture and land use change. They are measured in carbon dioxide-equivalents over a 100-year timescale.

Our World in Data

Table | Map | Chart

World



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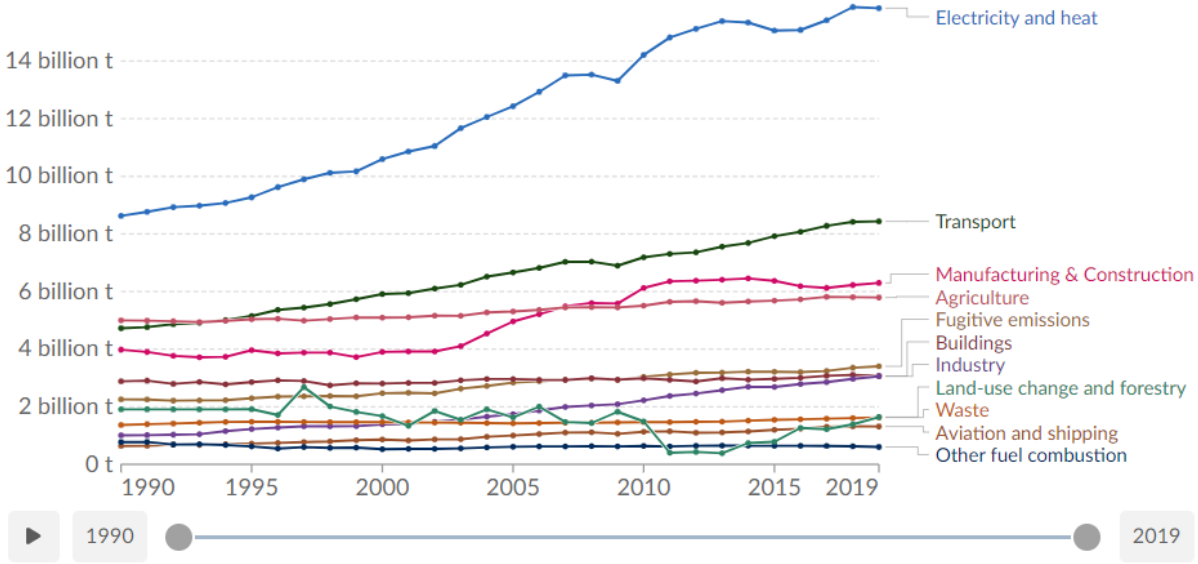
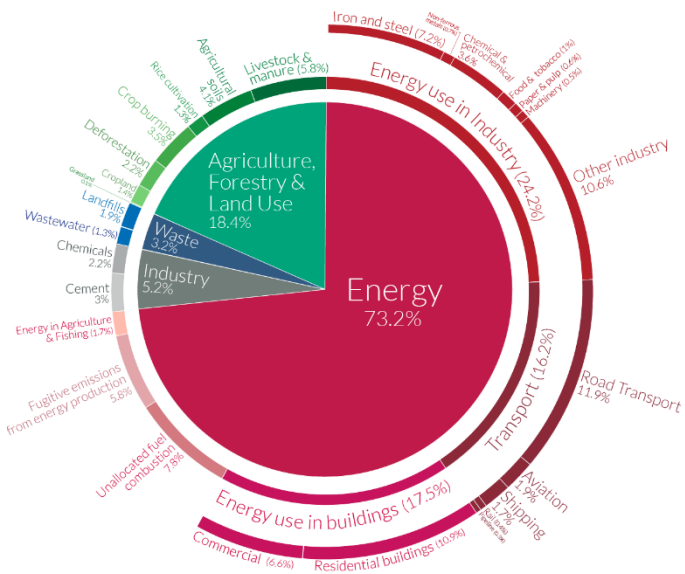
Greenhouse gas emissions by sector, World

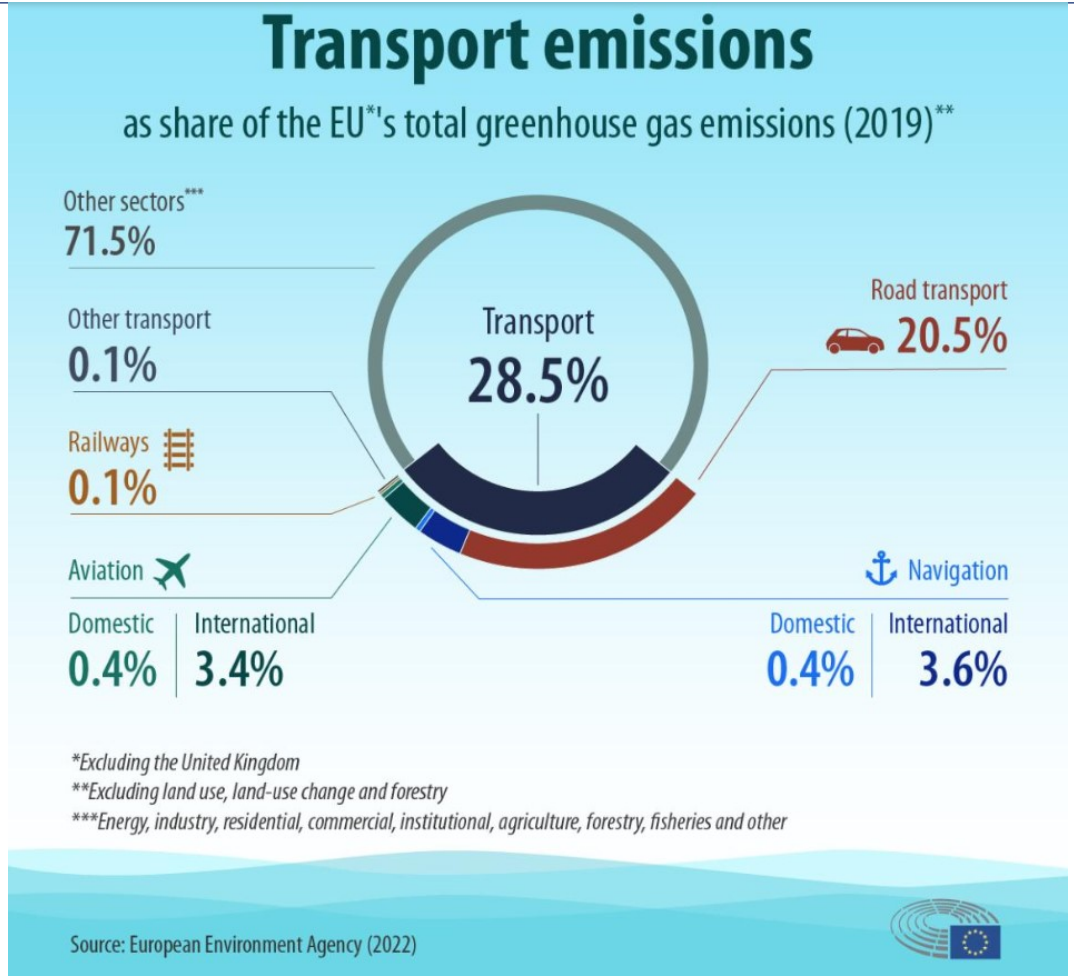
Our World in Data

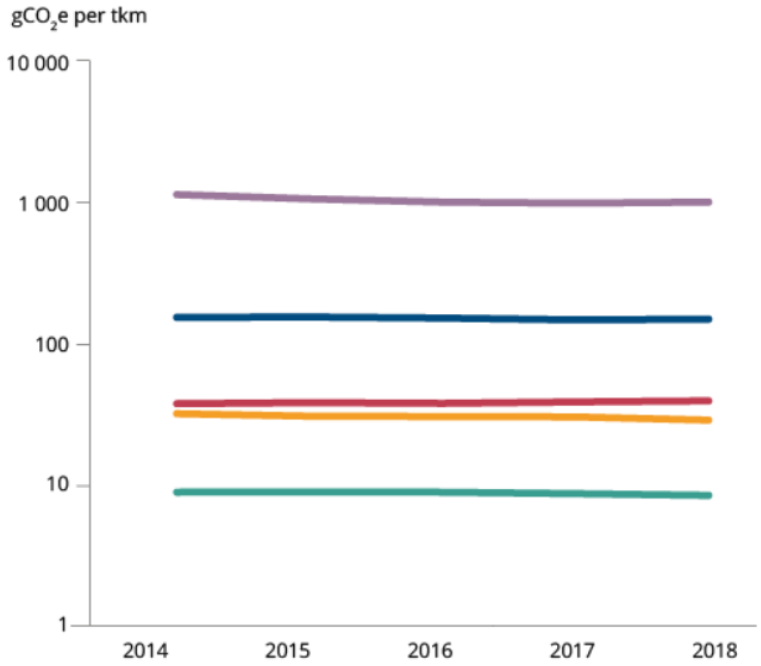
Emissions are measured in carbon dioxide equivalents (CO_2eq). This means non-CO_2 gases are weighted by the amount of warming they cause over a 100-year timescale.

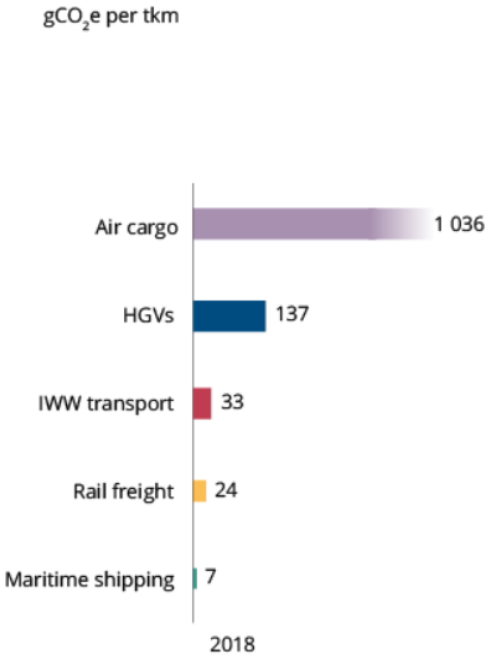
Table | Chart | Change country or region | Settings



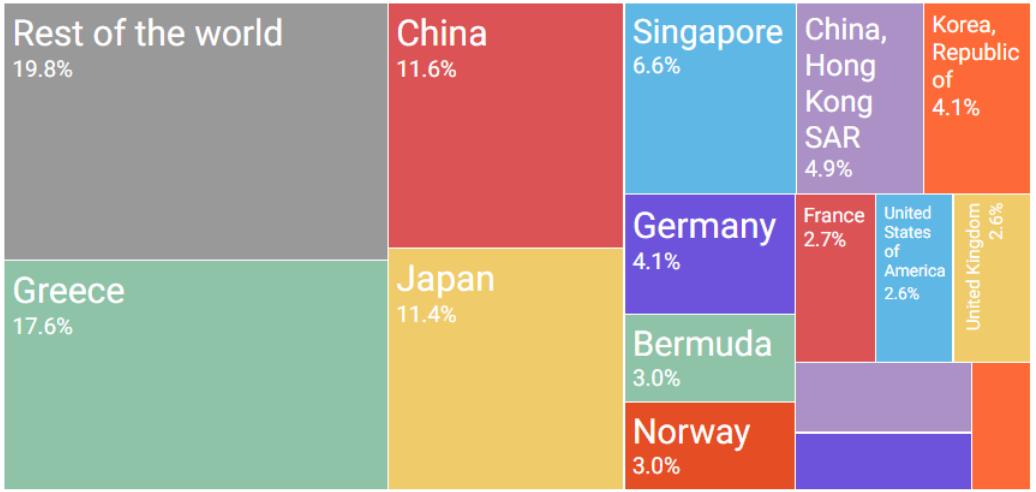



Transport emissions
as share of the EU*'s total greenhouse gas emissions (2019)**
Other sectors***
71.5%
Other transport
0.1%
Railways
0.1%
Aviation
Domestic
0.4%
International
3.4%
Transport
28.5%
Road transport
20.5%
Navigation
Domestic
0.4%
International
3.6%
*Excluding the United Kingdom
**Excluding land use, land-use change and forestry
***Energy, industry, residential, commercial, institutional, agriculture, forestry, fisheries and other
Source: European Environment Agency (2022)

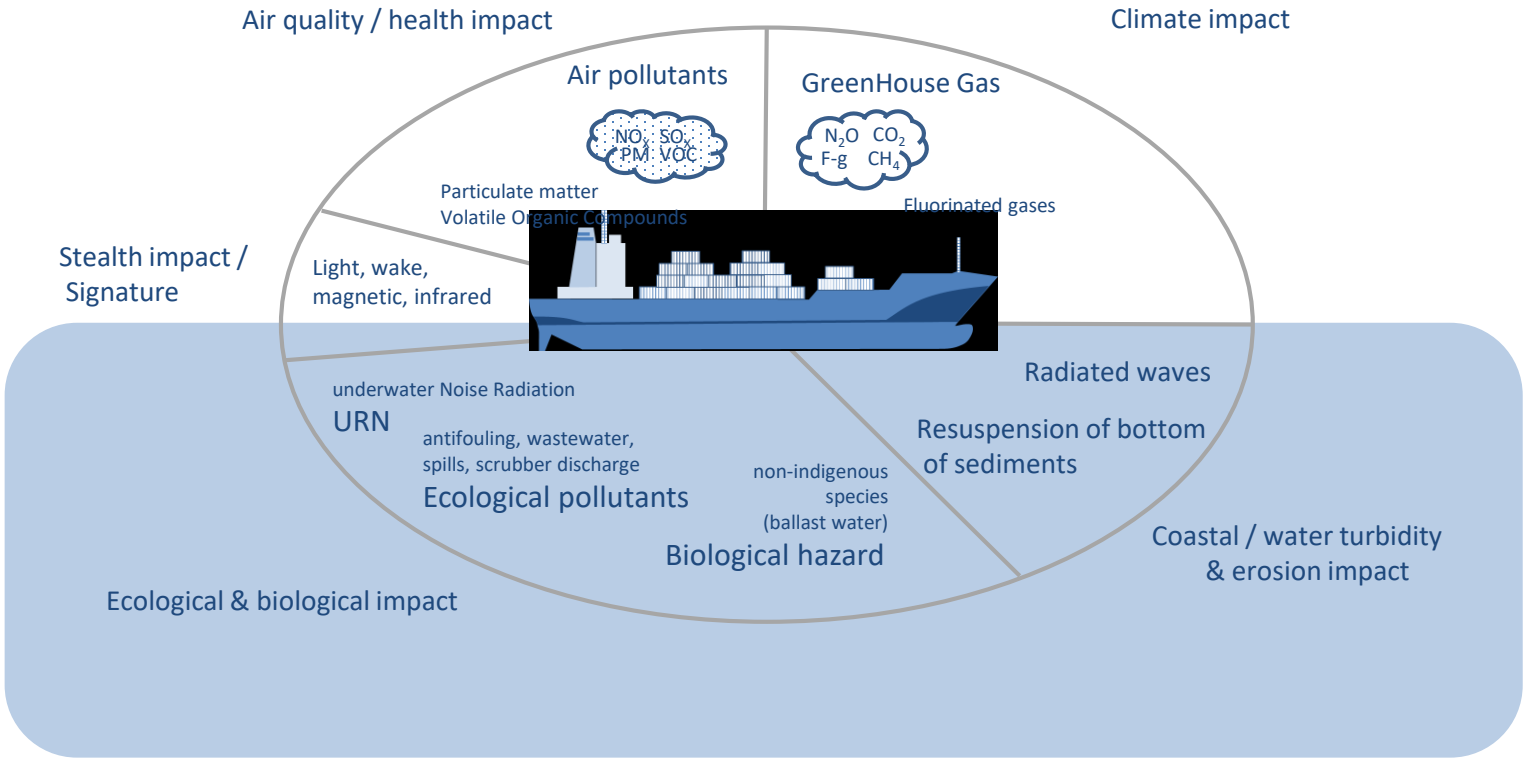

gCO2e per tkm
10 000
1 000
100
10
1
2014
2015
2016
2017
2018


gCO2e per tkm
Air cargo
1 036
HGVs
137
IWW transport
33
Rail freight
24
Maritime shipping
7
2018

Share of world fleet in % owned by top 15 countries in 2021 (> 5000GT)



Which emissions from ships?



theguardian.com/environment/2009/apr/09/shipping-pollution

This article is more than **14 years old**

Health risks of shipping pollution have been 'underestimated'

One giant container ship can emit almost the same amount of cancer and asthma-causing chemicals as 50m cars, study finds

lngtransfer.com/news/the-16-biggest-ships-produce-more-pollution-than-all-the-cars-in-the-world/

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21 Oct 2016

Home » News » The 16 biggest ships produce more pollution than all the cars in the World

The 16 biggest ships produce more pollution than all the cars in the World

Posted in News By Mark James On October 21, 2016

newatlas.com/shipping-pollution/11526/

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ENVIRONMENT

Big polluters: One massive container ship equals 50 million cars

April 23, 2009

CO2 emissions: claims and fact checks

Claim:
"The 16 largest ships emit as much CO2 emissions as all the cars in the world" (NRC.nl, 2014).

Evaluation CE Delft study (2021)*:
16 of the largest ships […] emitted between 1 and 4 million tons of CO2 in 2015, while all the cars in the world emitted between 1,900 and 3,500 million tons of CO2

16 of the largest ships produced as much CO2 emission than 0,1% of all the cars in the world

* Source: https://cedelft.eu/wp-content/uploads/sites/2/2021/04/CE_Delft_7N59_The_basic_facts_Summary_and_Conclusions.pdf

SOx emissions: claims and fact checks

"The 17 largest ships in the world emit more sulfur than all the cars in the world combined" (D66, 2017).

Evaluation CE Delft study (2021)*:
17 of the largest ships emitted in 2015, depending on how you define "large," between around 10 and 45 kilotons of SOX. Around 947 million cars worldwide emitted between around 70 and 350 kilotons of SOX in 2015.

'With an estimated 800 million cars driving around the planet, that means 16 super-ships **can** emit as much sulphur as the world fleet of cars' (Daily Mail Online, 2009).

Evaluation CE Delft study (2021)*:
If you define a 'super-ship' as a cruise ship and assume that the 16 largest cruise ships only operated on HFO (with the maximum allowable sulfur content of 3.5%), then the statement is correct. However, because cruise ships often sail in Emission Control Areas, (and the average sulfur content of HFO in 2015 was already at 2.45%), this statement was accurate in 2015 only under unrealistic assumptions.

One large container ship with over 14,500 TEU emitted around 1 kiloton of SOX in 2015. This is equivalent to about 3 to 12 million cars in 2015.

NOx emissions: claims and fact checks

Claim:
"Container ship as polluting as up to 50 million cars" (Groen7.NL, 2015).

16 of the largest container ships (with over 14,500 TEU) emitted around 45 kilotons of NOX in total in 2015. 50% of the cars worldwide emitted around 5,900 kilotons of NOX in 2015, which is 130 times more.

1 large container vessel emits per year as much nitrous dioxide than about 250.000 cars

Designing sustainable ships and waterborne operations is technically possible but necessitates a holistic approach, full of challenges and requires making choices and accepting changes.

- Ship design
- Ship operations
- Fuel & Transport Infrastructures
- Fleet & Logistics

Three main drivers

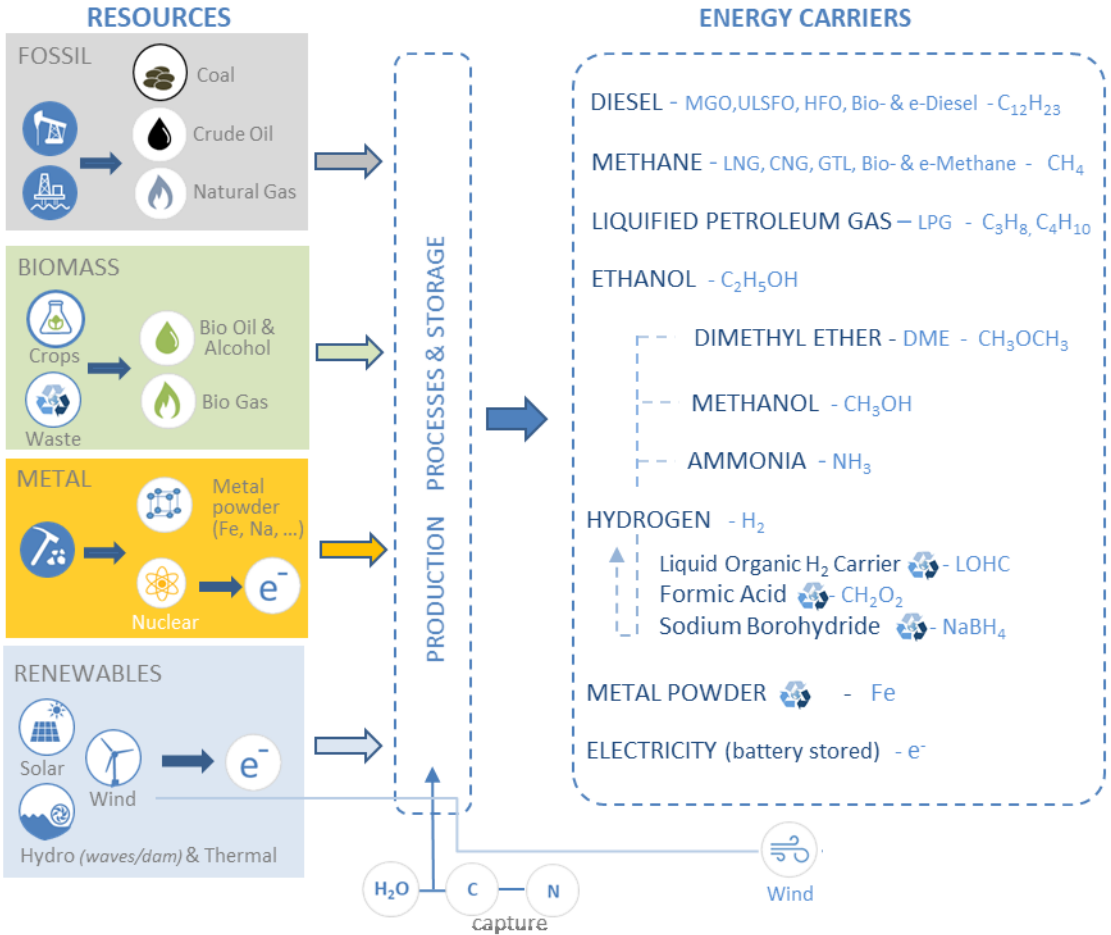
- **Use sustainable energy**
- **Design for operations**
- **Use less energy**

One ready to implement solution

- **Use freely available energy**

SUSTAINABLE ENERGY


RESOURCES
FOSSIL
Coal
Crude Oil
Natural Gas
BIOMASS
Crops
Waste
Bio Oil & Alcohol
Bio Gas
METAL
Metal powder (Fe, Na, ...)
Nuclear
e-
RENEWABLES
Solar
Wind
e-
Hydro (waves/dam) & Thermal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Metal powder (Fe, Na, ...)
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e-
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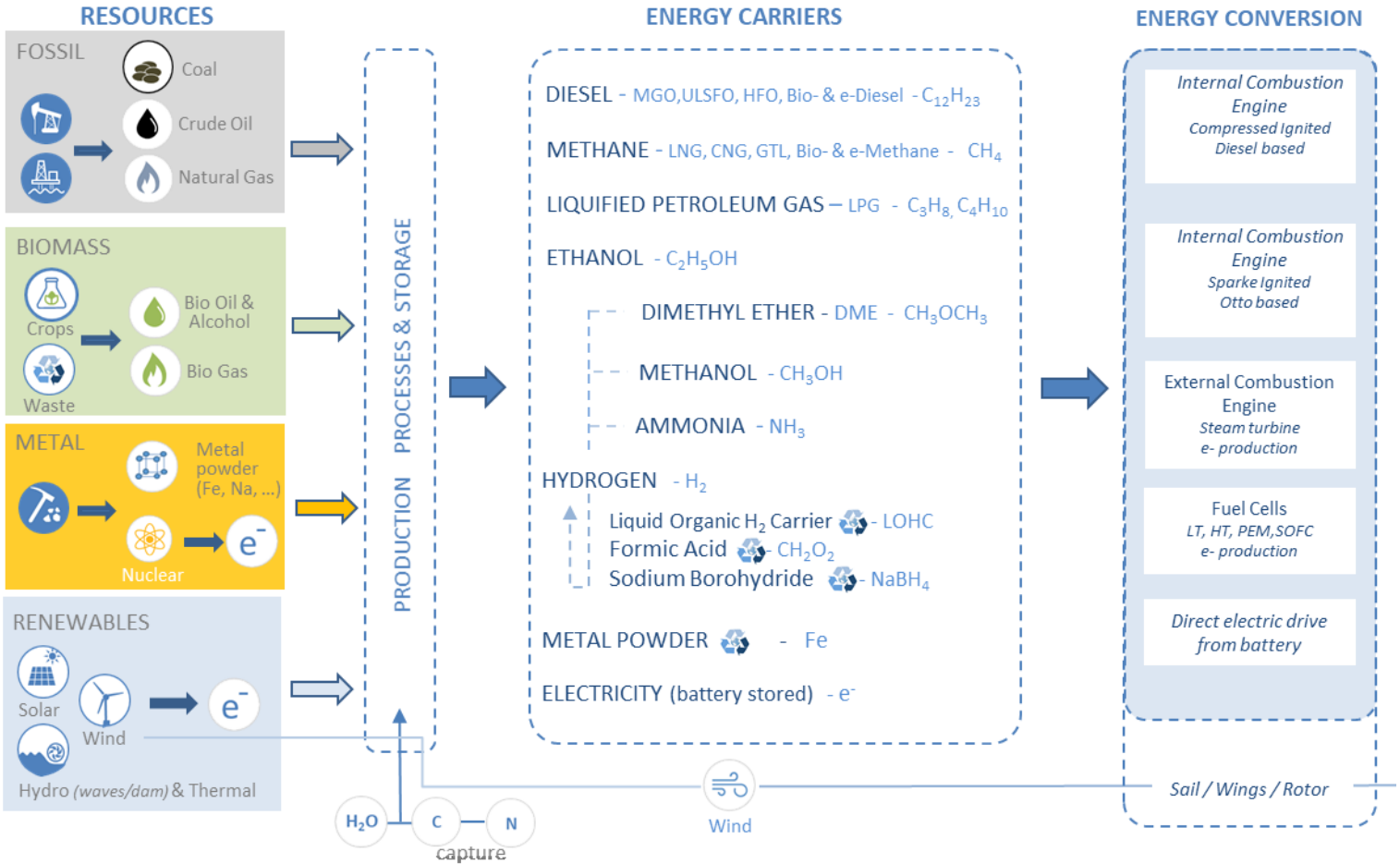
Wind
e-
Hydro (waves/dam) & Thermal
PRODUCTION PROCESSES & STORAGE
ENERGY CARRIERS
DIESEL - MGO,ULSFO, HFO, Bio- & e-Diesel - C12H23
METHANE - LNG, CNG, GTL, Bio- & e-Methane - CH4
LIQUIFIED PETROLEUM GAS – LPG - C3H8, C4H10
ETHANOL - C2H5OH
DIMETHYL ETHER - DME - CH3OCH3
METHANOL - CH3OH
AMMONIA - NH3
HYDROGEN - H2
Liquid Organic H2 Carrier - LOHC
Formic Acid - CH2O2
Sodium Borohydride - NaBH4
METAL POWDER - Fe
ELECTRICITY (battery stored) - e-
H2O
C
N
capture
Wind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DIMETHYL ETHER - DME - CH_3OCH_3
METHANOL - CH_3OH
AMMONIA - NH_3
HYDROGEN - H_2
Liquid Organic H_2 Carrier - LOHC
Formic Acid - CH_2O_2
Sodium Borohydride - $NaBH_4$
METAL POWDER - Fe
ELECTRICITY (battery stored) - e^-
ENERGY CONVERSION
Internal Combustion Engine
Compressed Ignited
Diesel based
Internal Combustion Engine
Sparke Ignited
Otto based
External Combustion Engine
Steam turbine
e- production
Fuel Cells
LT, HT, PEM,SOFC
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Direct electric drive from battery
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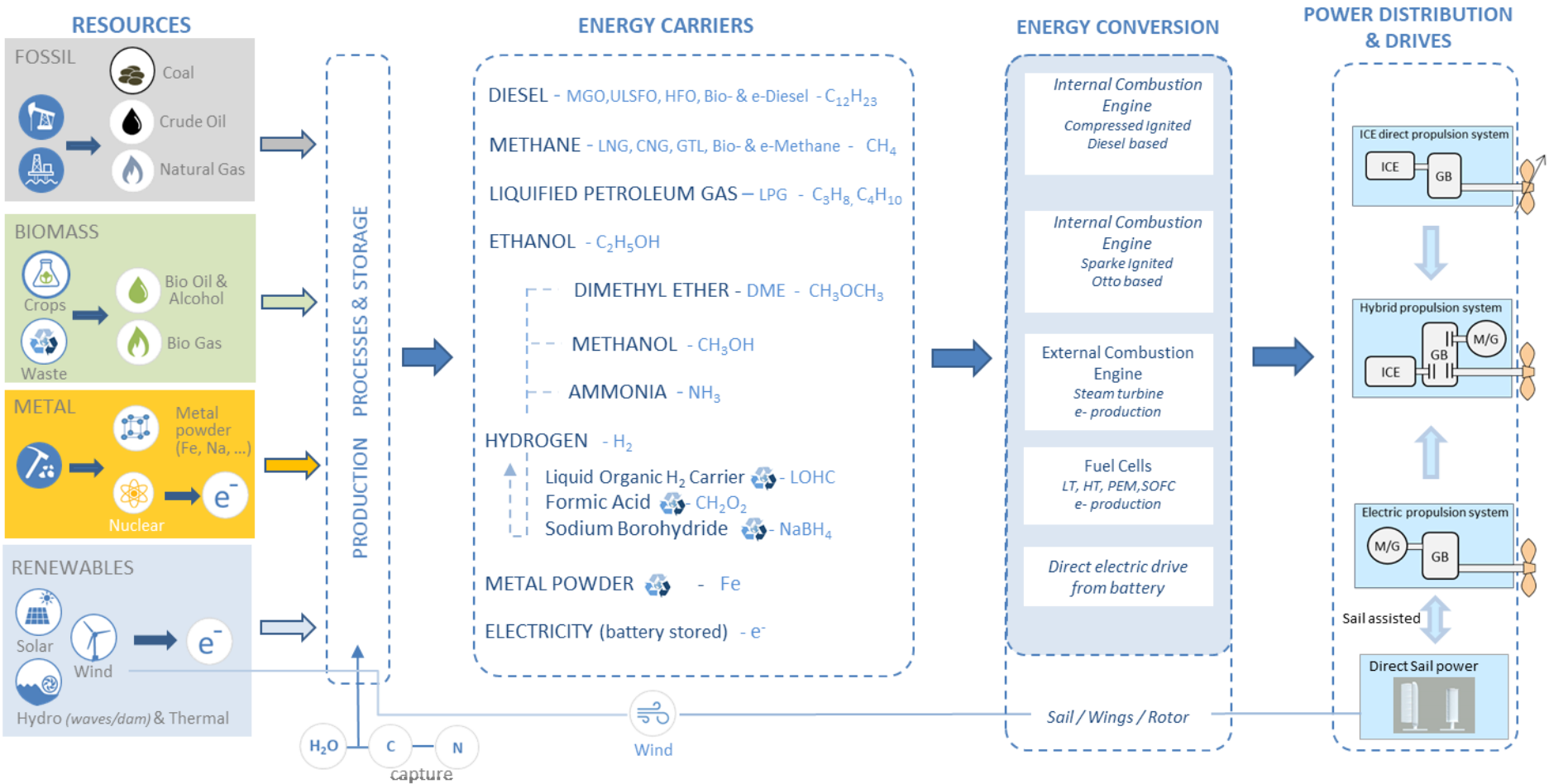
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ICE
GB
Hybrid propulsion system
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M/G
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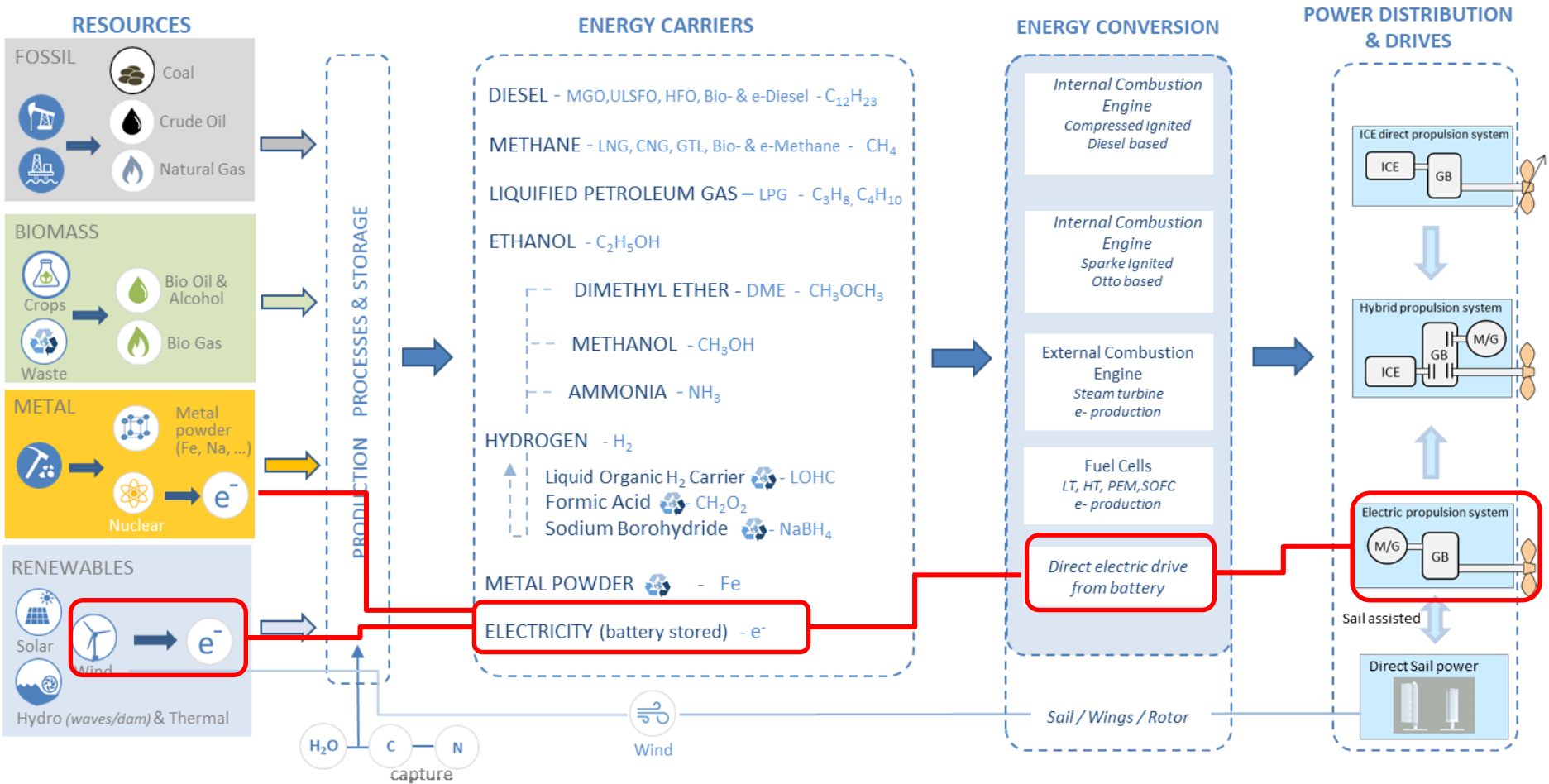
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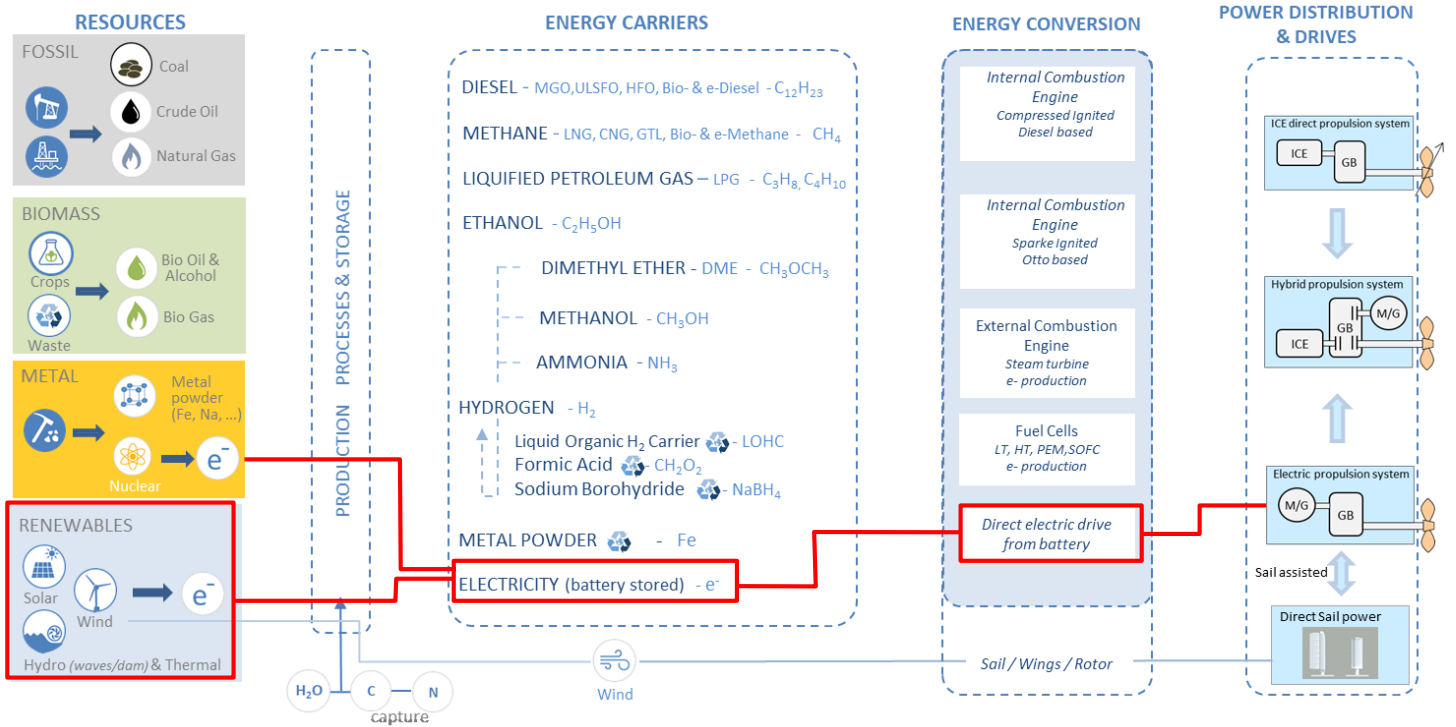
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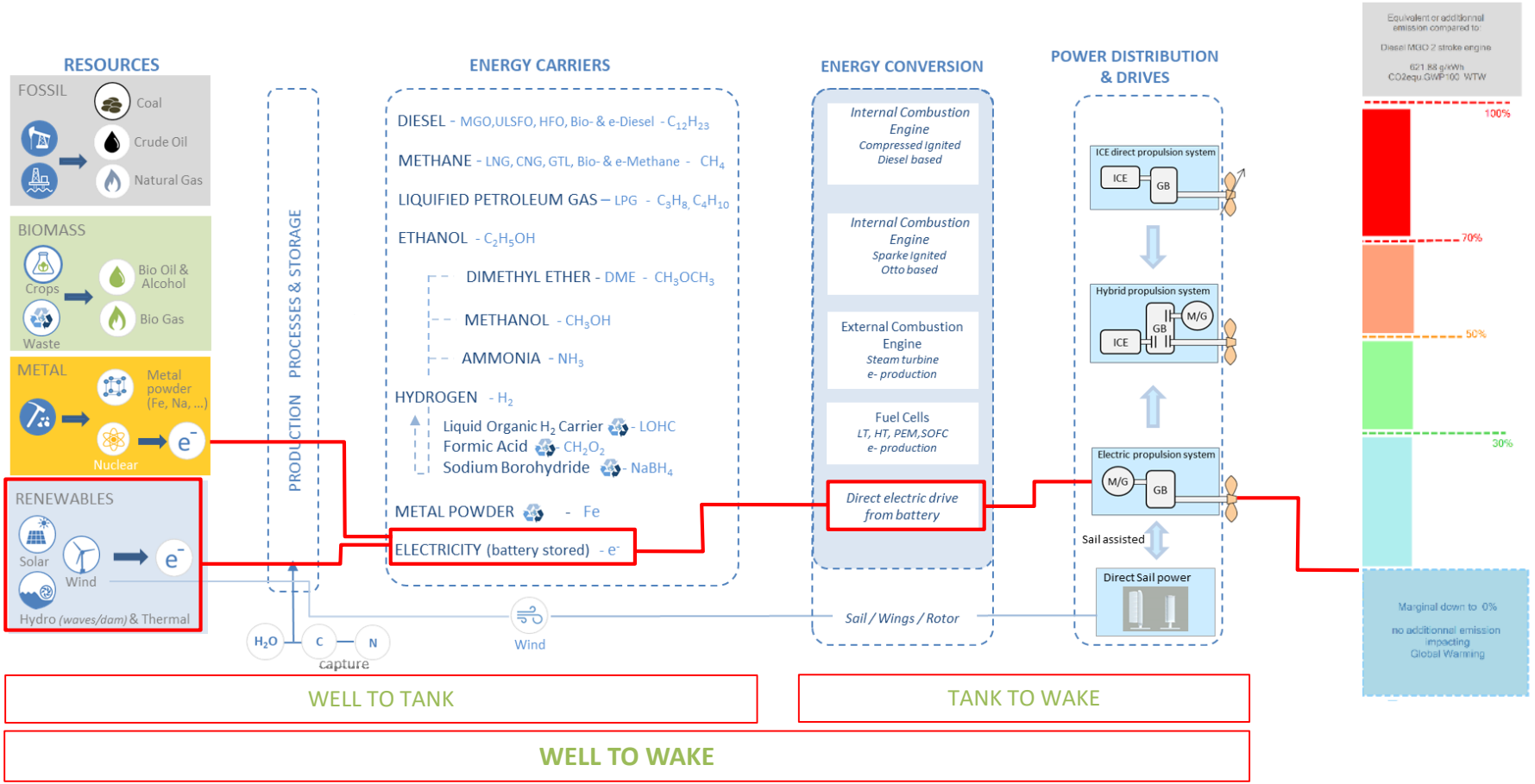
WTW CO_2eq. GWP100 [g/kWh]
WELL TO TANK
TANK TO WAKE
WELL TO WAKE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621.88 g/kWh
CO2equ.GWP100 WTW
100%
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Marginal down to 0%
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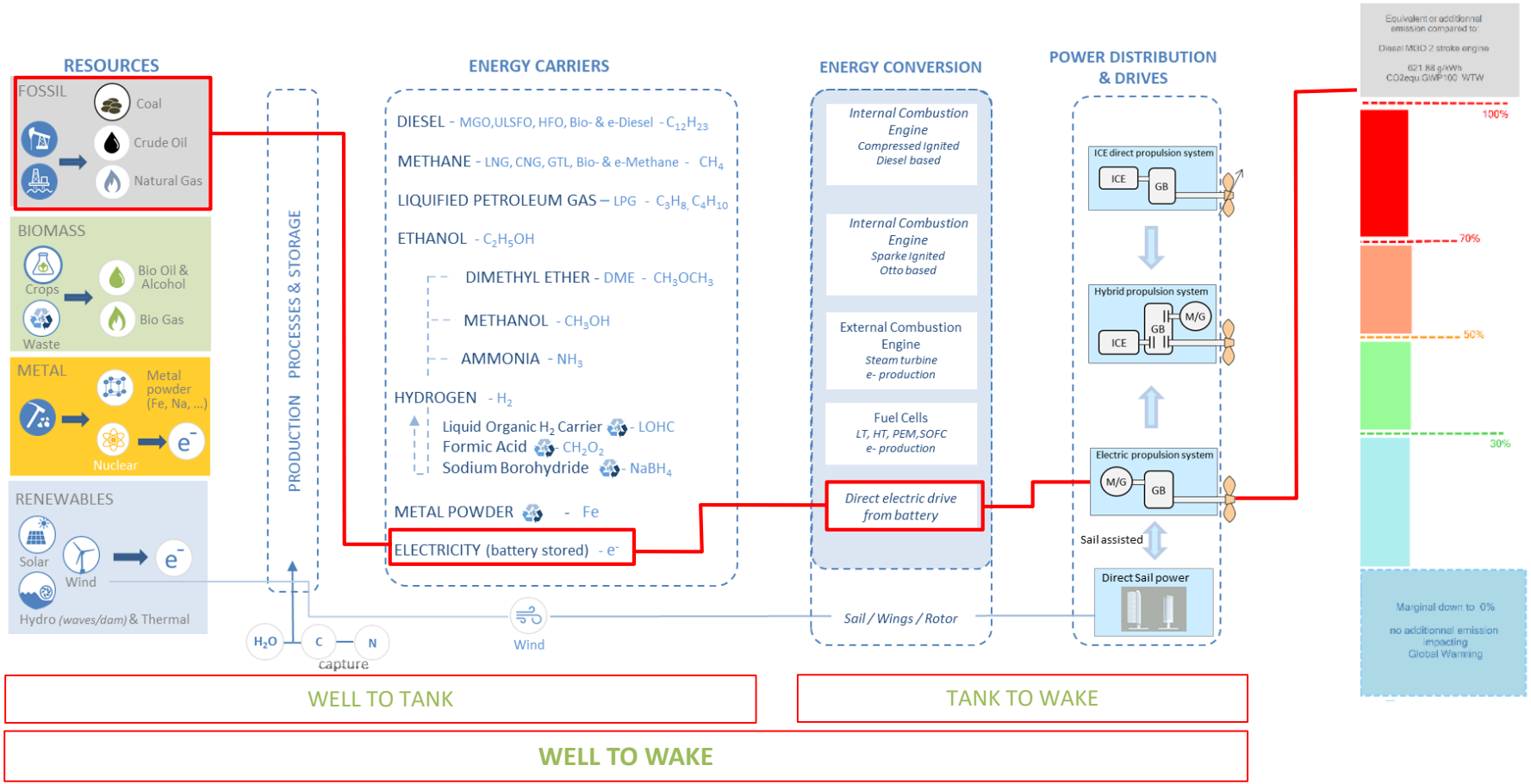
WELL TO WAKE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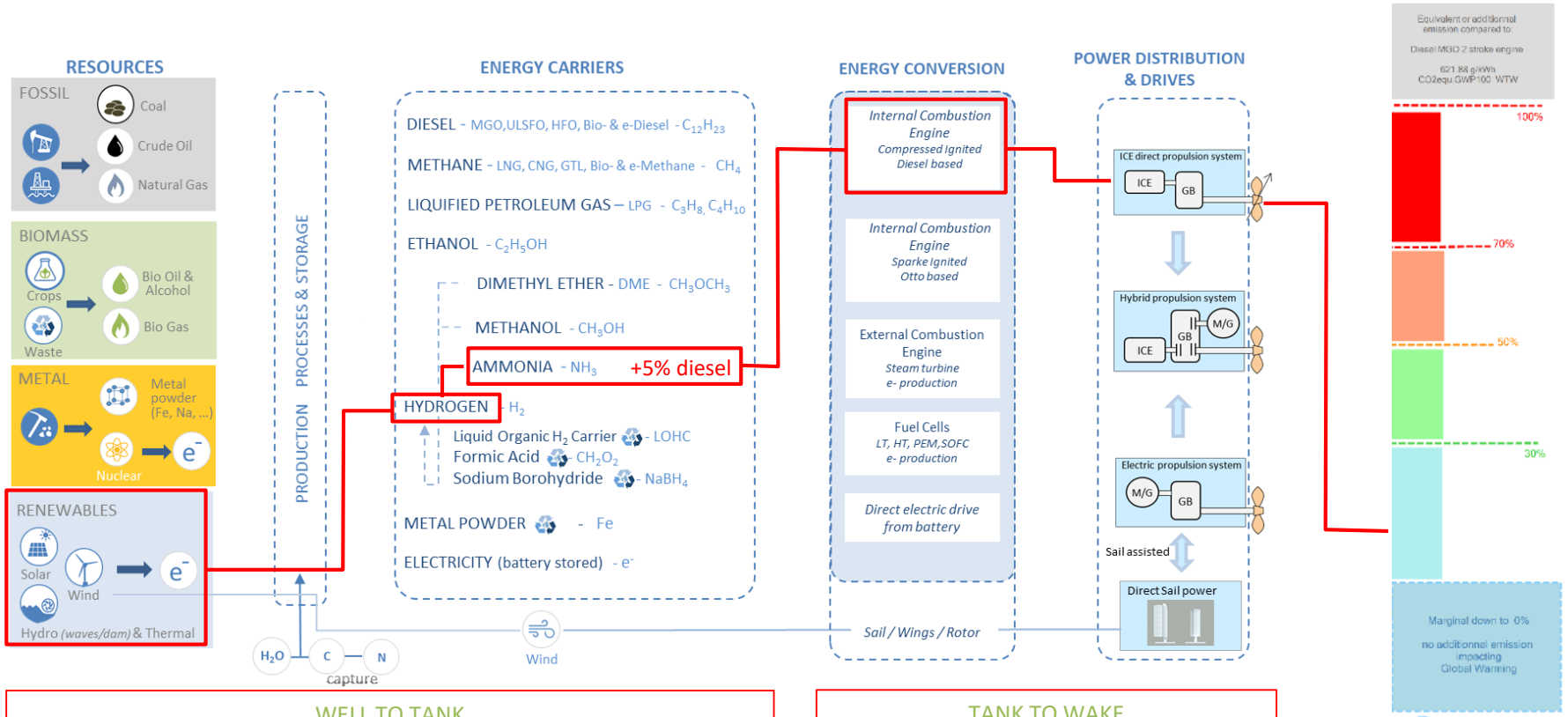
Direct Sail power
Equivalent or additional emission compared to:
Diesel MGO 2 stroke engine
621.88 g/kWh
CO2equ.GWP100 WTW
100%
70%
50%
30%
Marginal down to 0%
no additional emission impacting Global Warming
WELL TO TANK
TANK TO WAKE
WELL TO WAKE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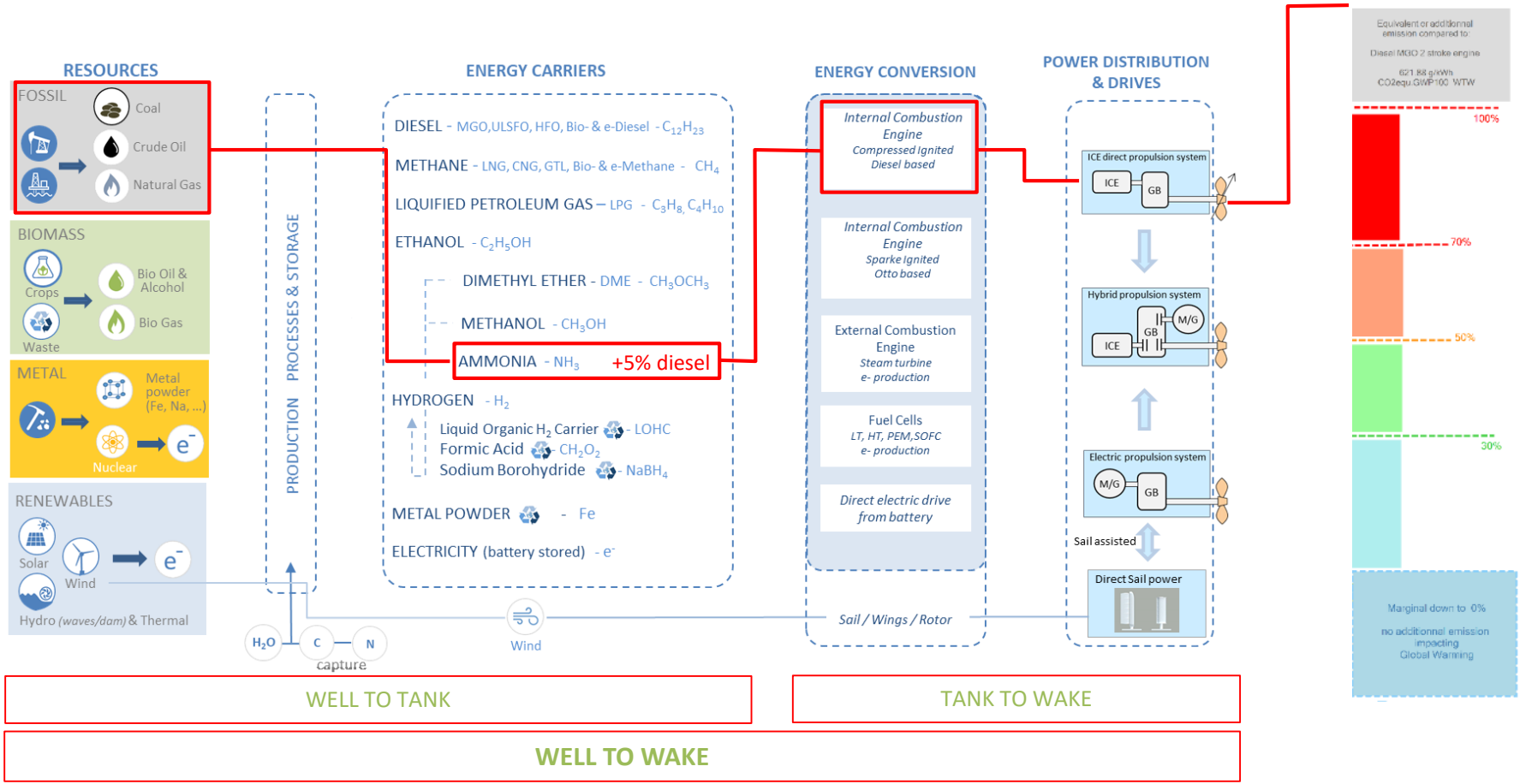
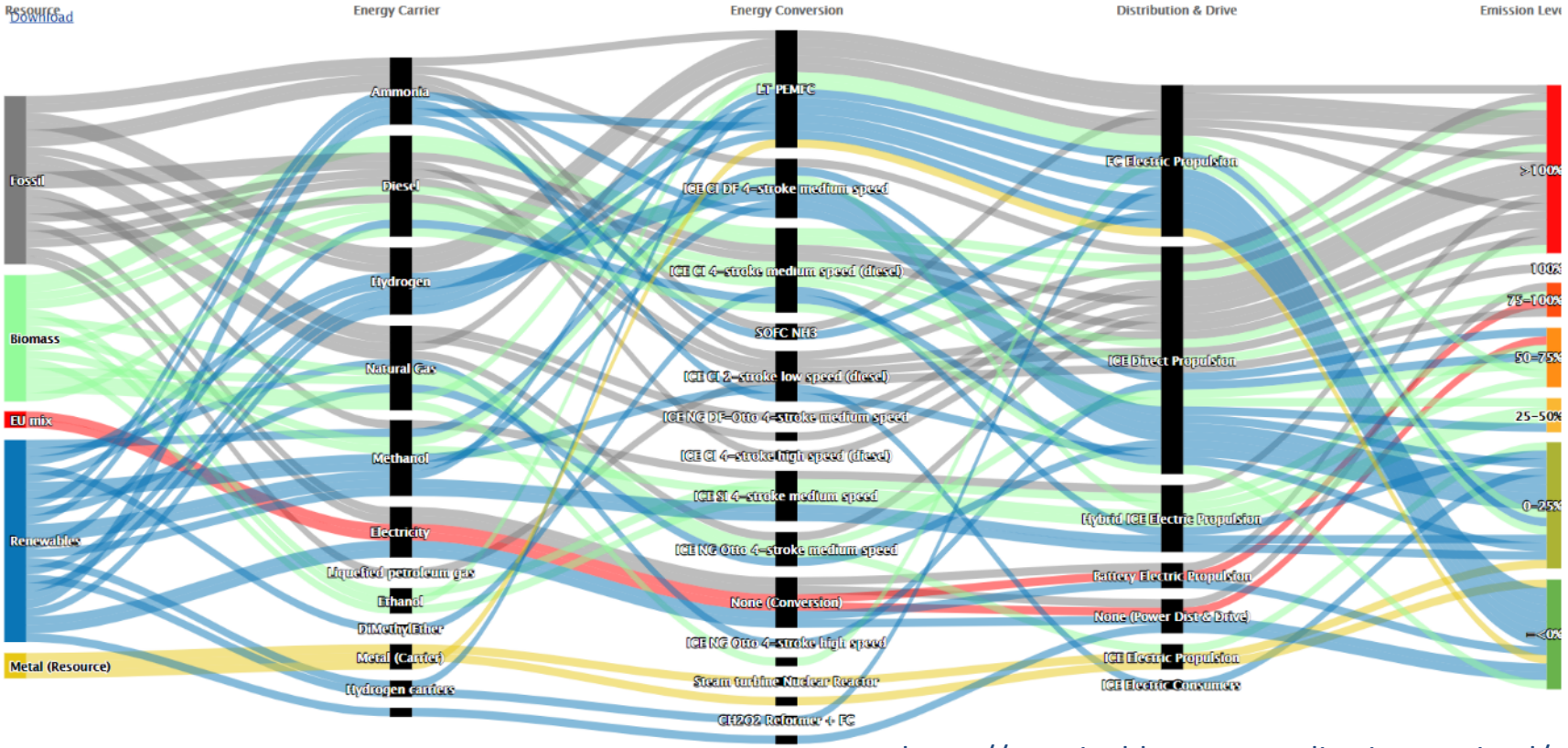
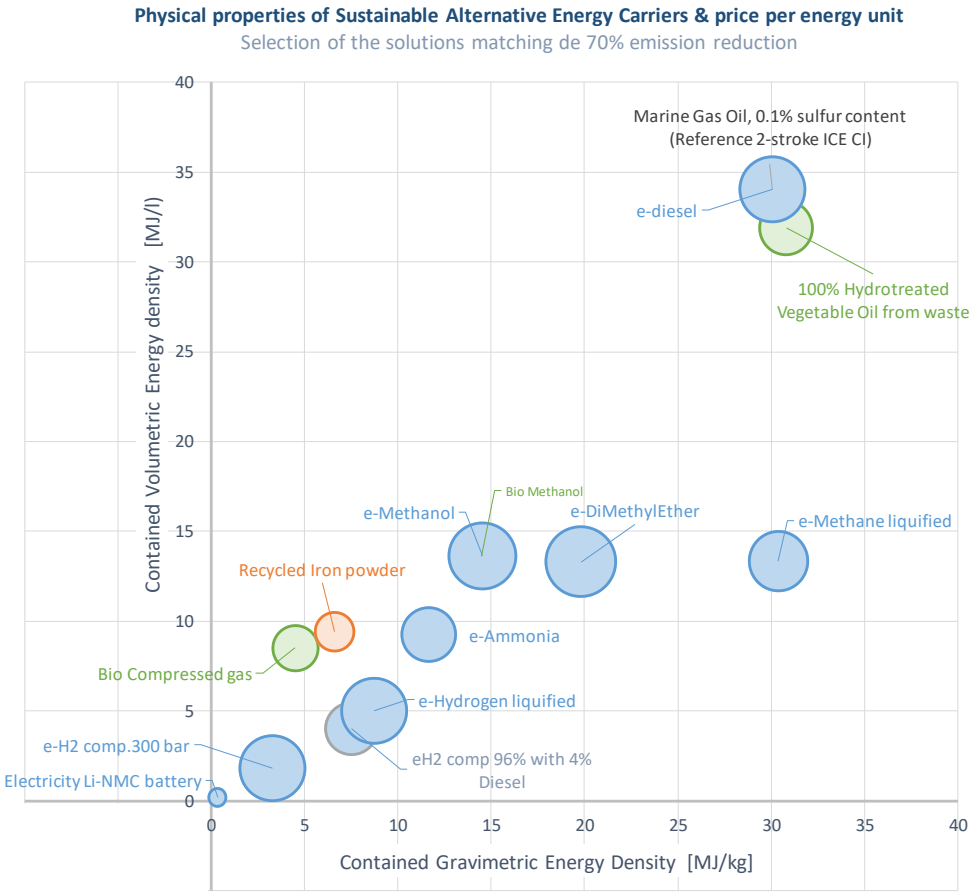
e- production
Direct electric drive from battery
Sail / Wings / Rotor
POWER DISTRIBUTION & DRIVES
ICE direct propulsion system
ICE
GB
Hybrid propulsion system
M/G
Electric propulsion system
Sail assisted
Direct Sail power
Equivalent or additional emission compared to:
Diesel MGO 2 stroke engine
621.88 g/kWh
CO2equ.GWP100 WTW
100%
70%
50%
30%
Marginal down to 0%
no additional emission impacting Global Warming
WELL TO TANK
TANK TO WAKE
WELL TO WAKE

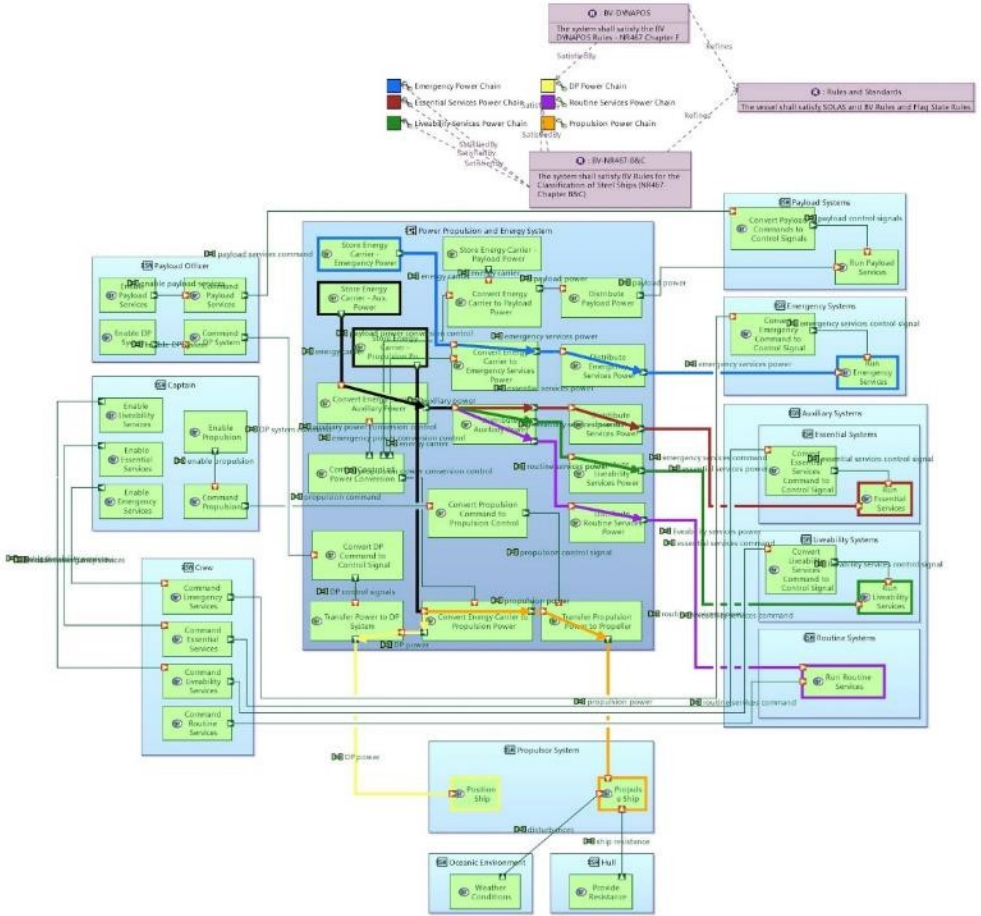

RESOURCES
FOSSIL
Coal
Crude Oil
Natural Gas
BIOMASS
Crops
Bio Oil & Alcohol
Waste
Bio Gas
METAL
Metal powder (Fe, Na, ...)
Nuclear
RENEWABLES
Solar
Wind
Hydro (waves/dam) & Thermal
PRODUCTION PROCESSES & STORAGE
ENERGY CARRIERS
DIESEL - MGO,ULSFO, HFO, Bio- & e-Diesel - $C_{12}H_{23}$
METHANE - LNG, CNG, GTL, Bio- & e-Methane - CH_4
LIQUIFIED PETROLEUM GAS – LPG - C_3H_8, C_4H_{10}
ETHANOL - C_2H_5OH
DIMETHYL ETHER - DME - CH_3OCH_3
METHANOL - CH_3OH
AMMONIA - NH_3 +5% diesel
HYDROGEN - H_2
Liquid Organic H_2 Carrier - LOHC
Formic Acid - CH_2O_2
Sodium Borohydride - $NaBH_4$
METAL POWDER - Fe
ELECTRICITY (battery stored) - e^-
H_2O
C
N
capture
Wind
ENERGY CONVERSION
Internal Combustion Engine
Compressed Ignited
Diesel based
Internal Combustion Engine
Sparke Ignited
Otto based
External Combustion Engine
Steam turbine
e- production
Fuel Cells
LT, HT, PEM,SOFC
e- production
Direct electric drive from battery
Sail / Wings / Rotor
POWER DISTRIBUTION & DRIVES
ICE direct propulsion system
ICE
GB
Hybrid propulsion system
M/G
Electric propulsion system
Sail assisted
Direct Sail power
Equivalent or additional emission compared to:
Diesel MGO 2 stroke engine
621.88 g/kWh
CO2equ.GWP100 WTW
100%
70%
50%
30%
Marginal down to 0%
no additional emission impacting Global Warming
WELL TO TANK
TANK TO WAKE
WELL TO WAKE



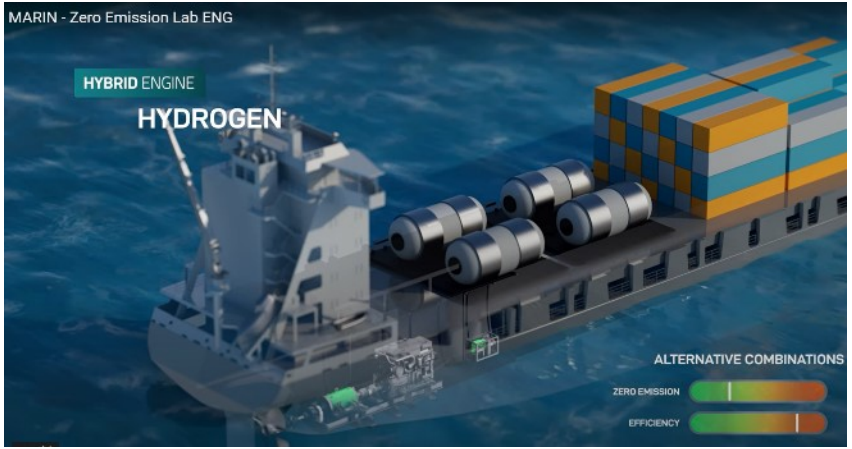
https://sustainablepower.application.marin.nl/

The energy density and energy storage challenge



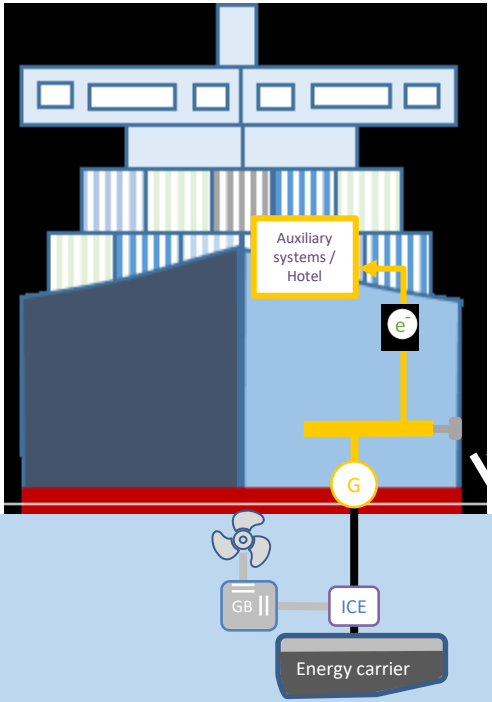

BV DYNAPOS
The system shall satisfy the BV DYNAPOS Rules - NR467 Chapter F
Satisfies
Refines
Emergency Power Chain
Essential Services Power Chain
Livability Services Power Chain
DP Power Chain
Routine Services Power Chain
Propulsion Power Chain
Satisfied by
Roles and Standards
The vessel shall satisfy SOLAS and BV Rules and Flag State Rules
BV-NR467-D&C
The system shall satisfy BV Rules for the Classification of Steel Ships (NR467 Chapter B&C)
Power Propulsion and Energy System
Payload Officer
Captain
Crew
Payload Systems
Emergency Systems
Auxiliary Systems
Essential Systems
Livability Systems
Routine Systems
Propulsor System
Oceanic Environment
Hull


ELECTRIC ENGINE
NO STORAGE
ZERO EMISSION
EFFICIENCY


MARIN - Zero Emission Lab ENG
HYBRID ENGINE
HYDROGEN
ALTERNATIVE COMBINATIONS
ZERO EMISSION
EFFICIENCY

ONBOARD POWER SUPPLY

From onboard conversion system using bunkered energy carrier



Legend & definition

Electricity path

Energy carrier path

G Generator

Battery

M/G Electric Motor (generator)

Fire / steam turbine power generation

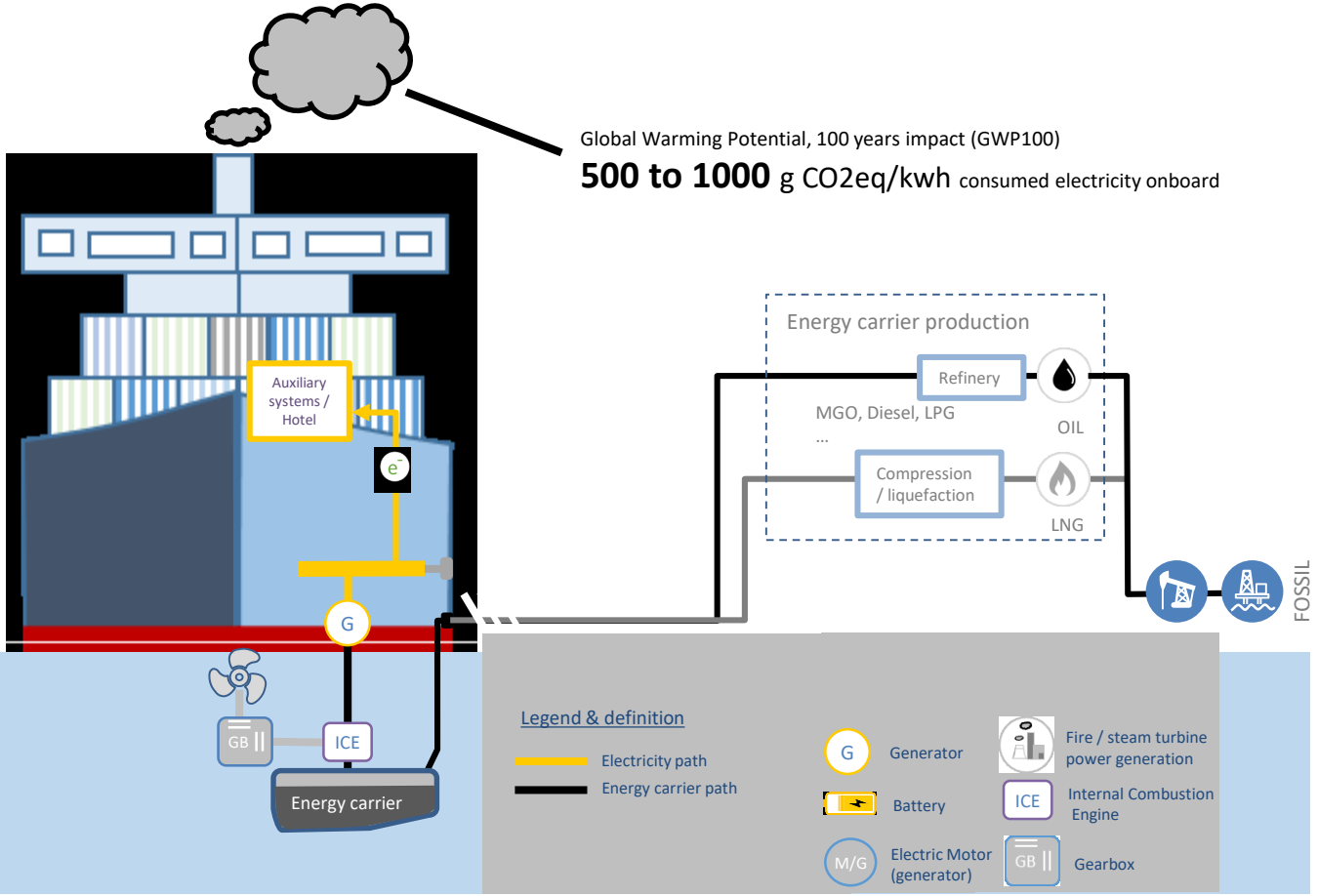
ICE Internal Combustion Engine

GB Gearbox

PATHWAY FROM ENERGY RESOURCE TO ONBOARD ENERGY CONSUMPTION
(auxiliary electric systems & hotel in harbor or at anchor)

ONBOARD POWER SUPPLY

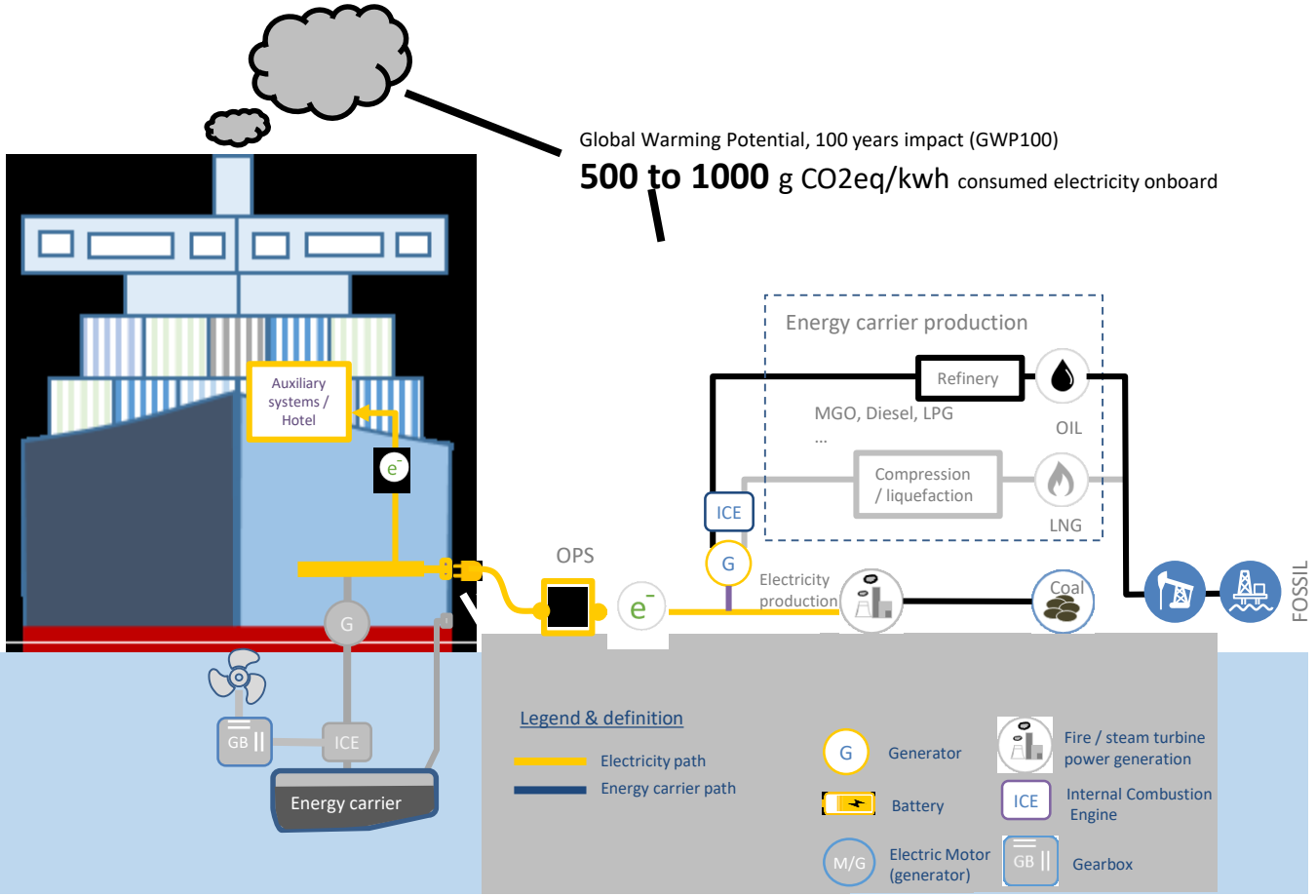
From onboard conversion system using bunkered energy carrier



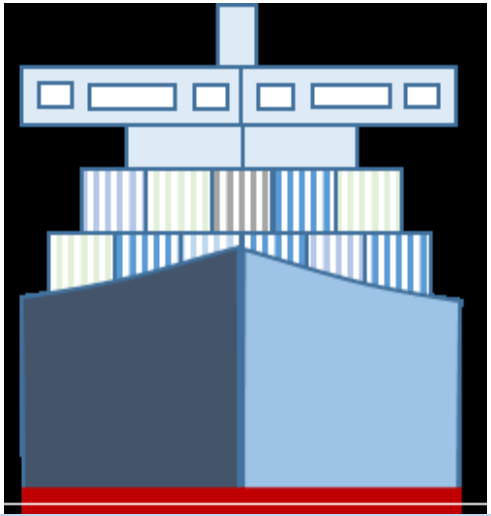
PATHWAY FROM ENERGY RESOURCE TO ONBOARD ENERGY CONSUMPTION
(auxiliary electric systems & hotel in harbor or at anchor)

ONSHORE POWER SUPPLY

From electricity delivered via an OPS system



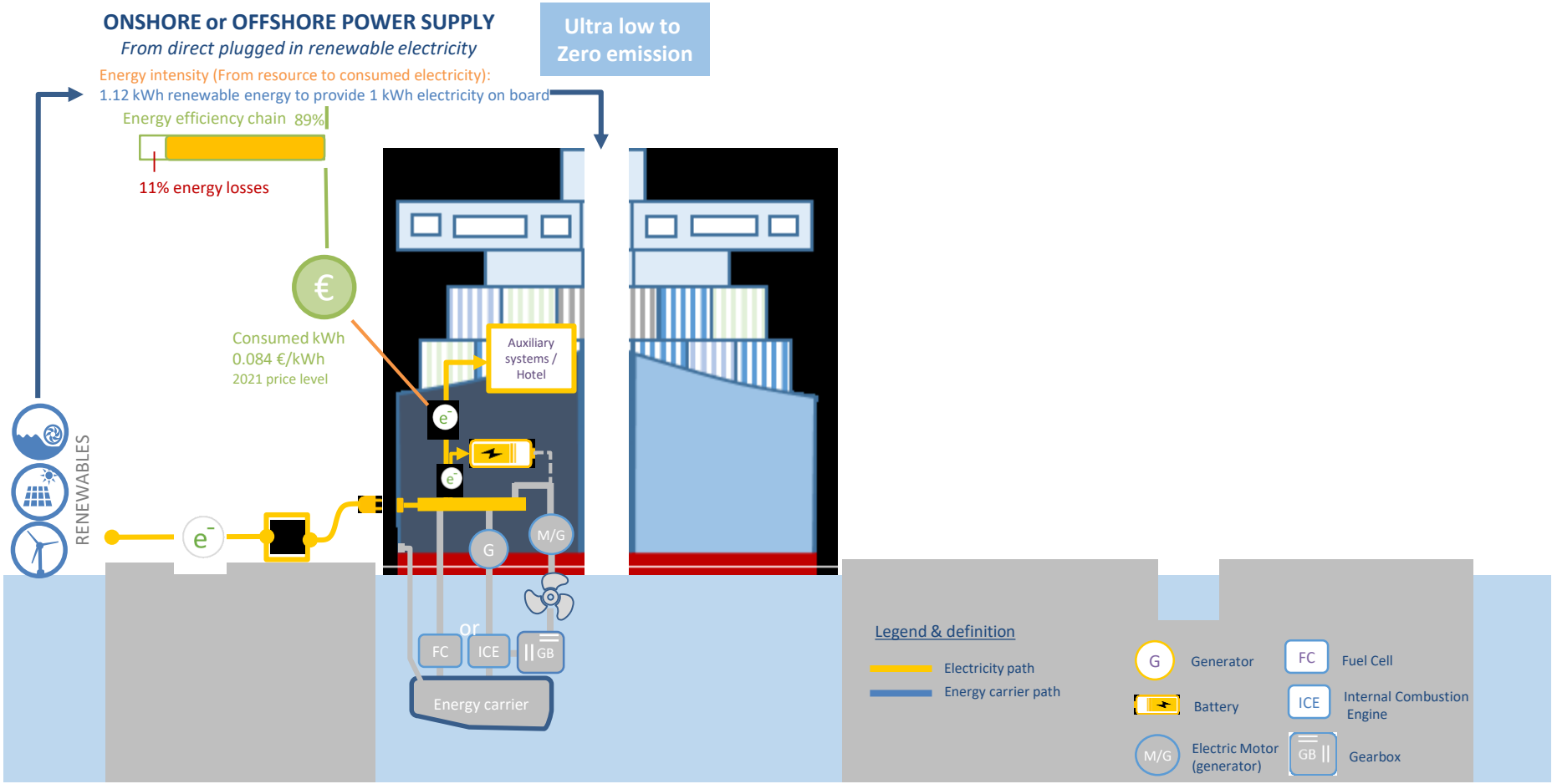
PATHWAY FROM ENERGY RESOURCE TO ONBOARD ENERGY CONSUMPTION
(auxiliary electric systems & hotel in harbor or at anchor)



Legend & definition

- Electricity path
- Energy carrier path
- G — Generator
- Battery
- ICE — Internal Combustion Engine
- M/G — Electric Motor (generator)
- GB — Gearbox

PATHWAY FROM ENERGY RESOURCE TO ONBOARD ENERGY CONSUMPTION
(auxiliary electric systems & hotel & battery charging in harbor or at anchor)



PATHWAY FROM ENERGY RESOURCE TO ONBOARD ENERGY CONSUMPTION

(auxiliary electric systems & hotel & battery charging in harbor or at anchor)

MARIN

ONSHORE or OFFSHORE POWER SUPPLY

From direct plugged in renewable electricity

Energy intensity (From resource to consumed electricity):
1.12 kWh renewable energy to provide 1 kWh electricity on board

Energy efficiency chain 89%

11% energy losses

Consumed kWh
0.084 €/kWh
2021 price level

Ultra low to Zero emission

SELF PRODUCED POWER SUPPLY

From onboard conversion system using bunkered renewable energy carrier

Energy intensity (From resource to consumed electricity):
Between 2.4 and 6.25 kWh renewable energy to provide 1 kWh electricity on board

Energy efficiency chain 15 to 40%

60 to 85% energy losses

0.146 – 0.95 €/kWh
2021 price level

RENEWABLES

Auxiliary systems / Hotel

Auxiliary systems / Hotel

FC ICE GB or GB ICE FC

Energy carrier

Energy carrier

Transport & bunkering

Energy carrier production

Synthesis

Methanol / Ammonia / DME …

N_2 or CO_2 capture

H_2

Hydrog

Compression / liquefaction

H_2O

Wat er

Electrolysis

RENEWABLES

Legend & definition

- Electricity path
- Energy carrier path
- G Generator
- FC Fuel Cell
- Battery
- ICE Internal Combustion Engine
- M/G Electric Motor (generator)
- GB Gearbox

Engines off, Shore Power on!

Heerema’s offshore vessels successfully plugged in at the largest shore power installation of Europe in Rotterdam

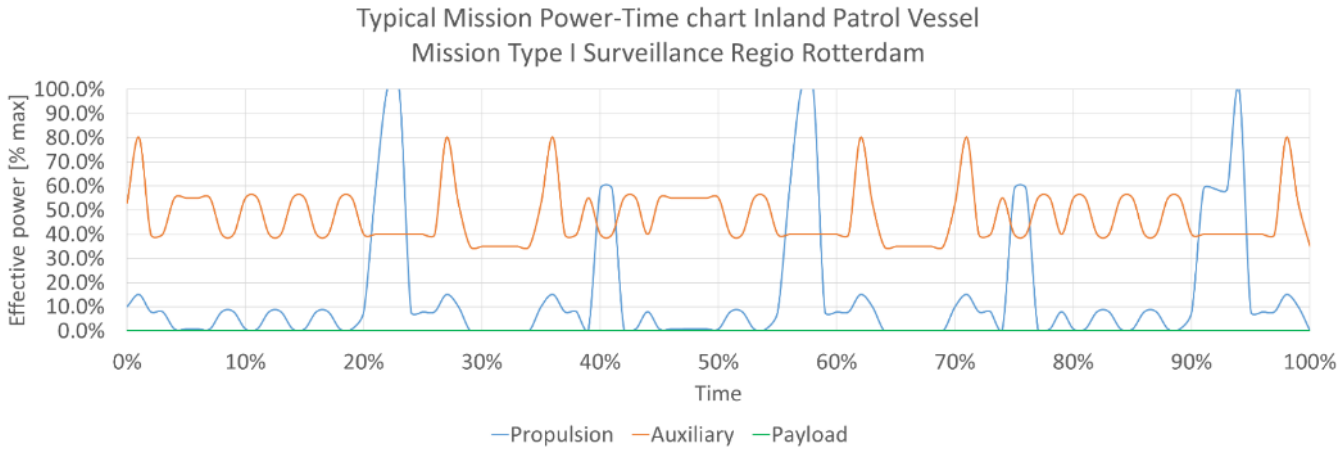
The Shore Power connection has a 20 MW capacity, which is the energy equivalent of around 15,000 homes. As the vessels turn off their engines when connected to Shore Power, virtually all emissions and particulate matter is prevented because no more marine gas oil or LNG in Sleipnir’s case will be used. This action has direct benefits for local residents with air quality improvements and a reduction in CO2. Also, without the engines running there is a significant reduction in noise nuisance.

When Heerema's vessels turn off their engines when moored in the Port of Rotterdam for a standard repair and maintenance period there is a saving of 15,000 metric tons of CO2, 20 metric tons of particulate matter, 5 metric tons of sulfur, and a significant amount of nitrogen– comparable to the annual emissions of 5,000 diesel cars.

DESIGN FOR OPERATIONS

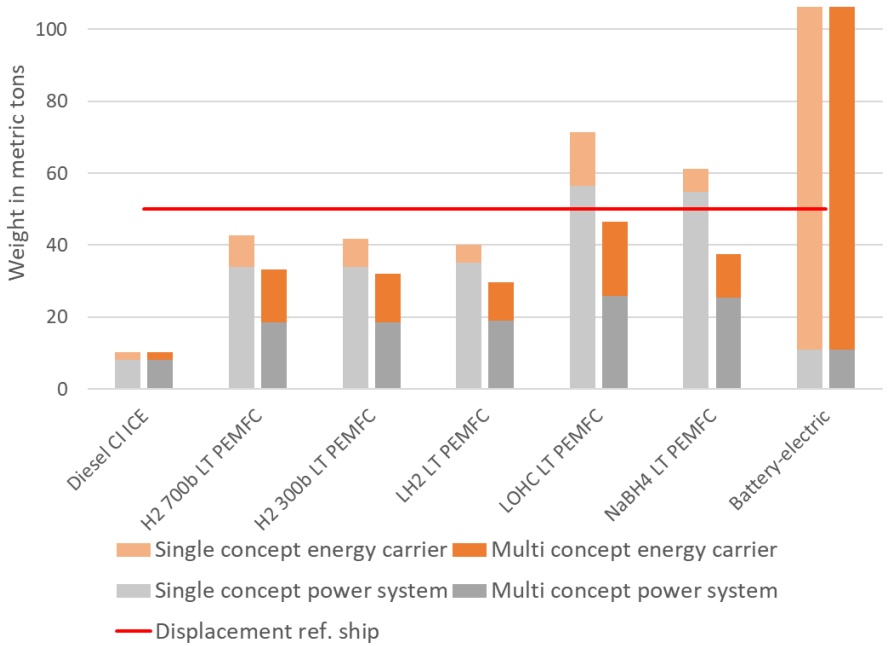
Ship design perspective

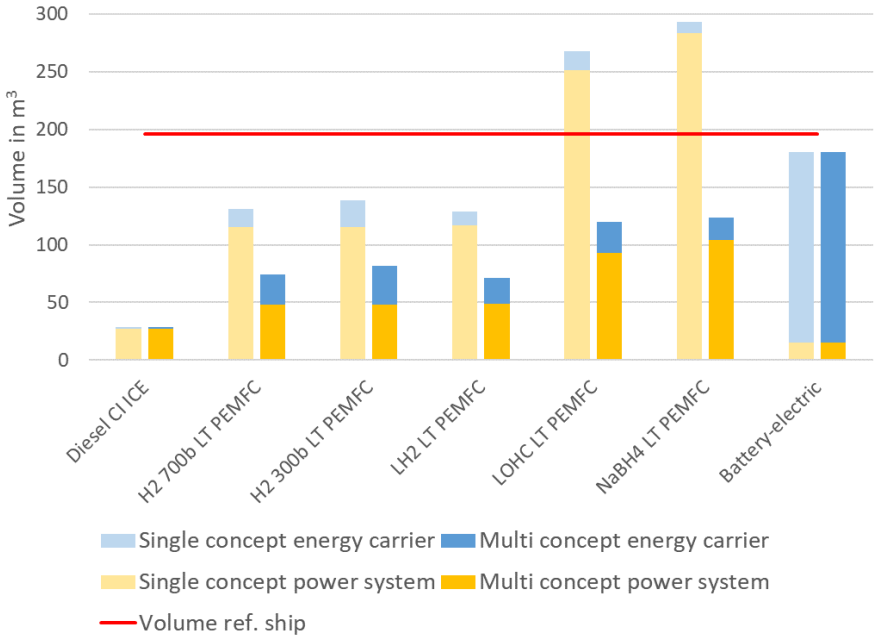
Mission reconstructions: combination of operational input and power performance evaluations



Note, propulsive and auxiliary maximum powers are different

Mission Type	Maximum total effective power & Effective Energy			Requirements
	Criterion	[kW]	[MWh]	GHG and Pollutants
I – Surveillance (Region Rotterdam)	Endurance: 24 hrs	1236	5,1	Zero Emission
II – Surveillance (Region Dordrecht)	Endurance: 16 hrs	1236	6,5	Zero Emission
III – Surveillance (Region Amsterdam)	Endurance: 16 hrs	1236	2,3	Zero Emission





System Abbreviations	Short description
Diesel CI ICE	Diesel in Compression ignited internal combustion engine
H2 700b LT PEMFC	Compressed hydrogen (700 bars) in Low Temperature PEM Fuel Cell
H2 300b LT PEMFC	Compressed hydrogen (300 bars) in a Low Temperature PEM Fuel Cell
LH2 LT PEMFC	Liquified (cryogenic) hydrogen in a Low Temperature PEM Fuel Cell
LOHC LT PEMFC	Liquid Organic Hydrogen Carrier in a Low Temperature PEM Fuel Cell
NaBH4 LT PEMFC	Sodium Borohydride in a Low Temperature PEM Fuel Cell
Battery-electric	Battery-electric

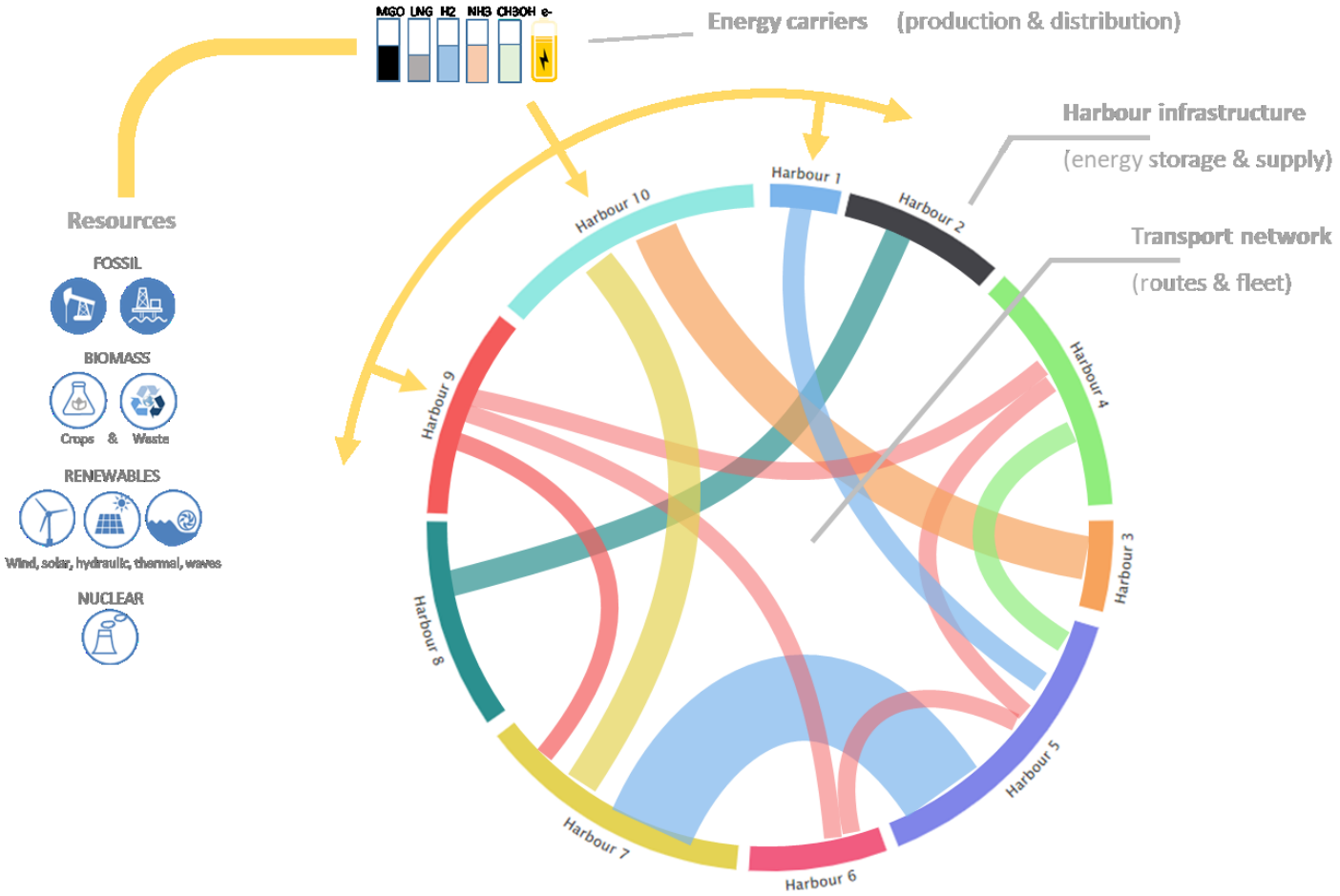
DESIGN FOR OPERATIONS

Macro perspective

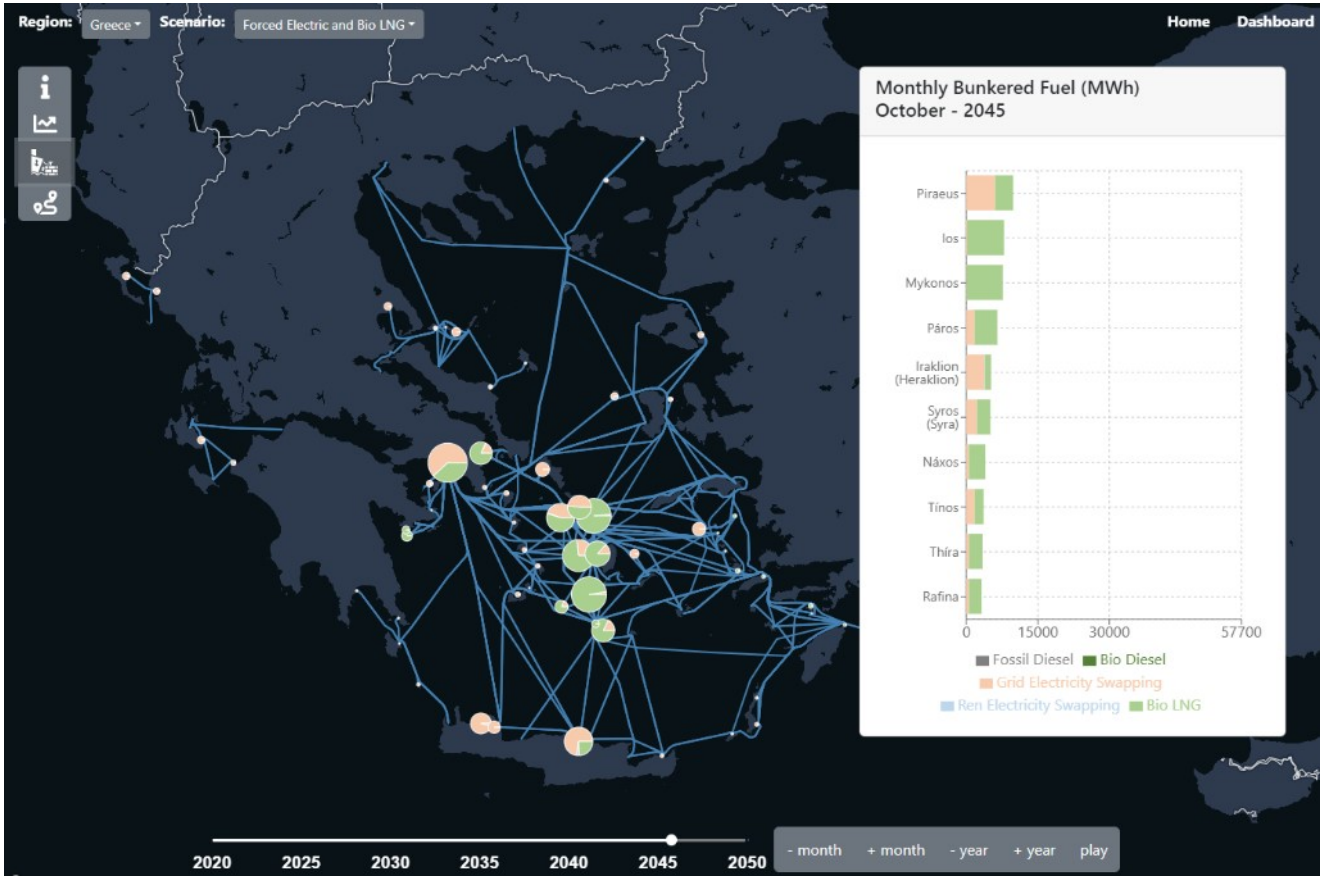
DESIGN FOR OPERATIONS

Macro perspective

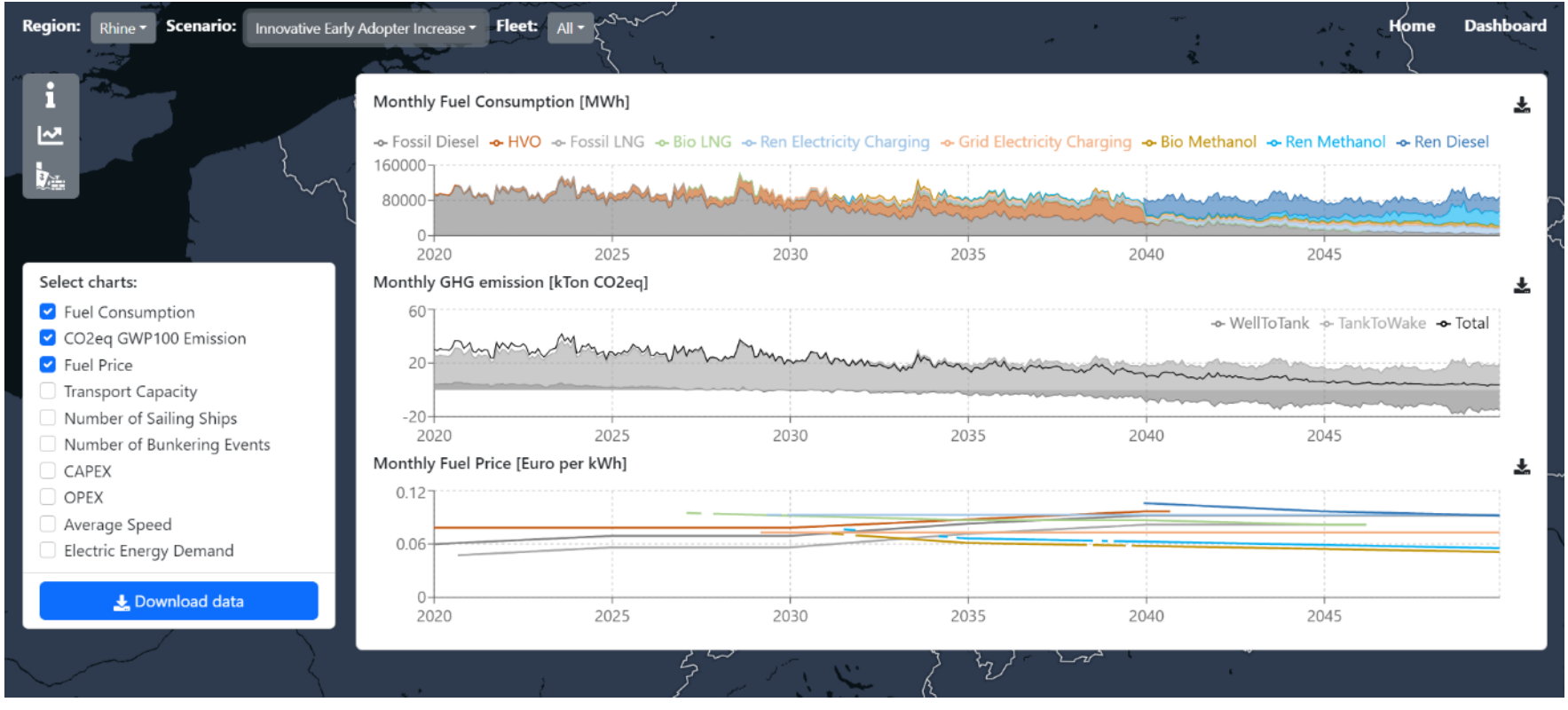
ENERGY - INFRASTRUCTURE - SHIPS & OPERATIONS


MGO LNG H2 NH3 CH3OH e-
Energy carriers (production & distribution)
Harbour infrastructure
(energy storage & supply)
Transport network
(routes & fleet)
Resources
FOSSIL
BIOMASS
Crops & Waste
RENEWABLES
Wind, solar, hydraulic, thermal, waves
NUCLEAR
Harbour 1
Harbour 2
Harbour 3
Harbour 4
Harbour 5
Harbour 6
Harbour 7
Harbour 8
Harbour 9
Harbour 10

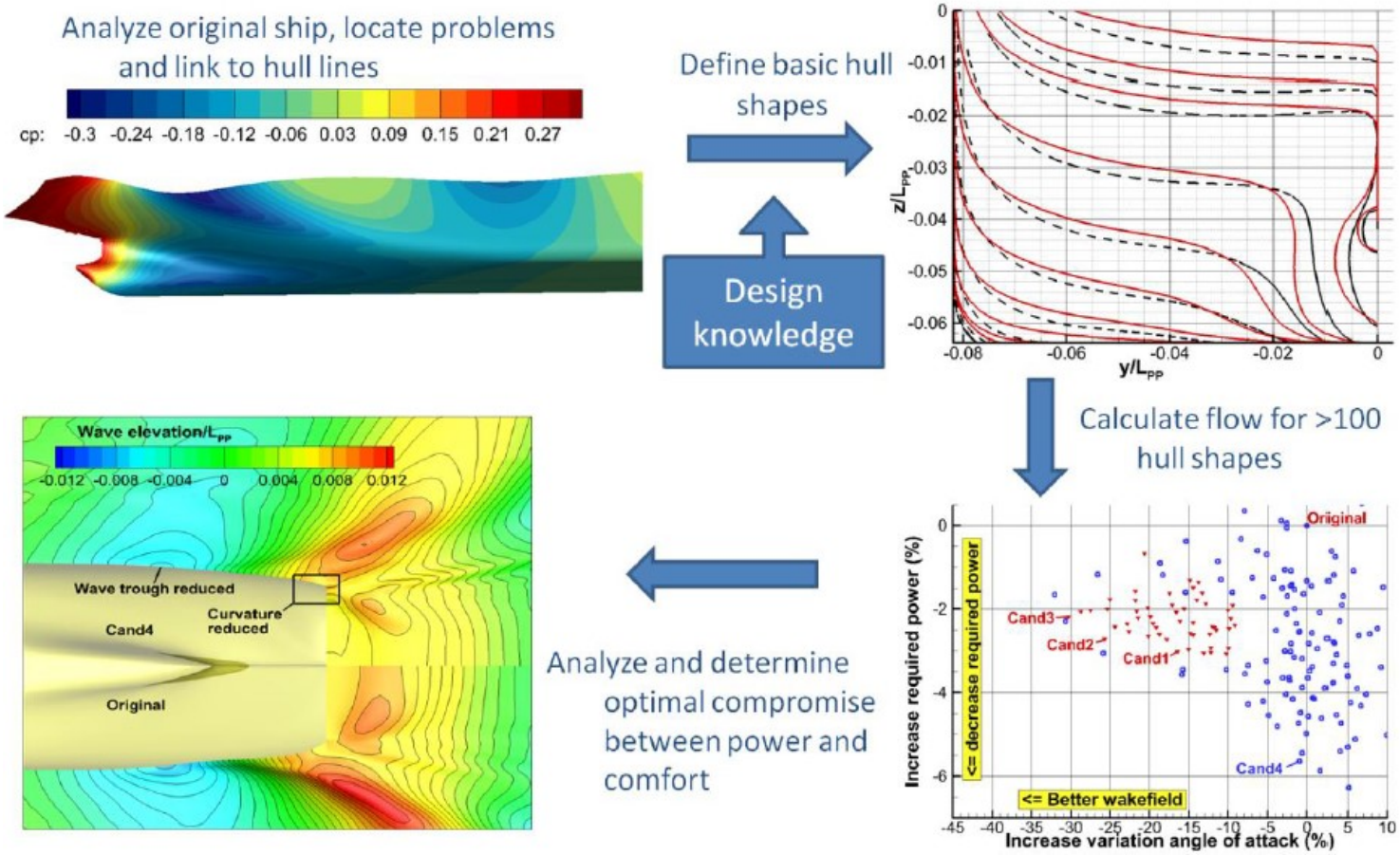
- Online dashboard example studies: https://needs.application.marin.nl

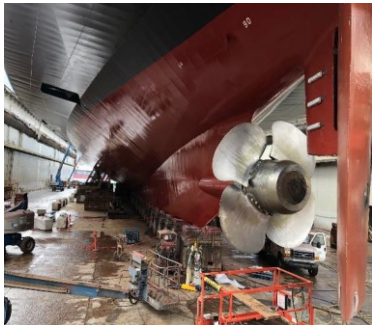


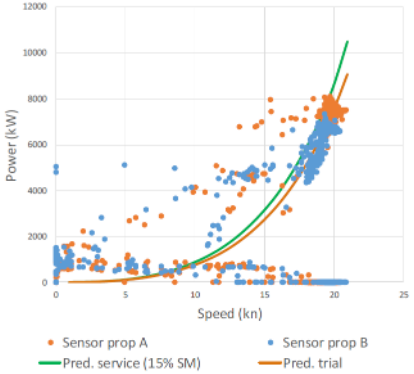
- Online dashboard example studies: https://needs.application.marin.nl

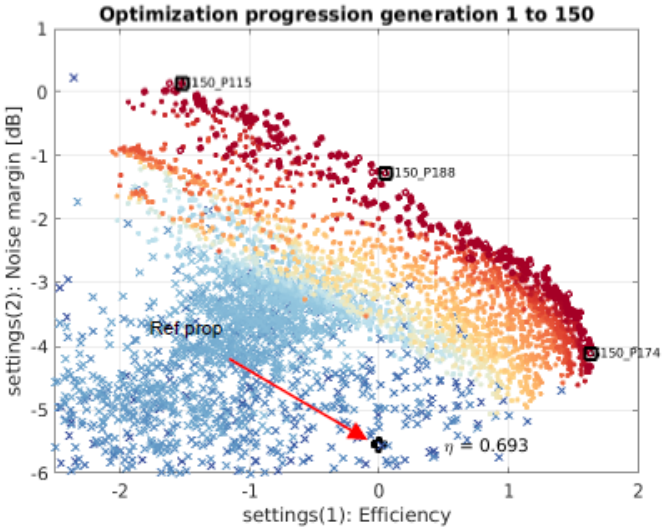


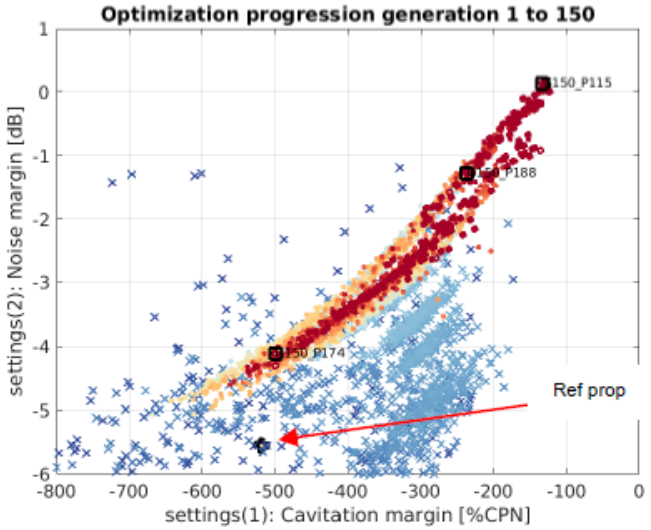
USE LESS ENERGY

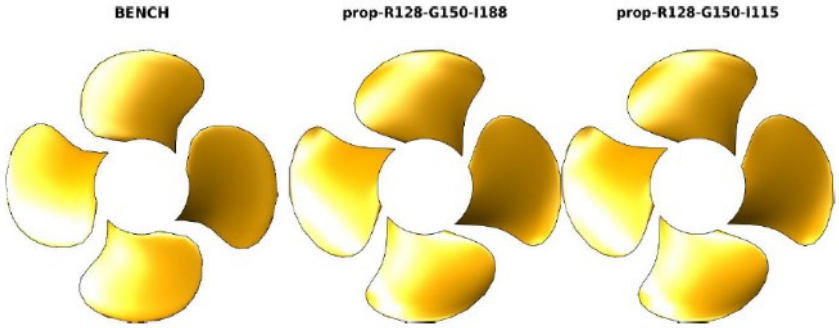

Analyze original ship, locate problems and link to hull lines
cp: -0.3 -0.24 -0.18 -0.12 -0.06 0.03 0.09 0.15 0.21 0.27
Define basic hull shapes
Design knowledge
z/L_PP
y/L_PP
Calculate flow for >100 hull shapes
Original
Cand3
Cand2
Cand1
Cand4
<= decrease required power
Increase required power (%)
<= Better wakefield
Increase variation angle of attack (%)
Analyze and determine optimal compromise between power and comfort
Wave elevation/L_PP
-0.012 -0.008 -0.004 0 0.004 0.008 0.012
Wave trough reduced
Curvature reduced
Cand4
Original




Power (kW)
Speed (kn)
Sensor prop A
Sensor prop B
Pred. service (15% SM)
Pred. trial


Optimization progression generation 1 to 150
settings(2): Noise margin [dB]
settings(1): Efficiency
150_P115
150_P188
150_P174
Ref prop
η = 0.693

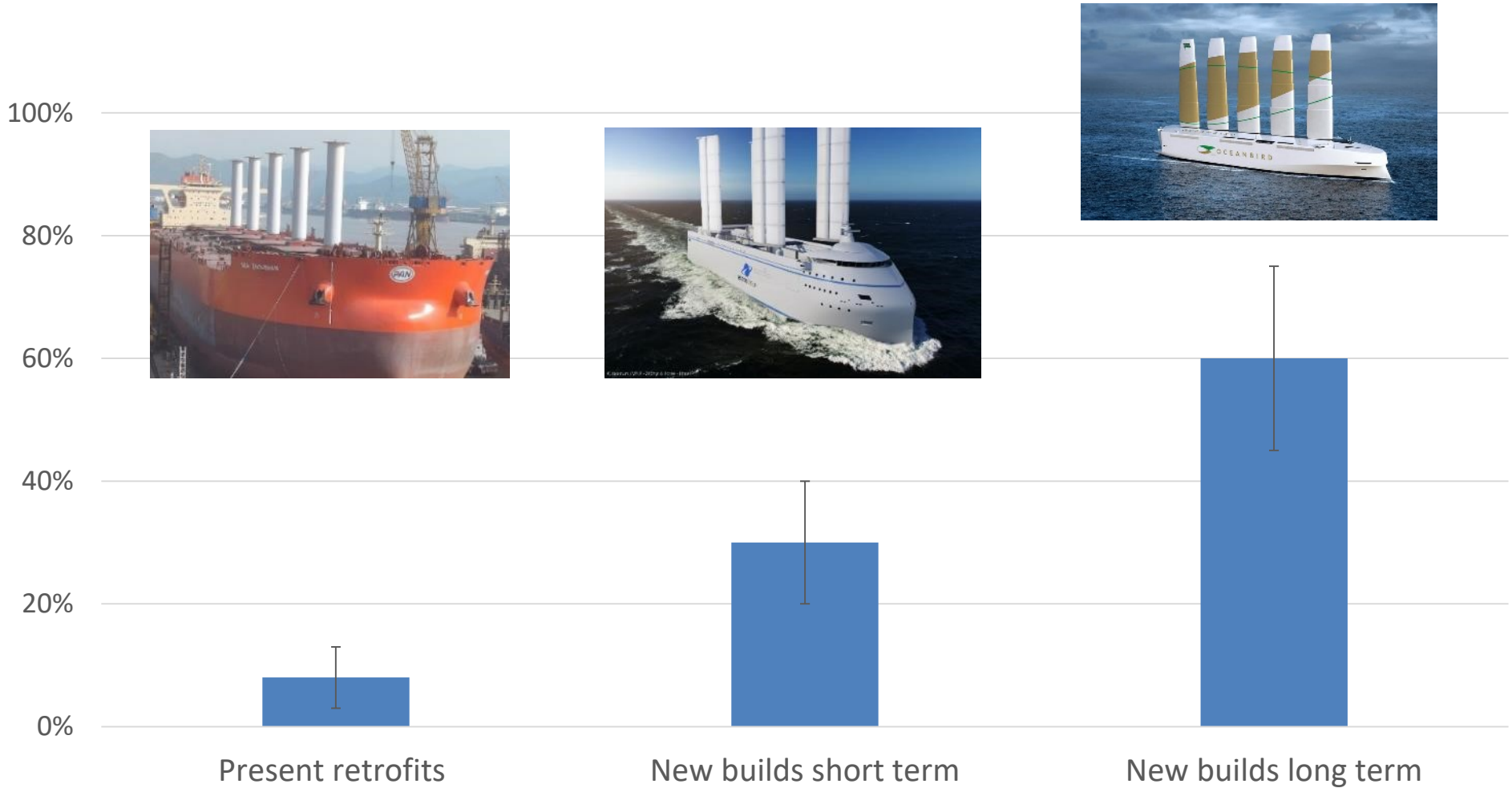

Optimization progression generation 1 to 150
settings(2): Noise margin [dB]
settings(1): Cavitation margin [%CPN]
150_P115
150_P188
150_P174
Ref prop


BENCH
prop-R128-G150-I188
prop-R128-G150-I115

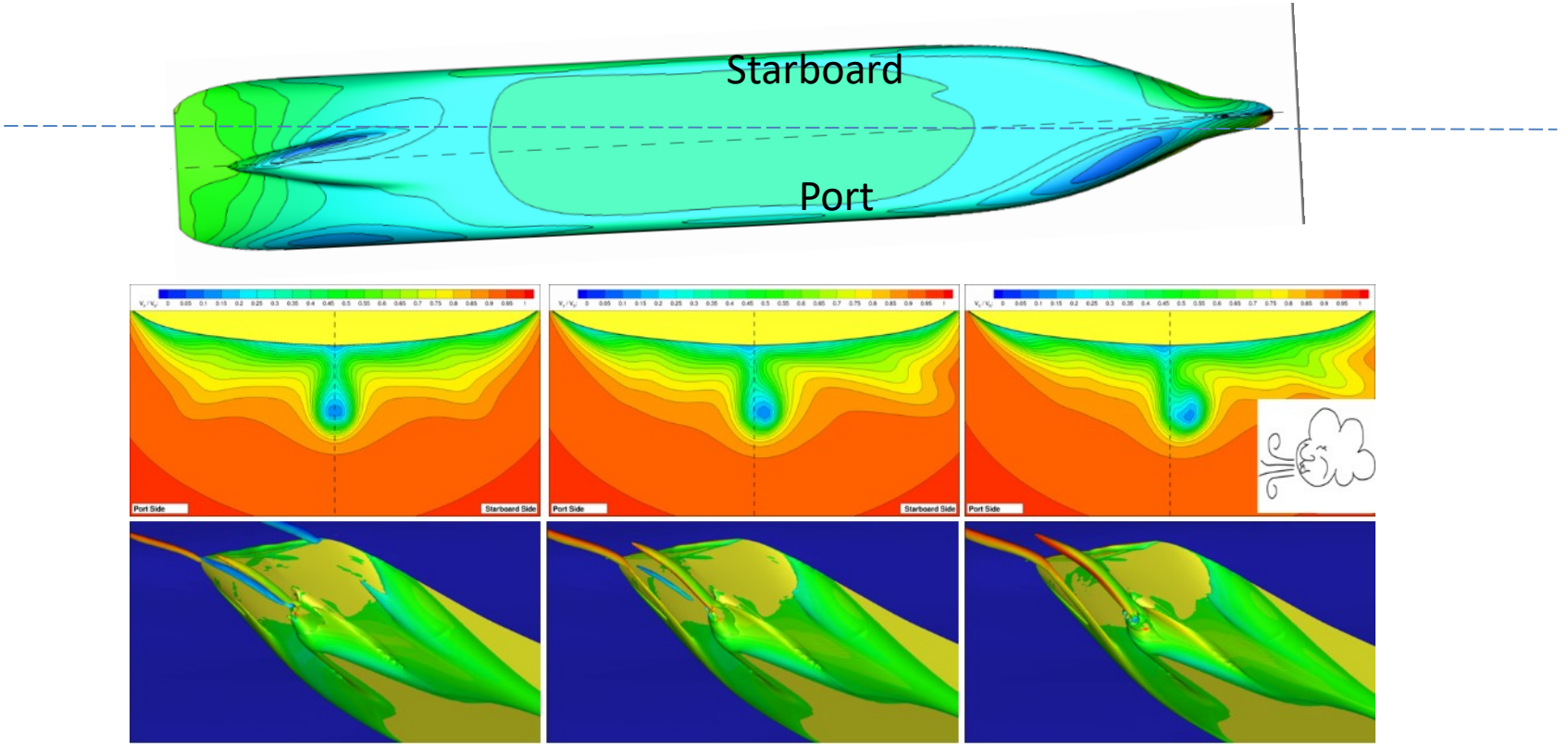
USE FREE AVAILABLE ENERGY

WIND

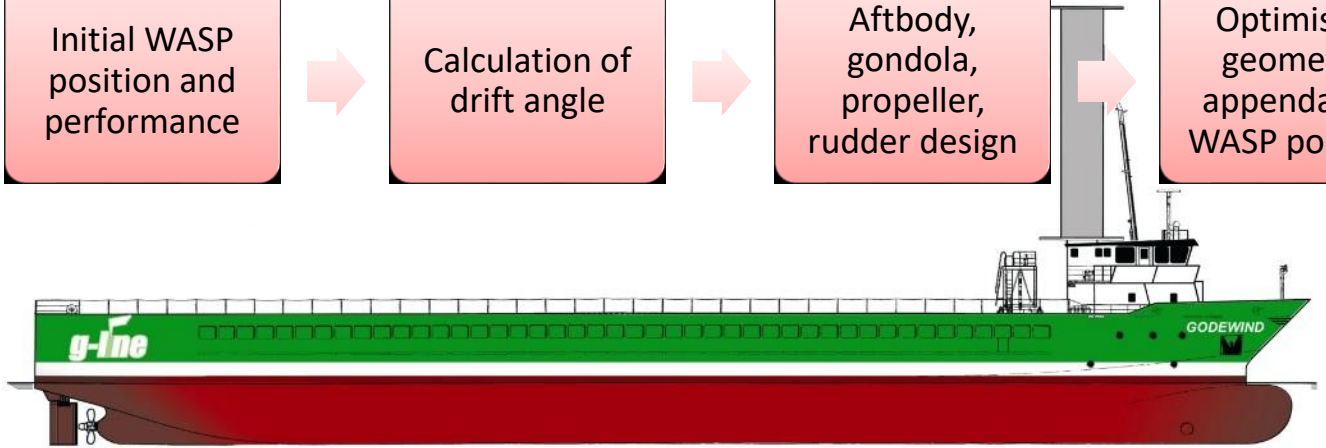
The most sustainable energy is simply the energy you don’t use…

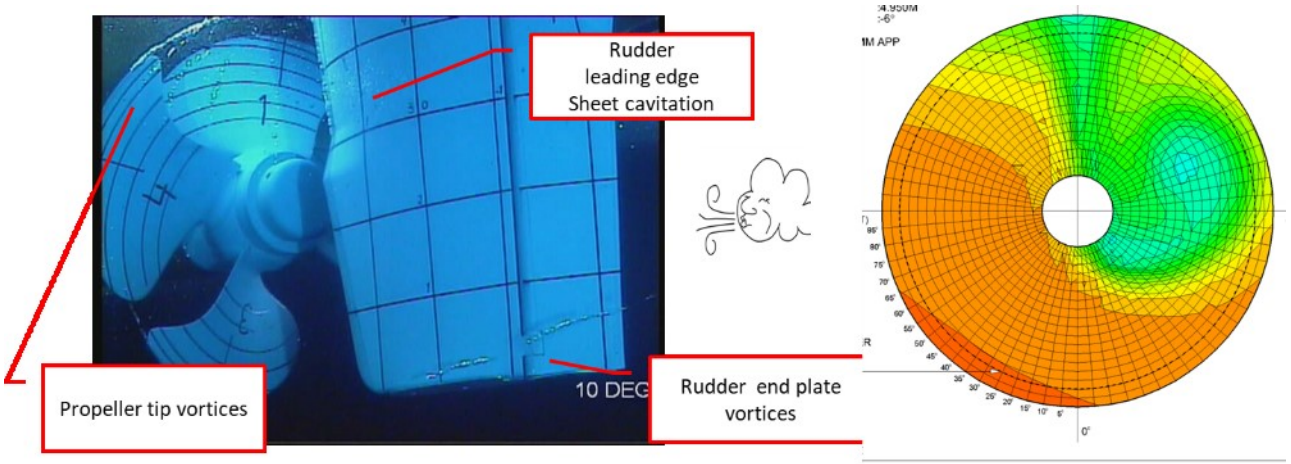

100%
80%
60%
40%
20%
0%
Present retrofits
New builds short term
New builds long term

Drifting to port at angles 0, 2 and 4 degrees:
The vortices from the gondola affect the wake

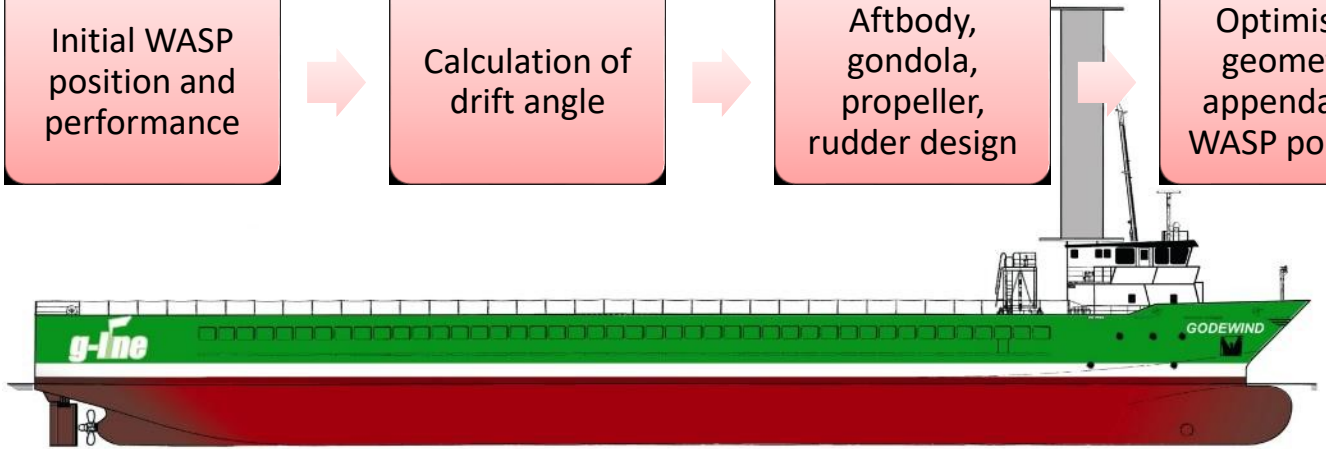


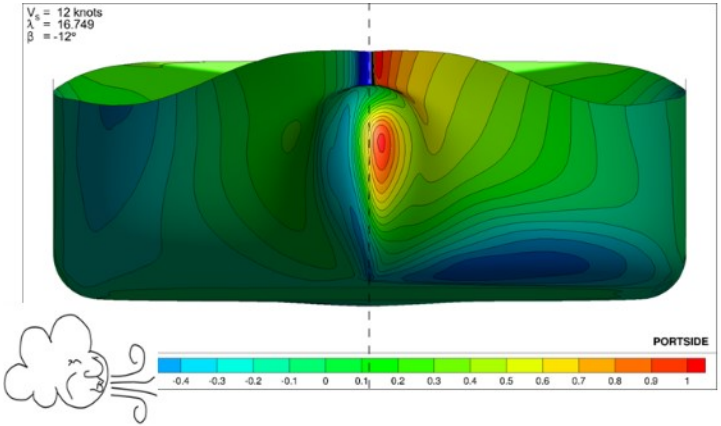
Initial hull geometry → Initial WASP position and performance → Calculation of drift angle → Aftbody, gondola, propeller, rudder design → Optimised, geometry, appendages, WASP position

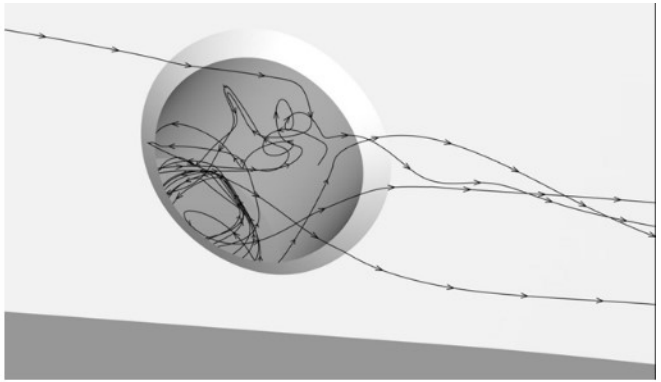




Initial hull geometry → Initial WASP position and performance → Calculation of drift angle → Aftbody, gondola, propeller, rudder design → Optimised, geometry, appendages, WASP position



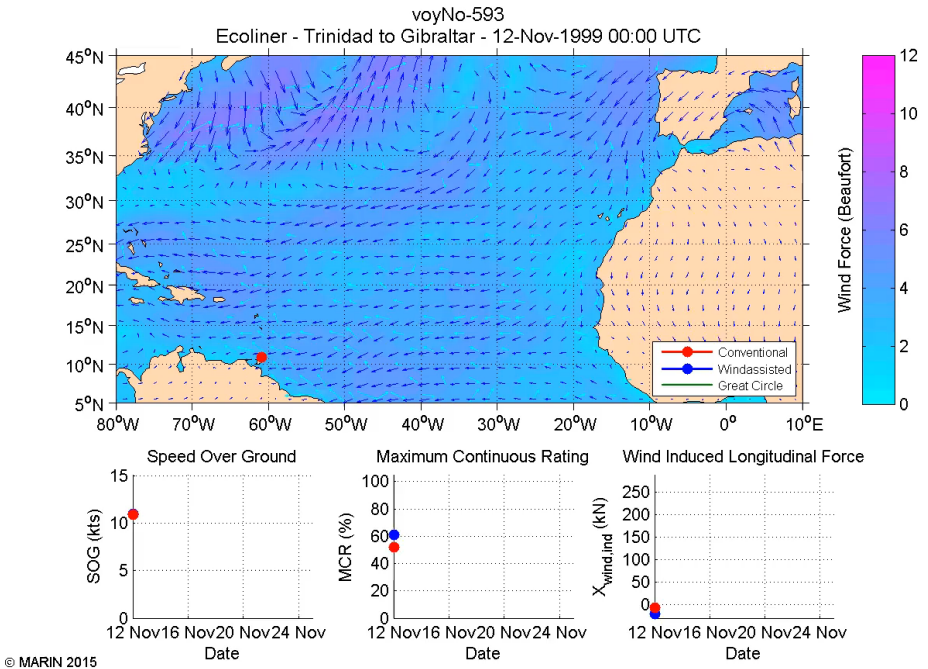




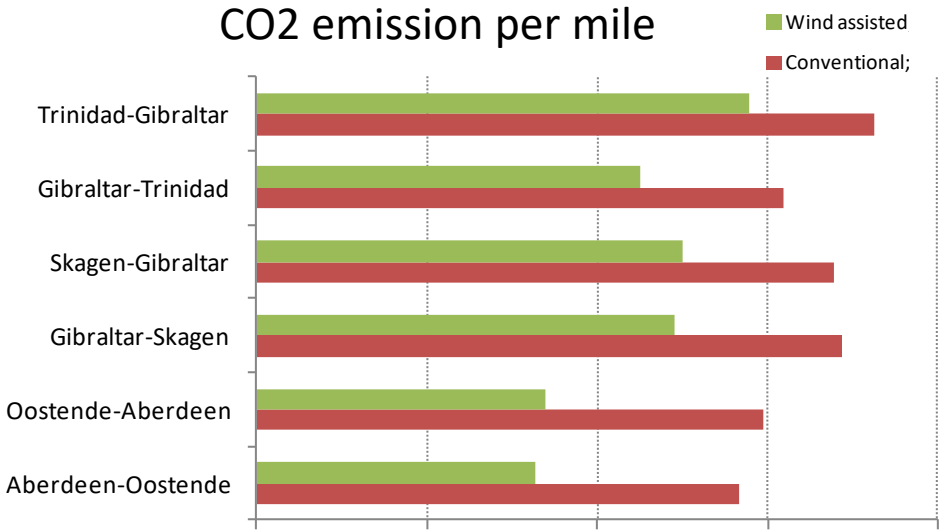
- Design changes:
  - Change hull dimensions (more draught, …)
  - Use V-shaped sections or box keels (in stern area)
  - Avoid wide flat transom
  - Enlarge skegs and bilge keels
  - Use appendages (like keels or dagger boards)
  - High-lift/multiple rudders


ship-technology.com / Yamanaka shipbuilding

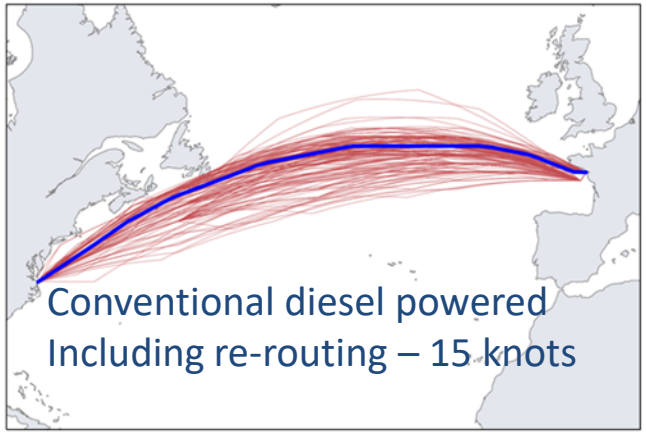
- Most of these modifications come with performance degradation when sailing straight, in low wind.
- Find best compromise considering operational profile.

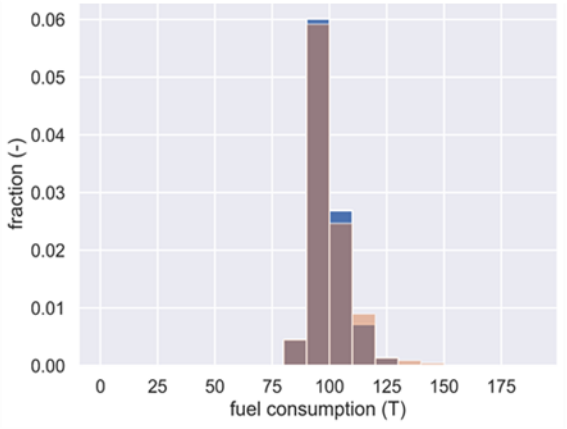


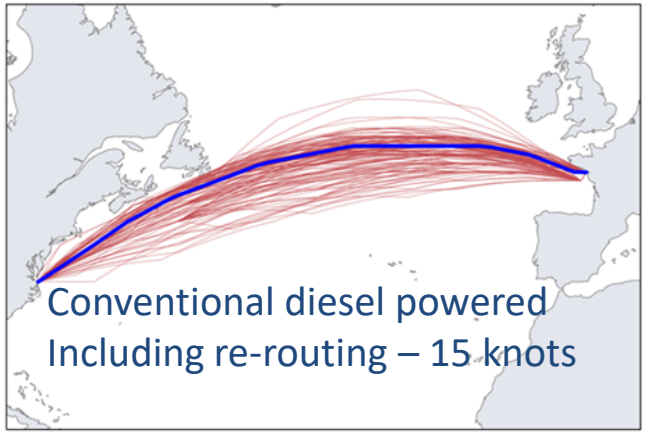
Animation made with Weather Route Ani 1.88 on 19 January 2015

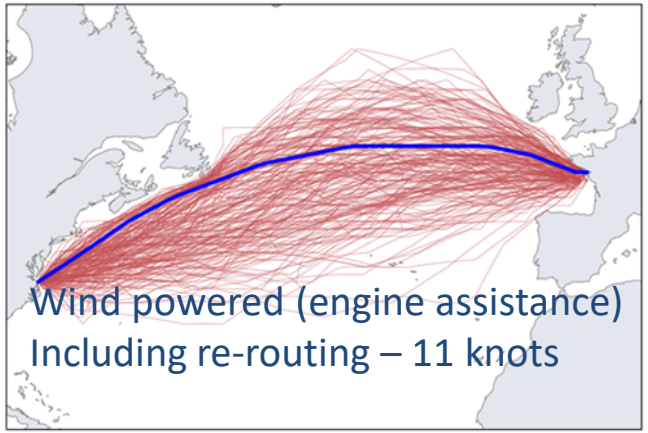


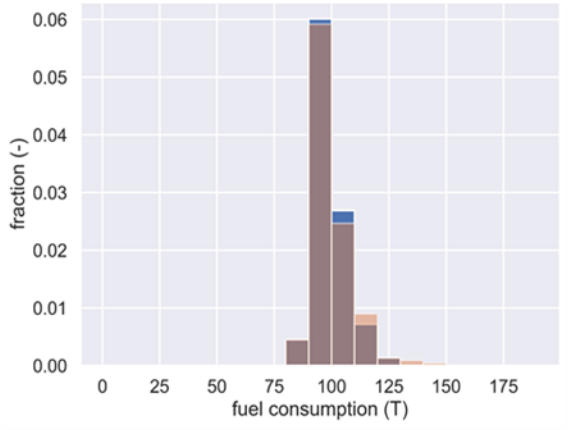
"Wind Assisted Ship Propulsion" (WASP) can save between 5% and 40% on emissions, but route should be optimized

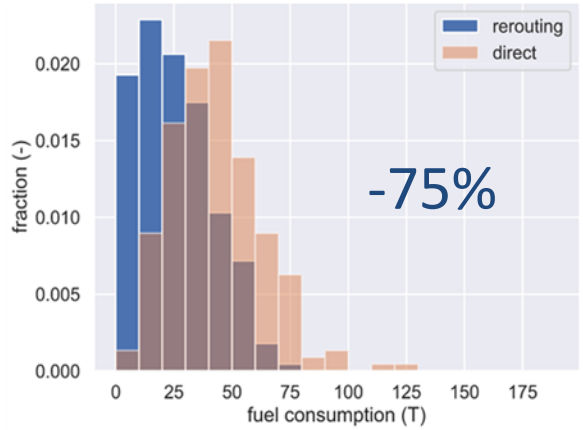

Conventional diesel powered
Including re-routing – 15 knots


0.06
0.05
0.04
0.03
0.02
0.01
0.00
fraction (-)
0
25
50
75
100
125
150
175
fuel consumption (T)


Conventional diesel powered
Including re-routing – 15 knots


Wind powered (engine assistance)
Including re-routing – 11 knots


0.06
0.05
0.04
0.03
0.02
0.01
0.00
fraction (-)
0
25
50
75
100
125
150
175
fuel consumption (T)


rerouting
direct
0.020
0.015
0.010
0.005
0.000
fraction (-)
-75%
0
25
50
75
100
125
150
175
fuel consumption (T)

Designing sustainable ships and waterborne operations is technically possible but necessitates a holistic approach, full of challenges and requires making choices and accepting changes.

- **Use sustainable energy**
- **Know and optimise energy operational profile**
- **Design only for operations**
- **Adapt infrastructure**
- **Use less energy**
- **Use Wind whenever possible (freely available energy)**


WALLENIUS
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VIRTUAL CONFERENCE
Canopée, the first modern sail ship Zéphyr & Borée
CANOPÉE
2021
NATURAL PROPULSION IN SHIP DESIGN CONFERENCE
16 NOVEMBER 2021
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Webb Institute

Success is not final

Failure is not fatal

It is the courage to continue that counts

Churchill

Simplicity is the ultimate sophistication

Da Vinci

Thank you for your attention!