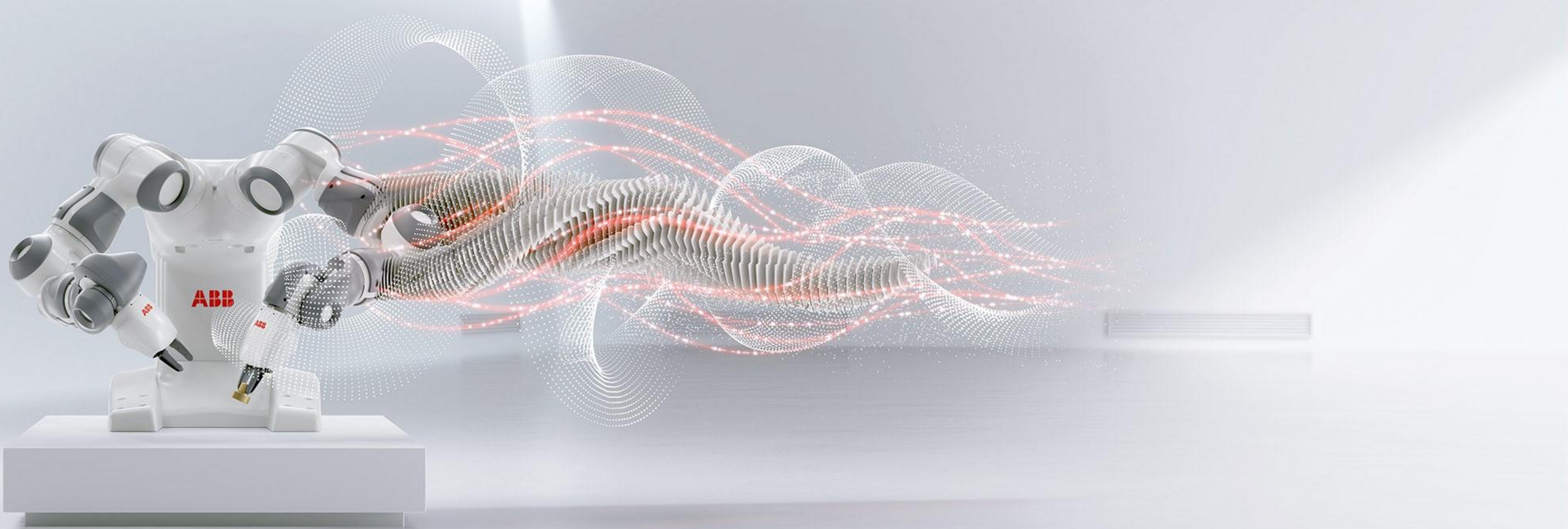

ABB JIANGJIN TURBO SYSTEMS, HU BOZONG, 2019-10-11

Green ammonia for IMO GHG 2050 strategy

11th CIMAC CASCADES, Wuxi, China

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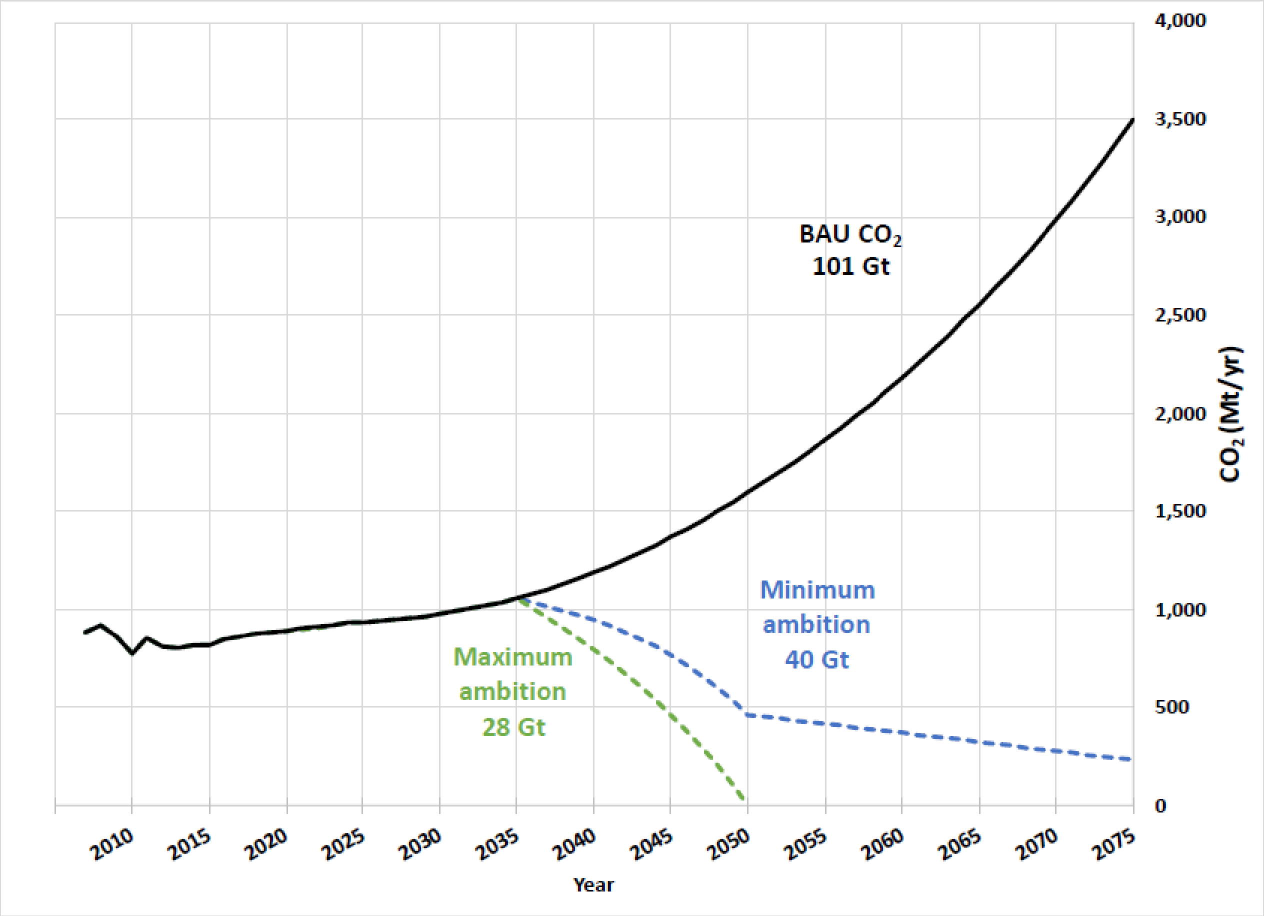
IMO strategy for major reductions in GHG emissions from shipping



The strategy includes carbon intensity and GHG reduction targets:

1. At least a 40% reduction in carbon intensity by 2030 and pursuing efforts towards a 70% reduction by 2050, both compared to 2008 levels.
2. Peak GHG emissions from international shipping as soon as possible and reduce them by at least 50% by 2050 compared to 2008 levels

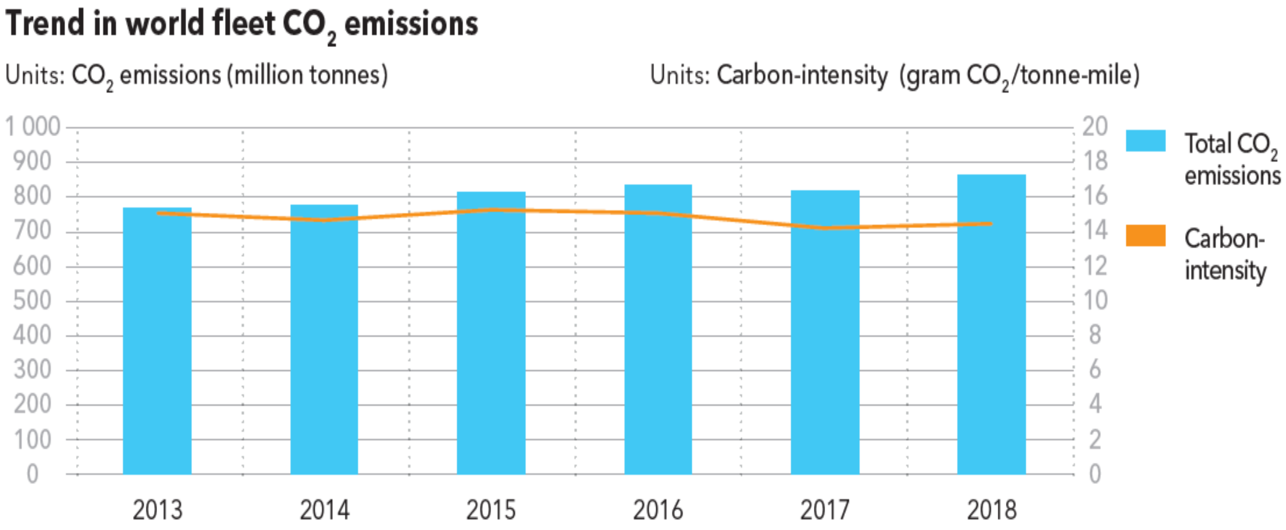
* Carbon intensity refers to the CO2 emissions relative to the transport work (deadweight tonnage x distance), greenhouse gas (GHG) emissions assume the total emission of CO2 and CO2 equivalent emissions

* CO2 emissions from international shipping under IMO's initial GHG strategy (blue and green) vs. BAU (black), with cumulative emissions 2015 through 2075.

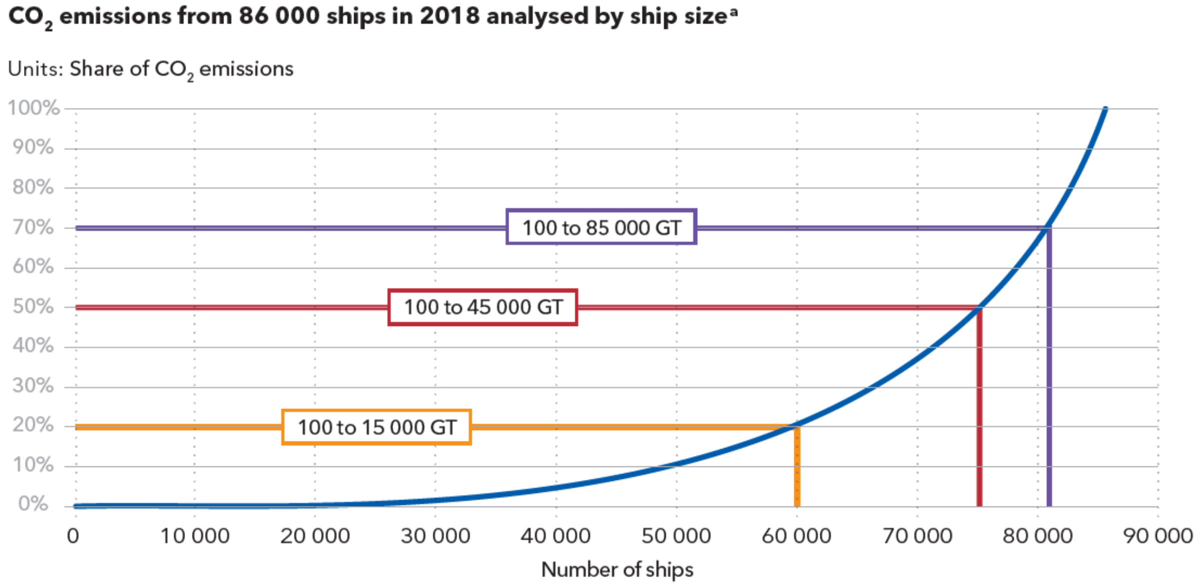
Possible measures for IMO GHG 2050 strategy

Type	Years	Measure	Target	Current status
Short-term	2018-2023	New Energy Efficiency Design Index (EEDI) phases	New vessels	-10% in 2015 -20% in 2020 -30% in 2025
		Operational efficiency measures (e.g. SEEMP, operational efficiency standard)	In-service vessels	SEEMP planning required
		Existing fleet improvement program	In-service vessels	
		Speed reduction	In-service vessels	
		Measures to address methane and VOC emissions	Engines and fugitive emissions	
Mid-term	2023-2030	Alternative low-carbon and zero-carbon fuels implementation program	Fuels/new and in-service vessels	
		Further operational efficiency measures (e.g. SEEMP, operational efficiency standard)	In-service vessels	SEEMP planning required
		Market-based Measures (MBMs)	In-service vessels/ fuels	
Long-term	2030+	Development and provision of zero carbon or fossil-free fuels	Fuels/new and in-service vessels	

World fleet CO2 emissions from 2013-2018



Source: DNV-GL



[a] Data for this analysis are accumulated CO_2 emissions for 86 000 ships observed in the AIS system in 2018 as a function of ship size in gross tonnage (GT), as calculated in our study.

Source: DNV GL

- World fleet CO2 emissions have grown steadily from 770 Mt in 2013 to 870 Mt in 2018.
- All ships above 15,000 GT account for 80% of the CO2 emissions and involve only 30% of the entire fleet.
- If the IMO targets are to be met, it is vital that uptake of low- and zero-carbon emission technologies should begin on large ocean-going ships in the near future.

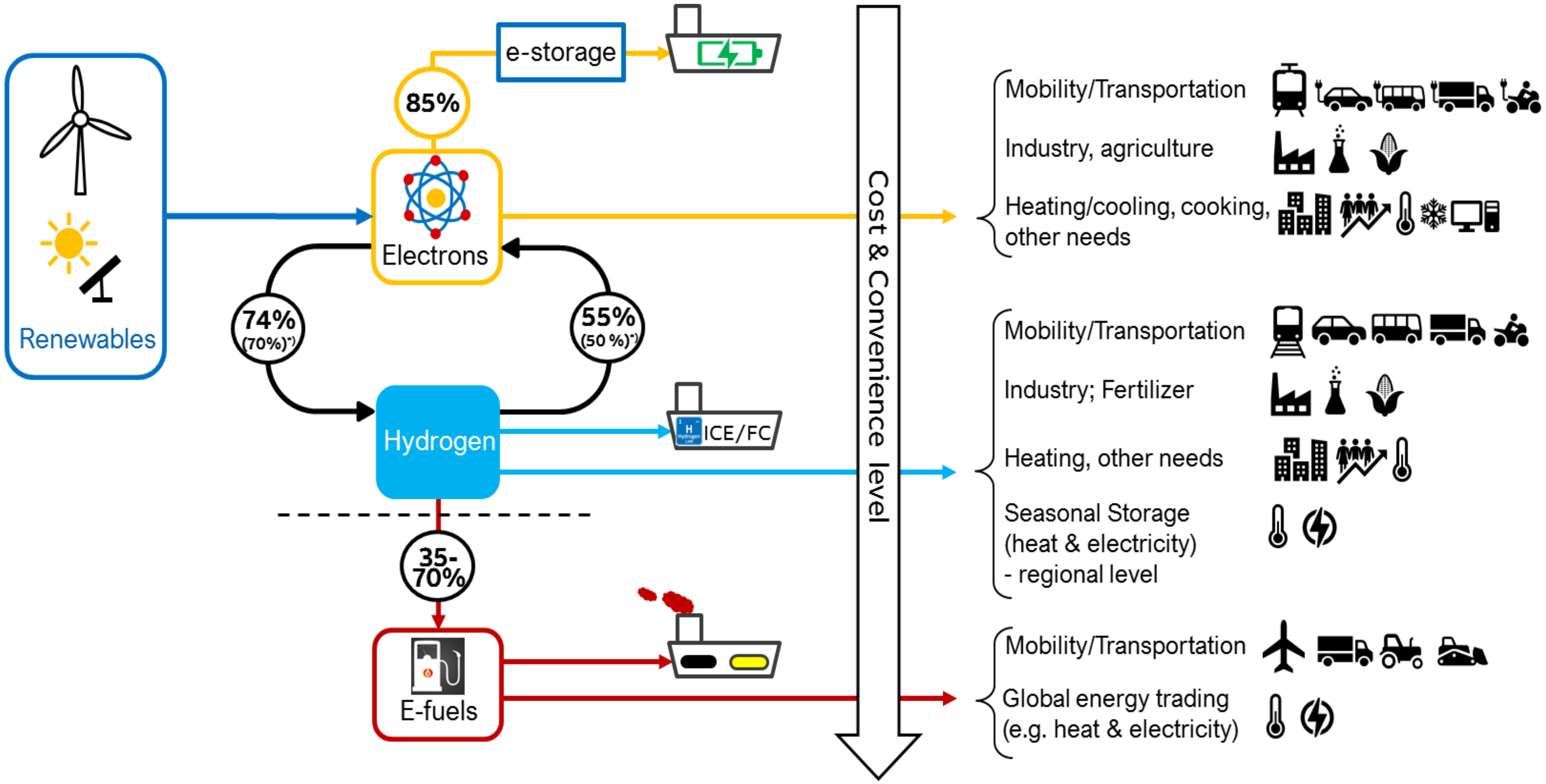
Alternative fuels and energy converters for global shipping

Ammonia produced with renewable electricity is a promising zero GHG emission fuel

Alternative fuel	Energy converter	Advantage	Disadvantage
LNG	Gas/DF ICE	1. Emission reduction potential (NOx, SOx, PM, CO2) 2. Competitive price (based on oil/gas price gap) 3. LNG available globally	1. Methane slip with Otto cycle, only up to 20% GHG reduction 2. Higher CAPEX (10%-30% higher than Diesel engine) 3. Larger space required for LNG/LPG fuel tank 4. Lack of the bunkering infrastructure
Biofuels	ICE	1. Blended with conventional fuels or used as drop-in fuels fully substituting conventional fossil fuels 2. Can be used directly in existing ICE	1. High fuel cost and limited global biofuel production 2. Potential negative net impact on GHG emissions 3. Lack of the bunkering infrastructure
Hydrogen	ICE/FC	1. Zero carbon emission if produced from wind/solar/ nuclear/SMR with CCS	1. Expensive and energy intense for production 2. Cooled to -253˚C or pressured to between 350bar to 700bar 3. Energy losses during conversion & logistic steps 4. Fuel cell technology with high cost and low power density
Ammonia (nitrogen based e-fuel)	ICE/FC	1. Zero carbon emission if produced from renewable electricity 2. Easier for transportation, storage and handling 3. Can be applied on ICE and deep sea shipping	1. Expensive and energy intense for hydrogen production 2. Energy losses during conversion & logistic steps 3. Corrosive and toxic (additional measures required) 4. NOx emission require SCR technology
Carbon based e-fuels	ICE	1. Easier for transportation, storage and handling 2. Can be applied on ICE and deep sea shipping	1. Expensive and energy intense for hydrogen production 2. CO2 emission during the combustion 3. High production cost due to CO2 sequestration from air
Electricity	Battery	1. Zero emission from renewable sources 2. Easier to optimize in terms of performance, safety and efficiency	1. Low power density 2. Limited to the short sea ships 3. High cost (CAPEX and OPEX)

DF: Dual-fuel, ICE: Internal Combustion Engine, FC: Fuel Cell, SMR: Steam Methane Reforming , CCS: carbon capture and storage, E-fuels: carbon-based fuels such as diesel, methane and methanol

Competition for the renewable electricity and clean hydrogen



Renewables

Electrons

85%

e-storage

74% (70%)*)

55% (50 %)*)

Hydrogen

ICE/FC

35-70%

E-fuels

Cost & Convenience level

Mobility/Transportation

Industry, agriculture

Heating/cooling, cooking, other needs

Mobility/Transportation

Industry; Fertilizer

Heating, other needs

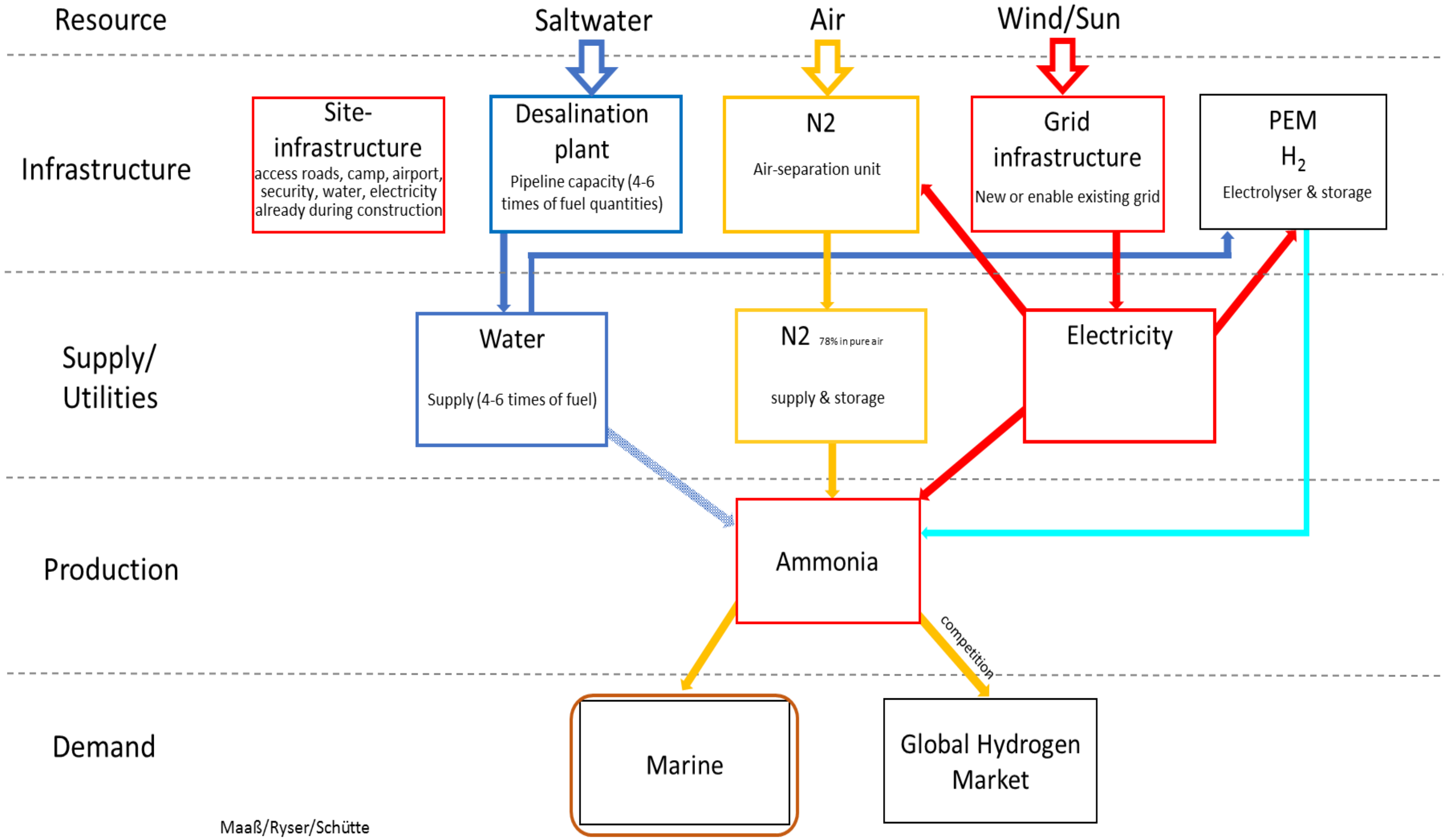
Seasonal Storage (heat & electricity) - regional level

Mobility/Transportation

Global energy trading (e.g. heat & electricity)

Pathways to green ammonia

Production with renewable energy



Resource

Saltwater

Air

Wind/Sun

Infrastructure

Site-infrastructure
access roads, camp, airport, security, water, electricity already during construction

Desalination plant
Pipeline capacity (4-6 times of fuel quantities)

N2
Air-separation unit

Grid infrastructure
New or enable existing grid

PEM
H_2
Electrolyser & storage

Supply/
Utilities

Water
Supply (4-6 times of fuel)

N2 78% in pure air
supply & storage

Electricity

Production

Ammonia

competition

Demand

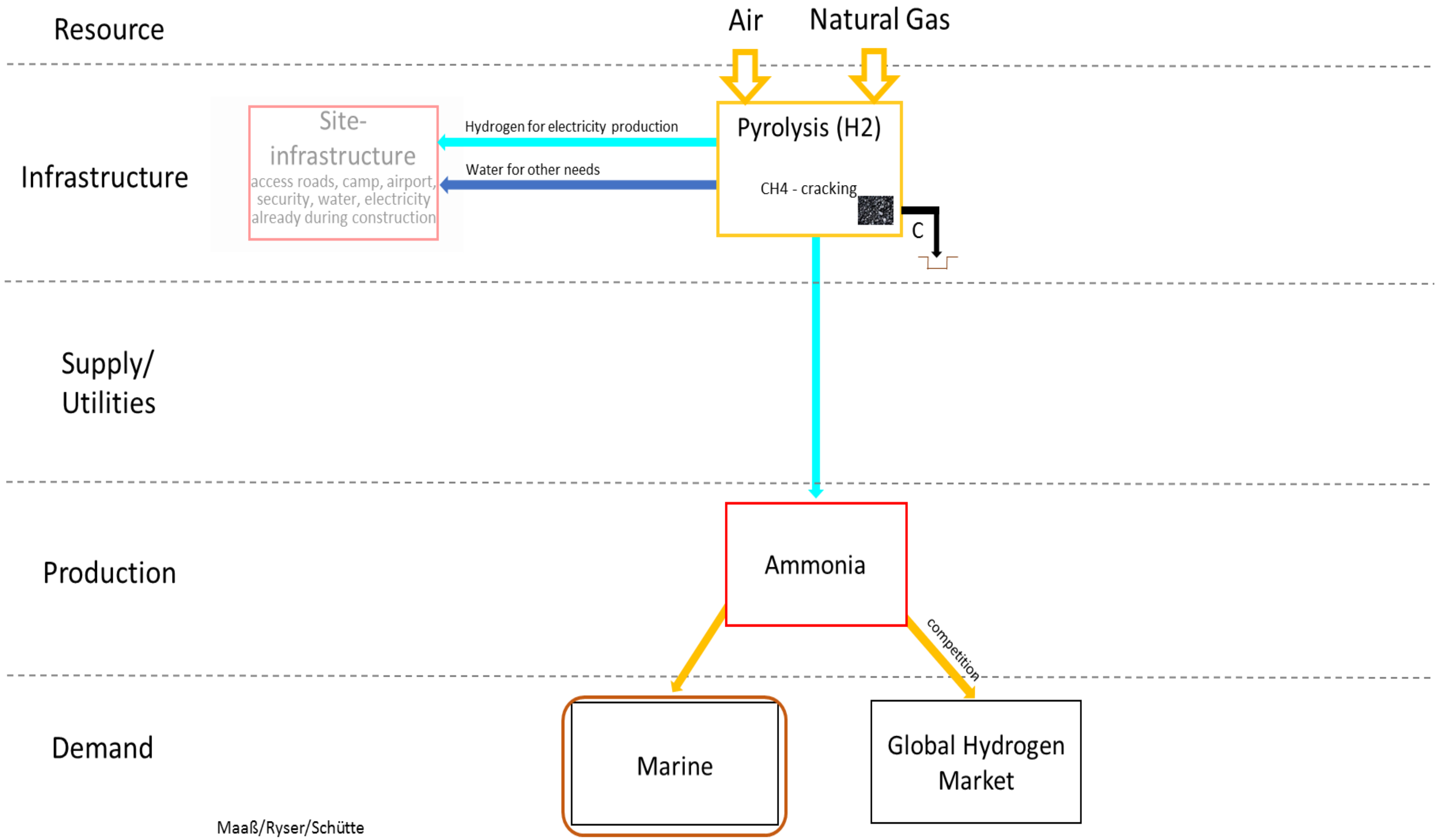
Marine

Global Hydrogen Market

Maaß/Ryser/Schütte

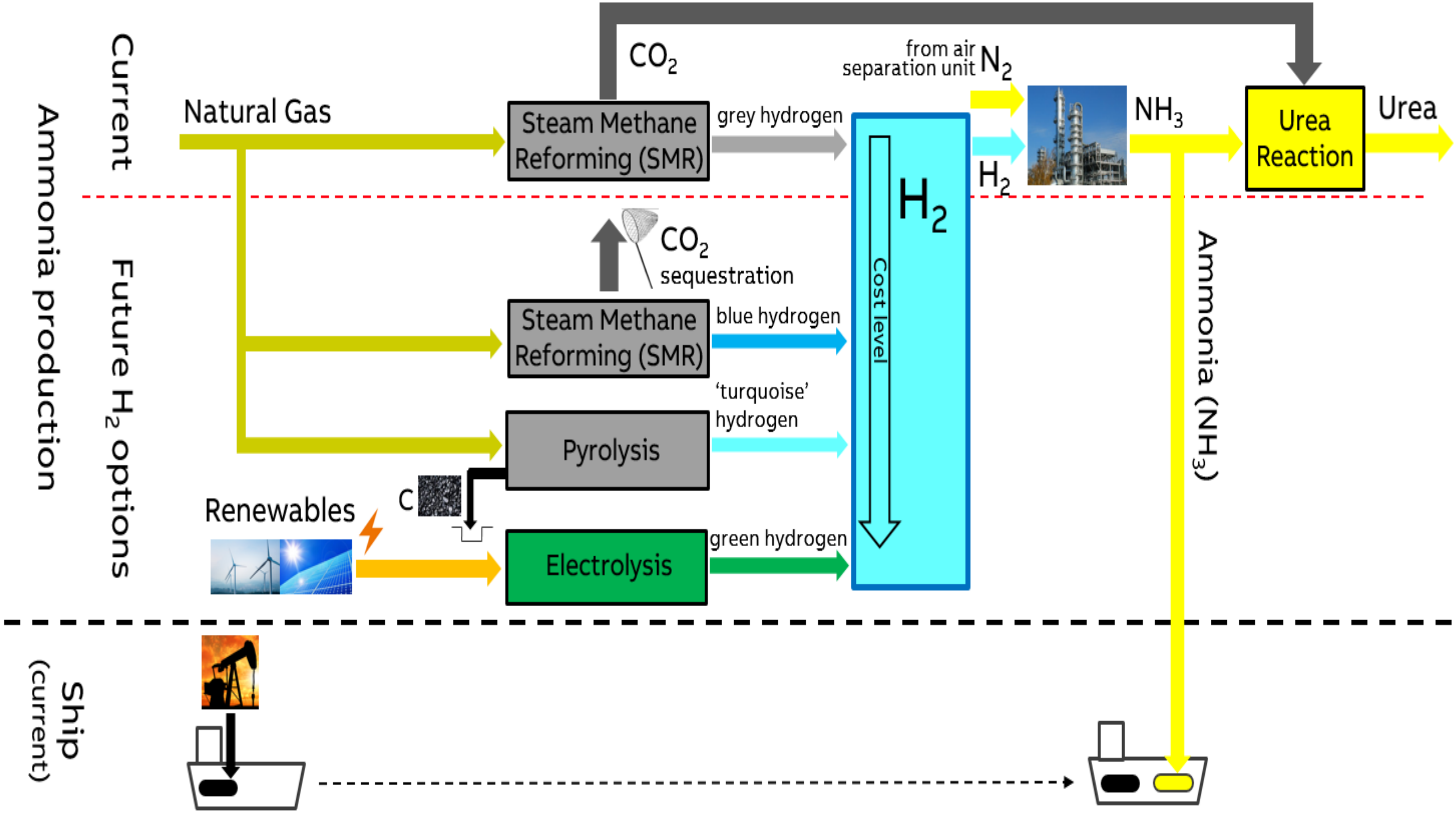
Pathways to green ammonia

Bridging technologies – Pyrolysis

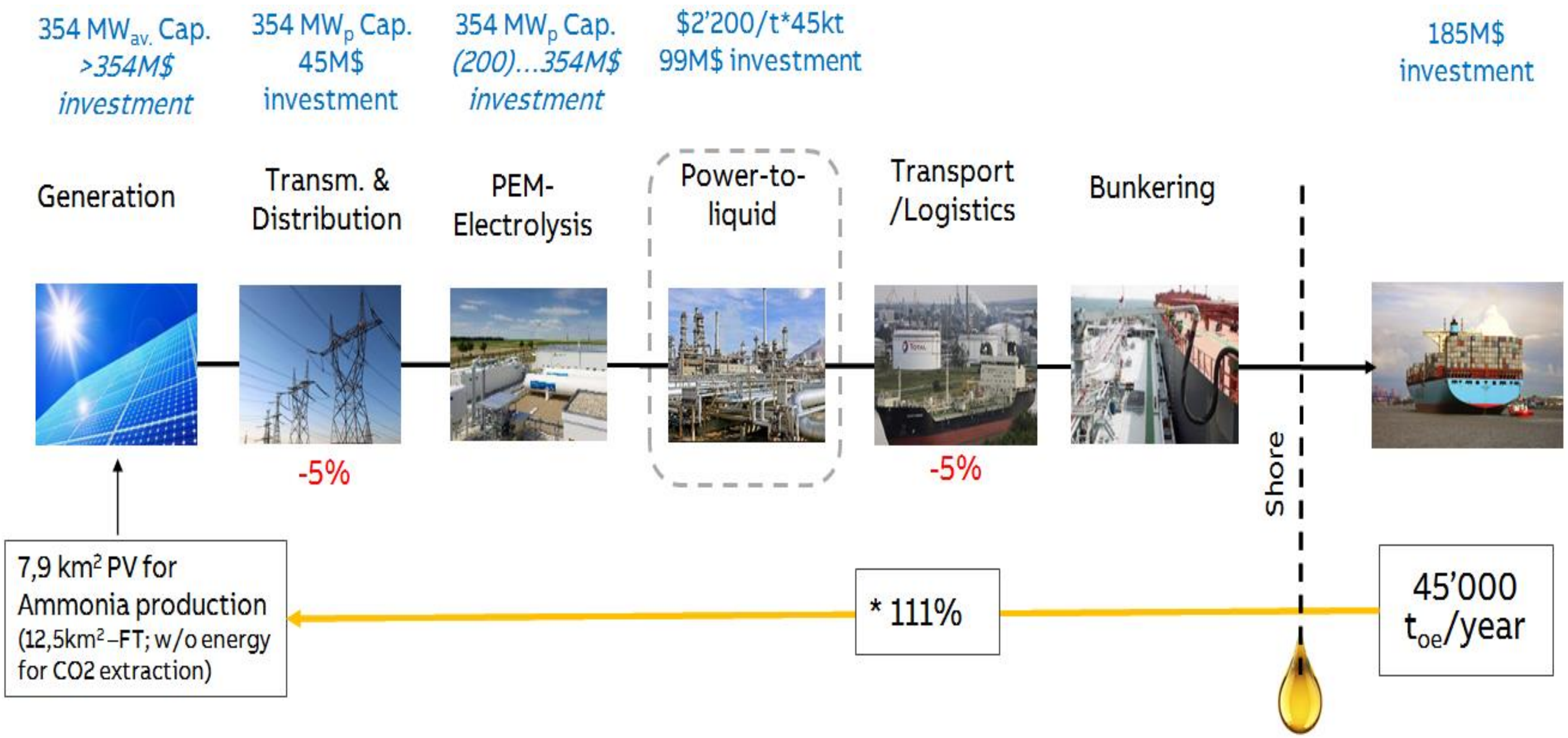


Maaß/Ryser/Schütte

Possible roadmaps for ammonia production



Up-front cost and land use for green ammonia propulsion



354 $MW_{av.}$ Cap.
>354M$
investment

354 MW_{p} Cap.
45M$
investment

354 MW_{p} Cap.
(200)…354M$
investment

$2'200/t*45kt
99M$ investment

185M$
investment

Generation

Transm. & Distribution

PEM-Electrolysis

Power-to-liquid

Transport /Logistics

Bunkering

Shore

-5%

-5%

7,9 km^2 PV for Ammonia production (12,5km^2–FT; w/o energy for CO2 extraction)

* 111%

45'000 t_{oe}/year

Summary

- IMO GHG 2050 strategy cannot be met without low/zero carbon fuels such as LNG, bio-fuel, hydrogen, e-fuels and electricity for large ocean going vessels
- Hydrogen produced with renewable energy is an important element to address the IMO GHG 2050 strategy
- Green ammonia as zero GHG fuel is suitable for large ocean going shipping
- Ammonia produced with pyrolysis using natural gas is less complex and expensive can be a bridging technology
- The investment cost for green ammonia as zero GHG marine fuel is too high that the regulatory and financial support is required

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